AGE DETERMINATION AND GROWTH OF FLATHEAD CATFISH

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OF FLATHEAD CATFISH

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PREFACE

An accurate method for determination of age and back-calculation of growth was developed for the flathead catfish, an important piscivore in Lake Carl Blackwell. Changes in the growth and fecundity were related to fluctuating water levels and population exploitation.

I would like to express by gratitude to Dr. R. C. Summerfelt, who was Unit Leader of the Oklahoma Cooperative Fishery Unit, for serving as major adviser and committee chairman. His helpful suggestions and guidance and review of this manuscript are sincerely appreciated. His contagious enthusiasm for scientific research was a continuing inspiration and, finally, his patience during the writing of this manuscript was invaluable.

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CHAPTER I

INTRODUCTION

The flathead catfish, Pylodictis olivaris Rafinesque, is found in large rivers and reservoirs throughout the Mississippi River and Gulf Coastal drainages (Moore 1957). Because it attains a large size and has piscivorous food habits, it has been widely introduced outside of its original range (Beckman 1963; Koster 1957; Minckley 1973). Its introduction as an auxiliary predator in ponds was considered undesirable in Alabama because it selected for fishes of a size utilized by fishermen (Hackney 1966; Swingle 1967). In Oklahoma reservoirs adult flathead catfish consumed mainly non-game prey fishes that were larger than those generally eaten by other predators (Turner and Summerfelt 1971a).

Because of good growth and relative abundance, the flathead catfish has been considered well-adapted to reservoirs, especially the more turbid ones (Buck 1956; Cross 1967). Of the commercial fishes harvested in Oklahoma from 1961 through 1969, the flathead catfish ranked second to buffalo fishes (Ictiobus spp.) in total weight harvested and total value, but first in price received per unit weight (Mensinger 1971). In a detailed one-year survey of commercial harvest, flathead catfish constituted 10.4% of a 510,989 kg harvest from four Oklahoma reservoirs (Parrack, Brown and Mensinger 1970). In 1970-1976, it usually ranked first in total value for commercial species harvested in Oklahoma (unpublished data, Oklahoma Department of Wildlife Conservation). The commercial catch of flathead catfish in many other states is included in "catfishes." Commercial overharvest has apparently reduced the relative abundance of flathead catfish in the Mississippi River, Iowa (Schoumacher 1968) and channelized portions of the Missouri, Nebraska (Holz 1969).

The flathead catfish is classified as a game species in many states. Frequent catches by anglers of fish >9 kg has made the Des Moines River, Iowa a popular flathead catfish fishery (Mayhew 1969). In Oklahoma where fish to 48 kg have been caught by sport fishermen (personal communication, P. E. Mauck, Oklahoma Department of Wildlife Conservation), most flathead catfish >5 kg are taken on either unbaited snaglines or trotlines baited with live fish. As flathead catfish probably attain a larger maximum and average weight than any species caught by hook and line in Oklahoma, it has considerable trophy appeal to sport fishermen.

Flathead catfish are valuable in waters where they convert underutilized prey species such as carp (*Cyprinus carpio*), freshwater drum (*Aplodinotus grunniens*), and large gizzard shad (*Dorosoma cepedianum*) to biomass which can be harvested by commercial and sport fishermen. Since large piscivores may enhance utilization and have a regulatory effect on size distributions of prey species, the flathead catfish may be an important factor when determining optimum sustainable yield for recreational fisheries (Anderson 1973, 1975).

The flathead catfish was the subject of intensive research by the Oklahoma Cooperative Fishery Unit (OCFU) from 1967-1972 on Lake Carl Blackwell: food habits in Oklahoma reservoirs (Turner 1971; Turner and Summerfelt 1971a); factors affecting condition and length-weight relationships (Turner and Summerfelt 1971b); age at sexual maturity, fecundity and the reproductive cycle in relation to ova diameters, gonadal and liver weights (Turner and Summerfelt 1971c); factors influencing horizontal distribution (Summerfelt 1971); estimates from 1968-1971 of population size, annual mortality rate, fishing mortality and movement patterns determined by conventional mark-and-recapture and telemetric methods (Hart 1974; Summerfelt et al. 1972). During these studies, several techniques were developed and evaluated. Methods for tagging flathead catfish were tested and rates of tag loss calculated from tagged fish recaptured by gill nets and fishermen (Summerfelt and Turner 1973). During 1967-1971, methods for surgically implanting ultrasonic transmitters in the abdominal cavity (Hart and Summerfelt 1975) and telemetric tracking of free-ranging flathead catfish in ponds and Lake Carl Blackwell were developed (Summerfelt et al. 1972). Homing and other major behavior patterns of flathead catfish tagged with ultrasonic transmitters in Lake Carl Blackwell were described by Hart and Summerfelt (1974). Prior to studies on Lake Carl Balckwell, information on flathead catfish in reservoirs was mainly restricted to reports on growth rate, commercial and sport harvest, and fragmented data on standing crop derived from cove rotenone samples.

The objectives of this report are: (1) to describe methods for age determination and back-calculation of growth for flathead catfish; (2) to relate growth pattern of flathead catfish in Lake Carl Blackwell to food habits and reproduction; and (3) to determine the effect of lake level fluctuation and population reduction on growth and fecundity.

CHAPTER II

DESCRIPTION OF STUDY AREA

Lake Carl Blackwell was created by the construction of an earth and rock-fill dam on Stillwater Creek in Sections 3 and 10, Township 19N, Range 1E. The reservoir is located 12.8 km west of Stillwater, Payne County, Oklahoma, and extends westward 8.5 km (Figure 1). The watershed is located within the Redbeds Plains physiographic region and has soils derived mainly from Permian clays and shale.

The dam was constructed in 1936-1938 by the Works Progress Administration to provide a reservoir for water-based recreation for the residents of north-central Oklahoma. The reservoir and part of its watershed was leased to Oklahoma State University in 1948 and eventually deeded to the university in 1954 to maintain as a recreation area. By law, fishing and boating permits must be purchased at the lake office. Since March 1950, the reservoir has served a municipal water source for Oklahoma State University and the City of Stillwater.

At the spillway elevation of 287.78 m, m.s. l. The reservoir has a surface area of 1401 ha, a volume of 67.84 million cubic meters, a shoreline length of 90.41 km, and a shoreline development index of 6.8 (Shirley 1975). However, surface area and volume averaged only 48.0 and 36.5% of their spillway values during the study period.

Although the watershed immediately adjacent to the reservoir has well-developed pastures of native grasses, the runoff of the inter-

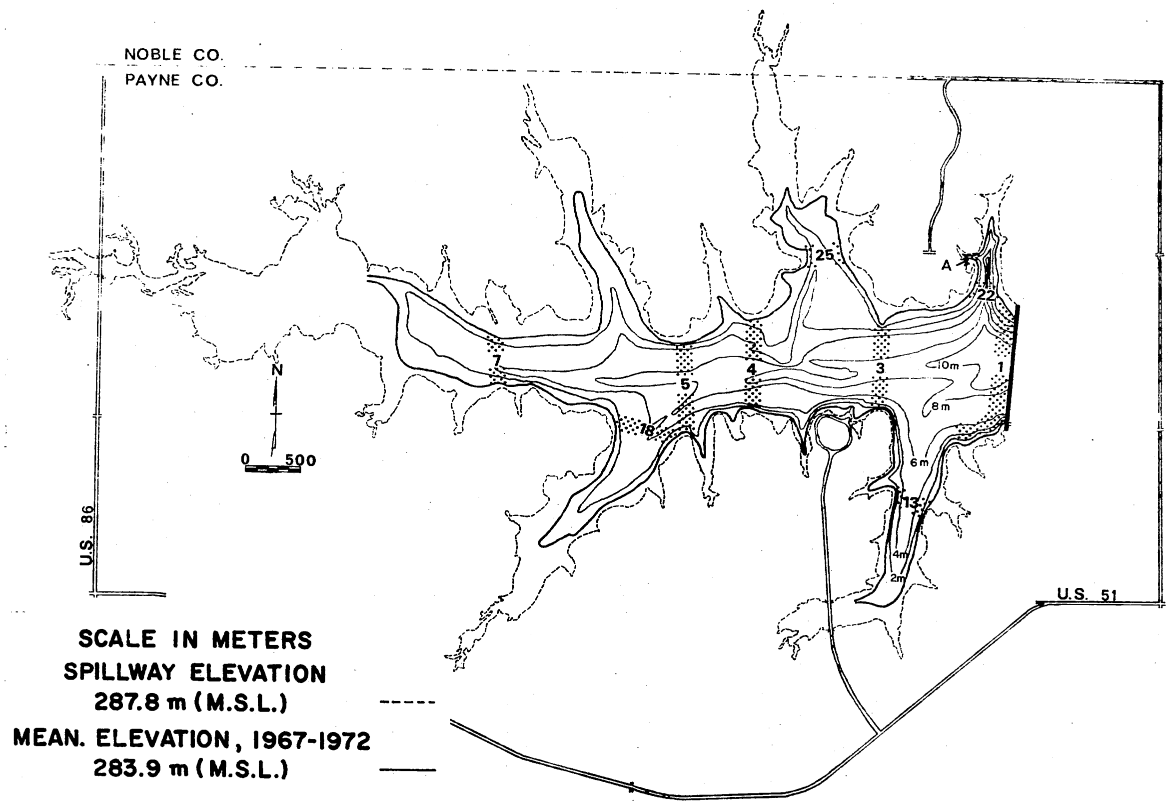


FIGURE 1.--Lake Carl Blackwell showing depth contours, netting transects (stipled areas) and rotenone cove (A).

mittent Stillwater Creek and its tributaries is highly turbid. Following heavy runoff, Secchi disc transparencies of 5-10 cm were recorded at transect 7 (Figure 1). A maximum transparency of 157.5 cm was measured during an unusually calm period in July 1971, but transparencies of 25-50 cm were more typical. Jackson Turbidity Unit measurements ranged from a minimum of 20 during calmer periods to a macimum of 180 in the shallow western end of the reservoir when wind-driven wave action caused resuspension of fine silt and clays (Norton 1968).

The lake generally had a well mixed and vertically homogeneous water column because of wave action associated with the unprotected shoreline, shallow depth and orientation of the reservoir. The wave-generated circulation generally prevented thermal stratification and oxygen depletion except during irregular intervals of a few days to a few weeks during the summer. Stratification typically occurred only during periods when surface water temperatures were $>$20C and wind velocities were unusually low for several days. Oxygen depletions were mainly restricted to deeper waters ($>$5m) in the main body and major coves of the reservoir from Area 5 eastward.

Mean depth of the reservoir at spillway elevation is 5.4 m. Two-meter depth contours indicate depth of the reservoir at the mean water level (283.9 m, M.S.L.) during this study (Figure 1). Water depths in the original stream channels, found in most major coves and the main reservoir west of Area 4, were up to one meter deeper.

The reduction in lake levels January 1962 through March 1968 exposed extensive areas of mud flats and reduced surface area and shoreline length by 56 and 64%, respectively. During the years of declining lake levels, extensive areas of terrestrial macrophytes developed on the mud flats in the westernmost areas of the reservoir and shallower coves. In 1968 and 1969, rising lake levels innundated much of this vegetation. Aside from 1968-1969, cover for flathead catfish in the littoral zone was limited to a few submerged trees and boulders. Decreasing lake levels, high turbidity, and wave action precluded the growth of aquatic plants. The littoral zone substrate of the reservoir is mainly sand and coarse silt (Norton 1969).

Most flathead catfish (>500mm) were collected in experimental gill nets set in nine areas (Figure 1). Details of the habitat in these areas were described by Turner (1971). Rotenone samples were taken periodically in a 0.5-ha cove in Area A. Since this cove was narrow, steep-sided, and well-protected from wave action, it was atypical of most coves. Research by the OCFU utilizing rotenone, experimental gill nets, and electrofishing in Lake Carl Blackwell have been summarized by Johnson (1974). Additional ecological studies of Lake Carl Blackwell which were concurrent with the present study include: sediment characteristics and macroinvertebrate-substrate relationships (Norton 1968); life history aspects of the carp, Cyprinus carpio (Mauck 1970), channel catfish, Ictalurus punctatus (Jerald 1970), and largemouth bass, Micropterus salmoides (Zweiacker 1972); factors affecting horizontal distribution of fishes (Summerfelt 1971); phytoplankton communities and nutrient relationships (Faust 1972); movements and home range of flathead catfish (Hart 1974); and influence of sediment cycling on primary productivity (Hysmith 1975).

CHAPTER III

PROCEDURES FOR AGE DETERMINATION AND GROWTH RATE CALCULATIONS OF FLATHEAD CATFISH

INTRODUCTION

Accurate age determination and back-calculation of growth is usually necessary for population analysis and knowledgeable management of a fish species. Although valid methods for age determination are known for many species, a method validated for one species should not be assumed accurate for other species until it has been tested. During studies begun in 1967, I found that methods commonly used for age determination of flathead carfish caused serious errors for fish older than age 2 from Lake Carl Blackwell, Oklahoma. Therefore, a thorough evaluation of the use of spine cross-sections for age determination of flathead catfish was made.

In most prior studies cross-sections cut from the distal end of the basal recess (BR sections) of either pectoral or dorsal spines were used to determine age and back-calculate growth of flathead catfish. The use of BR sections from the pectoral spine for age and growth determinations has been validated for channel catfish (Sneed 1951; Marzolf 1955), but not for flathead catfish. The central lumen found in BR sections of flathead catfish enlarges with growth of the pectoral spine, causing resorption of the surrounding bone tissue containing the earliest annuli (Muncy 1957; Langemeier 1965; and present report).

Langemeier (1965) and Holz (1969) recommended using cross-sections from the articulating process (AP sections) of the pectoral spine to determine the number of annuli missing in BR sections, but still used annuli measurements from BR sections to calculate growth.

The main purpose of this paper was to evaluate the accuracy of pectoral AP sections for age determination and growth back-calculation in the flathead catfish. In addition, age of fish obtained independently from AP sections of the dorsal spine are compared to ages previously determined from pectoral AP sections for a sample of fish. Also the error in age determination which results from using only pectoral BR sections for age determinations was determined by comparing the number of annuli found in AP and BR sections cut from the same pectoral spine for most fish. Growth of flathead catfish in Lake Carl Blackwell and Boomer Lake was described using the procedures developed in this paper.

MATERIALS AND METHODS

Collection of Materials

Pectoral and dorsal spines were removed from flathead catfish collected in Lake Carl Blackwell from June 1967 through July 1972. Fish >400 mm total length were captured mainly with experimental gill nets, but a few were captured by electrofishing, rotenone and barrel traps. Some spines were obtained from flathead catfish (593-1980 mm) caught by fishermen using snaglines--10, 12, 47, and 17 fish in 1968, 1970, 1971, and 1972, respectively. Fish <400 mm were collected by electrofishing and by poisoning of coves with rotenone.

Total length was measured to the nearest milimeter. Weight was determined to the nearest ounce for fish >1 kg and to the nearest gram for smaller fish. Sex was determined by dissection or examination of the genital area (Turner and Summerfelt 1971c). Mesh size (square mesh) and location of capture was recorded for fish collected by gill nets.

Prior to August 1967, all fish >400 mm were caught in the 76-mm mesh of experimental gill nets containing equal amount of 25-, 51-, and 76-mm mesh. From August 1967 through September 1968, flathead catfish were mainly captured in hobbled gill nets with mesh sizes of 76, 89, and 101 mm or gill nets with either 89-, 101-, or 127-mm mesh (Turner 1971). In 1969, hobbled gill nets had two 7.6-m panels per net of 25-, 63-, 76-, 89-, 101-, and 114-mm mesh. The panels of 25-mm mesh were removed and replaced with 127-mm mesh in 1970-1971. These nets were also used to collect 16 flathead catfish from Boomer Lake during the summers of 1971 and 1972. The age of fish from Boomer Lake was known because the lake had no flathead catfish in 1967 when hatchery-reared young-of-the-year (YOY) were stocked by the Oklahoma Department of Wildlife Conservation.

Pectoral spines were disarticulated by rotation of the unlocked spine towards the fish's ventral midline after first cutting through the skin and muscle at the base of the spine. In 1967-1968, the left pectoral and dorsal spine were usually removed from each fish. Beginning in 1969, both pectoral spines and the dorsal spine were removed unless they were broken. Spines were cleaned of most soft tissue and stored for up to two years in labeled coin envelopes prior to sectioning.

Preparation of Cross-Sections

Spines were sectioned with a modification of the instrument described by Witt (1961). The two modifications were: (1) a 180- by 305-mm aluminum plate attached just below the V-block and spine clamp; and (2) a hinge mechanism between the saw clamp and the mounting pillar. The plate kept bone fragments and water from fouling the sliding and screw mechanisms of the spine-holding unit. The hinge allowed the saw to be flipped up and over so that an articulating process section from a large pectoral spine could be sectioned from the opposite direction in the exact location and angle as for the initial, partially-completed cut.

Water was applied with an eye dropper to spines while cutting cross-sections to retard curling and scorching due to friction. In 1967-1968, sections were glued in serial order to numbered glass slides with mounting media. A drop of 50 per cent isopropyl alcohol placed on the sections improved differentiation of the annuli (Probst and Cooper 1955), but repeated application of alcohol eventually dissolved the mounting media holding sections to the slides. Microscopic examination of both surfaces before they were attached to slides insured that the surface having the greatest radius for the first annulus could be later used for measurements. Beginning in 1969, all cross-sections were returned to the labeled coin envelope after sectioning was completed.

A series of three to six cross-sections were cut from the articulating process of pectoral spines (Figure 2A) for age determination and back calculation measurements. The most usable AP sections of pectoral spines were 0.7 to 0. mm in thickness. Three sections were also cut

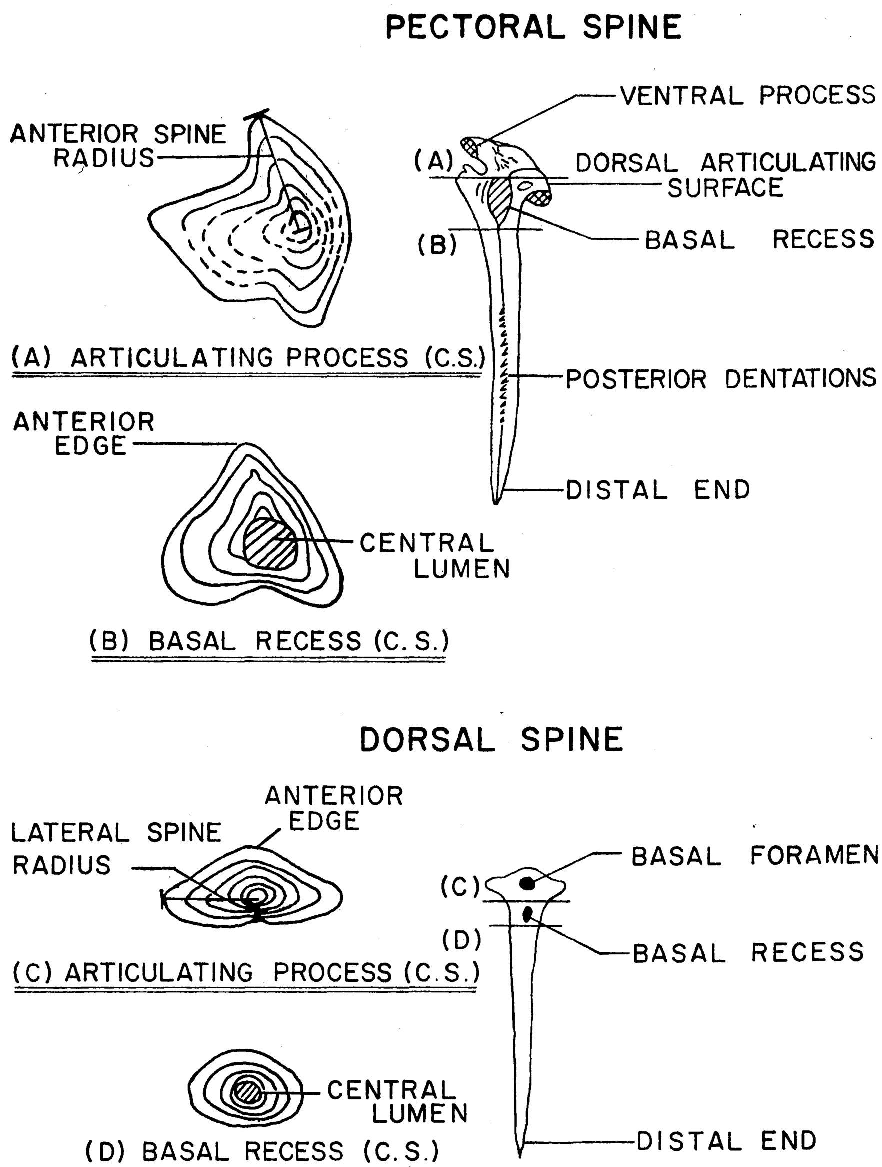


FIGURE 2.--Posterior views of the pectoral and dorsal spines showing the points of sectioning and the corresponding cross-sections used in age and growth determinations.

from the distal end of the basal recess of pectoral spines (Figure 28) to determine the number of annuli missing because of lumen enlargement. For dorsal spines, a series of five to ten cross-sections, 0.3 to 0.5 mm in thickness, were cut from between the basal recess and basal foramen (Figure 2C).

To obtain a section cut perpendicular to the axis of the spine, pressure (clamped to a sliding platform) had to be light, otherwise flexure of the thin saw blade caused the angle of the cut to vary from perpendicular. A perpendicular plane was required when cutting pectoral AP sections because it was often necessary to finish cutting pectoral AP sections by flipping the hinged saw assembly to the opposite side of the spine.

The most usable cross-sections were obtained with fine-toothed saw blades, 22.2 mm in diameter and 0.10 and 0.15 mm in thickness. The blade with 0.10 mm thickness was used on most spines, but the stroger 0.15 mm blade was more desirable on larger pectoral spines. Pectoral spines of fish >175 mm in length were too short to be held by the spine clamp while sectioning, therefore, they were glued to strips of acetate prior to sectioning. Spines of fish <100 mm (only eight collected) were too fragile and small (>10mm) to be sectioned, therefore, length frequencies in relation to date of capture and known spawning periods were used to estimate age of fish >100 mm.

Determination of Annuli

Cross-sections examined under reflected light had broad white zones alternating with narrow dark rings. The narrow dark rings seen under reflected light were considered year marks if they were distinct and occurred in all quadrants of cross-sections which normally had easily read annuli. Reflected light was normally used to determine age, but transmitted light was occasionally used for comparative purposes.

Year marks in AP sections of pectoral spines were apparent in only the anterior and posterior quadrants (Figure 2A). When dorsal AP sections were used to check age determined from pectoral AP sections, year marks were more ovoid and continuous (Figure 2C), but the first one or two annuli were often obscured by irregularities in the innermost bone deposits. Pectoral BR sections (Figure 2B) also had more continuous year marks, but one or more of the innermost annuli were usually missing on age-3 and older fish because of the enlargement of the spine lumen.

Less definite annulus-like markings were observed in fish in age-groups 2 and older. These marks were easily recognized as false annuli by their faint appearance and irregular spacing. After the fifth annulus, the false annuli were more distinct and continuous, especially on adult females. Most of these false annuli occurred within a third of the distance to the next true annulus and often had a halo-like effect. Adult fish collected in the fall and winter often would have these false annuli already present distal to the last true annulus. This indicated that the formation of false annuli after age 5 was related to a regularly-occurring event which took place in the late spring or summer.

The number of annuli observed in pectoral AP sections was compared to the known age of flathead catfish collected from Boomer Lake. Also the number of new annuli formed by tagged fish was determined by comparing cross-sections from the right pectoral spine (distal section removed at tagging) with sections from the left pectoral spine which was removed when the fish was recaptured.

Measurement of Annuli

Radii of spine cross-sections were measured with an ocular micrometer, subdivided into 200 units, in a binocular dissecting microscope at magnifications of 20X and 30X for pectoral and dorsal sections, respectively. Dorsal AP sections are bilaterally symmetrical; thus, measurements of radii were taken laterally from the midpoint of the innermost annulus (Figure 2C). Sections from the articulating process of pectoral spines are lobate; therefore, spine radius was measured in the plane from the midpoint of the innermost annulus to the tip of the lobe with the most distinct annular markings (Figure 2A). The lobe with the second greatest radius, the extension of the anterior edge of the spine into the dorsal articulating surface, was used for measurements. Only measurements from pectoral AP sections were used to back-calculate growth of fish in this paper.

Because annuli were discernible in only the anterior and posterior quadrants of pectoral AP sections, the midpoint of the innermost annulus was estimated by eye. It was easier to estimate this midpoint in pectoral AP sections than it would have been in pectoral BR sections. A relatively constant reference point for back calculations was obtained by using the section having the greatest radius for the innermost annulus.

Back-calculation of Growth

To determine the best equation describing the total length-pectoral spine radius relationship, I compared linear and curvilinear regressions for the total length and total spine radius measurements of pectoral AP sections of all 192 fish in the 1967-1968 sample. Also, for the same collection grouped in 50-mm length classes, linear regression was calculated using mean total lengths and mean spine radii of each 50-mm length class. The regression calculated from the means of 50-mm length classes was used for back-calculation of growth.

Back-calculations of total length at annulus formation were computed for the 1967 and 1968 samples from Lake Carl Blackwell and Boomer Lake by the Lee Method (Tesch 1971) for each fish using the following formula:

$$L_n = \frac{S_n}{S}(L-c) + c,$$

where L_n = estimated length at time of formation of annulus *n*: S_n = spine radius at *n*th annulus; S = total spine radius; L = total length at time of capture; and c = intercept value from the linear regression between total length and total spine radius. Mean lengths with 95% confidence limits for each year class at each annulus and their associated variances were computed for the 1968 sample from Lake Carl Blackwell to document variation in growth of individual fish.

Assigned age corresponded to the number of annuli found in spine cross-sections. Ages are expressed in arabic numerals as preferred by Tesch (1971) and Ricker (1975) to simplify references to the age of older fish. For example, a fish with five annuli would belong to age-group 5. In cases where the last annulus had not yet formed in fish collected after January 1, the total spine radius was considered as the unformed annulus.

Tagging Procedure and Growth of Tagged Fish

Other than fish to be autopsied, most flathead catfish captured in experimental gill nets were weighed, measured, sexed and tagged before being released. Except for strap tags attached to the hypural plate of 13 fish in 1967, most fish were tagged with both a spaghetti (anchor) tag through the bony tissue of the left opercle and a monel metal ring tag crimped around the base of the left pectoral spine. Details of the tagging method, description of the numbered tags, and estimates of the rate of the tag loss for spaghetti and ring tags were reported by Summerfelt and Turner (1973). Additional details concerning tag loss, minimum travel speeds, procedures and results of tracking by telemetry and population dynamics were discussed by Summerfelt et al. (1972). Ultrasonic transmitters were also surgically implanted in 22 of the externally-tagged fish to study daily movements (Hart and Summerfelt 1974). When tagged fish were recaptured, tag numbers were recorded, the fish were again weighed, measured and sexed. Growth rate was determined by dividing the increment of length change by the number of months at large. Growth rate was not determined for tagged fish recaptured by fishermen unless I measured the length of the recaptured fish.

Beginning in 1969 and continuing through 1970, the right pectoral spine distal to the basal recess was removed with bone snips and stored in a coin envelope before releasing tagged fish. In 1969-1971, the posterior portion of the adipose fin was removed in order to permanently mark fish.

RESULTS

Validation of Age Determination

Correlation between assigned age and length. As the number of annuli seen in pectoral AP sections increased, the mean length of fish in successive age groups also increased (Table 1). This regular increase in number of annuli indicated a systematic formation of annuli occurs with growth in length. Also, the observed modes in the length-frequency distribution of fish in 1967-1968 corresponded to modal lengths of fish in age-groups 1, 3 and 4. The range in lengths overlapped too much between age-groups 5 and older to allow use of the length-frequency method for validation of age in older fish.

Comparison of calculated lengths with empirical lengths. Calculated mean lengths at formation of annuli compared well with empirical lengths of the next youngest age group at time of capture (Table 2). The empirical length of fish in age-group 5 was greater than the calculated length of fish at the end of year 6 because only the largest age-5 fish were vulnerable to the smallest mesh size (76mm) of gill nets used in 1968; therefore both length at capture and lengths at annuli were biased upward for fish in age-group 5. As expected, the empirical lengths of fish collected in the spring and summer were greater for each age group than their calculated length at the time the last annulus was formed.

TABLE 1. Total length-frequency distribution by age groups of 210 flathead catfish collected from Lake Carl Blackwell in 1967-1968

Length class (mm)	Age group[a]													
	1	2	3	4	5	6	7	8	9	10	11	12	13	16
50 - 74	3													
75 - 99	4													
100 - 124	1													
125 - 149	-													
150 - 174	-													
175 - 199	-	1												
200 - 224	-	-	2											
225 - 249	-	-	2											
250 - 274	-	-	2	1										
275 - 299	-	-	-	-										
300 - 324	-	-	-	2										
325 - 349	-	-	-	-										
350 - 374	-	-	-	5										
375 - 399	-	-	-	1										
400 - 424	-	-	-	2										
425 - 449	-	-	-	-										
450 - 474	-	-	-	1	1									
475 - 499	-	-	-	-	1	1								
500 - 524	-	-	-	-	2	2								
525 - 549	-	-	-	-	3	3	4							
550 - 574	-	-	-	-	6	5	2							
575 - 599	-	-	-	-	3	4	3							
600 - 624	-	-	-	-	8	5	3	8	1					
625 - 649	-	-	-	-	4	8	4	2	3					
650 - 674	-	-	-	-	-	7	4	3	2	-	-	-	1	
675 - 699	-	-	-	-	2	4	4	2	1	3	-	-	-	

TABLE 1 (Continued)

Length class (mm)	Age group[a] 1	2	3	4	5	6	7	8	9	10	11	12	13	16
700 - 724	-	-	-	-	1	4	2	2	2	1	1	1	-	
725 - 749	-	-	-	-	-	-	2	3	3	3	2	-	-	
750 - 774	-	-	-	-	-	-	2	1	3	1	3	-	1	
775 - 799	-	-	-	-	-	-	1	2	2	4	-	-	1	
800 - 824	-	-	-	-	-	-	1	-	1	1	-	-	-	
825 - 849	-	-	-	-	-	-	-	2	-	-	-	1	-	
850 - 874	-	-	-	-	-	-	-	1	-	-	-	-	-	
875 - 899	-	-	-	-	-	-	-	-	-	-	-	1	-	
900 - 924	-	-	-	-	-	-	-	-	1	1	1	-	-	1
925 - 949	-	-	-	-	-	-	-	-	-	-	-	-	-	-
950 - 974	-	-	-	-	-	-	-	-	2	-	1	-	-	
975 - 999	-	-	-	-	-	-	-	-	-	-	-	-	-	
1000 -1024	-	-	-	-	-	-	-	-	-	-	-	-	1	
Number per age group	8	1	6	12	31	43	32	26	21	14	8	3	4	1
Per cent of total sample	3.8	0.5	2.9	5.7	14.8	20.5	15.2	12.4	10.0	6.7	3.8	1.4	1.9	0.5
Mean total length (mm)	81	177	240	360	586	623	653	702	738	758	792	812	809	921

[a]An age-group 0 fish (37 mm) collected 25 October 1967 and an age-group 21 female (1111 mm) collected in 1968 were not included in this table.

TABLE 2. Mean calculated total lengths at time of annulus formation for flathead catfish collected from Lake Carl Blackwell in 1968. Data show total lengths in millimeters and 95% confidence limits for length at end of year.

Year class	Age group	Number of fish	Length at capture	Mean calculated total length (mm) at end of year: 1	2	3	4	5	6	7	8	9	10	11	12	13
1965	3	3	237	53 ±12	94 ±41	147 ±53										
1964	4	10	356	49 ± 7	108 ±16	169 ±28	269 ±50									
1963	5	26	588	60 ± 3	121 ± 9	225 ±21	372 ±27	537 ±30								
1962	6	31	633	55 ± 3	110 ± 9	184 ±19	302 ±30	444 ±38	576 ±28							
1961	7	26	656	60 ± 4	119 ±10	194 ±15	296 ±28	430 ±38	557 ±36	627 ±31						
1960	8	22	702	60 ± 6	128 ±15	210 ±26	308 ±45	427 ±56	542 ±56	617 ±44	674 ±35					
1959	9	16	731	60 ± 6	118 ±11	196 ±21	286 ±33	413 ±61	544 ±78	630 ±74	685 ±64	722 ±58				
1958	10	14	758	65 ± 6	122 ±11	212 ±17	307 ±27	428 ±48	547 ±53	648 ±34	696 ±28	723 ±32	746 ±34			
1957	11	7	796	59 ±12	112 ±17	184 ±29	264 ±49	349 ±58	451 ±83	580 ±73	660 ±50	703 ±48	735 ±54	762 ±65		

TABLE 2 (Continued)

Year class	Age group	Number of fish	Length at capture	Mean calculated total length (mm) at end of year												
				1	2	3	4	5	6	7	8	9	10	11	12	13
1956	12	3	812	60	116	238	363	530	613	677	710	742	768	788	808	
				±16	±32	±121	±296	±408	±354	±227	±210	±215	±210	±201	±190	
1955	13	4	809	49	99	175	278	387	492	560	611	646	695	738	767	794
				±10	±23	±83	±201	±306	±287	±259	±230	±219	±234	±221	±216	±220
Grand mean length				58	117	198	309	446	549	623	678	714	738	761	785	794
Number of fish in mean				162	162	162	159	149	123	92	66	44	28	14	7	4

There was close agreement in mean calculated lengths of fish at age 1 (58 mm) in 1968 and the empirical lengths of age-1 fish determined by length-frequency distribution (Table 1). For example, the mean length was 88 and 76 mm for fish in age-group 1 collected by rotenone mainly in the summers of 1967 and 1968, respectively; also 12 age-1 fish collected by rotenone on 13 August 1973 averaged 67 mm.

Comparison between calculated growth histories. Calculated growth to the same age was similar for growth histories determined from collections in 1967 and 1968 (Table 3). The largest discrepancy between years, which seems related to year selectivity, was the lower calculated lengths and lengths at capture for age-7 and older fish in 1967. In 1967, most fish were collected in 76-mm mesh of gill nets whereas, in 1968 the largest mest size was 127 mm. As 76-mm mesh seldom caught flathead catfish > 700 mm, larger, more rapidly-growing fish in age groups 7 and older were poorly represented in collections in 1967.

Calculated growth to the same ages generally agreed between fish of different age groups in 1968 (Table 3). In particular, growth of age-groups 6-10 were similar.

Number of annuli observed for fish of known age. Flathead catfish were stocked as fry into Boomer Lake in 1967, therefore, the expected number of annuli for fish collected in 1971 and 1972 was four and five, respectively. All four fish collected in 1972 had five annuli visible in pectoral AP sections. Four annuli were seen in pectoral AP sections from 10 of 12 age-4 fish collected in 1971, but the first annulus was not visible in the other two fish. The absence of the first annulus was caused by poor sectioning technique for one fish, but could not be explained for the smallest fish (516 mm) in the 1971 sample.

TABLE 3. Empirical and calculated total length in millimeters of flathead catfish collected from Lake Carl Blackwell in 1967 and 1968.

Age group	1967 No. of fish	1967 Mean length at capture	1967 Mean calculated length	1968 No. of fish	1968 Mean length at capture	1968 Mean calculated length
1	3	88[a]	61	5	76[a]	58
2	1	177	118	0	-	117
3	1	256	197	5	234	198
4	0	-	310	10	356	309
5	4	575	454	26	588	446
6	10	596	552	31	633	549
7	6	638	604	26	656	623
8	3	647	640	22	702	678
9	3	690	673	16	731	714
10	0	-	719	14	758	738
11	1	761	742	7	796	761
12				3	812	785
13				4	809	794
Total	32	-	-	169	-	-

[a]Except for fish in age-group 1 (where age was estimated by the length frequency method, age was determined by examination of spine cross-sections. Not all fish in age-groups 2 and 3 were used when back-calculating growth in Table 3.

On both fish, the first (innermost) visible annulus was located where the second annulus was observed in other fish from Boomer Lake. The first annulus was also estimated to be missing on pectoral AP sections for 10 of 162 fish in the 1968 sample from Lake Carl Blackwell.

Formation of annuli by tagged fish. Six fish, tagged in 1970 and recaptured in 1971, had formed one new annulus between tagging and recapture. As the distal portion of the left pectoral spine had been removed when these fish were tagged August-September 1970, the number of outermost annuli could be compared between BR sections of the left and right pectoral spines. The two tagged fish which were recaptured later (October) in 1971 also had a faint "summer" or "spawning" mark between the new annulus and the total spine radius. By contrast, a gravid female which had grown 9 mm when recaptured on 14 July 1971 had not formed a summer mark.

Total Length-Pectoral Spine Radius Relationship

Linear and curvilinear regressions were computed between total length and total spine radius of pectoral AP sections of 192 fish (ranging from 208 to 1001 mm) collected in 1967 and 1968. The null hypothesis, that variation in total length did not contribute to variation in pectoral spine radius, was rejected by analysis of variance for both linear and curvilinear regressions. The probability of the computed F statistic testing the null hypothesis, $\beta = 0$, was less than 0.005 for both linear and curvilinear regressions. The null hypothesis that a significant reduction in variance resulted from computing the second degree equation was rejected (probability of the computed F was > 0.10). Therefore, the linear regression,

$$Y = 75.64 + 4.389\ X \text{ (Figure 3)}$$

where Y = total length in mm and X = spine radius in ocular units (1 unit = 0.038 mm), adequately described the body-spine radius relationship for all fish.

When the 75.6 mm intercept was used to back-calculate lengths at annuli in 1968, mean calculated lengths at ages 1-3 were greater than the mean lengths at capture of fish in age-groups 1-3. For example, mean calculated length at age 1 was 119 mm, but mean length was only 81 mm for eight age-1 fish captured June-October. Because the 75.6 mm intercept was computed from a sample where 84% of the fish were in the 500-800 mm length range, the computed linear regression was biased and mainly described the length-spine radius relationship of adult fish.

In order to give equal weight to measurements of fish of all lengths, a linear regression was computed from the mean lengths and mean pectoral spine radii of fish in 16 50-mm length classes. The computed linear regression was described by the equation:

$$Y = 11.03 + 4.9277\ X \text{ (Figure 3)}$$

The use of mean lengths and mean radii of fish in 50-mm lengths classes permitted calculation of a relationship which was weighted equally for length and spine radius measurements of fish in all length classes collected. Therefore, the intercept of 11.0 mm was used to back-calculate growth for fish from Boomer Lake and Lake Carl Blackwell in 1967 and 1968. When the intercept of 11.0 was used, mean calculated lengths at younger ages agreed well with lengths of fish at the time of capture (Table 3).

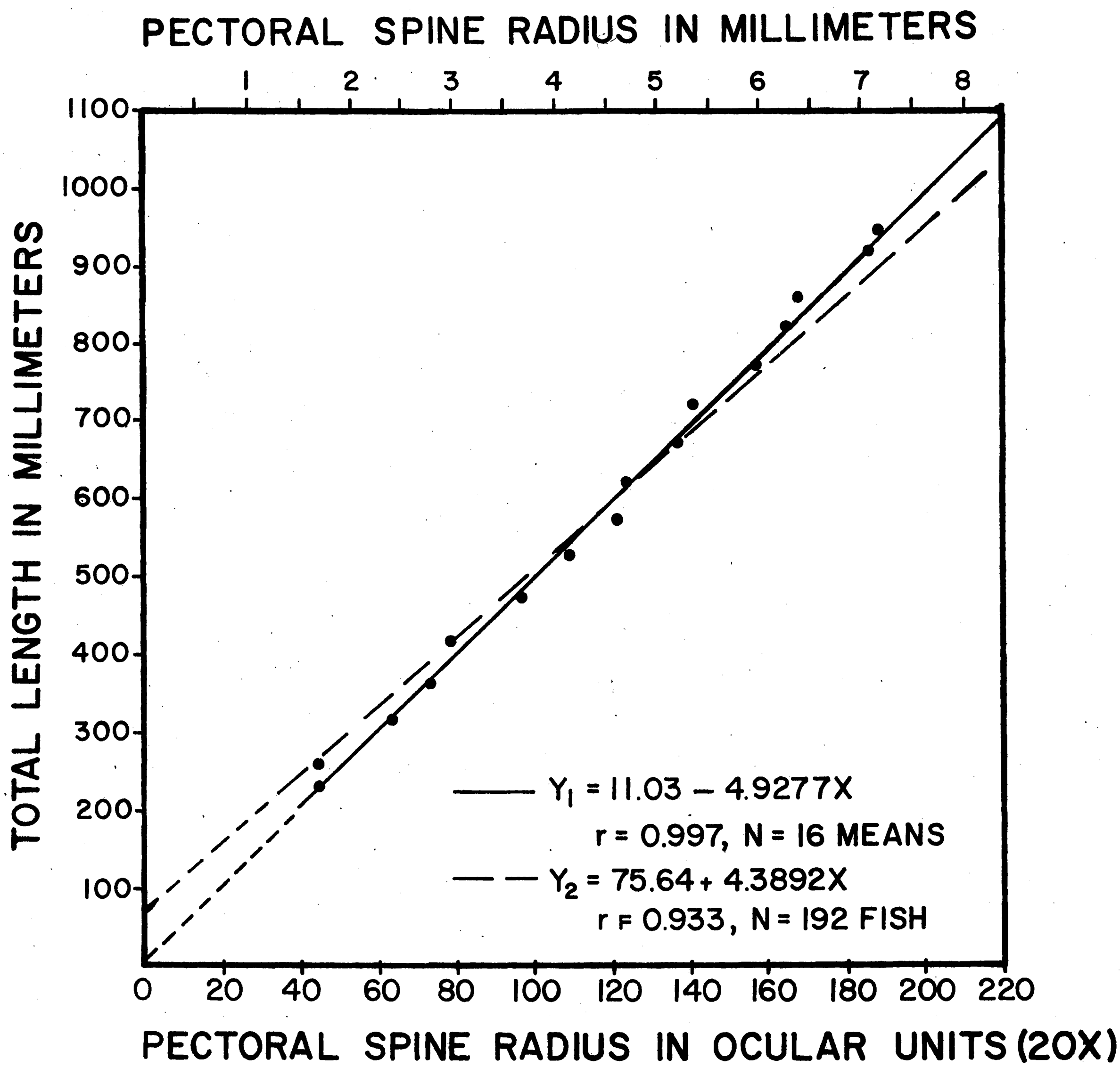


FIGURE 3.--Total length-pectoral spine radius relationships calculated from means of length classes (Y_1) and from all 192 flathead catfish (Y_2) collected from Lake Carl Blackwell in 1967-1968. Points represent mean spine radii and mean total lengths of fish in 50-mm length classes.

Accuracy of Back-calculated Growth

Evidence for the accuracy of calculated growth has been implied previously in this paper, particularly by the agreement between mean calculated lengths at age n and lengths at capture of fish in age-group $n-1$.

Growth of fish tagged in 1968 was similar to calculated growth increments of similar-sized fish in the 1968 sample. Mean growth rates for all males and females both tagged and recaptured in 1968 were 8.0 and 2.6 mm/month, respectively (Table 4). Because these growth rates were calculated from length increases during the growing season, they were probably greater than annual growth rates. Growth of fish tagged in 1968 and recaptured in 1969 was considered more comparable to annual length increments. These growth rates for tagged males and females were 3.6 and 2.4 mm/month (43 and 29 mm/year), respectively. In comparison, mean increments for males and females calculated for fish which were 630-800 mm at the beginning of the length increment were 51 and 31 mm, respectively. Tagged fish were also 630-800 mm when tagged in 1968. This agreement between two independent estimates of growth for both sexes substantiate the accuracy of the method used to back-calculate lengths from annuli measurements.

Annuli Loss Due to Lumen Enlargement

The percentages of fish in age-groups 3 to 21 having one, two, three, four, and five annuli completely missing from BR sections (cut from the distal end of the basal recess) of the pectoral spine were determined for 317 flathead catfish from Lake Carl Blackwell (Table 5).

TABLE 4. Growth of tagged flathead catfish in Lake Carl Blackwell during 1968 and 1969.

Tagging date	No. of fish	Mean length when tagged	Recapture date	Mean growth[a] (mm/month)
		Males		
March-June 1968	7	693	May-August 1968	8.0
March-May 1968 (spring)	2	684	October 1969 (fall)	3.6
		Females		
March-July 1968	19	698	May-September 1968	2.6
May-July 1968	8	692	June-October 1969	2.4

[a]Mean growth date was obtained by averaging growth rates of each fish in the sample.

TABLE 5. Percentages of flathead catfish captured in Lake Carl Blackwell from 1967-1971 which were missing one or more annuli from pectoral spine cross-sections cut from the distal end of the basal recess.

Age group	Number of fish	Percentage of fish missing annulus indicated				
		1st	2nd	3rd	4th	5th
3	10	60				
4	18	78	6			
5	45	96	31			
6	57	98	65	5		
7	49	100	55	8		
8	30	100	60	7	3	
9	34	100	88	21		
10	27	100	100	22	4	
11	18	100	100	61	6	6
12	8	100	88	75		
13	11	100	100	55	36	9
14	4	100	100	50		
15	3	100	100	67		
16	1	100	100	100		
17	1	100	100	100		
21	1	100	100	100	100	
Total of all age groups	317	97	65	16	3[a]	1[a]

[a]Total number used to calculate percentage missing for the fourth and fifth annuli does not include fish in age-groups 3 and 4, respectively.

When compared to the number of annuli found in pectoral AP sections, the first annulus was missing from 60, 78, 96, and 98% of the fish in age-groups 3, 4, 5 and 6, respectively. Two annuli were absent in 55 to 88% of the fish in age-groups 6-9. In age-groups 10 and older, all but one age-12 fish had two annuli missing. The first loss of the third annulus occurred in fish of age-group 6 and increased in percentage occurrence with age. Four annuli were missing from basal recess sections of the single fish in age group 21. One fish in each of age-groups 11 and 13 was missing five annuli.

The percentages when members of an age group lost the second through fifth annuli appears related to the variation in growth rate and relative location of the pectoral spine lumen in individual fish. A greater number of annuli was missing from spines where the lumen of the spine was anterior to its normal position (Figure 2B). Conversely, fewer annuli than the normal number of annuli for that age group (Table 5) were missing when the lumen was more posterior than normal.

For known-age fish from Boomer Lake, all pectoral BR sections of age-groups 4 and 5 were completely missing the first annulus. The percentage of fish missing the first and second annulus were as follows:

Age group	Number of fish	Percentage of fish missing annulus	
		1	2
4	12	100	18
5	4	100	24

Comparative Value of Pectoral and Dorsal AP Sections

Age of 56 flathead catfish (243 to 921 mm), collected June-August 1968, was determined by study of articulating process sections cut from both pectoral and dorsal spines. The frequency of bone degeneration obscuring the innermost annuli tended to increase with age. Forty-one per cent of the first and nine per cent of the second annuli were obscured in dorsal AP sections of fish in the sample (Table 6). These annuli could be seen in pectoral AP sections, but degenerative changes in the innermost bone tissue of dorsal spines obscured the annular marks in AP sections.

The most recently-formed annulus seen in pectoral AP sections was not visible in 9% of dorsal AP sections (Table 6). These missing annuli were either too indistinct to observe or had not yet formed in dorsal AP sections. The last annulus had not yet formed on either pectoral or dorsal AP sections of five fish collected in June. However, annulus formation on pectoral AP sections usually occurred in April-June for adult flathead catfish.

Annuli in the peripheral region of dorsal AP sections were either too indistinct or too difficult to read for six fish so they were not included in Table 6. Additional dorsal sections were cut distal to the basal recess in an attempt to reconcile the differences seen in dorsal and pectoral AP sections. A series of cross-sections were made on the dorsal spines of two age-10 females at 5 mm intervals from the basal foramen distally to the longitudinal midpoint of the spine. The most recently-formed annuli, which had been missing or obscure in the peripheral region of dorsal AP sections, were discernible in sections cut

TABLE 6. Percentages of flathead catfish captured June-August 1968 in Lake Carl Blackwell which were missing annuli in articulating process sections of the dorsal spine.

Age group	Number of fish	Length at capture (mm)	Percentage[a] of fish missing annulus indicated			
			First	Second	Last	Other
3	2	251	0	0	0	0
4	9	344	0	0	0	0
5	8	585	38	0	0	0
6	15	632	53	0	20	13
7	9	656	44	11	11	0
8	5	658	60	20	20	0
9	4	677	50	50	0	0
10	3	810	67	33	0	33
11	1	763	100	0	100	0
Total of all age groups	56	-	41	9	9	5

[a]The number of fish missing annuli were determined by comparing dorsal AP sections with pectoral AP sections from the same fish.

more distally on the dorsal spine. Therefore, the outermost annuli were either not formed or were too close together to distinguish in dorsal AP sections of these large (832 and 786 mm) fish. The growth in diameter of the dorsal spine near its base is quite small in some older, slow-growing fish, thereby limiting the use of dorsal AP sections for age determination.

Back-calculated Growth

Lake Carl Blackwell. The range in calculated lengths at a specific age increased after age 3 because of the period of accelerated growth which usually occurred in the fourth through seventh years of life (Figure 4). The greatest differences between maximum and minimum lengths of individual fish at a specific age were at ages 4-8. The great variation in length at ages 4-8 was caused by the timing of the growth spurt. In fast-growing fish, this spurt occurred earlier and had greater magnitude; whereas, slow-growing fish had relatively slow growth until the eighth and ninth years.

The range and standard deviation of calculated lengths at specific ages (determined for all fish in 1968) increased rapidly from age 1 through age 5 and then decreased until age 10 (Figure 4). Standard deviation of lengths increased at ages 11-13, but range in maximum and minimum length was similar.

In contrast to the highly variable growth of individual fish, mean hrowth of year classes with sample sizes of $\geq$ 10 fish was similar (Figure 5). Mean lengths at ages 4 and 5 were greater for the 1963 year class than for other year classes.

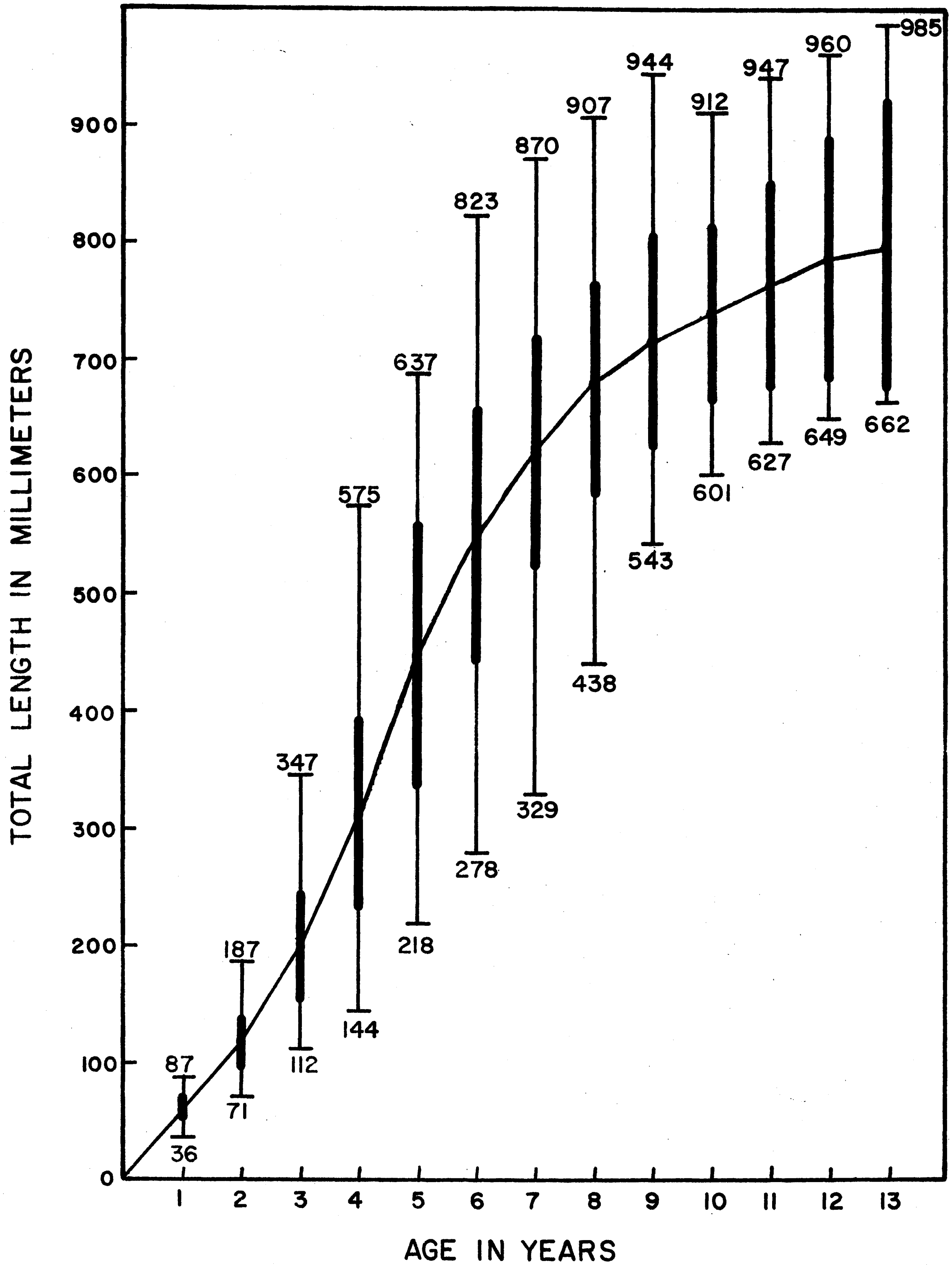


FIGURE 4.--Grand mean total lengths of flathead catfish collected from Lake Carl Blackwell in 1968. The thin vertical lines and numbers represent the range from maximum to minimum total lengths calculated for individual fish at each age. The heavier vertical lines indicate ± one standard deviation from mean calculated length.

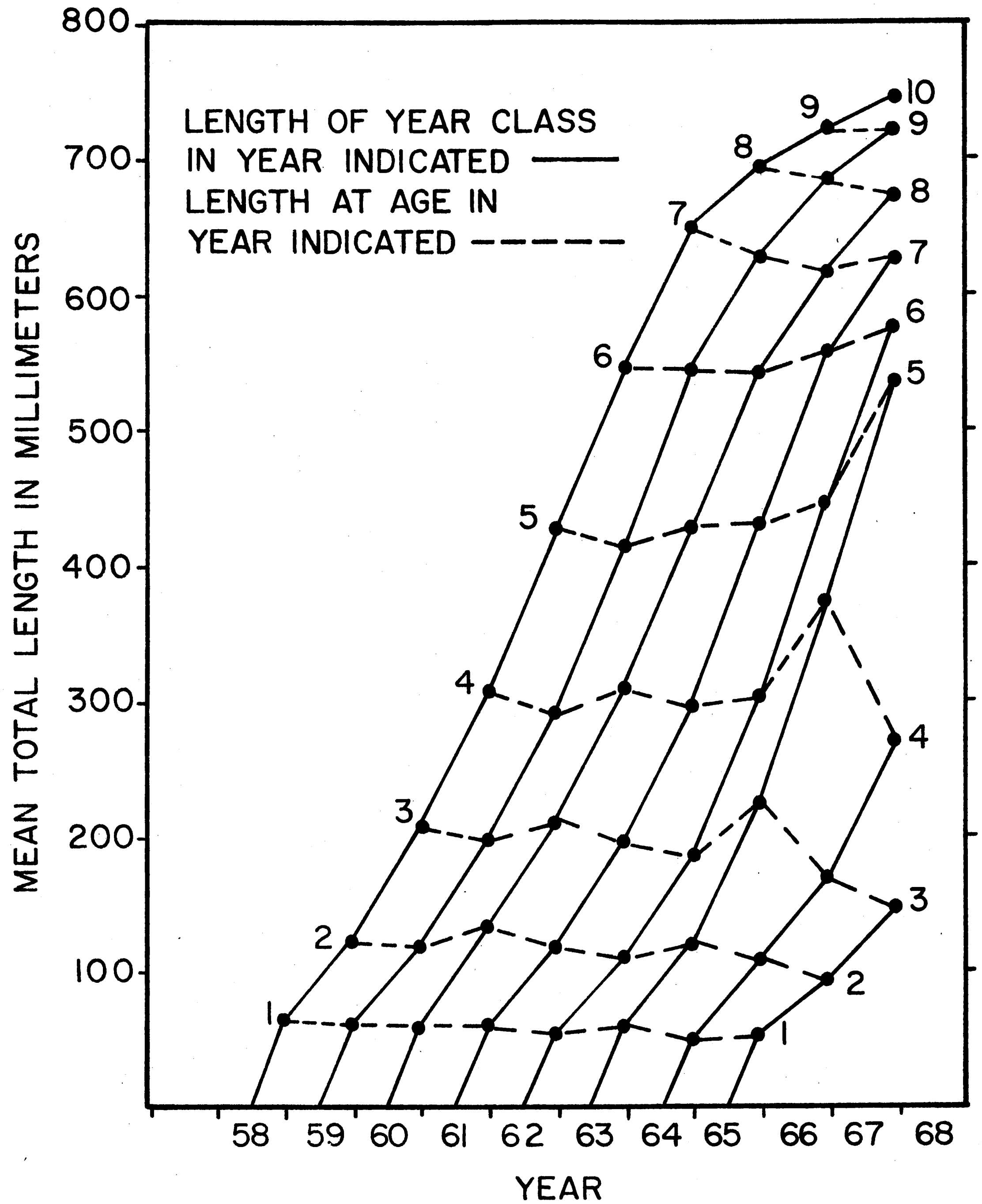


FIGURE 5.--Calculated growth history for the 1958-1965 year cleasses of flathead catfish collected from Lake Carl Blackwell in 1968.

But only fish > 500 mm were caught in the smallest mesh size (76 mm) of gill nets in 1968. Therefore, slower-growing members (<500 mm) of the 1963 year class were not caught, causing calculated growth to be overestimated. This inference was supported by the smaller confidence limits for length at age 5 of the 1963 year class (Table 2). Also lengths of fish in the 1963 year class were less at ages 3-5 when they were calculated from collections in later years (Appendix A).

Boomer Lake. The success of the 1967 introduction of YOY flathead catfish into Boomer Lake was unknown until 1971 when substantial numbers of flathead catfish were caught by fishermen.

Mean length of 18 flathead catfish collected from Boomer Lake by gill nets in August 1971 was 655 mm. Six of these fish were instrumented with untrasonic transmitters and transported to Lake Carl Blackwell. The remaining 12 fish collected in 1971 and 4 fish collected in 1972 were used to calculate growth. The slower growth calculated of fish collected in 1972 suggests that smaller, slower-growing fish were not caught in gill nets in 1971 (Table 7). One unusually slow-growing (465 mm) female captured in 64-mm mesh substantially reduced the growth rate calculated for the 1972 sample. Growth increments were greatest for the third and fourth years of life in both 1971 and 1972.

The five females collected in 1971 had not attained sexual maturity during their fifth summer. Two of the three age-5 females captured in late June 1972 had ripe ovaries. The immature female was the slow-growing (465 mm) fish.

TABLE 7. Calculated total lengths (mm) at time of annulus formation for flathead catfish of known age collected from Boomer Lake in 1971 and 1972.

Year collected (month)	Age group	Number of fish	Mean length at capture (range)	Calculated length at end of year (Range in length)				
				1	2	3	4	5
1971 (August)	4	12[a]	646 (516-715)	65 (46-83)	157 (106-248)	412 (282-598)	593 (466-687)	
1972 (June)	5	4	586 (465-657)	63 (54-71)	111 (94-131)	300 (174-411)	480 (294-579)	560 (413-633)
1971 and 1972	-	16	-	64	145	384	565	560

[a]Six additional fish used in telemetry experiments at Lake Carl Blackwell in 1971 had an average length of 672 mm.

DISCUSSION

Age and growth determined from pectoral AP sections were considered accurate for the following reasons: (1) close agreement between assigned age and length of fish; (2) agreement between calculated lengths and empirical lengths of fish at time of capture; (3) similarity of calculated growth histories in 1967 and 1968; (4) agreement between annular marks and age of fish from Boomer Lake which were of known age; (5) only one annulus formed per year on spines of tagged fish; and (6) growth determined for tagged fish was similar to growth calculated from annuli measurements of pectoral AP sections.

Different methods of age determination and back-calculation of channel catfish growth have been described and validated by Appelget and Smith (1951) using the fifth vertebra, and by Sneed (1951) using pectoral spine sections from the distal end of the basal recess (BR sections). Marzolf (1955) compared the use of these methods on channel catfish and recommended BR sections of the pectoral spine for age determinations over vertebra because spines were easiler to collect, prepare, read and had fewer false annuli. However, he noted the following problems: (1) as the lumen of the pectoral spine increased in diameter in age, degeneration of the innermost bone tissue partially obscured the first annulus; and (2) the basal recess enlarges and elongates distally as the spine grows, causing increasing error in calculated length at age 1.

The two problems noted by Marzolf (1955) were found to be more serious in flathead catfish than for channel catfish because of differences in the morphology and growth of the pectoral spine. The distance from the proximal portion of the pectoral spine to the end of the basal recess averaged 27% of spine length for five flathead catfish compared to 19% for four channel catfish of similar size. In addition the diameter and length of the pectoral spine (compared to total length) was less for young flathead catfish than for channel catfish which have a relatively large, elongate spine at age 1. Also, the pectoral spine lumen of adult flathead catfish has a relatively greater diameter than the spine lumen of channel catfish of similar lengths. These differences in spine morphology and growth, coupled with the greater potential length of flathead catfish, combine to make Sneed's (1951) method for age determination of channel catfish unsatisfactory for determining the age of large flathead catfish. In fact, use of only pectoral BR sections could also cause underestimation of age in large channel catfish, especially if growth had been slow in the first few years of life.

To minimize the problem of lumen enlargement in pectoral spines, Jenkins (1954) used BR sections from dorsal spines for larger flathead catfish because of their greater summetry and smaller spine lumen. Layher (1976) found dorsal BR sections gave more accurate estimates of age for flathead catfish than pectoral AP sections (Table 8). However, I found AP sections of dorsal spines, which have no lumen, less desirable for age determinations than pectoral AP sections because of the following: (1) degeneration of the interior region of dorsal AP sections often obscures the innermost (first) annulus; (2) annular marks were relatively less distinct in dorsal AP sections; (3) the minimal growth in diameter of the dorsal spine near its base in older, slow-growing fish caused the outermost annuli to be so closely spaced that they were impossible to see when using AP or BR sections for some older fish.

TABLE 8. Ages when total lengths could not be calculated from pectoral spine cross-sections cut from the distal end of the basal recess of flathead catfish.

Habitat (Reference)	Procedures for estimation	Ages when calculation of length at annulus not possible (Age when annulus first observed missing)[a]				
		1	2	3	4	5
Upper Des Moines River, Iowa (Muncy, 1957)	Series of size classes, personal judgment	≥ 5	9, 12-15	14		
Lower Des Moines River, Iowa (Mayhew, 1969)	Comparison of calculated total lengths of age groups	≥ 6	≥ 8			
Missouri River, Nebraska (Langemeier, 1965)	Articulating process sections of pectoral spines	≥ 4 (2)	≥ 9 (4)	≥ 12 (7)	≥ 15 (15)	
(Holz, 1969)		≥ 5 (1)	≥ 9 (5)	- (10)		
Milford Reservoir, Kansas (Layher, 1976)	Comparison of BR sections of pectoral and dorsal spines or comparison of calculated lengths at age	7 (3)	10 (4)	11.14 (5)	16 (7)	
Lake Carl Blackwell, Oklahoma (Present study)	Articulating process sections of pectoral and dorsal spines	≥ 7 (3)	10, 11, 13 (4)	≥ 16	21 (8)	- (11)

TABLE 8 (Continued)

Habitat (Reference)	Procedures for estimation	Ages when calculation of length at annulus not possible (Age when annulus first observed missing)[2]				
		1	2	3	4	5
Boomer Lake, Oklahoma (Present study)	Articulating process sections of known age 4 and 5 fish	4, 5 (4)	- (4)			

[a]In Langemeier (1965) and Holz (1969) this was the age at which the annulus was first observed missing along the antero-lateral radius used for radii measurements. In Layher (1976) and the present study the annulus was completely missing from pectoral BR sections for fish in age groups indicated.

[b]In this study the age when annuli were first missing was not indicated. It was also unclear as to whether the inability to back calculate for a given age indicated the annulus was completely missing or only missing along the maximum posterior radius used for measurements.

Muncy (1957) estimated the first and second annuli were lost because of enlargement of the lumen in pectoral BR sections for flathead catfish older than ages 5 and 12, respectively (Table 8). Mayhew (1969) also estimated the first and second annuli were incomplete or missing by ages 6 and 8, respectively, in pectoral BR sections of flathead catfish.

Langemeier (1965) determined the number of annuli missing in pectoral BR sections of flathead catfish by making comparisons to the number of annuli in AP sections of the pectoral spine. He found the first annulus was missing along the antero-lateral radius of BR sections of all age-4 and older fish (Table 8). Two annuli were missing in pectoral BR sections of all age-9 and older fish. Ihm (1968) also used pectoral AP sections as an aid in distinguishing between the outermost annuli in the peripheral region of pectoral BR sections of channel catfish and black bullhead, *Ictalurus melas*.

The age of older flathead catfish could be accurately determined only by using AP sections of the pectoral spine (Langemeier 1965; Holz 1969; present report). The loss of the first annulus typically occurs by age 5 and up to four additional annuli were lost in older fish (Table 8). Loss of annuli because of lumen enlargement in pectoral BR sections has probably resulted in underestimation of the age of older fish in many reports. If so, growth rates of flathead catfish calculated from measurements of annuli found in pectoral BR sections would be overestimated. Even the comparability in growth between different waters by the same worker would be affected because errors in age determination would vary with growth rate.

Although Langemeier (1965) used pectoral AP sections to determine age, he resorted to pectoral BR sections for measurements of annuli because AP sections lacked a "constant reference point such as the center of the lumen" which could be used as the origin of the spine radius. However, my experience indicates that it is undesirable to use the center of the lumen of pectoral BR sections as the origin of the spine radius for the following reasons: (1) the pectoral spine lumen is not necessarily in the center of the spine (Muncy 1957; present report); (2) lumen enlargement obliterates one to five of the innermost annuli, it would be necessary to extrapolate the origin of the radius used for measurements; (3) as the basal recess enlarges and elongates distally during growth, the point of sectioning also moves distally; and (4) even when the origin is accurately estimated, measurements of annuli for back calculation of length is impossible for the missing annuli in BR sections. Considering these problems, encountered when using pectoral BR sections for measurements of annuli, pectoral AP sections are recommended for age determination and back calculation of growth. Although AP sections of pectoral spines may underestimate age of flathead catfish if sections were not made in the region containing the first year's spine growth, a series of carefully cut AP sections from both pectoral spines should provide at least one section having the correct number of annuli. AP and BR sections from the dorsal spine can also be helpful in distinguishing false annuli and recently formed annuli, but the potential for underestimation of age in older fish always remains a possibility.

Growth of flathead catfish in Lake Carl Blackwell was slower at ages 1-4 than in fish from other waters where data appears accurate, but was similar at age 5 and older to growth in the Missouri River (Table 9).

TABLE 9. Calculated total lengths (mm) of flathead catfish in studies where the loss of annuli was realized as a problem when using BR sections of the pectoral spine.

Habitat	Number of fish (Number $>$ age 5)	Mean calculated total length (mm) at end of year														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Upper Des Moines River, Iowa (Muncy 1957)	61 (22)	76	163	236	333	439	526	612	676	747	810	861	902	927	894	815
Lower Des Moines River, Iowa (Mayhew 1969)	282 (25)	142	269	393	469	550	600	674	714							
Missouri River, Nebraska																
Unchannelized (Langemeier 1965)	195 (22)	93	184	273	356	451	520	603	642	691	776	819	842			
(Holz 1969)	158 (42)	79	169	260	331	395	455	517	560	598	717					
Channelized (Langemeier 1965)	195 (8)	90	181	298	399	466	515	528	637	762	816					
(Holz 1969)	212 (6)	75	188	321	411	487	541	536	541							
Milford Reservoir, Kansas (Layher 1976)	196 (76)	164	230	316	412	517	591	700	796	837	869	894	909	926	942	915
Lake Carl Blackwell, Oklahoma (Present study, 1968)	162 (123)	58	117	198	309	446	549	623	678	714	738	761	785	794		
Boomer Lake, Oklahoma (Present study)	16 (0)	64	145	384	565	560										

Although Mayhew's (1969) fish were collected downstream from those of Muncy (1957), the large difference in growth between studies was difficult to reconcile. Mayhew's (1969) data indicates either substantially faster growth in the lower portion of the Des Moines River or underestimation of age. Likewise, the rapid growth in Milford Reservoir, Kansas (Layher 1976) may be related to either more favorable growing conditions than existed in Lake Carl Blackwell or errors in age determination caused by using BR sections of the dorsal spine.

Length of flathead catfish at ages 1-5 in Boomer Lake greatly exceeded growth of fish in the established population in Lake Carl Blackwell (Table 9). Calculated lengths at ages 3 and 4, of fish from Boomer Lake were nearly twice the lengths of fish from Lake Carl Blackwell. As flathead catfish were stocked in Boomer Lake as fingerlings in 1967 to increase predation on slow-growing white crappie (Pomoxis annularis) and sunfishes (Lepomis spp.), the supply of prey fishes may have been greater in Boomer Lake than in Lake Carl Blackwell where intraspecific competition from other age-groups of flathead catfish was a factor.

The lengths of immature females (640-695 mm) collected from Boomer Lake in August 1971 at age 4 exceeded the length of the largest immature female (573 mm) collected in Lake Carl Blackwell (Turner and Summerfelt 1971c). Females reached sexual maturity at age 5 in both reservoirs.

CHAPTER IV

GROWTH OF FLATHEAD CATFISH IN LAKE CARL BLACKWELL

INTRODUCTION

Brown (1957) has concluded that food supply is the most important factor affecting the growth of fishes and that increased food supply can result in improved growth. Changes in the type and quantity of food has been related to growth for many piscivores (Ruelle 1971), but not for flathead catfish in reservoirs. Variation in the taxa of foods utilized by fish of different sizes have been reported for flathead catfish (Minckley and Deacon 1959; Langemeier 1965; Turner 1971; Layher 1976). Here, the growth pattern of flathead catfish is examined in relation to changes in the type of foods used, age at sexual maturity and sex. The effects of gear selectivity on calculated growth is also discussed.

METHODS

Flathead catfish were collected in Lake Carl Blackwell from June 1967 through July 1972. Methods used in the collection of fish, determination of age, calculation of growth in 1967-1968, and tagging of fish were given previously (Chapter III).

Linear regressions were calculated between total length (Y) and spine radii (X) of pectoral AP sections for all fish in the 1969, 1970 and 1971 collections and between mean lengths and mean spine radii of fish in 50 mm length classes for the 1967-1971 collections. Mean lengths at the end of each year of life and mean length increments were computed from annuli measurements of each fish using the intercept and slope of the linear regression calculated from the 1967-1971 data. Growth histories were computed separately for fish in 1969, 1970, 1971, and 1972. A combined growth history was determined by a weighted summation of calculated lengths for all fish in the 1967-1972 collections. Grand mean length increments were summed through each year of life. Weights were determined for fish of a length equivalent to each successive sum of length increments using the length-weight relationship of fish in 1967-1968 (Turner and Summerfelt 1971b). The differences in weight between successive ages were used as estimates of weight gains during each year of life.

Grand mean lengths and length increments were calculated separately for males and females in the 1968 and 1971 collections. Weighted summations of calculated lengths and increments were determined for males and females from data in 1968 and 1971. Cumulative sums of mean increments also were calculated for both sexes to produce a smooth growth curve (after Hile 1941).

The selectivity of each mesh size of experimental gill nets was determined by calculating the percentage of fish caught in a specific mesh size that were in each 40-mm length class. These percentages were based on fish collected from 1967-1971. The effects of sampling bias on calculated growth was evaluated by comparing growth of the same year class determined from fish collected in different years.

RESULTS

Calculated growth and length-spine radius relationships of flathead catfish collected in 1967 and 1968 were discussed in Chapter III. Separate growth histories were calculated for fish collected in 1968 (Table 3) and in 1967, 1969, 1970, 1971, and 1972 (Appendix A). Number of flathead catfish either removed from Lake Carl Blackwell for life history studies or tagged and released were stratified by month and year (Table 10).

Total Length-Spine Radius Relationship

Total length was linearly related to spine radius of pectoral AP sections for all fish in 1969, 1970, and 1971. However, the variation in the slope and intercept between the following linear regressions in different years made growth comparisons between years impractical:

Year	Number of fish	Intercept	Slope	Correlation coefficient
1969	23	84.28	4.149	0.851
1970	29	-38.52	5.222	0.952
1971	80	31.47	4.731	0.892

Therefore, a single regression describing the length-spine radius relationship for all fish collected during 1967-1971 was calculated from the mean lengths and mean spine radii of fish in 18, 50-mm classes. This regression was described by:

$$Y = 14.56 + 4.848\ X \ (r = 0.997)$$

TABLE 10. Number of flathead catfish from Lake Carl Blackwell removed for life history studies or tagged and released.

Month	1967		1968		1969		1970		1971		Total	
	Removed	Tagged	Removed	Tagged	Removed	Tagged	Removed	Tagged	Removed	Tagged	Removed	Tagged
January	-	-	-	-	-	1	1	-	1	3	2	4
February	-	-	4	-	-	-	-(1)	-	1	5	5(1)	5
March	-	-	16	24	-	-	-	6	2(1)	21	18	51
April	-	-	18	18	-	-	1	12	3(3)	6	22(2)	36
May	-	-	49(6)[a]	32	5	3	5(2)	8	11(6)	22	70(19)	65
June	17	13	39(4)	42	11	43	9(5)	23	30(19)	44	106(26)	165
July	5	-	28	33	10	8	8(4)	20	27(16)	9	78(19)	70
August	13	17	26	3	4	-	3	8	9(2)	2	55(2)	30
September	4	4	7	-	1	3	1	2	1	-	14	9
October	3	-	-	-	5	12	1	13	17	19	26	43
November	-	-	2	3	-	-	2	27	3	-	7	30
December	4	-	-	-	-	-	1	16	-	-	5	15
Total	46	34	189(10)[a]	155	36	70	32(12)	135	105(47)	131	425(86)[b]	525

[a]Number of flathead catfish carcasses obtained from snagline fishermen. Spines and ovaries were removed from these fish for analysis.

[b]This number included 17 fish captured by snagline fishermen in 1972.

where Y = total length in millimeters and X = total spine radius in ocular units. This linear regression was used when lengths at the end of each year of life were calculated for fish in 1969-1972.

Sex Differences in Growth

Mean calculated lengths. At ages 3-7, grand mean lengths of females were 12-22 mm greater than for males in 1968 (Table 11). In contrast, males had greater mean lengths than females at ages 9-13. In 1971, males had slightly greater grand mean lengths than females at ages 1-4. Mean lengths were 27-88 mm greater for males than females at ages 5-14. The percentage of males in age-groups 9 and older was greater in 1971 than in 1968 (Appendix A). When 1968 and 1971 data were combined, males had 24-73 mm greater grand mean lengths than females at ages 8-14 (Figure 6).

Mean growth increments. Grand mean increments were 1-8 mm greater for females than for males for the first four years of life in 1968 but mean increments of males exceeded those for females by 10-32 mm for the seventh through twelfth years (Table 12). In 1971, grand mean increments usually were greater for males than for females for the fifth-thirtheenth years. When increments in 1968 and 1971 were combined, growth in the fifth-thirteenth years was 6-18 mm greater for males than for females.

In 1968, the sum of the first eight increments was 32 mm greater for males than for females (Table 12). The sum of the first 13 increments was 112 mm greater for males than for females. Summation of mean increments in 1971 also emphasized the greater increments for males in most years of life.

TABLE 11. Grand mean calculated total lengths of female and male flathead catfish collected from Lake Carl Blackwell in 1968 and 1971

Year and sex[a]	Grand mean length (mm) at end of year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1968														
Females	59 (89)[b]	119 (89)	203 (89)	315 (88)	453 (84)	559 (72)	632 (55)	681 (41)	716 (29)	738 (19)	764 (6)	802 (3)	734 (1)	
Males	58 (71)	115 (71)	191 (71)	297 (68)	438 (63)	537 (50)	614 (37)	678 (25)	721 (15)	758 (9)	779 (8)	814 (4)	879 (3)	
1971														
Females	63 (49)	121 (49)	195 (47)	313 (47)	449 (46)	549 (40)	610 (33)	656 (22)	699 (20)	728 (15)	723 (10)	756 (7)	781 (4)	789 (2)
Males	65 (39)	123 (39)	204 (38)	325 (37)	476 (35)	592 (32)	663 (26)	715 (24)	753 (17)	780 (13)	811 (9)	781 (4)	811 (3)	816 (1)
1968 and 1971														
Females	60 (138)	120 (138)	200 (136)	314 (135)	452 (130)	555 (112)	624 (88)	672 (63)	709 (49)	734 (34)	738 (16)	770 (10)	772 (5)	789 (2)
Males	60 (110)	118 (110)	196 (109)	307 (105)	452 (98)	558 (82)	634 (63)	696 (49)	738 (32)	771 (22)	796 (17)	798 (8)	845 (6)	816 (1)

[a] Separate growth history tables for females and males in both 1968 and 1971 are in Appendix A.

[b] Number in parenthesis is the number of fish used to determine grand mean length.

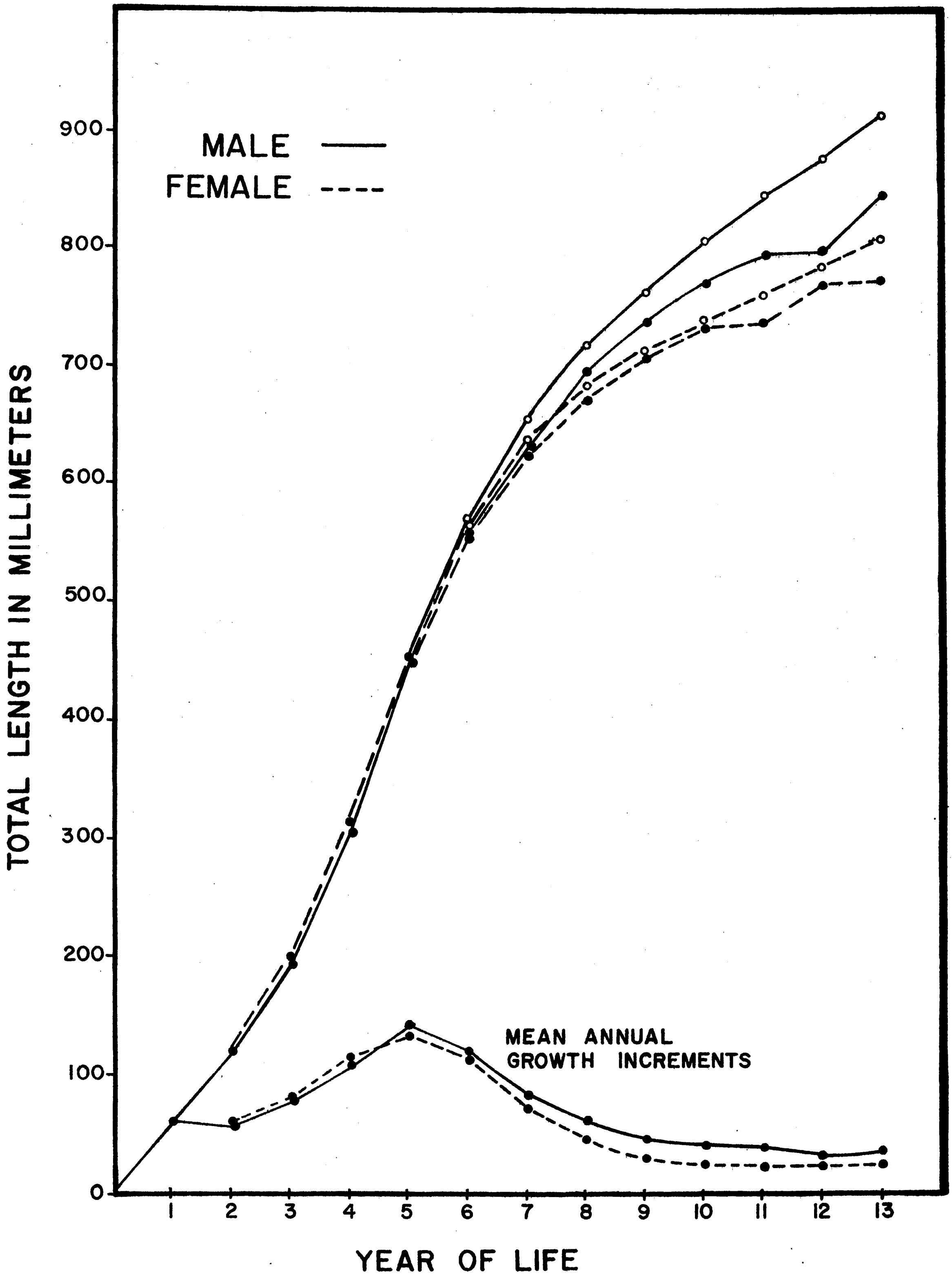


FIGURE 6.--Grand mean calculated lengths ←(●) and cumulative sums of grand mean increments (o) for male and female flathead catfish collected from Lake Carl Blackwell in 1968 and 1971.

TABLE 12. Grand mean increments in millimeters and cumulative sums of increments for females (F) and males (M) collected from Lake Carl Blackwell in 1968 and 1971.

Ages	1968				1971				1968 and 1971			
	Grand mean increment[a]		Cumulative sum of increments		Grand mean increment[a]		Cumulative sum of increments		Grand mean increments		Cumulative sum of increments	
	F	M	F	M	F	M	F	M	F	M	F	M
0-1	59	58	59	58	63	65	63	65	60	60	60	60
1-2	60	57	119	115	58	58	121	123	59	57	119	117
2-3	83	77	202	192	76	81	197	204	81	78	200	195
3-4	112	104	314	296	118	121	315	325	114	110	314	305
4-5	134	138	448	434	137	154	452	479	135	144	449	449
5-6	119	123	567	557	109	118	561	597	115	121	564	570
6-7	80	90	647	647	61	78	622	675	73	85	637	655
7-8	44	76	691	723	49	49	671	724	46	63	683	718
8-9	28	48	719	771	35	46	706	770	31	47	714	765
9-10	22	44	741	815	28	41	734	811	25	42	739	807
10-11	19	39	760	854	23	38	757	849	22	38	761	845
11-12	18	32	778	886	26	33	783	882	24	32	785	877
12-13	30	34	808	920	22	39	805	921	24	36	809	913
13-14	-	-	-	-	24	19	829	940	24	19	833	932

[a]Tables giving mean increments for each year class collected in 1968 and 1971 are available for males and females in Appendix A.

The cumulative sum of increments was 27 mm greater for males than for females after 5 years and increased to a difference of 116 mm in favor of males after 13 years. When mean increments were combined for 1968 and 1971, the sum of the first five increments were equal for males and females (Figure 6). The greater cumulative sum of increments for males after 5 years increased from 6 mm after 6 years to 104 mm after 13 years.

Growth of tagged fish. Mean growth of adult fish between tagging and recapture was usually greater for males than for females, e.g., growth of 7 males and 19 females tagged and recaptured in 1968 averaged 8.0 and 2.6 mm/month, respectively (Table 4). Growth of males also was greater than for females in 1969 and 1971. Mean growth of all same-year recaptures of tagged fish was 7.7 mm/month for 10 males and 2.8 mm/month for 27 females (Appendix B). Growth rate of fish tagged in 1968 and recaptured in 1969 was 3.6 mm/month for males and 2.4 mm/month for females (Table 4).

Effect of Sampling Bias on Calculated Growth

Comparisons of grand mean lengths computed separately by year for fish taken in 1967-1972 indicated growth rates were similar in most years, particularly in 1968-1971 (Table 13). Mean lengths of fish collected in 1967 were less at ages 7-9 than in other years. Except for five fish, flathead catfish in 1967 were caught in gill netting of 76-mm mesh. This mesh size rarely catches fish > 700 mm (Figure 7). As fish at age 7 and older were often > 700 mm in other years, the larger, more rapidly-growting fish in age-groups 7-9 were not caught in 1967.

TABLE 13. Grand mean calculated total lengths in millimeters for flathead catfish collected from Lake Carl Blackwell in 1967-1972. Number in parentheses indicates the number of fish in each mean.

Year of Collection	Grand mean total length (mm) at end of year																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1967	61 (27)	118 (27)	197 (27)	310 (27)	454 (27)	552 (23)	604 (13)	640 (7)	673 (4)	719 (1)	742 (1)						
1968	58 (164)	117 (164)	198 (164)	309 (161)	447 (151)	551 (125)	625 (94)	680 (68)	718 (46)	744 (30)	771 (16)	806 (9)	832 (6)	938 (2)	962 (2)	979 (2)	1055 (1)
1969	68 (23)	133 (23)	223 (23)	347 (23)	488 (23)	588 (17)	647 (11)	693 (7)	735 (6)	737 (3)	755 (2)						
1970	63 (27)	128 (27)	243 (27)	381 (26)	529 (26)	618 (24)	664 (17)	698 (10)	731 (9)	718 (7)	729 (4)	777 (3)	816 (1)				
1971	64 (96)	121 (96)	199 (93)	318 (92)	459 (89)	566 (80)	633 (66)	685 (53)	718 (41)	744 (32)	757 (23)	759 (14)	784 (10)	798 (4)			
1972	60 (17)	116 (17)	207 (17)	325 (17)	474 (17)	583 (17)	664 (17)	706 (15)	744 (15)	784 (12)	813 (12)	832 (11)	814 (7)	829 (4)	833 (3)	790 (1)	800 (1)
Weighted mean	61	120	204	320	461	565	633	684	722	747	770	794	806	838	885	916	928
Number in mean	354	354	351	346	333	286	218	160	121	85	58	37	24	10	5	3	2

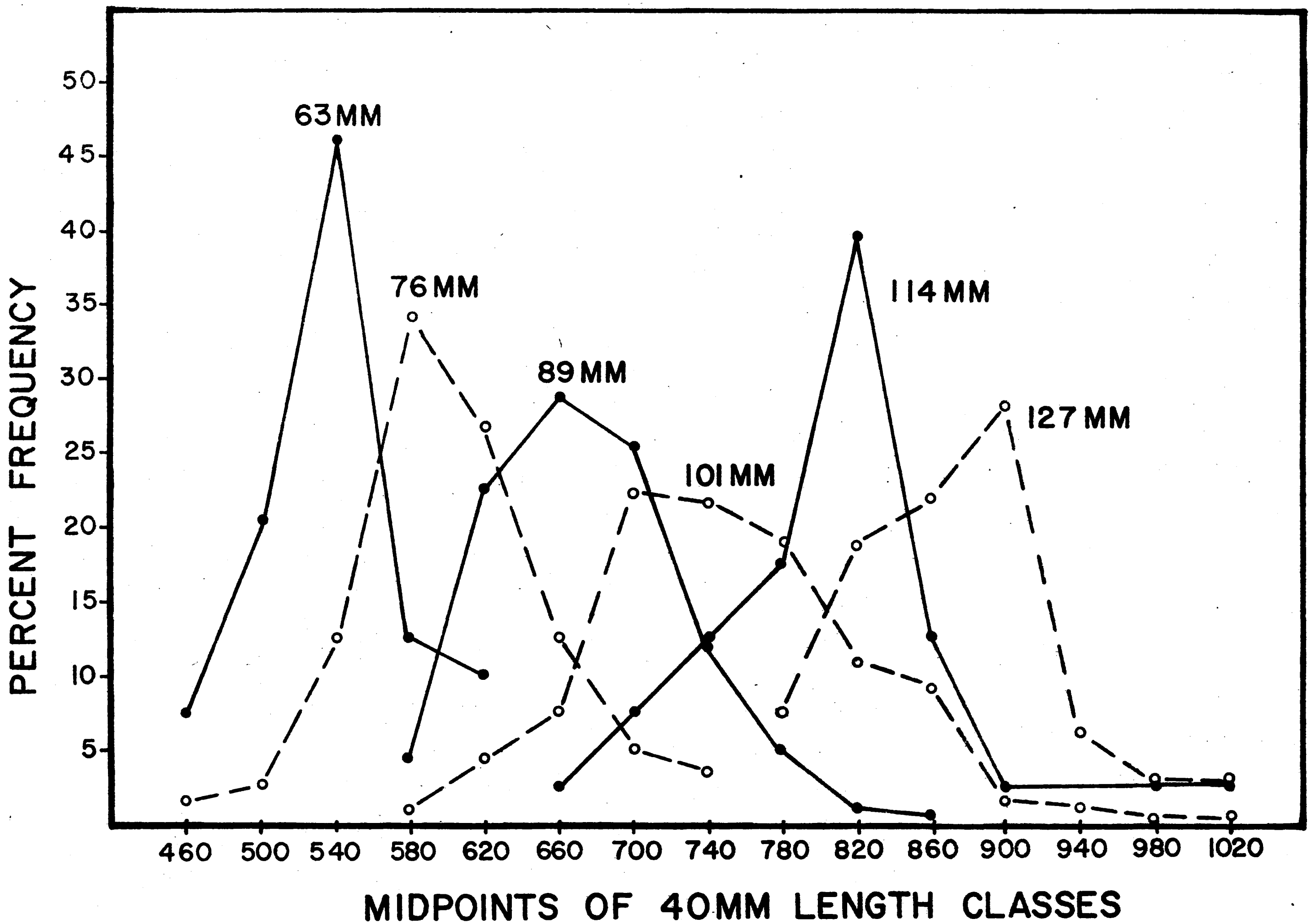


FIGURE 7.--Percent frequency of flathead catfish in 40-mm length classes that were caught in different mesh sizes (square) of hobbled gill nets. Frequencies were based on fish collected 1967-1971.

Therefore, growth of fish in age-groups 7-9 was underestimated, causing grand mean lengths to be lower at ages 7-9 in 1967 than in other years.

Lengths were greater for fish collected in 1972 than in other years (Table 13). The greater mean length (826 mm) and mean age (12) of fish in the 1972 collection probably was influenced by all fish being collected by snagline fishermen. Flathead catfish caught by snaglines were typically larger than fish collected in gill nets. Mean length of fish in the 1972 sample was high, even for fish caught by snag lines. For example, mean length of fish caught by snaglines was 760 mm in 1971. Calculated lengths of the 1957-1960 year classes usually were greater at ages 8-12 for fish in 1972 than for other years (Table 14).

Sampling bias also was apparent for fish in age-group 5 in 1967 and 1968. As the smallest mesh size (76 mm) used in 1967-1968 rarely caught fish $>$ 500 mm (Figure 7), only the larger age-5 fish ($>$ 500 mm) were vulnerable to gill nets in 1967 and 1968. Therefore, growth of the fish in the 1962 and 1963 year-classes was overestimated in 1967 and 1968 when they were age 5.

Growth of Fish in Combined Collections

Mean calculated length. When growth data from all fish collected in 1967-1972 were combined, growth was similar for most year classes represented by $>$ 5 fish (Table 15). Small sample sizes reduced the reliability of calculated lengths for the 1967-1969 and 1956 and older year classes. Mean lengths at ages 1-3 varied little among the 1957-1966 year classes (Figure 8).

TABLE 14. Mean total lengths in millimeters for the 1955-1965 year classes of flathead catfish from Lake Carl Blackwell calculated separately for different collection years.

Year class	Year of capture	Age group	Number of fish	Mean calculated total length at end of year, mm														
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1965	1968	3	3	53	94	147												
	1970	5	2	58	121	245	437	588										
	1971	6	14	62	112	178	312	473	586									
	1972	7	2	59	120	234	400	582	684	720								
	Total		21	60	111	185	336	498	598	720								
1964	1968	4	10	49	108	169	269											
	1969	5	6	70	143	257	408	578										
	1970	6	7	66	130	253	383	564	670									
	1971	7	13	65	124	203	312	450	557	617								
	Total		36	62	124	212	330	510	597	617								
1963	1968	5	26	60	121	225	372	537										
	1969	6	6	67	123	213	339	478	623									
	1970	7	7	67	135	253	399	522	630	682								
	1971	8	12	67	129	210	354	495	579	655	706							
	1972	9	3	60	116	198	314	474	575	653	695	727						
	Total		54	63	125	222	365	520	601	683	704	727						
1962	1967	5	4	65	130	240	387	533										
	1968	6	31	55	110	184	302	444	576									
	1969	7	4	71	138	213	342	493	613	681								
	1970	8	1	53	121	194	379	530	617	666	709							
	1971	9	9	62	111	184	320	484	593	652	701	742						
	Total		49	58	114	191	317	464	661	702	742							
1961	1967	6	10	62	121	191	298	454	568									
	1968	7	26	60	119	194	296	430	557	627								
	1969	8	1	49	87	141	199	272	359	544	656							
	1970	9	2	61	117	267	447	646	738	802	845	889						
	1971	10	9	66	125	201	312	478	604	662	707	752	789					
	1972	11	1	66	123	277	468	648	674	704	740	802	859	900				
	Total		49	61	120	198	307	454	574	644	727	779	796	900				
1960	1967	7	6	55	106	179	301	465	566	617								
	1968	8	22	60	128	210	308	427	542	617	674							
	1969	9	3	57	115	193	282	400	594	675	724	759						
	1970	10	3	66	133	217	335	450	581	651	682	712	745					
	1971	11	9	66	132	210	313	452	574	642	690	727	764	798				
	1972	12	4	58	112	177	268	452	602	694	748	794	836	870	900			
	Total		47	61	124	203	305	439	562	634	689	744	778	820	900			
1959	1967	8	3	62	111	206	288	407	527	592	636							
	1968	9	16	60	118	196	286	413	544	630	685	722						
	1969	10	1	97	180	282	408	583	622	665	690	719	743					
	1970	11	1	53	112	209	257	291	340	462	549	568	602	646				
	1971	12	4	58	103	151	236	381	522	613	653	678	702	734	765			
	1972	13	3	62	114	187	267	376	492	629	685	716	748	778	808	830		
	Total		28	61	116	194	281	406	530	618	669	708	711	740	783	830		
1958	1967	9	3	65	120	180	283	388	518	595	637	667						
	1968	10	14	65	122	212	307	428	547	648	696	723	746					
	1969	11	2	70	143	236	338	430	520	578	666	707	734	755				
	1970	12	2	58	117	219	330	415	517	605	658	692	721	748	770			
	1971	13	6	62	116	176	245	341	475	564	617	669	699	730	760	789		
	1972	14	1	53	111	231	370	519	616	673	721	750	774	798	817	856	880	
	Total		28	64	121	204	297	408	527	617	669	703	733	744	769	799	880	
1957	1968	11	7	59	112	184	264	349	451	580	660	703	735	762				
	1970	13	1	58	151	287	355	457	510	622	670	709	748	772	792	816		
	1971	14	4	58	109	211	312	401	510	607	656	686	712	729	749	775	798	
	1972	15	2	62	112	235	382	495	595	655	695	728	752	775	802	818	845	865
	Total		14	59	114	206	301	392	493	601	665	702	732	755	770	793	814	865
1956	1967	11	1	63	128	213	334	400	494	583	663	691	719	742				
	1968	12	3	60	116	238	363	530	613	677	710	742	768	788	808			
	Total		4	61	119	232	356	498	583	654	698	729	756	776	808			
1955	1968	13	4	49	99	175	278	387	492	560	611	646	695	738	767	794		
	1972	17	1	65	140	216	307	377	458	543	614	656	674	694	709	719	745	770
	Total		5	52	107	183	284	385	485	557	612	648	691	729	755	779	745	770

TABLE 15. Calculated mean total length in millimeters for 354 flathead catfish from Lake Carl Blackwell, 1967-1972.

Year								Weighted mean total length (mm) end of year																				
class	1967	1968	1969	1970	1971	1972	(Total)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1969	-	-	-	-	3	-	(3)	65	160																			
1968	-	-	-	-	1	-	(1)	49	102	194																		
1967	-	-	-	1	3	-	(4)	61	132	262	376																	
1966	-	-	-	-	9	-	(9)	69	122	218	362	501																
1965	-	3	-	2	14	2	(21)	60	111	185	336	498	598	720														
1964	-	10	6	7	13	-	(36)	62	124	212	330	510	597	617														
1963	-	26	6	7	12	3	(54)	63	125	222	365	520	601	683	704	727												
1962	4	31	4	1	9	-	(49)	58	114	191	317	464	584	661	702	742												
1961	10	26	1	2	9	1	(49)	61	120	198	307	454	574	644	727	779	796	900										
1960	6	22	3	3	9	4	(47)	61	124	203	305	439	562	634	689	744	778	820	900									
1959	3	16	1	1	4	3	(28)	61	116	194	281	406	530	618	669	709	711	740	783	830								
1958	3	14	2	2	6	1	(28)	64	121	204	297	408	527	617	669	703	733	744	769	799	880							
1957	-	7	-	1	4	2	(14)	59	114	206	301	392	493	601	665	702	732	755	770	793	814	865						
1956	1	3	-	-	-	-	(4)	61	119	232	356	498	583	654	698	729	756	776	808									
1955	-	4	-	-	-	1	(5)	52	107	183	284	385	485	557	612	648	691	729	755	779	745	770	790	800				
1952	-	1	-	-	-	-	(1)	55	109	174	337	486	570	654	698	738	763	787	822	857	886	906	921					
1947	-	1	-	-	-	-	(1)	48	117	219	340	591	744	795	828	856	879	902	935	962	990	1018	1037	1055	1078	1092	1102	1111
Totals	27	162	23	27	96	17	354																					
Weighted mean lengths								61	120	204	320	462	565	635	684	722	747	770	794	806	838	885	916	928	1078	1092	1102	1111
Number in mean								354	354	351	346	333	286	218	160	121	85	58	37	24	10	5	3	2	1	1	1	1

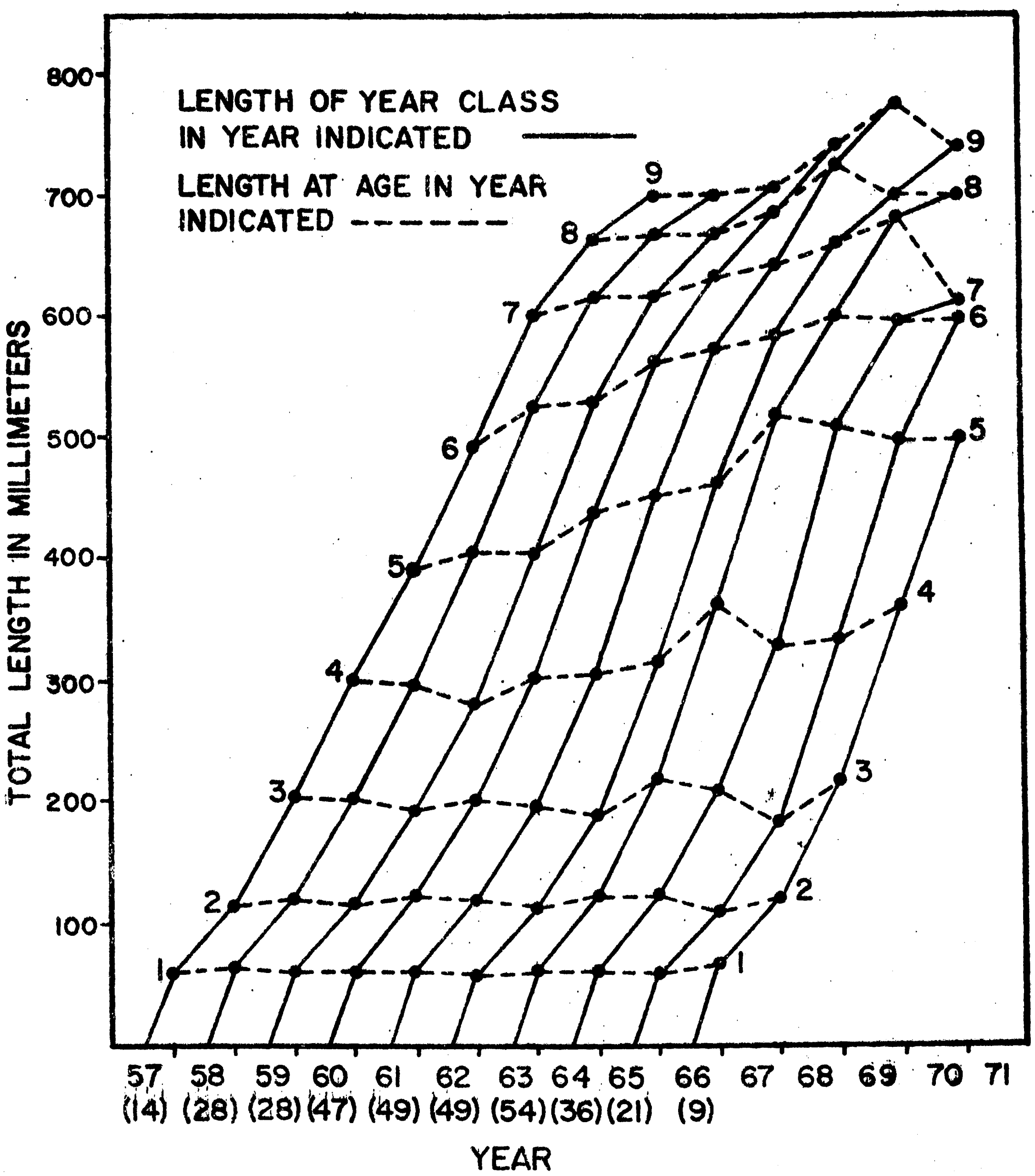


FIGURE 8.--Calculated growth history for the 1957-1966 year classes of flathead catfish collected from Lake Carl Blackwell in 1967-1972. Number in parentheses below year indicates number of fish in year class.

In contrast, comparison of mean lengths of fish at ages 4-7 indicated an increase in growth from 1964 through 1969. For example, the mean length at age 5 of the 1959 year class was 406 mm, chereas length of the 1964 year class at age 5 had increased to 510 mm.

Length and weight increments. Grand mean length increments increased from 59 mm for the second year of life to 142 mm for the fifth year (Figure 9). Length increments then decreased in each year of life until the tenth year (26mm). Length increments then increased slightly in the 11th and 12th years of life before decreasing again the the 13th and 14th years.

Weight increments were represented by differences in estimated weights of fish between each year of life (Figure 9). Although these weight differences were not grand mean weight increments, the estimated gains in weight during each year of life had a pattern similar to that observed for length increments. Greatest weight gains were in the sixth and seventh years of life, rather than the fifth year when greatest length increments were noted for most year classes. Weight gains during the 8-14 years of life varied in a fashion similar to length increments.

DISCUSSION

Sex differences in growth rates of sexually mature flathead catfish in Lake Carl Blackwell were observed in recaptures of tagged fish and growth histories of fish collected in 1968 and 1971. Growth of males exceeded that of females after sexual maturity was attained in the fifth or sixth year of life. The slower growth of adult females may be related to their large relative biomass of sex products, 8.0 to 16.4% of their body weight in 1967-1968 compared to only 0.35% for the

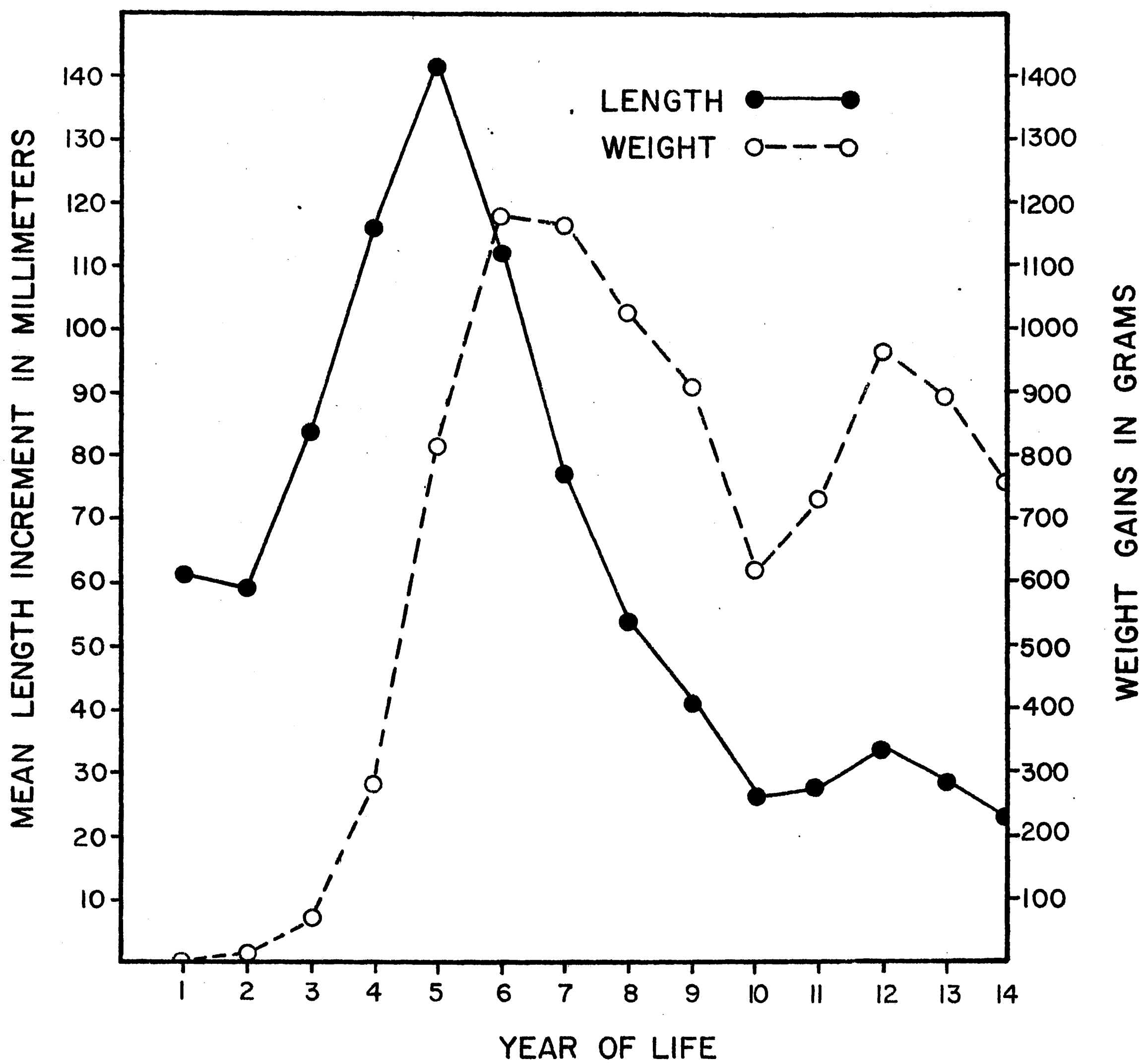


FIGURE 9.--Grand mean length increments and associated differences in weight between each cumulative sum of length increments.

testes of males (Turner and Summerfelt 1971c). The weight of the spawned ova in 1968 was estimated to be 18-57% of net production (weight of ova plus weight increment) for females in age-groups 5-10.

Albaugh (1969) reported 34% greater weight gains for male black bullheads than for females when fed 2% of body weight per day. As spawning occurred during this feeding trail, slower growth of females may have been related to their loss of relatively greater biomass of gametes than lost by males. Langemeier (1965) reported greater length increments for male flathead catfish after the fifth year than for females in the Missouri River, Nebraska. He considered the greater growth of males to be an artifact of small sample sizes, but my findings indicated adult males grow more rapidly than females in Lake Carl Blackwell.

Interpretation of the effects of sampling bias on calculated growth was added by concurrent study of the selectivity of experimental gill nets. The desirability of having growth data from several years (Carlander 1974; Linfield 1974) was obvious when interpreting growth of flathead catfish collected in Lake Carl Blackwell. Comparisons of growth of the same year class in different years confirmed several instances where samples bias affected calculated growth of fish collected in 1967, 1968 and 1972. Except for the 1963 and 1964 year classes in 1968, calculated lengths of fish collected in 1968 and 1971 were considered unbiased estimates of growth because of large sample sizes and a wide range of mesh sizes of gill nets. The influence of sampling bias on calculated growth was reduced or eliminated for the 1957-1965 year classes by combining data from fish collected in four or more years. The pattern of increasing lengths for fish at ages

4-7 during 1964-1969 probably was not caused by size-selective mortality or sampling bias. Although these factors also can cause growth of older fish to appear slower than for younger fish (Ricker 1969), the similar growth of fish of the same year class in each of four to six years eliminates size-selective mortality and sampling bias as possible causes for increasing growth during 1964-1969. Other factors which may have affected growth in 1964-1969 were exploitation and fluctuations in water level.

The pattern of increasing length and weight increments through the fifth year of life was unusual when compared to most species of fresh-water fishes. Increasing length increments rarely occur past the third year of life, but weight increments commonly increase for a longer period (Ricker 1969). However, the pattern of increasing length increments in Lake Carl Blackwell) was not unusual for flathead catfish. Langemeier (1965) found length increments in the first five years were similar (93-101 mm) for flathead catfish from unchannelized sections of the Missouri River. Also, flathead catfish in the Des Moines River, Iowa had length increments of 76-99 mm for the first seven years of life, with greatest increments in the fourth or fifth year (Muncy 1957).

Growth pattern of flathead catfish appears to be related to changes in the type of food eaten and age at sexual maturity. Small length increments occur in the first two years of life when larval dipterans and chironomids were the major food items for flathead catfish (Turner 1971). Although these insects were the most abundant aquatic invertebrates in Lake Carl Blackwell, their relative density was low compared to that in other reservoirs (Norton 1968). The transition to a diet of crayfish and minnows in the third year of life and then to a diet consisting almost entirely of fish in the fifth year (Turner 1971) coincided with increasing length increments in the third through fifth years of life. However, weight increments increased to nearly 1.2 kg in the sixth and seventh year of life when prey species were mostly age 1 and older gizzard shad, Dorosoma cepedianum, and freshwater drum, Aplodinotus grunniens (Turner and Summerfelt 1971a). Minckley and Deacon (1959) also attributed the more rapid growth of flathead catfish in a turbid river, compared to a clearer river, to an earlier change to a fish diet in the turbid river.

Decreasing length and weight increments after age 6 in Lake Carl Blackwell appeared to be related to attainment of sexual maturity, which typically occurs during the sixth year. Weight gains increased after the tenth year of life which by inference seems related to consumption of larger prey species such as carp and river carpsucker, Carpiodes carpio, which were abundant in the reservoir. A river carpsucker (0.5 kg) was observed protruding from the mouth of a 4.2 kg flathead catfish in 1969. In addition, carp were common prey in two Oklahoma reservoirs (Turner and Summerfelt 1971a) and a New Mexico reservoir (Jester 1971).

Published data on growth of flathead catfish in rivers and reservoirs are compared to growth rate in Lake Carl Blackwell in Appendix C. Reliability of the reported growth data is discussed in relation to the problems of age determination.

CHAPTER V

EFFECTS OF WATER LEVEL FLUCTUATIONS AND EXPLOITATION ON GROWTH AND FECUNDITY OF FLATHEAD CATFISH

INTRODUCTION

The use of short-term reservoir drawdowns to improve the balance between prey and predatory fishes has become a widely-recognized management tool (Bennett 1954; Lantz et al. 1965; Pierce et al. 1965; Bennett et al. 1969). Lewis (1967) considers the management success of these drawdowns to be related to alteration of prey vulnerability. Although reservoir drawdowns have resulted in improved growth of largemouth bass (Hulsey 1957; Heman et al. 1969), the effect of longer periods of declining water levels has seldom been evaluated for piscivores.

Another factor lacking adquate study in reservoirs is the potential compensatory responses of piscivorous fishes to heavy exploitation. In less complex communities, major reductions in population density of a fish species typically result in increased growth rate (Backiel and Le Cren 1967). Fish also compensate for exploitation by reduced mortality rates of small fish, increased numbers of eggs per unit of body weight and reduced age at sexual maturity (Regier and Loftus 1972).

This paper reports the effects of nine years of declining or low water levels and exploitation--removal of 49% of the adults in the 600-800 mm length range--on the growth and fecundity of flathead catfish. Growth was evaluated separately for fish of different sex or age and related to mean annual lake level during different years. An attempt was made to separate the effects of exploitation and water level fluctuations on growth and fecundity.

METHODS

The methods used to collect flathead catfish, determine their sex, remove spines, and take length and weight measurements were described previously (Chapter III).

Mean reservoir elevation (m.s.l.) was determined monthly for 1956-1972 from records of the USDA Agriculture Research Service, Water Conservation Structures Laboratory, Oklahoma State University. Mean annual water level was the average of the 12 monthly means.

Surface area and volume of the reservoir were determined from USDA aerial photographs and depth contours made in 1967. Area and volume were computed for the lake at spillway elevation (287.78 m) and at successive 0.03 m intervals below spillway elevation from a fifth degree polynomial equation by OCFU personnel.

Exploitation

Total harvest was estimated from data on the catch of two snag line fishermen who recorded the weights of all flathead catfish caught and the tag numbers of each tagged fish. Total number of flathead catfish harvested (H) was determined using data on the number of tagged flathead catfish caught by the two snagline fishermen (R), their total catch of flathead catfish (C), and the total number of tagged flathead catfish reported by all fishermen (M):

$$H = \frac{C \times M}{R}$$

The biomass harvested was determined by multiplying the mean weight of all flathead catfish caught by the two cooperating snag line fishermen times the total number harvested by all fishermen using snag lines and trot lines. As no fish < 500 mm were tagged, flathead catfish < 500 mm were not included in the estimate of total number harvested (H).

Fishermen were informed of the need to report tagged fish by the use of posters, newspaper articles, a notice on the fishing permit which was required at Lake Carl Blackwell, and personal contacts. In 1968-1972, waterproof reward posters (Figure 10) were put up around the reservoir and at the lake office where fishermen purchased permits. The posters advertised a $1.00-5.00 reward for the return of tags and information about tagged fish to either the lake office or office of the Oklahoma Cooperative Fishery Research Unit. The conventional and ultrasonic tagging projects and rewards for returned tags were periodically discussed in an outdoor column in the Stillwater newspaper. Although these measures were helpful, periodic discussions about the need for tag returns with fishermen using trotlines or snaglines was considered a more successful way of encouraging tag returns.

Catch of flathead catfish by noodlers, who used large hooks lashed to the end of short hand-held willow poles, was not included in estimates of harvest by other fishermen in 1968-1970. These men did not purchase the fishing permit required at the lake and failed to report tag numbers of tagged fish which they caught under rocks at the south end of Area 1. After the significance of noodling was realized, these men were observed and personally contacted on numerous occasions.

REWARD

The Oklahoma Cooperative Fishery Unit at O.S.U. is presently doing an intensive study of the flathead catfish and largemouth bass populations at Lake Carl Blackwell. This study involves the capture and tagging of these two fish species with the two types of tags indicated below. The recapture of these tag-bearing fish provides essential information on population size, growth, movements, and harvest rates. It is hoped that the information gained will improve fishing for these species.

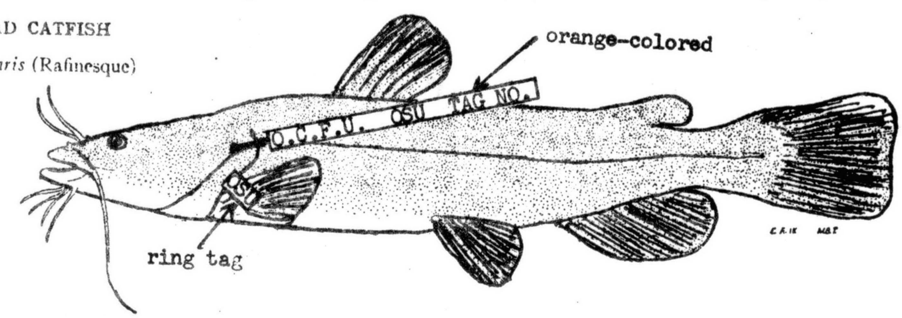
A $1.00 reward will be given for the return of each tag. If the fish have two tags, a $2.00 reward will be given. Tags can be returned to the office of the fee fishing pond at Lake Carl Blackwell or mailed to the Oklahoma Cooperative Fishery Unit; 433 Life Sciences West; Oklahoma State University; Stillwater, Oklahoma 74074. If the tags are mailed, the reward plus a 6¢ stamp will be mailed to the sender. The length, weight, catch date, and location of each tagged fish is required if at all possible. Information on the lengths, weights, dates, and numbers of untagged flatheads caught by fishermen (any method) is also desired. This information can be mailed to the Fishery Unit or phoned in if easier (FR2-6211, extension 6279). Incidently tag numbers and other pertinent information can also be reported by phone as we have a record of all fish tagged. If the tags are phoned in, the reward will be mailed to the person reporting the tag numbers.

In addition, a number of flathead catfish have had a small radio transmitter surgically implanted in their abdominal cavity to permit tracking of flathead movements. As these tags can be reused, a $5.00 reward will be given for the return of each radio tag, plus the reward for the externally-attached tags. These white radio tags will be found internally near the stomach region and are about the size of a man's thumb.

The types of tags used and example locations are indicated below. The ring tag which is crimped around the base of the pectoral spine of flathead catfish is fairly easy to overlook.

FLATHEAD CATFISH

Pilodictis olivaris (Rafinesque)



NORTHERN LARGEMOUTH BLACKBASS

Micropterus salmoides salmoides (Lacépède)

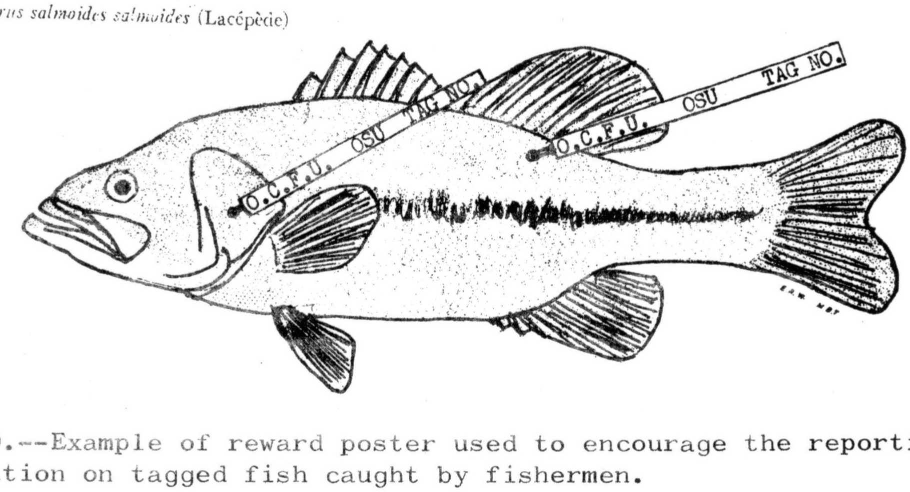


FIGURE 10.--Example of reward poster used to encourage the reporting of information on tagged fish caught by fishermen.

When they became confident that interest in their activities was because of scientific purposes, several members of the group provided verbal estimates of their 1968-1970 catch. Noodling was banned at Lake Carl Blackwell after 1970 by the Oklahoma Department of Wildlife Conservation, at the request of the lake manager.

Growth

Methods used for age determination, back-calculation of lengths and to calculate growth of tagged fish were described previously (Chapters III and IV). Mean length increments for males, females, and all fish combined were computed separately for each year class in both 1968 and 1971 collections. Mean growth increments of males, females, and all fish collected in 1971 were then arranged to allow growth in each year of life to be compared between calendar years. Linear regressions between mean length increments (Y) of all fish combined and mean annual water level (X) in 1961-1970 (i.e. X_{1965}, Y_{1965}, X_{1966}, Y_{1966}, etc.) were calculated for the third, fourth, fifth, sixth, seventh, and eighth years of life. Separate linear regressions were also calculated between mean lake level (X) and mean increments (Y) for both males and females during each of the fourth through seventh years of life.

The mean length increment of fish at ages 3-8 in 1969 was compared to the length increment predicted for 1969 by linear regressions calculated from data in earlier years. For example, the regression between mean lake levels (X) and mean increments in the seventh year of life for 1963-1968 was used to predict the expected seventh-year increment in 1969 (based on the mean water level in 1969).

Per cent deviation from "mean growth" also was determined for 1963-1970 using the sum of mean increments in the fourth through seventh years of life. Mean growth was the mean of the four increments for the eight calendar years. Mean increments prior to 1968 were weighted means of the combined collections in 1968 and 1971. Mean growth was subtracted from the sum of increments for each year. This difference was then divided by the mean sum of increments to determine per cent deviation from mean growth.

Fecundity

The total number of maturing or mature ova in both ovaries was estimated gravimetrically for mature females from two subsamples of oven-dried ova (Turner and Summerfelt 1971c). Only ovaries collected June-August which had mean ova diameters $>$ 3.33 mm for maturing ova were used. As recommended by Bagenal (1967), fecundity relationships were determined by computing linear regressions with $\log_{10}$ ova number (in thousands) and $\log_{10}$ total length (in millimeters) as the dependent and independent variables, respectively. Separate regressions were computed for each year and the null hypotheses of equal slopes of lines and equal adjusted means were evaluated by analysis of covariance to test for differences in fecundity between collection years.

A linear regression was calculated between mean water level and mean number of ova per female (adjusted for differences in length) for 1967, 1968, 1970, and 1971. Mean water level in the year preceeding ova production was used as the independent variable (X) because it was considered more likely to influence numbers of prey fishes available to adult female during ovary development.

RESULTS

Effects of Water Level Fluctuations

Below average rainfall resulted in a 4.5 m drop in water level from 1962 through March 1968 (Figure 11). Increased rainfall in the springs of 1968 and 1969 temporarily halted the decreasing lake levels, but mean lake level remained low (284.0-284.6) in 1968-1970.

Growth of tagged fish. Mean growth of female flathead catfish which were tagged and recaptured in the same year increased from 2.1 mm/month in 1968 to 5.6 mm/month in 1969 (Table 16). Likewise, a male tagged and recaptured in 1969 grew 11.5 mm/month, whereas the growth of 7 males averaged 7.1 mm/month in 1968. Mean growth rates of males and females in 1971 were similar to growth rates in 1968.

Growth rates of tagged fish recaptured after being at large one or more years were greater when the period before recapture included 1969; e.g., the growth rate of 2 males was 1.2 mm/month in 1967-1968, but increased to 3.5 mm/month for 2 males in 1968-1969. Mean growth of 3 tagged males was only 1.4 mm/month for the 1970 to 1971 interval. Growth of tagged females from 1967 to 1968 and from 1970 to 1971 averaged 1.6 and 1.9 mm/month, respectively. By contrast, growth rates of females were greater for the interval between tagging and recapture when growth in 1969 was represented in the time interval (Table 16).

Mean growth increments. The per cent deviation from the mean sum of the fourth through seventh length increments was similar for males and females for the 1966-1970 interval (Figure 12). Growth of both sexes decreased in 1967 and 1968, but improved substantially in 1969. Sums of increments in 1969 were 15.4 and 31.7% greater for males and

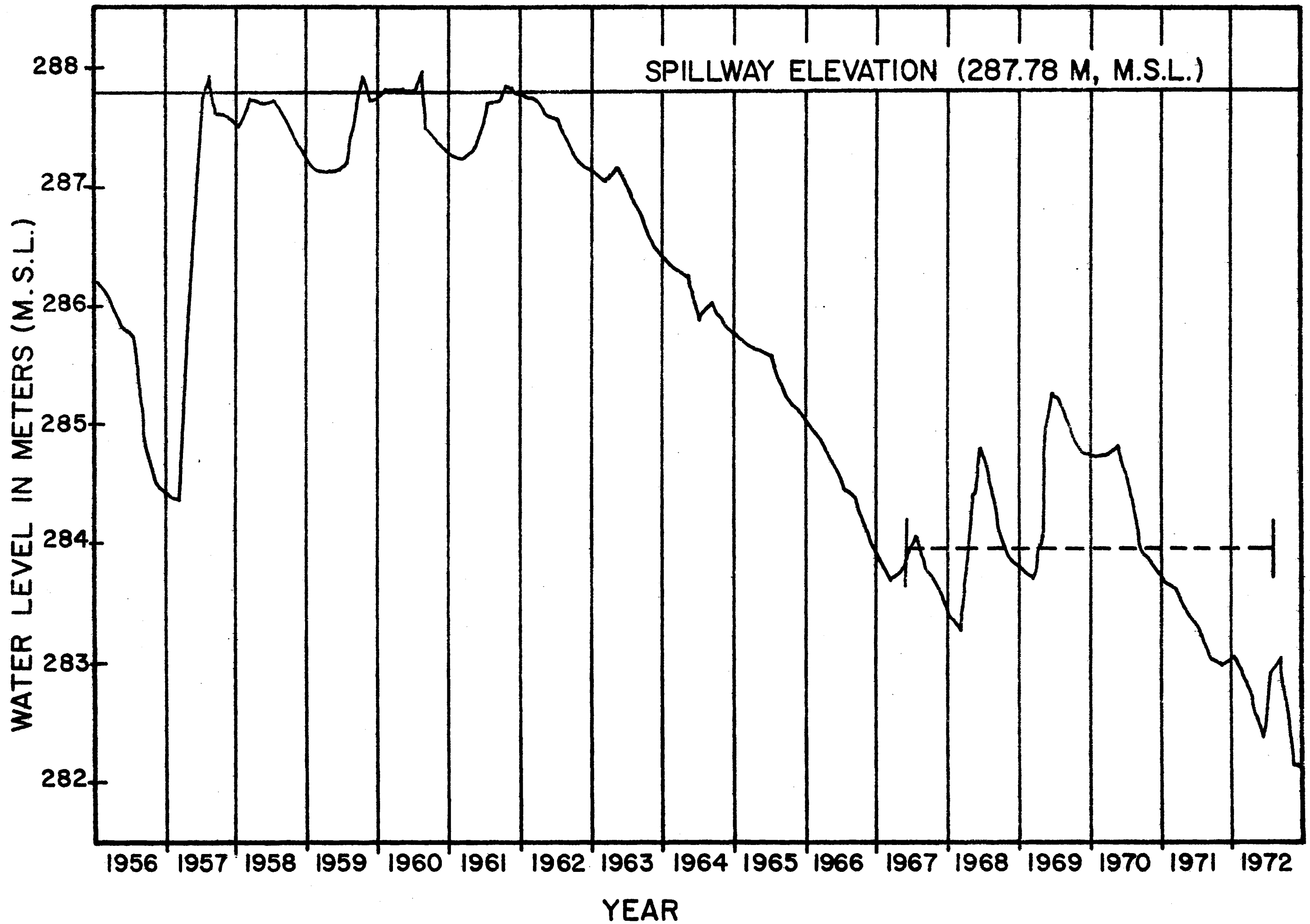


FIGURE 11.--Water level in meters (m.s.l.) for Lake Carl Blackwell, Oklahoma in 1956-1972. Mean lake level during the study (---) was 283.9 m.

TABLE 16. Growth of tagged flathead catfish in Lake Carl Blackwell.

Year tagged	Year recaptured	No. of fish	Mean months at large	Mean total length when tagged	Mean growth rate mm/month	Mean growth rate mm/day
			Males			
1968	1968	7[a]	2.1	693	7.1	0.24
1969	1969	1	3.9	724	11.5	0.38
1971	1971	2	4.0	783	7.5	0.25
1967	1968	2	11.6	641	1.2	0.04
1968	1969	2	19.0	684	3.5	0.12
1969	1970	1	23.9	698	3.7	0.12
1969	1970	1	12.1	769	4.3	0.14
1970	1971	3	5.7	739	1.4	0.05
			Females			
1968	1968	19	1.9	698	2.1	0.07
1969	1969	2	4.8	610	5.6	0.19
1971	1971	6	3.4	670	2.4	0.08
1967	1968	2	12.1	602	1.6	0.05
1968	1969	9	13.0	677	2.5	0.08
1968	1970	3	24.7	696	2.2	0.07
1968	1971	3	32.6	651	2.3	0.08
1969	1970	4	12.9	690	3.9	0.13
1969	1971	5	23.8	606	3.7	0.12
1970	1971	11	11.3	715	1.9	0.06

[a]Date and length at tagging and recapture are given for each fish in Appendix B.

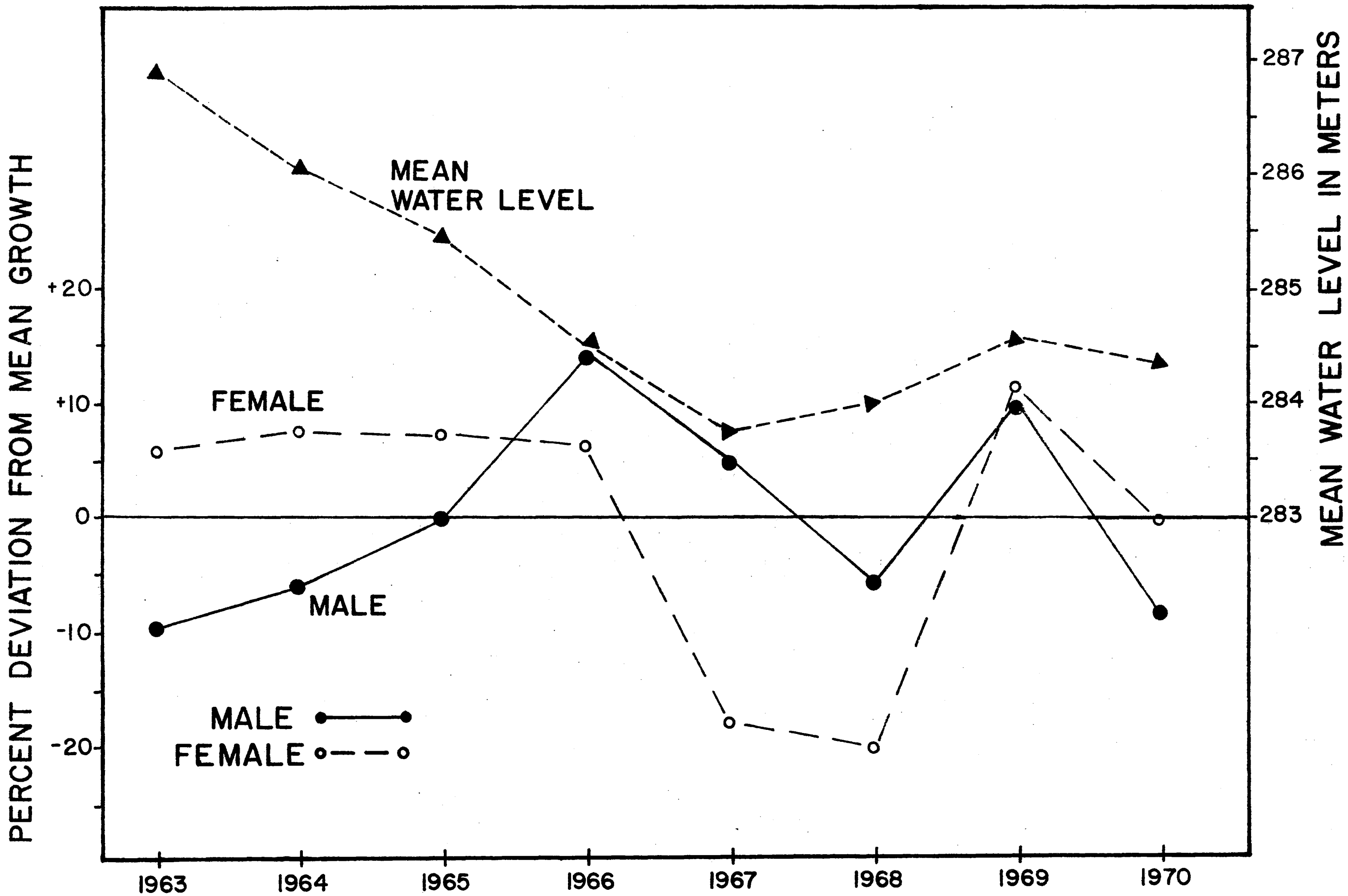


FIGURE 12.--Percent deviation from the mean length increments of 4-7 year-old flathead catfish in Lake Carl Blackwell.

females, respectively, than in 1968. Despite decreasing lake levels, sum of length increments in the fourth through seventh years increased for males from 1963 through 1966. In contrast, the nearly equal sums of these length increments for females in 1963-1966 indicated growth of females was initially unaffected by decreasing water levels.

Growth in different years of life. Mean length increments calculated for flathead catfish collected in 1971 appeared to be related to fluctuations in mean lake level from 1961 through 1970 (Figure 13). Therefore, linear regressions were calculated between annual lake level and length increments of fish in the third through eighth years of life (Table 17). The years used for each regression were either based on the pattern of increasing or decreasing increments in Figure 13 or included all years for which length increments were available. Growth response to declining lake level differed between fish in different years of life because of differences in size, food habits and age when fish reached sexual maturity. For example, mean increments in the fourth year of life increased from 1961 through 1966, whereas growth in the sixth year increased from 1962 through 1964 and then decreased until 1968.

The correlation coefficients between length increments of four- and five-year old flathead catfish and mean lake levels in 1961-1966 and 1961-1965 (Figure 14) were -0.96 and -0.90, respectively; both were statistically significant (P of $r < 0.05$). Length increments of fish in the third year also were inversely related to lake level, but the correlation coefficient was non-significant (P of $r > 0.10$). The unusually high third-year increment in 1969 and low increment in 1967 were inconsistent with the regression between lake level and growth

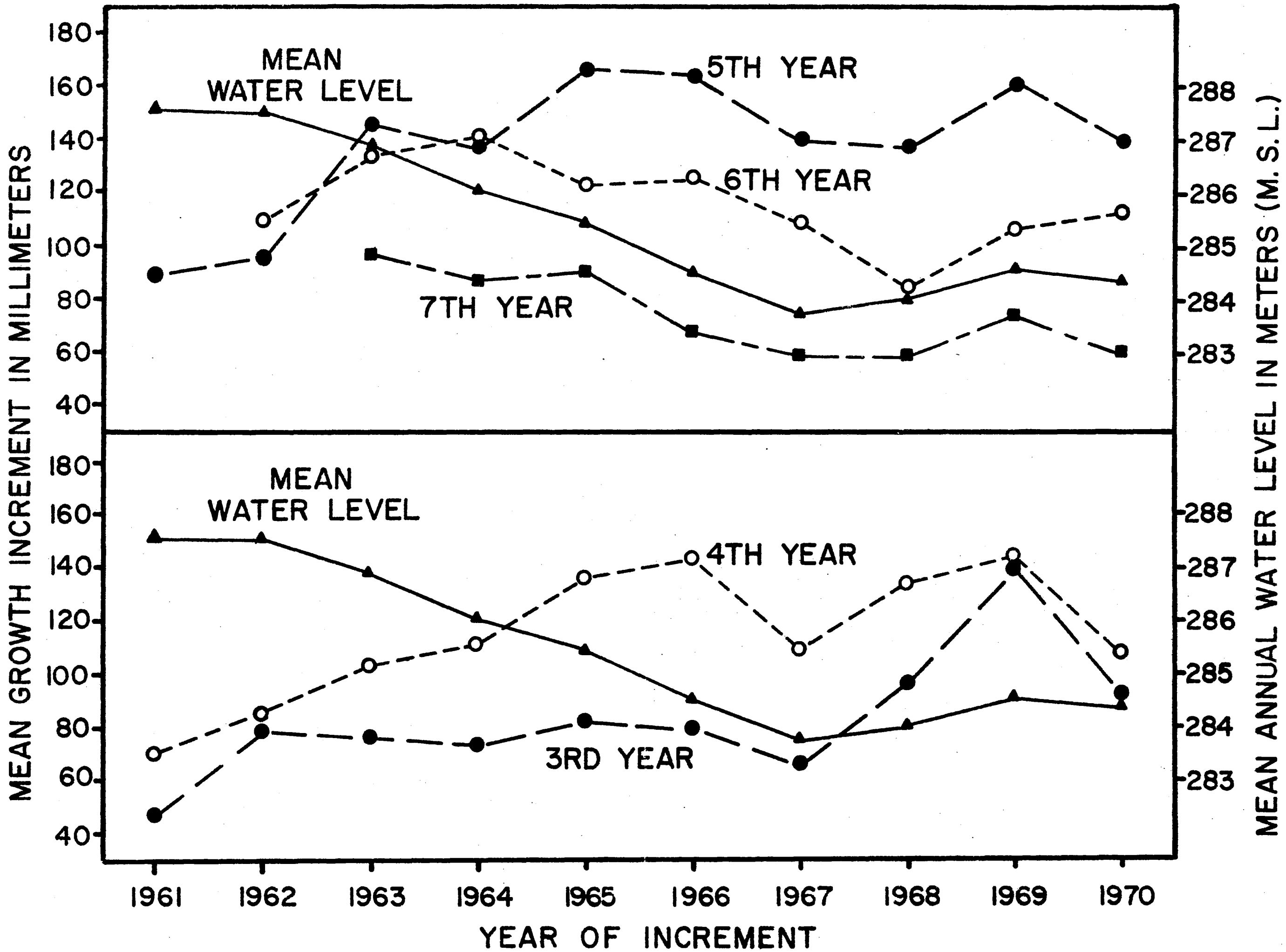


FIGURE 13.--Yearly fluctuations in mean annual growth increments of flathead catfish in their third-eighth years of life compared to mean annual water level in 1961-1970.

TABLE 17. Relationships between mean annual lake level in meters (X) and growth increments in millimeters (Y) for flathead catfish collected from Lake Carl Blackwell in 1971.

Year of growth increment	Mean annual water level in meters	Growth increments in total length (mm) during year of life indicated							
		3rd	4th		5th		6th	7th	8th
1970	284.37	92	107		140		113	61	51
1969	284.57	140	144		161		107	75	49
1968	284.00	96	134		138		85	59	44
1967	283.76	66	109		141		109	59	48
1966	284.53	79	143		164		126	68	40
1965	285.46	82	136		166		123	91	53
1964	286.06	73	111		139		141	88	48
1963	286.89	76	103		146		134	97	-
1962	287.50	79	85		96		109	-	-
1961	287.54	47	70		89		-	-	-
Years included in linear regression		1961-1970	1961-66	1966-70	1961-65	1965-70	1964-70	1963-70	1964-70
Correlation coefficient (r)		-0.464	-0.963	0.570	-0.899	0.796	0.791	0.944	0.320
Estimated probability of calculated r		0.151	0.002	>0.10	0.039	0.059	0.036	0.0004	>0.10
Determination of coefficient		22	93	32	81	63	63	89	10

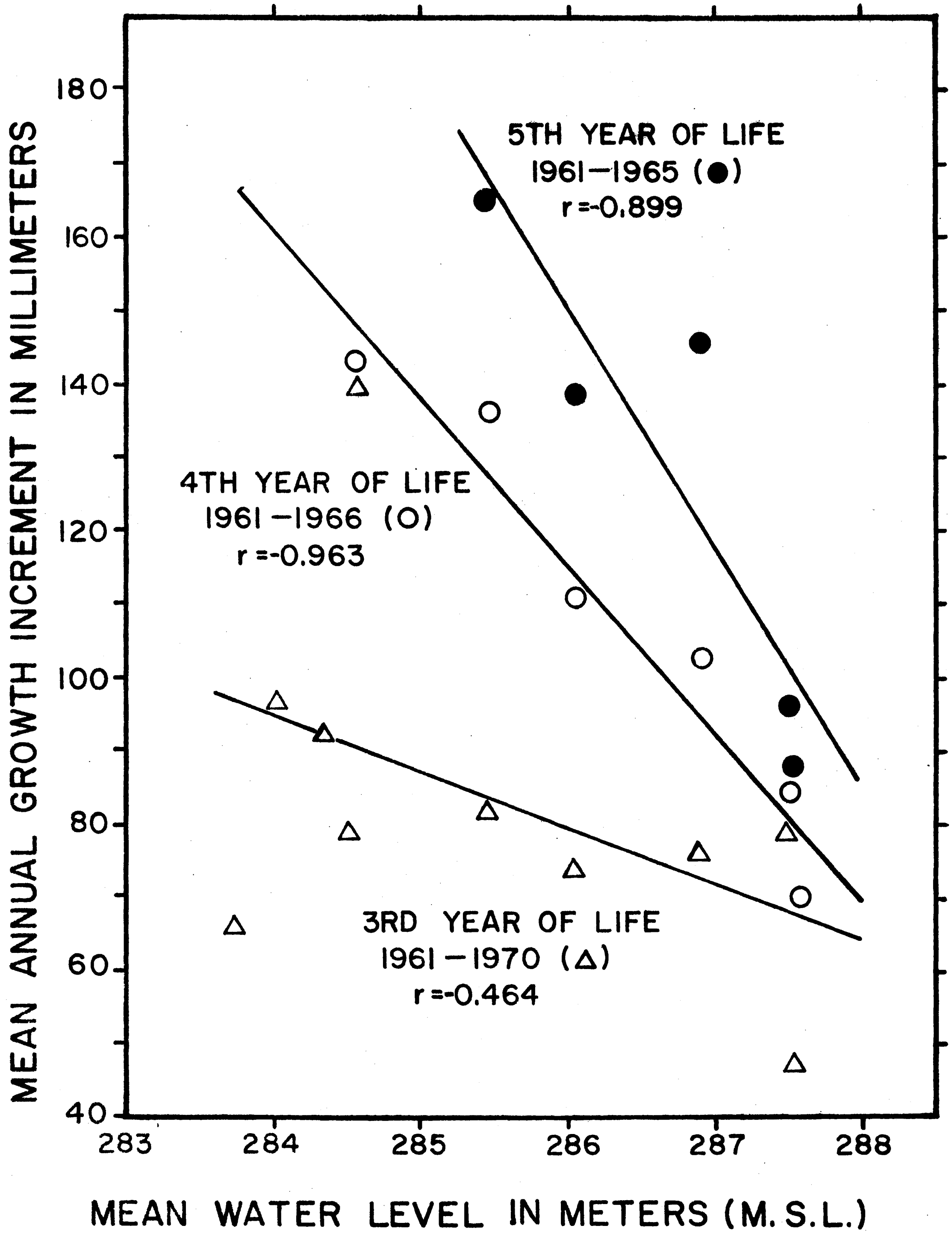


FIGURE 14.--Relationships between mean annual water level and mean annual growth increments of flathead catfish during the third, fourth, and fifth years of life.

for 1961-1970.

Mean lake level was significantly and positively correlated with length increments of fish in their fifth, sixth and seventh years of life during 1965-1970, and 1963-1970, respectively (Figure 15). Fourth and eighth year growth was also positively correlated with lake level in 1966-1970 and 1964-1970, respectively, but not significantly so (P of $r > 0.10$). Two inconsistencies in the fit of regressions with positive correlations were: (1) decreased or equal growth increments in the fifth through eighth years in 1968, despite a 0.24 m increase in mean lake level; and (2) mean increments for the third, fourth, fifth, seventh, and eighth years in 1969 were greater than predicted by the regressions (Figures 14 and 15).

Fecundity

Logarithmic transformations of number of maturing ova (in thousands (Y) and total length in millimeters (X) for females collected in 1967-1971 were described by linear regressions which were statistically significant (Table 18). Variation in total length of flathead catfish accounted for 74% (1967) to 93% (1968) of the variation in ova number in different years.

When ova number-total length regressions were compared between years, the slope of the regression line for 1969 was less than in other years (Figure 16). The probability (P) of the F statistic testing the null hypothesis of equal slopes between years was $0.05 > p > 0.10$. Comparison of the slopes of regression lines between years (1967-1971) indicated that females $<$ 700 mm had a greater number of ova per female in 1969 than in other years.

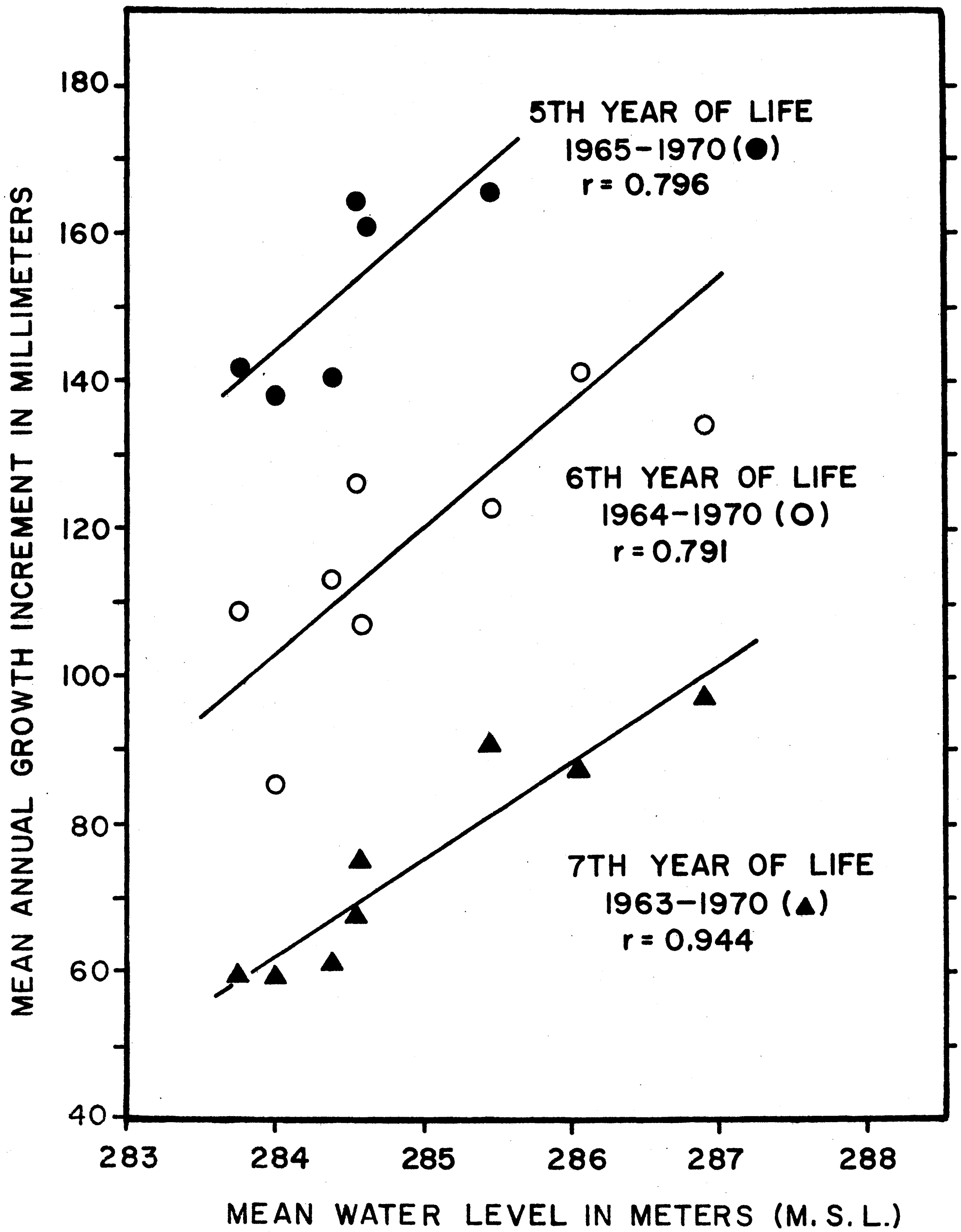


FIGURE 15.--Relationships between mean annual water level and mean annual growth increments of flathead catfish during the fifth, sixth, and seventh years of life.

TABLE 18. Computed linear regressions between $\log_{10}$ total length in millimeters (X) and $\log_{10}$ ova number in thousands (Y) of flathead catfish collected from Lake Carl Blackwell in 1967-1971.

Year	No. of fish	Linear regression	F[a]	Probability of F	Coefficient of determination
1967	9	Y = 5.2467 + 2.2660X	20.43	0.0027	0.7444
1968	16	Y = 6.9212 + 2.8479X	198.97	0.0001	0.9343
1969	8	Y = 3.0030 + 1.4854X	18.41	0.0051	0.7542
1970	6	Y = 5.3243 + 2.2991X	12.29	0.0248	0.7545
1971	13	Y =-6.2955 + 2.6487X	131.66	0.0001	0.9229

[a] F statistic for testing the null hypothesis, b = 0.

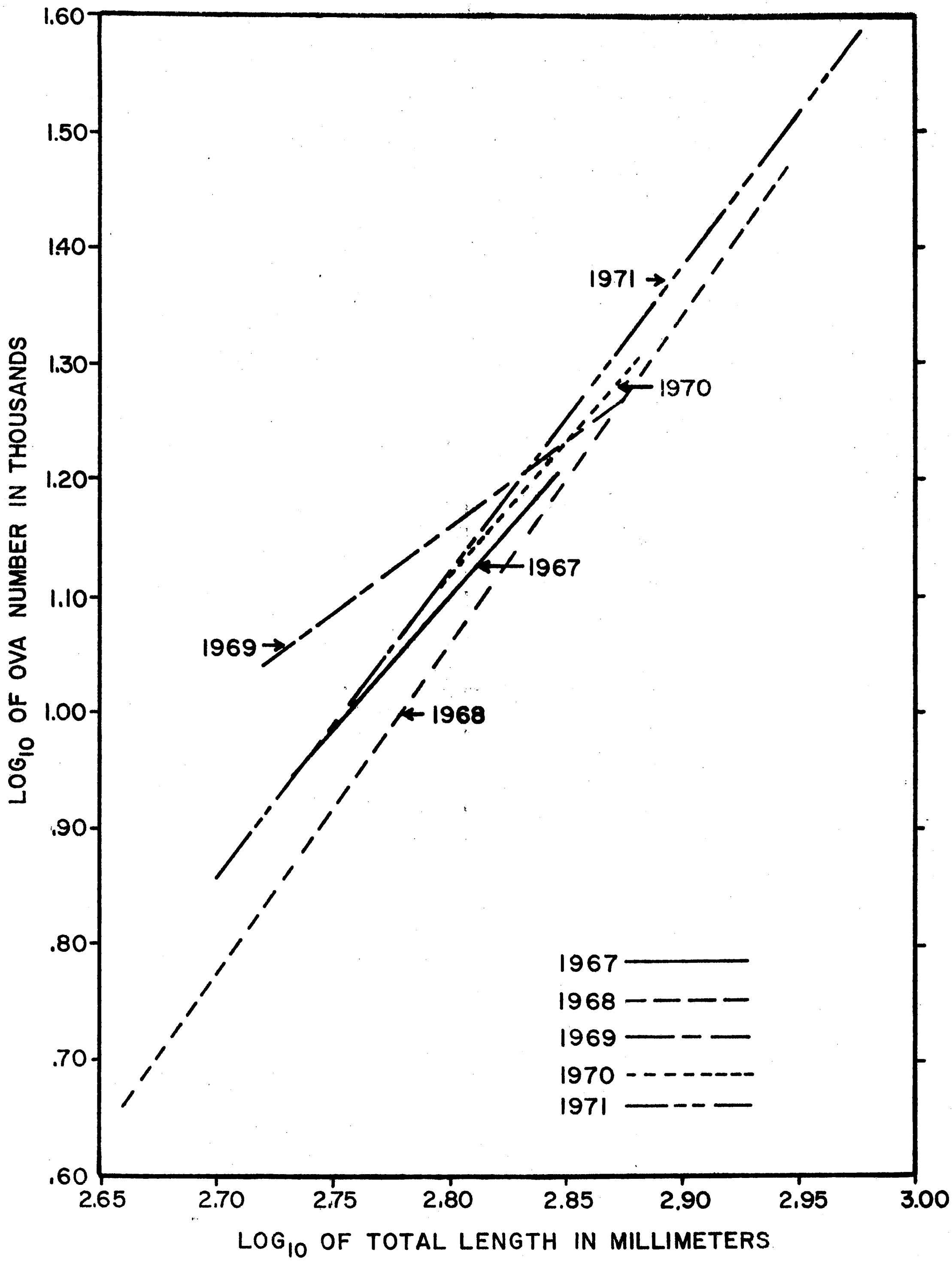


FIGURE 16.--Linear regressions between $\log_{10}$ total length and $\log_{10}$ ova number (thousands) for flathead catfish collected from Lake Carl Blackwell in 1967-1971. Length of regression lines indicates length range of fish for which ova number was estimated in that year.

The null hypothesis of no difference in adjusted means (of ova number) was rejected (P of F = 0.004). Therefore, fecundity differed significantly between years. When mean ova number per female was adjusted for differences in total length between years, mean number of ova was as follows:

Year	Mean ova number per female	Mean annual lake level (m)
1967	14530	283.76
1968	13179	284.00
1969	16538	284.57
1970	14641	284.37
1971	15325	283.32

Mean number of ova per female was the least in 1968 following six years of declining lake levels. Adjusted number of ova per female was greater in 1969 after two years of rising lake levels in the spring and heavy exploitation of flathead catfish in 1968.

Exploitation

Although commercial fishing was not allowed after 1963, exploitation of flathead catfish by fishermen using snag and trot lines and by noodlers was substantial in some years. In 1968, 7 of 72 flathead catfish (> 500 mm) caught by two cooperating fishermen had been previously tagged (Table 19). Based on this ratio and data on total number of tagged fish caught, the estimated harvest by fishermen in 1968 was 185 flathead catfish which weighed 1148 kg. I also removed 163 fish (> 500 mm), which weighed 741 kg., from Lake Carl Blackwell in 1968. In addition, noodlers removed approximately 100 fish by hand

TABLE 19. Reported commercial harvest in 1957-1963 and estimated catch in 1967-1972 of flathead catfish in Lake Carl Blackwell.

Flathead catfish catch	Reported commercial harvest (kg)[a]								Estimated harvest (kg)				
	1957	1957-58	1958	1959	1960	1961	1961	1963	1967	1968	1969	1971	1972
Number of fish in reported catch[b]	620	1270	-	-	-	-	-	-	91	72	9	71	55
Total weight of reported catch	3056	5912	2992	541	446	577	57	572	625	449	63	509	405
Mean weight of fish in known catch	4.9	4.7	-	-	-	-	-	-	6.8	6.2	7.0	7.2	7.3
Number of tagged fish in reported catch	-	-	-	-	-	-	-	-	2	7	1	13	8
Total number of tagged fish	-	-	-	-	-	-	-	-	2	18	10	18	14
Estimated total number harvested (total weight)	-	-	-	-	-	-	-	-	-	185 (1148)	90 (630)	98 (708)	96 (703)

[a]Harvest data for 1957 is derived from Elkin (1959); for 1957-1958 from Heard (1959); for 1958, 1959 and 1960 from Jones (1961); and for 1961-1963 from Mensinger (1971).

[b]Either number in commercial harvest (1957-1963) or number caught on snaglines by two fishermen who kept records.

fishing during the late spring and early summer of 1968. Noodling activity by 3-5 men was observed on numerous occasions. On one occasion, noodlers had captured five flathead catfish weighing from 3 to 10 kg each from under boulders near the south end of the dam. A local newspaper also pictured a 22 kg flathead catfish caught by noodlers from Lake Carl Blackwell in 1968. If fish caught by noodlers were similar in weight to fish caught by snag and trot lines (6.2 kg), the harvest by noodlers would have been 620 kg. The total number of flathead catfish removed from Lake Carl Blackwell in 1968 was 448 fish which weighed 2509 kg.

Effects of Exploitation

Growth. Although growth in most years of life were significantly correlated with mean water level, mean length increments in the fifth through eighth years of life were less than predicted by the regression lines in 1968 (Figure 16). Likewise, growth in 1969 was greater than predicted by regressions for most years of life, suggesting that exploitation in 1968 ~~influenced length~~ increments in 1969.

Fecundity. Mean number of ova per female (adjusted for difference in length between years) was positively correlated with mean lake level in the previous year for 1967, 1968, 1970, and 1971. The correlation coefficient ($r = 0.81$) of the linear regression was not statistically significant ($P > 0.05$) because adjusted ova number was available for only four years. Using a mean lake level of 284.0 m, the regression predicted a mean of 13834 ova per female for 1969. However, adjusted fecundity in 1969 was actually 16538 ova per female.

DISCUSSION

Growth and fecundity of flathead catfish was affected by six years of decreasing lake levels, which reduced area and volume of the reservoir by 56 and 67%, respectively. Dropping lake levels initially coincided with improved growth of flathead catfish in the fourth through sixth years of life. In contrast, growth of species like carp (Johnson 1974), largemouth bass (Zweiaker et al. 1973), and white crappie (Johnson and Andrews 1974) in their first year of life was positively correlated with lake levels in Lake Carl Blackwell during the same period. Three years of decreasing water levels also reduced growth of white crappie in Lake Spavinaw, Oklahoma (Jackson 1958). Davis (1959) reported that droughts reduced the volume of water and caused decreased growth rate of channel catfish in Kansas waters.

The improved growth of flathead catfish during the early stages of dropping lake levels may have been related to an increase in prey vulnerability (Lewis 1967). Zweiacker et at. (1973) also reported increased growth of age-2 largemouth bass in Lake Carl Blackwell in 1962-1967. Carroll and Hall (1964) reported improved growth of flathead catfish in age-groups 3-5 after an extreme winter drawdown in Norris Reservoir, Tennessee. But their data indicates the apparent improved growth was probably biased by the selectivity of commercially-fished gill and trammel nets ($\geq$ 76 mm square mesh), which mainly captured larger, more rapidly-growing fish in age-groups 4 and 5.

As lake level continued to decline in 1965 through 1967, growth of flathead catfish also decreased. I believe the decreased growth was related to a decreased abundance of prey species which have shorter average life spans than flathead catfish. Growth of older fish was negatively affected sooner than growth of younger fish. The greater food requirements of older fish which have much greater annual weight increments than younger fish, probably caused the earlier decreases in growth of older fish. As fish in age-groups 4-8 prey mainly on age-1 and older gizzard shad and freshwater drum (Turner and Summerfelt 1971a) older flathead catfish would need to consume much greater numbers of an equal-sized prey to have similar length increments as fish in younger age groups. Energy requirements associated with reproduction probably was another reason for differences in growth response of adult fish (ages 5 and older).

The reduced growth of fish in age-groups 5-8 in 1967 and 1968 might be a function of increased intraspecific competition associated with increases in number of flathead catfish per hectare following six years of declining lake levels. Also, the increased area and volume associated with the 1.5-m rise in lake level in April 1968 should have decreased the density of age-1 and older prey. Comparable estimates of standing crop determined by cove rotenone samples in May of 1967 and 1968 indicated that density of gizzard shad and all fish combined decreased in 1968 (Johnson 1974). Decreased availability of prey fishes during ovary development in April-June may help explain the low number of ova per female in 1968 and high percentage of unspawned females (45%) found resorbing their ova in late July and August 1968 (Turner and Summerfelt 1971c). Increases in intraspecific competition in rainbow trout, Salmo gairdneri, has been cited as causing decreases in egg numbers "commensurate with the degree of starvation" (Scott 1962). In addition, growth rate of adult females tagged in the spring 1968 was only 0.3 and 1.6 mm/month for fish recaptured the same spring and summer, respectively.

A 0.57-m increase in mean lake level in 1969 coincided with increased growth of flathead catfish in age-groups 3 and older and an increase of 25% in mean adjusted fecundity. Increases in either food supply or exploitation often results in increased fecundity (Nikolskii 1962). Increased production of invertebrate and vertebrate prey of flathead catfish may have occurred in 1969 following the flooding of substantial areas of terrestrial macrophytes in springs of 1968 and 1969. The drying out and subsequent reflooding of the reservoir bottom has been commonly assumed to increase nutrients available for fish food production especially if innundation of terrestrial vegetation occurs (Cooper 1967). Reflooding of Lake Tohopekaliga, Florida after a 2.1-m drawdown resulted in substantial increases in standing crop of aquatic macroinvertebrates (Wegener et al. 1975) and a greater than twofold increase in fish standing crop within two years after reflooding (Wegener and Williams 1975). Data on changes in prey abundance in Lake Carl Blackwell were limited to rotenone samples in one small atypical cove. Poor growth of largemouth bass in the first through fourth years of life in 1969 indicates reduced prey populations (Zweiacker et al. 1973). However, the lack of useful data on prey abundance in 1969 makes it difficult to separate the effects of exploitation and rises in lake level on growth and fecundity.

Backiel and Le Cren (1967) concluded that growth of fish species with a limited food supply could be expected to vary inversely with population density. Although the relative prey abundance was not known in Lake Carl Blackwell, prey availability probably was affected by fluctuations in lake level. Therefore, decreased growth of fish in the fifth through seventh years probably was a response to a reduction in food supply. Likewise, improved growth in the third and fourth years of life in 1968 and improved growth of age-2 and -3 fish in 1969 probably were related to increased food availability. However, increases in growth of age-4 and older fish and in fecundity of females in 1969 coincided with the removal of 448 flathead catfish (> 500 mm) in 1968. Of the estimated 632 fish in the 600 to 800-mm length range in 1968, 308 fish (49%) were removed from the reservoir in 1968 (Summerfelt et al. 1972). An estimate of the number of flathead catfish in the 575 to 850-mm range in 1969 was 532 fish. As the estimate in 1969 included fish with a greater range in length than in 1968, the removal of 448 fish in 1968 had a major impact on population numbers.

Enhanced growth following population reductions caused by decreased water levels have been reported for bluegill, Lepomis macrochirus (Pierce et al. 1965) and "sunfishes and perch" (Cooper 1967). Likewise, Langemeier (1965) and Holz (1969) found growth of flathead catfish after the first year of life was greater in channelized sections of the Missouri River, Nebraska, which had more intensive commercial exploitation than unchannelized sections.

In summary, the significant correlations between lake levels and growth of flathead catfish in Lake Carl Blackwell probably have limited predictive value under a different pattern of changing lake levels. However, changes in growth and fecundity of flathead catfish indicate that fluctuations in water level of reservoirs can have measurable effects on predatory fishes. Although improved growth and fecundity of fish in 1969 probably was influenced by exploitation, the relative effects of rises in lake level and exploitation cannot be adequately separated.

CHAPTER VI

IMPLICATIONS

Theoretically, the major goal of fisheries research is to learn more about fish species and their interactions with environmental factors in order to better manage waters for an optimum sustainable yield (OSY) of products for public consumption. Therefore, completed aquatic studies should always be scrutinized for possible management implications. The potential contribution of the flathead catfish to OSY can be roughly divided into two categories: (1) commercial and sport fishing value where the catch is directly utilized; and (2) possible regulatory effect the species may have as a large predator on carp and freshwater drum which are often too large to be eaten by other piscivorous sport species. The latter indirect contribution to OSY is suggested by food habits in Oklahoma reservoirs (Turner and Summerfelt 1971a), but can only be assumed and will not be discussed. However, findings in Lake Carl Blackwell can be considered in relation to exploitation.

In a review of the dynamics of exploited lake whitefish, *Coregonus clupeaformis*, Healey (1975) assumed that the difference between maximum growth and growth of unexploited populations represented the potential of the fish to respond to exploitation. In Lake Carl Blackwell, the combination of low exploitation rates and decreasing lake levels from 1962 through March 1968 eventually depressed growth and fecundity of the flathead catfish. Increased growth and fecundity in 1969 was probably a response to either exploitation or water level rises or both. However, the much greater growth rates of some fish in Lake Carl Blackwell and most fish in Boomer Lake indicate good potential for compensatory increases in growth when populations are heavily exploited. Potentially, the species could be harvested at rates which would result in increased growth and annual production in waters where it was underexploited.

Reported commercial harvest of flathead catfish in Lake Eufaula has averaged 0.57 kg/ha for the last 11 years without any reduction in the number and average weight of the flathead catfish in the commercial harvest (Mensinger 1971; unpublished data of Oklahoma Department of Wildlife Conservation). Likewise, commercial harvest of flathead catfish from Lake Oologah has averaged 0.81 kg/ha for the last four years. Commercial harvest from Lake Carl Blackwell was 2.18 and 2.14 kg/ha (based on the area of the lake at spillway elevation) in 1957 and 1958, respectively (Heard 1959). The one-year removal of 2509 kg of flathead catfish in 1968 was equivalent to a harvest of 1.78 kg/ha from the lake at spillway elevation. This exploitation included an estimated 49% of the flathead catfish in the 600-800-mm length range. By comparison, the annual total mortality rate was 41% (based on the 1968 catch curve of fish of ages 6-13) (Summerfelt et al. 1972). It is unlikely that a harvest rate of greater than 2.0 kg/ha/year could be maintained in Lake Carl Blackwell without compensatory increases in growth rate and annual natural mortality rate. However, increased growth and fecundity of flathead catfish in 1969 indicates a potential for compensatory responses to exploitation. Therefore, it is impossible to predict a maximum sustainable yield for flathead catfish in Lake Carl Blackwell without observing the effects of a high exploitation rate ($\geq$ 2.0 kg/ha/year) for three or more consecutive years.

Because of high vulnerability of adult flathead catfish to hobbled gill nets (Heard 1959; present study) and small lake size, it would probably be more practical to either not allow commercial fishing in Lake Carl Blackwell or allow it only periodically. The latter policy would permit an increase in biomass of flathead catfish biomass in off years and improve catch rates during years when commercial fishing was permitted. This fishing policy could also be altered to allow netting during years when lake levels were low. In addition, the rate of commercial harvest could be controlled to evaluate the effects of heavy exploitation on the population dynamics of flathead catfish.

Commercial fishing for flathead catfish in larger reservoirs probably can be allowed on a continual basis in Oklahoma. However, the density and age structure of the population should be checked periodically to determine if commercial harvest was having undesirable effects on the population in a specific reservoir. An important fact to consider in managing a fishery for flathead catfish is age at sexual maturity. In the Mississippi River, Iowa, Schoumacher (1968) indicated that the flathead catfish:channel catfish ratio in the commercial catch had decreased to 1:49 by 1963 compared to a 1:4 ratio in 1944-1946 (Barnickol and Starrett 1951). The likely reason for this decline in flathead catfish abundance was heavy commercial fishing with a 330 mm minimum length limit for all catfish species. Barnikol and Starrett (1951) indicated females reached maturity at 350-510 mm and 66% of the flathead catfish caught in 1963 were $<$ 483 mm

(Schoumacher 1968). It appears that heavy exploitation before females reach maturity may have reduced flathead catfish abundance. Holz (1969) also indicated that overharvest in the channelized portion of the Missouri River, Nebraska greatly reduced numbers of older flathead catfish. Langemeier (1965) reported females reach maturity at 3 to 5 years of age (346-508 mm) in the Missouri River, so the presence of only six fish older than age 5 out of 220 fish collected by Holz (1969) indicates a serious reduction of mature females.

Data on lake whitefish in Lake Ontario suggested that the average fish should be assured a chance to spawn at least 1.5 times if the population were to remain stable (Regier and Loftus 1972). Female flathead catfish reached sexual maturity at 458-573 mm (ages 5-7) in Lake Carl Blackwell (Turner and Summerfelt 1971c), therefore, a minimum size limit of 600 mm would insure females the opportunity to spawn at least once. In other reservoirs, the size when sexual maturity was attained would have to be determined before setting a minimum size limit. For example, females in the more rapidly-growing population in Boomer Lake were immature at lengths of 640-695 mm as age-4 fish. As fish collected by gill nets in Lake Carl Blackwell survived well, release of flathead catfish less than 600 mm by fishermen may not cause excessive mortalities if they are carefully handled. Commercial fishermen may not run their nets as often or handle their fish as carefully as in this study;therefore, a minimum mesh size of 89 mm (square) for gill netting might be a better method for regulating harvest of immature females. This mesh size would reduce the numbers of largemouth bass and white crappie caught (Heard 1959; present report) and eliminate potential mortality associated with release of flathead catfish caught in gill nets. In reservoirs where other commercial species such as buffalo and carp are harvested in large numbers, a 600 mm minimum size limit would be more desirable. However, if periodic sampling indicated a normal age distribution and unchanging relative abundance of flathead catfish, it would not be necessary to institute either a minimum size limit or minimum mesh regulation.

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APPENDIXES

APPENDIX A

BACK-CALCULATED GROWTH IN LAKE CARL BLACKWELL

TABLE 20. Mean calculated total lengths in millimeters for flathead catfish collected from Lake Carl Blackwell in 1967.

Year class	Age group	Number of fish	Mean calculated total length (mm) at end of year										
			1	2	3	4	5	6	7	8	9	10	11
1962	5	4	65	130	240	387	533						
1961	6	10	62	121	191	298	454	568					
1960	7	6	55	106	179	301	465	566	617				
1959	8	3	62	111	206	288	407	527	592	636			
1958	9	3	65	120	180	283	388	518	595	637	667		
1956	11	1	63	128	213	334	400	494	583	663	691	719	742
Weighted mean length			61	118	197	310	454	552	604	640	673	719	742
Number of fish in mean			27	27	27	27	27	23	13	7	4	1	1

TABLE 21. Mean calculated total lengths in millimeters for flathead catfish from Lake Carl Blackwell in 1969.

Year class	Age group	Number of fish	Mean calculated total length (mm) at end of year										
			1	2	3	4	5	6	7	8	9	10	11
1964	5	6	70	143	257	408	578						
1963	6	6	67	123	213	339	478	623					
1962	7	4	72	138	213	342	493	613	681				
1961	8	1	49	87	141	199	272	359	544	656			
1960	9	3	57	115	193	282	400	594	675	723	759		
1959	10	1	97	180	282	408	583	622	666	690	719	743	
1958	11	2	70	143	236	338	430	520	578	666	707	734	755
Grand mean length			68	133	223	347	488	588	647	693	735	737	755
95% confidence limits			±5	±11	±21	±32	±47	±60	±60	±42	±41	±39	±31
Number of fish in mean			23	23	23	23	23	17	11	7	6	3	2

TABLE 22. Mean calculated total lengths in millimeters for flathead catfish collected from Lake Carl Blackwell in 1970.

Year class	Age group	Number of fish	Mean calculated total length (mm) at end of year												
			1	2	3	4	5	6	7	8	9	10	11	12	13
1967	3	1	58	102	209										
1965	5	2	58	121	245	437	588								
1964	6	7	66	130	253	383	564	670							
1963	7	7	67	135	253	399	552	630	682						
1962	8	1	53	121	194	379	530	617	666	709					
1961	9	2	61	117	267	447	646	738	802	845	889				
1960	10	3	66	133	217	335	450	581	651	682	712	745			
1959	11	1	53	112	209	257	291	340	462	549	568	602	646		
1958	12	2	58	117	219	330	415	517	605	658	692	721	748	770	
1957	13	1	58	151	287	355	457	510	622	670	709	748	772	792	816
Grand mean length			63	127	243	381	529	618	664	698	731	718	729	777	816
95% confidence interval			±3	±7	±18	±31	±40	±42	±48	±74	±88	±66	±109	±119	
Number of fish in mean			27	27	27	26	26	24	17	10	9	7	4	3	1

TABLE 23. Mean calculated total lengths in millimeters for flathead catfish collected from Lake Carl Blackwell in 1971.

Year class	Age group	Number of fish	Mean calculated total length (mm) at end of year													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1969	2	3	65	160												
1968	3	1	49	102	194											
1967	4	3	62	128	269	376										
1966	5	9	69	122	218	362	501									
1965	6	14	62	112	178	312	473	586								
1964	7	13	65	124	203	312	450	557	617							
1963	8	12	67	129	210	354	495	579	655	706						
1962	9	9	62	111	184	320	484	593	652	701	742					
1961	10	9	66	125	201	312	478	604	663	707	752	789				
1960	11	9	66	132	210	313	452	574	642	690	727	764	798			
1959	12	4	58	103	151	236	381	522	613	653	678	702	734	765		
1958	13	6	62	116	176	245	341	475	564	617	669	699	730	760	789	
1957	14	4	58	109	211	312	401	510	607	656	686	712	729	749	795	797
Grand mean length			64	121	199	318	459	566	633	685	718	744	757	759	784	798
95% confidence limits			±2	±5	±10	±17	±23	±24	±26	±29	±31	±37	±38	±34	±46	±57
Number of fish in mean			96	96	93	92	89	80	66	53	41	32	23	14	10	4

TABLE 24. Mean calculated total lengths in millimeters for flathead catfish collected from Lake Carl Blackwell in 1972.

Year class	Age group	Number of fish	Mean calculated total length (mm) at end of year																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1965	7	2	59	120	234	400	582	684	720										
1963	9	3	60	116	198	314	474	575	653	695	727								
1961	11	1	66	123	277	468	648	674	704	740	802	859	900						
1960	12	4	58	112	177	268	452	602	694	748	794	836	870	900					
1959	13	3	62	114	187	267	376	492	629	685	716	748	778	808	830				
1958	14	1	53	111	231	370	519	616	673	721	750	774	798	817	856	880			
1957	15	2	62	112	235	382	495	595	655	695	728	752	775	802	818	845	865		
1955	17	1	65	140	216	307	377	458	543	614	654	674	694	709	719	745	770	790	800
Grand mean length			60	116	207	325	474	583	664	706	744	784	813	832	814	829	833	790	800
95% confidence limits			±3	±8	±24	±48	±64	±54	±38	±38	±41	±58	±61	±68	±64	±103	±162	-	-
Number of fish in mean			17	17	17	17	17	17	17	15	15	12	12	11	7	4	3	1	1

TABLE 25. Mean calculated total lengths in millimeters for male and female flathead catfish collected from Lake Carl Blackwell in 1968.

Year class	Age group	Number of fish	Sex	Mean calculated total length (mm) at end of year												
				1	2	3	4	5	6	7	8	9	10	11	12	13
1965	3	3	Male	53	94	147										
	3	1	Female	47	92	133										
1964	4	5	Male	48	102	166	271									
	4	4	Female	54	116	160	240									
1963	5	13	Male	58	120	223	354	530								
	5	12	Female	60	120	222	384	532								
1962	6	13	Male	56	111	179	287	426	574							
	6	17	Female	56	113	191	310	468	579							
1961	7	12	Male	57	108	177	270	410	553	637						
	7	14	Female	64	129	208	319	447	560	618						
1960	8	10	Male	60	124	194	284	402	505	603	688					
	8	12	Female	60	132	222	327	447	572	628	662					
1959	9	6	Male	66	130	210	295	421	526	602	674	730				
	9	10	Female	56	110	188	281	408	554	646	691	718				
1958	10	1	Male	71	127	223	319	486	643	739	815	865	901			
	10	13	Female	65	122	211	306	423	539	642	687	713	734			
1957	11	4	Male	66	122	200	283	357	453	570	650	700	742	776		
	11	3	Female	48	98	163	239	339	449	592	674	706	727	744		

TABLE 25 (Continued)

Year class	Age group	Number of fish	Sex	Mean calculated total length (mm) at end of year 1	2	3	4	5	6	7	8	9	10	11	12	13
1956	12	1	Male	55	105	195	255	359	454	574	613	643	673	698	723	
	12	2	Female	62	122	260	416	616	693	728	759	792	816	834	851	
1955	13	3	Male	54	105	184	327	466	545	609	670	707	760	810	845	879
	13	1	Female	45	103	142	182	221	397	529	577	626	660	685	704	734
Grand mean length			Male	58	115	191	297	438	537	614	678	721	758	779	814	879
			Female	59	119	203	315	453	559	632	681	716	738	764	802	734
Number of fish in mean			Male	71	71	71	68	63	50	37	25	15	9	8	4	3
			Female	89	89	89	88	84	72	55	41	29	19	6	3	1

TABLE 26. Mean calculated total lengths in millimeters for male and female flathead catfish collected from Lake Carl Blackwell in 1971.

Year class	Age group	Number of fish	Sex	Mean total length at age													
				1	2	3	4	5	6	7	8	9	10	11	12	13	14
1969	2	1	Male	63	151												
	2	2	Female	66	165												
1968	3	1	Male	49	102	194											
	0	0	Female	0	0	0											
1967	4	2	Male	61	136	272	374										
	4	1	Female	63	112	262	379										
1966	6	6	Male	71	120	212	359	496									
	5	6	Female	68	123	220	363	504									
1965	6	6	Male	62	110	196	343	518	623								
	6	7	Female	62	110	157	279	430	551								
1964	7	2	Male	73	134	211	296	432	547	627							
	7	11	Female	64	122	201	315	453	559	616							
1963	8	7	Male	68	135	228	387	534	613	686	734						
	8	2	Female	68	136	189	318	367	410	500	583						
1962	9	4	Male	66	112	169	298	491	630	707	757	799					
	9	5	Female	58	110	195	337	478	563	608	657	696					
1961	10	4	Male	64	126	208	310	472	604	668	712	755	794				
	10	5	Female	67	124	196	314	482	604	659	702	749	784				
1960	11	5	Male	68	133	199	290	438	604	691	737	777	820	862			
	11	3	Female	62	130	220	314	442	513	562	620	654	687	708			
1959	12	1	Male	63	112	165	238	413	578	680	719	743	768	787	806		
	12	3	Female	57	100	146	235	371	504	591	632	656	680	716	751		

TABLE 26 (Continued)

Year class	Age group	Number of fish	Sex	Mean total length at age 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1958	13	2	Male	58	97	138	182	260	364	464	542	634	687	734	777	819	
	13	2	Female	66	138	223	333	476	649	683	707	729	743	758	775	797	
1957	14	1	Male	63	116	223	355	466	549	622	651	685	714	738	763	797	816
	14	2	Female	58	112	199	274	355	483	593	651	683	707	721	743	765	789
Grand mean length			Male	65	123	204	325	476	592	663	715	753	780	811	781	811	816
			Female	63	121	195	313	449	549	610	656	699	728	723	756	781	789
± 95% confidence limits			Male	±3	±6	±12	±17	±17	±18	±17	±7	±13	±7	±9	±21	±21	
			Female	±3	±6	±9	±15	±14	±15	±10	±10	±8	±5	±7	± 9	± 4	±62
Number of fish in mean			Male	39	39	38	37	35	32	26	24	17	13	9	4	3	1
			Female	49	49	47	47	46	40	33	22	20	15	10	7	4	2

TABLE 27. Mean calculated growth increments in millimeters stratified by year of growth for male and female flathead catfish collected from Lake Carl Blackwell in 1968.

Year of increments	Sex	Mean growth increment (mm) in year of life												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1967	Male	-[a]	-[a]	53	105	176	148	84	85	56	36	34	25	34
	Female	-	-	41	80	148	111	58	34	27	21	17	17	30
1966	Male	-	41	64	131	139	143	98	72	50	42	25	35	
	Female	-	45	44	162	158	113	56	45	26	21	18	19	
1965	Male	53	54	103	108	140	103	76	76	50	30	50		
	Female	47	62	102	121	128	125	92	45	32	24	25		
1964	Male	48	62	68	93	118	105	96	80	30	53			
	Female	54	60	78	111	120	146	103	82	33	34			
1963	Male	58	55	69	90	126	157	117	39	37				
	Female	60	57	79	105	127	116	143	31	49				
1962	Male	56	51	70	85	167	96	120	61					
	Female	56	65	90	93	117	110	37	48					
1961	Male	57	64	80	96	74	95	64						
	Female	64	72	78	95	100	77	132						
1960	Male	60	64	96	83	104	79							
	Female	60	54	89	76	200	176							
1959	Male	66	56	78	60	139								
	Female	56	57	65	156	39								

TABLE 27 (Continued)

Year of increments	Sex	Mean growth increment (mm) in year of life												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1958	Male	71	56	90	143									
	Female	65	50	138	40									
1957	Male	66	50	79										
	Female	48	60	39										
1956	Male	55	51											
	Female	62	58											
1955	Male	54												
	Female	45												
Grand mean increment	Male	58	57	77	104	138	123	90	76	48	44	39	32	34
	Female	59	60	83	112	134	119	80	44	28	22	19	18	30

[a]No sample available for this year.

TABLE 28. Mean calculated growth increments in millimeters which occurred in the years 1959-1970 for male and female flathead catfish collected from Lake Carl Blackwell in 1971.

Year of increments	Sex		Mean growth increment (mm) in year of life											
			1	2	3	4	5	6	7	8	9	10	11	12
1970	Male		-[a]	87	92	102	136	105	80	48	43	39	42	19
	Female		-	100	-	117	142	121	57	82	39	35	21	36
1969	Male	1	63	53	136	147	175	114	72	50	44	43	19	
	Female	2	66	-	151	142	151	106	90	49	47	32	36	
1968	Male	1	49	75	92	147	136	79	76	44	40	24		
	Female	0	-	49	97	122	138	44	46	44	34	24		
1967	Male	2	61	49	86	85	148	140	64	47	24			
	Female	1	63	55	47	114	49	84	54	58	24			
1966	Male	3	71	48	78	159	193	131	86	39				
	Female	6	68	48	80	129	141	122	49	40				
1965	Male	6	62	61	93	129	163	166	102					
	Female	7	62	58	53	142	168	71	87					
1964	Male	2	73	67	57	102	149	165						
	Female	11	64	68	86	118	128	133						
1963	Male	7	68	46	81	90	175							
	Female	2	68	52	72	94	136							
1962	Male	4	66	62	66	73								
	Female	5	58	57	91	89								

TABLE 28 (Continued)

Year of increments	Sex	Mean growth increment (mm) in year of life 1	2	3	4	5	6	7	8	9	10	11	12
1961	Male 4	64	65	53									
	Female 5	67	68	45									
1960	Male 5	68	49										
	Female 3	62	44										
1959	Male 1	63											
	Female 3	57											
Grand mean increment	Male	65	58	81	121	154	118	78	49	46	41	38	33
	Female	63	58	76	118	137	109	61	49	35	28	23	26

[a]No sample available for this year.

APPENDIX B

GROWTH OF TAGGED FISH

TABLE 29. Known growth in total length between tagging and recapture for 97 flathead catfish in Lake Carl Blackwell in 1967-1971.

Sex	Tagging date	Recapture date		Months between	Total length (mm) Tagging	Total length (mm) Recapture	Growth (mm) Total	Growth (mm) mm/month
			Tagged with strap tag					
Male	6-15-67	6-24-68		12.3	574	592	18	1.5
Male	6-21-67	5-17-68		10.9	709	719	10	0.9
Female	6-15-67	6-20-68		12.2	607	605	-2	-0.2
Female	6-20-67	6-18-68		12.0	597	637	40	3.3
?	6-21-67	4-16-68		8.9	559	567	8	0.9
			Means	11.3	609	624	15	1.3[a]
Female	6-15-67	7-11-69		24.9	663	699	36	1.4
?	6-20-67	5-25-69		23.8	610	673	63	2.6
			Means	24.4	636	686	50	2.0
Female	6-15-67	10-25-70		40.3	663	742	79	2.0
Female	7-11-69	10-25-70		15.5	699	742	43	2.8
			Tagged with ring (butt-in) tag only					
Female	8-17-67	8-02-68		11.5	561	569	8	0.7
?	8-15-67	3-07-68		7.7	648	650	2	0.3
?	9-30-67	4-10-68		7.3	604	607	3	0.4
?	9-30-67	7-10-68		9.3	858	860	2	0.2
			Means	9.0	668	672	4	0.4

TABLE 29 (Continued)

Sex	Tagging date	Recapture date	Months between	Total length (mm)		Growth (mm)	
				Tagging	Recapture	Total	mm/month
Male	8-08-67	6-19-70	34.3	655	786	131	3.8
Tagged with both ring and spaghetti tags							
Male	3-15-68	8-29-68	5.5	686	711	25	4.6
Male	3-18-68	5-28-68	2.3	673	688	15	6.5
Male	4-27-68	6-14-68	1.5	704	719	15	10.0
Male	5-08-68	6-20-68	1.4	815	819	4	2.9
Male	5-10-68	6-18-68	1.2	632	642	10	8.3
Male	6-07-68	7-19-68	1.4	676	691	25	17.9
Male	6-18-68	8-09-68	1.7	663	673	10	5.9
		Means	2.1	693	706	15	7.1
Female	3-19-68	6-18-68	3.0	704	706	2	0.7
Female	3-21-68	7-19-68	3.9	663	686	23	5.9
Female	3-21-68	7-26-68	4.2	676	684	8	1.9
Female	3-25-68	5-30-68	2.2	683	683	0	0.0
Female	4-05-68	5-30-68	1.8	747	740	-7	-3.9
Female	4-19-68	7-26-68	3.2	660	655	-5	-1.6
Female	5-08-68	6-20-68	1.7	735	737	2	1.2
Female	5-16-68	9-05-68	3.6	775	790	15	4.2
Female	5-25-68	8-06-68	2.5	711	706	-5	-2.0
Female	5-28-68	7-03-68	1.2	739	742	3	2.5
Female	5-30-68	6-18-68	0.6	554	556	2	3.3
Female	5-30-68	7-03-68	1.2	742	740	-2	-1.7

TABLE 29 (Continued)

Sex	Tagging date	Recapture date		Months between	Total length (mm)		Growth (mm)	
					Tagging	Recapture	Total	mm/month
Female	5-30-68	7-26-68		1.9	681	686	5	2.6
Female	6-14-68	7-09-68		0.9	630	632	2	2.2
Female	6-27-68	7-19-68		0.7	655	672	17	24.3
Female	6-27-68	7-31-68		1.1	752	757	5	4.6
Female	7-10-68	7-19-68		0.3	711	711	0	0.0
Female	7-17-68	7-26-68		0.3	686	686	0	0.0
Female	7-17-68	9-06-68		1.6	763	770	7	4.4
			Means	1.9	698	702	4	2.1
Male	3-18-68	10-06-69		17.4	698	790	92	5.3
Male	5-14-68	10-25-69		20.6	670	710	40	1.9
			Means	19.0	684	750	66	3.5
Female	5-14-68	6-25-69		13.4	721	770	49	3.7
Female	5-25-68	7-02-69		13.2	714	720	6	0.4
Female	5-30-68	6-20-69		12.7	551	586	35	2.8
Female	6-07-68	6-25-69		12.6	724	744	20	1.6
Female	6-18-68	7-09-69		12.7	640	676	36	2.8
Female	6-27-68	6-20-69		11.8	698	716	18	1.5
Female	6-27-68	6-25-69		11.9	663	687	24	2.0
Female	7-29-68	10-06-69		14.2	686	733	47	3.3
Female	7-31-68	10-09-69		14.3	694	750	56	3.9
			Means	13.0	677	709	32	2.5
Male	5-14-68	5-11-70		23.9	698	787	89	3.7

TABLE 29 (Continued)

Sex	Tagging date	Recapture date	Months between	Total length (mm)		Growth (mm)	
				Tagging	Recapture	Total	mm/month
Female	5-28-68	7-29-70	26.0	750	818	68	2.6
Female	6-27-68	6-26-70	24.0	663	728	65	2.7
Female	6-27-68	7-02-70	24.2	675	703	28	1.2
		Means	24.7	696	750	54	2.2
Female	6-07-68	2-19-71	32.4	614	704	90	2.8
Female	7-17-68	7-10-71	35.8	719	817	98	2.7
Female	11-16-68	4-06-71	29.7	620	640	40	1.4
		Means	32.6	651	720	76	2.3
Male	6-27-69	10-25-69	3.9	724	769	45	11.5
Female	1-22-69	10-09-69	8.6	575	624	49	5.7
Female	9-19-69	10-21-69	1.1	644	649	5	4.6
		Means	4.8	610	636	27	5.6
Male	10-25-69	10-28-70	12.1	779	821	52	4.3
Female	6-20-69	6-10-70	11.7	740	778	38	3.2
Female	6-25-69	6-26-70	12.0	687	728	41	3.4
Female	7-11-69	10-25-70	15.5	699	742	43	2.8
Female	10-09-69	10-17-70	12.3	632	710	78	6.3
		Means	12.9	690	740	50	3.9
Female	10-09-69	2-23-71	15.5	837	850	13	0.8

TABLE 29 (Continued)

Sex	Tagging date	Recapture date	Months between	Total length (mm) Tagging	Total length (mm) Recapture	Growth (mm) Total	Growth (mm) mm/month
Female	6-09-69	6-21-71	24.4	640	726	86	3.5
Female	6-20-69	6-29-71	24.3	586	666	80	3.3
Female	6-25-69	5-22-71	22.9	675	736	61	2.7
Female	6-25-69	6-24-71	24.0	561	677	116	4.8
Female	6-27-69	6-18-71	23.3	566	661	95	4.1
		Means	23.8	606	693	88	3.7
Male	9-30-70	3-30-71	6.0	810	818	8	1.3
Male	11-20-70	5-21-71	6.0	701	707	6	1.0
Male	12-21-70	5-28-71	5.2	706	715	9	1.7
		Means	5.7	739	747	8	1.4
Female	11-04-70	6-12-71	7.2	640	640	0	0.0
Female	11-07-70	7-13-71	8.3	580	590	10	1.2
Female	11-25-70	7-14-71	8.6	697	697	0	0.0
		Means	8.0	639	642	3	0.4
Female	12-31-70	7-14-71	6.5	572	615	43	6.6
Female	5-04-70	10-09-71	17.2	813	860	47	2.7
Female	6-19-70	5-24-71	11.2	562	621	59	5.3
Female	7-03-70	7-08-71	12.2	761	780	19	1.6
Female	7-24-70	10-28-71	15.1	832	851	19	1.3
Female	8-04-70	6-13-71	10.3	632	658	26	2.5
Female	10-10-70	10-12-71	12.0	720	740	20	1.7
Female	11-04-70	10-12-71	11.2	834	853	19	1.7
Female	11-25-70	10-28-71	11.1	800	821	21	1.9
		Means	12.5	744	773	29	2.3

TABLE 29 (Continued)

Sex	Tagging date	Recapture date	Months between	Total length (mm) Tagging	Total length (mm) Recapture	Growth (mm) Total	Growth (mm) mm/month
Female	7-01-70	2-23-71	7.7	995	1011	16	2.1
Male	3-30-71	10-12-71	6.5	876	923	47	7.2
Male	5-01-71	6-18-71	1.6	690	702	12	7.5
		Means	4.0	783	812	30	7.5
Female	5-21-71	6-14-71	0.8	516[b]	529	13	16.2
Female	3-30-71	6-18-71	2.7	637	636	-1	-0.4
Female	4-02-71	10-13-71	6.4	731	757	16	2.5
Female	5-30-71	7-23-71	1.8	711	726	15	8.3
Female	6-07-71	7-13-71	1.2	632	630	-2	-1.7
Female	6-13-71	10-23-71	4.3	658	660	2	0.5
Female	6-18-71	10-09-71	3.7	641	656	15	4.0
		Means	3.4	670	678	8	2.4

[a]Mean growth rate was calculated by dividing mean growth in millimeters by the mean number of months between tagging and recapture.

[b]This fish was immature when collected.

APPENDIX C

COMPARISON OF GROWTH RATES

Comparison of Growth Rates

Published growth rates of flathead catfish were evaluated based on the findings of this study. Several authors have noted the problem of annuli loss due to lumen enlargement in basal recess (BR) sections of the pectoral spine (Muncy 1957; Langemeier 1965; Mayhew 1969; Holz 1969; Layher 1976). Other workers, unaware of the problem of annuli loss, would have assumed the innermost annulus to represent the first annulus. Because these authors would have measured growth to age 1 of older fish from the center of a relatively large lumen, calculated lengths at age 1 would be unusually great. Therefore, one indicator of errors in age determination would be relatively great calculated lengths at age 1.

The first annulus typically was absent from pectoral BR sections of fish in age-group 5 (by 500 mm) (Langemeier 1965; Holz 1969; and present paper). Therefore, reports where lengths of flathead catfish exceeded 500 mm were more likely to have underestimated age of older, larger fish. In the following comparison, reports where errors in age determination were more likely are noted.

Growth Rates in Rivers. Reported growth of flathead catfish in rivers (Table 30) should be considered more accurate when loss of annuli because of lumen enlargement of the pectoral spine was recognized and corrections made. Growth rates reported by workers who do not mention loss of annuli may still be relatively accurate if their samples included few fish > 500 mm. However, growth rates reported for some rivers probably were overestimated because of errors in determining the age of older, larger fish (McCoy 1955, and Linton 1961). In addition, age of fish > 500 mm probably was underestimated by Cross and Hastings (1956) and Schoumacher (1968).

TABLE 30. Comparison of mean calculated total lengths in millimeters at ages 1-10 for flathead catfish in river habitats.

River and state	No. of fish	Mean total length at end of year, mm										Reference
		1	2	3	4	5	6	7	8	9	10	
Missouri R., Nebraska	-[a]	84	180	288	374	450	508	546	595	684	770	
Unchannelized	195	93	184	273	346	451	520	603	642	691	776	Langemeier 1965
	158	79	169	260	331	395	455	517	560	598	717	Holz 1969
Channelized	195	90	181	298	399	466	515	528	637	762	816	Langemeier 1965
	212	75	188	321	411	487	541	536	541			Holz 1969
Mississippi R., Iowa	303[b]	-	355	406	462	533	556	686	663	655	620	Schoumacher 1968
Mississippi R., Iowa	-	178	254	305	386	444	533	610	660	711	838	Barnickol and Starrett 1951
Mississippi R., Missouri	-	203	305	406	444	482	559	698	813	889		Barnickol and Starrett 1951
Turbid rivers (Oklahoma)	-[a]	128	251	353	455	503	542	639	776			
Verdigris R.	28	91	155	206	274	320	373	419	523	584	614	Jenkins and Finnell 1957
Cimmaron R.	16	134	289	371	452	493	579	660	703			Linton 1961
Poteau R.	14	122	241	386	515	612	675	838	1102			McCoy 1955
Arkansas R.	24	167	320	449	579	587						Linton 1961
Turbid rivers (Not Oklahoma)	-[a]	109	212	306	396	492	516	610	666	673		
Des Moines R., Iowa												
upper portion	59	76	162	236	333	439	526	612	675	747		Muncy 1957
lower portion	302	142	269	393	469	550	600	674	714			Mayhew 1969
Big Blue R., Kansas	75	142	261	366	482	630	-	701	772			Minckley and Deacon 1959
Salt R., Missouri	52	76	155	231	299	348	421	452	503	599		Purkett 1958
Kansas R., Kansas	29	209	254	400	622	648	819	851	-	1022	1118	Cross and Hastings 195[illegible]
Rivers of lower turbidity	-[a]	88	203	298	402	451	528	572				
Neosho R., Kansas	79	88	231	307	390	432						Minckley and Deacon 1959
Illinois R. System, Oklahoma												
Tenkiller Reservoir (year of impoundment)	19	84	201	330	439	516						Jenkins 1954
Quall's Cut-off Lake (one year after flooding)	23	71	178	277	351	406	528	572				Jenkins 1954
Salt Creek, Oklahoma	9	107	203	277	427							Elkin 1955

[a]Unweighted average for river(s) in the group.

[b]Average length at capture of fish at age indicated (not included in average growth rate).

Growth of flathead catfish was slightly greater in the downstream channelized section than in the upstream unchannelized section of the Missouri River, Nebraska (Langemeier 1965). In a second study of the same areas, Holz (1969) concluded that greater length at ages 2-7 in the downstream channelized area was probably related to a reduction in intraspecific competition because of heavier exploitation by commercial fishermen.

Mayhew (1969) reported greater calculated lengths of flathead catfish at ages 2-5 in the Des Moines River, Iowa than Muncy (1957) calculated for fish of ages 3-6 in same river about 100 miles upstream. Although it seems unlikely, the possibility that Mayhew underestimated the age of all fish by one year must be considered.

Minckley and Deacon (1959) reported growth of flathead catfish was greater in a turbid river than in a clearer river. They attributed greater growth in the Big Blue River, Kansas to an earlier, more exclusive change to a fish diet. However, the larger sizes of flathead catfish collected from the Big Blue River increased the possibility of error in age determinations. The slowest growth rates for flathead catfish in rivers were in the turbid Verdigris River, Oklahoma (Jenkins and Finnell 1957) and the turbid Salt River, Missouri (Purkett 1958).

Growth of flathead catfish in Lake Carl Blackwell was less at ages 1-3 than reported for any river. However, greater length increments during the fourth through sixth years of life in Lake Carl Blackwell resulted in calculated lengths at age 6 and older generally exceeding growth rates in rivers.

Growth Rates in Reservoirs. Although growth rates have been reported for numerous reservoirs (Table 31), the accuracy of many of these reports is unknown, Jenkins (1954) and Carroll and Hall (1964) refer to the lumen enlargement problem which occurs when sections are cut from distal end of the basal recess, but do not disucss whether complete annuli were missing at particular sizes or ages. Jenkins (1954) and Layher (1976) used BR sections of dorsal spines because of its smaller lumen. However, use of AP sections of dorsal spines in the present report would have caused errors in age determination. Because most growth studies in reservoirs used BR sections of pectoral spines and failed to mention loss of annuli by lumen enlargement, errors in age determination probably were common for flathead catfish > 500 mm, especially for fish with slow initial growth. Even the same worker (such as McCoy 1955) probably made errors of differing magnitude when determining the age of fish from different populations, particularly when the age and length distribution of samples differed between waters. The potential for errors in age determination reduce the comparability of reported growth data and should be considered in the following discussion.

With the exception of lower mean lengths at ages 3 and 4 for lower Grand Lake (Jenkins 1954), mean lengths at ages 1-4 in Lake Carl Blackwell were less than reported for any reservoir (Table 31). By contrast, mean lengths of fish at ages 6-9 generally were intermediate to other growth rates. The slower growth rates noted in Table 31 probably were more accurate than the faster growth rates (McCoy 1955; Houser and Heard 1957; Houser 1958; Carroll and Hall 1964). For example example, McCoy (1955) reported a faster growth rate for flathead catfish in lakes Ardmore, Walters, Boomer, Duncan, and Texoma than I calculated for the reintroduced population in Boomer Lake.

TABLE 31. Comparison of mean calculated total lengths at ages 1-10 of flathead catfish in Oklahoma and Tennessee reservoirs.

Reservoir	Surface area (ha)	Number of fish	Mean calculated total length at end of year (mm) 1	2	3	4	5	6	7	8	9	10	Reference
Oklahoma reservoirs													
Boomer	105	16	65	145	384	565	560						Present report
Carl Blackwell	808	354	61	120	204	320	462	565	635	684	722	747	Present report
Newkirk City	18	9	104	160	259	371	391	460	546	579	617		McCoy 1955
Pawhuska	38	4	185	419	691	741	777						McCoy 1955
Ardmore City	47	12	167	266	454	642	787	843	889	925			McCoy 1955
Walters	63	69	89	208	363	561	678	752	818	856	902	944	McCoy 1955
Pawnee	104	4	71	180	322	495							McCoy 1955
Boomer	105	75	-[a]	287	460	638	742	826	884	927	968	1003	McCoy 1955
Clinton	136	5	86	213	363	465	533	551	604	642			McCoy 1955
Duncan	162	58	63	172	302	538	645	741	876	940	1003	1105	McCoy 1955
Greenleaf	373	6	101	165	264	358	513						McCoy 1955
Heyburn	433	15	162	317	564								McCoy 1955
		-[a]	124	279	535	718							Buck 1956
Spavinaw	663	14	130	213	300	361	399	513	521	638	645		Jackson 1966
Eucha	1166	7	147	257	401	602	754						McCoy 1955
Lawtonka	757	4	124	307	541	665							Houser 1960
Murray	2320	2	139	391	470	655	680						McCoy 1955
Wagonor	-[a]	31	89	228	393	492	626	637					Jenkins, Leonard and
Tenkiller	243	19	84	201	330	439	516						Hall 1952
Tenkiller	5062	35	114	254	429	566	688	785					Houser and Heard 1957
		17	94	180	266	353	424						Summers 1961
Ft. Gibson	7695	43	101	239	401	477	597	627					McCoy 1955
Ft. Gibson		47	106	213	335	493	653	782	904	991			Houser and Heard 1957
Ft. Gibson		314	132	264	378	508	648	737	831	897			Houser 1960

TABLE 31 (Continued)

Reservoir	Surface area (ha)	Number of fish	Mean calculated total length at end of year (mm)										
			1	2	3	4	5	6	7	8	9	10	
Grand	18752												
lower reservoir		59	63	127	185	259	340	386	454	442			Jenkins 1954
upper reservoir		61	86	175	287	411	465	543	625				McCoy 1955
Neosho R. arm		86	139	259	381	490	584	655	719	785	879	945	McCoy 1955
main body		221	86	160	241	322	383	439	485	518			Jenkins 1953
Texoma	36940	27	157	274	437	569	683	759	846	917	970	925	McCoy 1955
Oklahoma average													
(18 lakes)	-	723	116	246	385	507	593	657	733	822	890	971	McCoy 1955
(all waters)	-	-[a]	114	233	358	485	579	620	685	764	777	848	Houser and Heard 1963
Tennessee reservoirs													
Boone	1782	18	162	264	378	475	548	602	721				Richard Fitz,
Watauga	2604	3	160	264	325								personal
South Holston	3070	22	121	195	284	358	437	508	564	622	655		communication
Cherokee	12272	6	81	193	233	360							Above
Watts Bar	15795	20	91	157	251	327	388	484	603				Above
Norris	13892	201	132	239	350	472	589	670	736	790	841	879	Carroll and Hall 1964
Kansas reservoir Milford	6488	196	164	230	316	412	517	591	700	796	837	869	Layher 1976

[a]Information not given.

Jenkins (1954) found that growth in the clearer, rocky lower portions of Grand Lake was slower than in the more turbid upper reservoir characterized by mud flats. He reported faster growth for larger fish collected by commercial fishermen in the Neosho River arm of the reservoir. However, the greater lengths of fish in the latter sample increased the potential for errors in determining age. Faster growth reported for Lake Eucha, when compared to the upstream Spavinaw Lake, also may have been affected by the larger size of the fish examined from Eucha Lake (Jackson 1966).

McCoy (1955) reported faster growth of flathead catfish in new reservoirs and in small reservoirs without successful reproduction. Although he reported reservoir size and degree of turbidity did not affect growth rate, the likelihood of errors in age determination probably invalidate these conclusions. Growth rate in the turbid Heyburn Reservoir was exceptionally rapid (McCoy 1955; Buck 1956) and flathead catfish appear to be well-adapted to turbvid reservoirs (Buck 1956; Cross 1967; present report).

Unweighted mean growth rates were determined for flathead catfish in each of three reservoir sizes (40-400, 400-5000, >5000 ha). Mean growth rate at ages 1-4 was greater for reservoirs of 400-5000 ha, but growth at ages 5-10 was greater for reservoirs of 40-400. As most reservoirs in the 40-400 ha category were reported by McCoy (1955), the significance of differences in growth of fish among reservoir sizes is unknown. Growth rates in Oklahoma reservoirs >400 ha usually exceeded growth reported for Tennessee reservoirs.

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