DYNAMICS OF THE FISH POPULATIONS IN A WARM-WATER STREAM

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Kenneth Jack Linton

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ABSTRACT

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by Kenneth Jack Linton

The fish in the Red Cedar River, a warm-water stream in central Michigan, were investigated to determine what differences existed between the major fish populations in five arbitrarily selected zones comprising 30 miles of the main stream. The characteristics studied included growth rates, standing crop in numbers and biomass, and net production in the Ivlev sense.

A limited study of fish movement revealed that a portion of the rock bass population maintains a small range of movement.

The growth study was based on the results of scale reading and back-calculation of the total length at annulus formation for about 3100 fish including 13 species. Significant differences in the rates of growth for the rock bass and hog suckers in the five zones were demonstrated, with growth being generally faster in the three upstream zones. No significant differences in the growth rates of white suckers and redhorse were found.

The standing crops of fishes were estimated by the Petersen method employing an electrofishing technique, after a comparison of several methods indicated that this was the most practical means for the present study. A source of bias in the Petersen method when applied to small samples is suggested as being the effect of estimating a continuous distribution with a discrete distribution. Population estimates were made for each of the five zones during four sampling

periods over a span of three years. Significant heterogeneity was demonstrated in the number of fish per acre for the five zones, but the differences in the biomass estimates were not statistically significant. Zone III, in the middle of the study section, most consistently exhibited the largest standing crop of fishes, while Zone I, furthermost downstream, supported the smallest. A downward trend in the abundance of all species was noted for Zone I. The mean estimate of the standing crop of fishes (other than minnows, darters, and mudminnows) was 101 lbs/acre with the individual estimates ranging from 18 to 338 lbs/acre.

The rates of net production were estimated using the technique of Ricker. Estimates of the instantaneous mortality rates were obtained by the Chapman-Robson method and these were used to back-calculate each population estimate to the beginning of the growing season. The mean total net production for all of the major species in the river was estimated to be 13.43 mg dry weight/m^2/day in the 180 day growing season with a range of 7.37 to 18.68 mg dry weight/m^2/day. Zone III was estimated to have the highest rate of net production of fishes, but it was determined in a previous study to have the second lowest rate of primary production. This apparent discrepancy was attributed to the fact that Zone III receives the greatest supply of allochthonous nutrients and supports the largest production of heterotrophic aufwuchs.

DYNAMICS OF THE FISH POPULATIONS
IN A WARM-WATER STREAM

By

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INTRODUCTION

In 1958, a study of the fixation and utilization of solar energy was commenced on the Red Cedar River, a warm-water stream. For this study, the river was arbitrarily divided into five zones which were believed to represent somewhat distinct ecological communities. The original plan called for five major phases of study: (1) fish sampling in each of the zones; (2) measurement of primary production on artificial substrates; (3) determination of the level and source of nutrients in the stream; (4) measurement of the composition and amount of suspended materials; and (5) estimating the production rates of bottom faunal material.

Emphasis in the early part of the study was placed on physical and chemical factors and on primary production in the several zones. Results of the chemical and hydrological investigations were presented by Vannote (1961, M. S. thesis). Grzenda (1960, Ph. D. thesis) has reported the results of the study of primary production on artificial substrates and nutrient utilization. Rawstron (1960, M. S. thesis) provides further information on the growth of periphyton on artificial substrates. In the following years, emphasis was shifted to the utilization and exchange of energy among consumers. King (1961, M. S. thesis) provides the results of the early investigations of the distribution and biomass of benthic organisms.

The intention and thesis of this study may be stated: there are recognizable and demonstrable differences in the fish community structure of the five zones of the Red Cedar River. The data and observations in this thesis are the results of the first four years of study of the characteristics of the major fish populations.

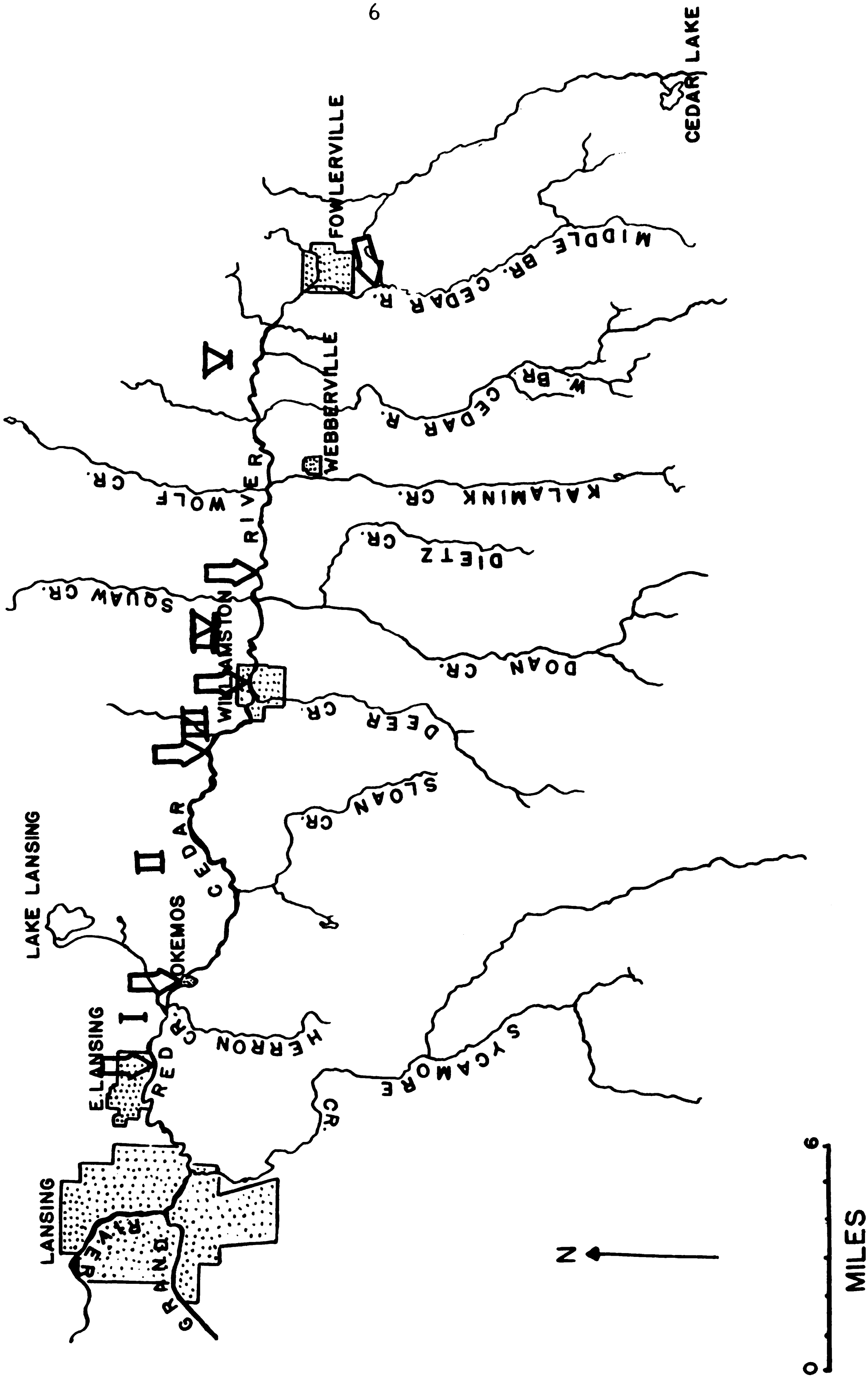
DESCRIPTION OF THE RIVER

The study was conducted on the Red Cedar River, a warm-water stream in the south-central portion of the Lower Peninsula of Michigan. The river arises in Cedar Lake, Marion Township, Livingston County (T1N, R3E) and flows in a northwesterly direction about 19 miles through Livingston County and about 29 miles through Ingham County, reaching its confluence with the Grand River within the city of Lansing. The Red Cedar River receives the waters of twelve major tributaries, the largest being Sycamore Creek, and drains a total area of about 472 square miles (Figure 1). The upper portion of the river flows through grain and dairy farm lands and is used in part for irrigation of crops and watering of livestock. The channel has been dredged and straightened throughout much of this portion as part of a program of land reclamation. In the lower part of the drainage, it flows through farm lands and extensive urban areas where it is used for domestic, industrial, and recreational purposes.

There are two major impoundments on the main stream. The largest of these is at Williamston and is used to provide power for a private frozen food storage plant. It is a concrete and wooden structure maintaining a 13-foot head of water. The other dam is on the Michigan State University campus in East Lansing. It is a concrete and rock dam which maintains a water supply for the steam generating power plant on the university campus. At least two other small dams (maximum two-foot head) are found on the main stream. Further discussion of the history and characteristics of the dams on the Red Cedar River may be found in Brehmer (M. S. thesis, 1956).

The study section is about 30 miles long and extends from the Farm Lane bridge on the Michigan State University campus in East Lansing to the VanBuren Road bridge about one mile upstream from Fowlerville. The Sycamore Creek drainage is not included in this

Figure 1. Map of the Red Cedar River watershed showing the location of study zones.



LANSING
GRAND RIVER
E. LANSING
RED CR.
HERRON CR.
OKEMOS
LAKE LANSING
I
II
III
IV
V
CEDAR RIVER
SYCAMORE CR.
SLOAN CR.
DEER CR.
WILLIAMSTON
DOAN CR.
SQUAW CR.
DIETZ CR.
WOLF CR.
KALAMINK CR.
WEBBERVILLE
W. BR. CEDAR R.
FOWLERVILLE
MIDDLE BR. CEDAR R.
CEDAR LAKE
N
0
6
MILES

system, so the drainage for the study section is about 355 square miles. Table 1 and Figure 2 include information on the discharge for the years 1958 through 1961. These data were furnished by the United States Geological Survey, which maintains a data recording station at the Farm Lane bridge.

The study section has been divided into five zones for this investigation. Zone I includes that three and one-half mile portion of the stream from the Farm Lane bridge to Okemos Road (Figure 1). The water here is slow-moving and drops silt and detritus on the mud bottom. The river is influenced by the dam mentioned above, which is located about one-fourth mile below the Farm Lane bridge. The bottom at the upstream end of this zone is largely sand and rubble.

Zone II (eight and one-half miles long) consists of that part from the Okemos Road bridge to the Zimmer Road bridge below Williamston. It is the cleanest of the five zones, having a sand bottom in a large portion and gravel and boulders in most of the remaining portion. There are no urban areas in this part of the river except for the influence of Okemos at the extreme lower end. The number of riffle-pool combinations is higher in the part from the bridge at US 16 to Zimmer Road than in any other part of the river (Robin Vannote, personal communication). Below US 16, the water is slower and deeper with fewer riffles.

Zone III extends from Zimmer Road bridge to the dam at Williamston, two and one-half miles upstream. The bottom varies from silt to sand and cobbles, with some detritus. It is strongly influenced by the Williamston urban area, particularly by the Williamston sewage disposal plant. Raw sewage may be seen seeping from the banks and draining into the river in the urban area proper. There are extensive beds of rooted higher aquatic plants immediately below the dam.

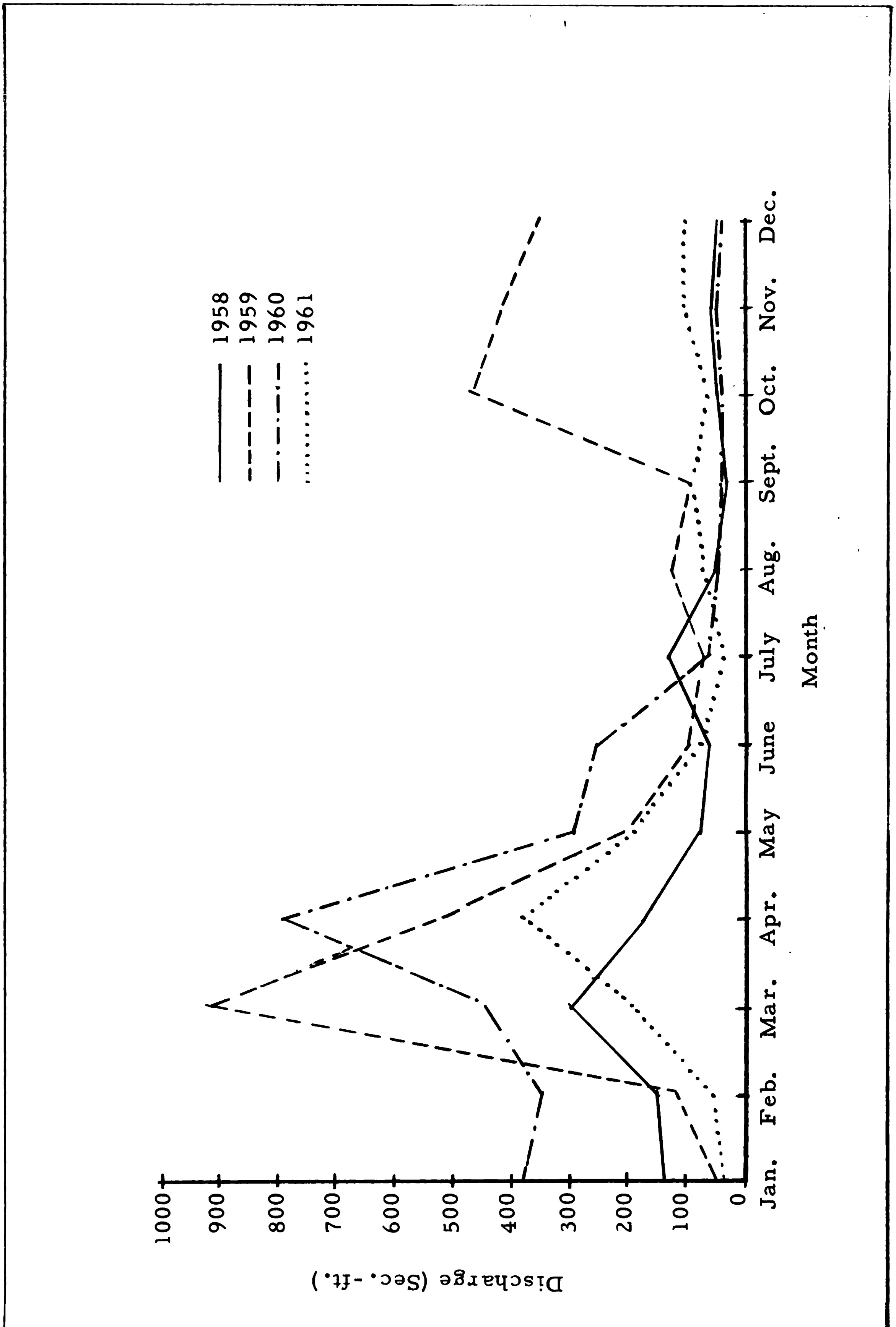
Table 1. Monthly maximum and minimum discharge of the Red Cedar River recorded at Farm Lane Bridge for the years of 1958 through 1961.* (cfs)

	1958		1959		1960		1961	
Month	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
January	260	94	60	41	1150	168	60	13
February	780	71	264	47	867	143	118	14
March	800	148	1810	258	3530	118	413	109
April	292	121	1540	163	3240	351	1090	90
May	110	49	475	115	505	208	550	72
June	94	41	343	47	872	104	142	36
July	546	47	339	11	109	30	60	16
August	81	28	272	60	88	17	202	25
September	49	11	186	30	72	14	199	50
October	71	36	2210	94	82	16	104	36
November	81	45	950	209	75	21	173	62
December	60	38	775	180	60	16	189	60

*Data provided by the United States Geological Survey Field Office, Lansing, Michigan

Figure 2. Monthly mean discharge* at Farm Lane bridge for the years 1958 through 1961.

*Data provided by the United States Geological Survey Field Office, Lansing, Michigan.


1958
1959
1960
1961
Discharge (Sec.-ft.)
1000
900
800
700
600
500
400
300
200
100
0
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Month

Zone IV includes the largest impoundment in the system and extends from the dam at Williamston to the bridge at Dietz Road. The reservoir proper comprises approximately half of the four mile length, but the influence of the reservoir extends throughout the zone. The reservoir is confined to a narrow basin, but the flow is very slow. For the fish study, the reservoir has been disregarded due to sampling problems and other considerations. Therefore, the results discussed refer only to the upstream portion of this zone, arbitrarily that portion where the river is no more than 100 feet wide. The mean width included in the calculations is also based only on this upstream portion. Further description of the impoundment may be found in Brehmer (ibid.).

Zone V represents the remaining 12 miles of the study section from the Dietz Road bridge to the bridge at VanBuren Road. It is influenced by the Webberville urban area. Probably the greatest influence is the industrial waste of the metal plating plant in Fowlerville. A large portion of this zone has been dredged and straightened and flows through farm land. The bottom is largely silt and mud. The depth and width of the dredged portions are, of course, quite uniform and the flow is slow.

METHODS

The fish were collected with a 220-volt Homelite direct-current generator which was placed in an eight-foot wooden boat. The hand-held positive electrodes consisted of coiled copper tubing mounted on six-foot wooden handles and were opposed by a metal negative electrode plate in the bottom of the boat. The stunned fish were retrieved at the positive electrodes with dip nets having a one-fourth-inch mesh woven nylon bag or a graded mesh (one inch to one-eighth inch) cotton bag.

The stations (Table 2) were randomly selected within the limits of accessability. In 1958, the collections were made without the use of block nets since only growth data were being collected. In subsequent years, nets were placed in the river in such a manner as to prevent the movement of fish into or out of the station. The nets were suspended on metal fence posts and secured to the bottom of the river with rocks, logs, and fence posts. The block nets consisted of one-fourth-inch woven mesh nylon nets (one net 25 feet by 4 feet and two nets each 50 feet by 6 feet) or three-eighths-inch bar mesh cotton net (one net 75 feet by 4 feet).

The nets were placed in the river with as little disturbance of the fish as possible. In 1959 and 1960, the procedures were similar. The crew started at the downstream net and shocked upstream, fin-clipping all fish and releasing them at the approximate place of capture, recording only the number of fish of each species. On the second and subsequent runs, the fish were placed in a metal tub in the boat. About half-way through the station and again at the end, the fish would be weighed to the nearest gram and measured to the nearest millimeter. Scale samples were taken from the region near the tip of the compressed pectoral fin, recaptures recorded, and all fish were released. In 1960, the rock bass were tagged prior to release.

Table 2. List of dates and locations of fish collections with the length of station sampled and the mean width of the zones.

Zone	Station	Length	Collection Dates	Mean Width
I				79.7 feet
	A	-	7/30/58	
		-	8/18/58	
	B	-	8/13/58	
		-	8/18/58	
		528'	9/18/59	
		716'	7/18/60	
		716'	9/12/60	
		300'	6/26/61	
II				65.5 feet
	A	-	7/30/58	
		528'	8/6/59	
		300'	6/21/61	
		300'	7/11/61	
		300'	9/12/61	
	B	-	8/19/58	
		528'	9/17/59	
		612'	7/15/60	
		612'	9/13/60	
	C	300'	6/28/61	
III				62.4 feet
	A	-	7/31/58	
		722'	7/13/60	
		722'	9/14/60	
	B	-	8/14/58	
		528'	9/14/59	
		300'	7/5/61	
		300'	9/20/61	
	C	300'	6/30/61	
		300'	7/18/61	
IV				60.9 feet
	A	-	8/14/58	
		-	8/15/58	
	B	-	8/8/58	
		-	8/19/58	
		528'	9/10/59	
		910'	7/11/60	
		910'	9/15/60	
		300'	7/7/61	
		300'	9/19/61	

Continued

Table 2 - Continued

Zone	Station	Length	Collection Dates	Mean Width
V				34.3 feet
	A	-	8/7/58	
		820'	7/6/60	
		820'	9/16/60	
	B	528'	9/9/59	
	C	-	8/1/58	
	D	-	8/7/58	
		300'	7/19/61	
		300'	8/28/61	
	E	300'	7/10/61	

In 1961, the procedures were altered somewhat. Six live-boxes were constructed prior to commencing the summer operation. These consisted of three-fourths inch diameter steel conduit welded frames with one-fourth inch woven mesh nylon bags laced to the frames. They were designed so that three boxes would nestle for easy storage. The largest were 28 inches by 28 inches by 40 inches and the smallest were 20 inches by 20 inches by 32 inches.

The block nets were placed in the stream as before. Then if the conditions warranted it, one one-inch bar mesh nylon net (50 feet by 4 feet) was placed in the river about 15 feet upstream from each of the block nets to catch detritus. The live-boxes were then placed in the station at approximately 50-foot intervals. The crew shocked upstream, putting all fish in the live-boxes. At the completion of a run, growth data were collected at each live-box and the fish were tagged and released. On subsequent runs, recaptures were recorded and released and growth data were collected on the remaining fish.

In 1961, an attempt was made to estimate the populations by the DeLury method (Ricker, 1958), retaining all fish in the live-boxes after the first run. However, it was found that this method was not feasible due to the low efficiency of collection and to the limited number of runs it was possible to make during daylight hours (maximum of four runs). The nets could not be left overnight due to the increased pressure with accumulation of detritus and to the possibility of theft. An attempt was also made to estimate the populations by the Schnabel method (Ricker, ibid.). Again, the number of fish of any species on any run was so low that nothing was gained. It was decided that the Petersen method (Ricker, ibid.) was most useful. In previous years, the following formula was used to estimate the populations:

$$\hat{T} = \frac{MC}{R}$$

where $\hat{T}$ equals the estimate of the population in the station, M equals the number of fish marked on the first run, C equals the number of fish captured on the subsequent runs, and R equals the number of recaptures. If the value of either C or R were zero, then the equation used was the same as that used for all of the 1961 estimates, which is the Bailey equation:

$$\hat{T} = \frac{M(C+1)}{R+1}$$

where the symbols are as previously explained. If the value of M was zero, as sometimes occurred, a one was substituted.

In 1960, the rock bass were tagged with plastic flutter tags attached by means of a small nylon thread. The tags were applied with a curved surgical needle just anterior or posterior to the dorsal fin. Of the 225 tags applied, only five were recovered and the fish were in extremely poor condition. It is suspected that the tags were pulled out when they became entangled in the brush where the rock bass were found.

In 1961, Monel metal band tags (Style 4-1242M, National Band and Tag Company) were used as jaw tags for several species of fish, including suckers. Three sizes of bands were used: Nos. 5, 7, and 8. It was found that the smaller size was more difficult to apply without damage to the mandible and offered no apparent advantage over the largest size used. Even the smallest of the tags could not be used with fish such as the bluegill due to the size of the plier nose. The No. 8 bands were found to be satisfactory when used on larger-mouthed fish such as the rock bass if the fish was about nine centimeters long or longer. With the band tag, a larger percentage were recovered and the fish were in better condition.

For the growth study, impressions were made of the scales on small squares of acetate without heat, as described by Smith (1954).

These were then projected at a magnification of about 22 diameters with a Bausch & Lomb Tri-Simplex Micro-projector. Annuli were observed and marked off on ruled data cards. The total length-scale radius regression line was calculated for each species (Table 3) using a minimum of 150 fish except for those species for which fewer were available, in which case all data were used. Back-calculations were made according to the method of Hile (1941) and others, assuming a linear relationship.

Initially, it was planned to compute the scale length-body length regression line for each sample of each species. This was done, but it was found that the intercept values varied quite widely. Analysis of covariance showed that the slopes of the lines were nearly always significantly different. A scatter diagram was constructed using the data from a well-distributed sample of hog suckers. This showed that the reason for the difficulties was a tendency for the scale diameter to vary quite widely for any given length of fish. This was especially true of the suckers, with the minimum effect occurring in the rock bass. Those samples which contained fish of a limited size range would, therefore, show small slopes and elevated intercept values. Consequently, it was decided that a common intercept value for each species would be more realistic and would be conservative with respect to statistical comparisons between the zones.

Biomass estimates were made by converting the estimated number of fish in each mile of stream to number per acre using the mean width of the zones as they appear in Table 2. These were then multiplied by the mean weight of the fish in the sample from which the estimate was made. Grams per acre were then converted to pounds per acre using the conversion factor of 2.205 pounds per kilogram.

The net production (in the Ivlev sense) of centrarchid and catostomid fishes was estimated with the technique of Ricker (1958) as

Table 3. List of constants for the regression* of total length on scale radius used in estimating growth for thirteen species of fish.

Species	a (cm.)	b
White sucker	7.52	2.705
Northern hogsucker	5.62	2.362
Spotted sucker	5.05	2.031
Redhorse	3.77	2.044
Rock bass	2.20	1.686
Warmouth	4.77	1.533
Green sunfish	0.62	2.691
Pumpkinseed	3.25	1.526
Bluegill	1.58	2.225
Longear sunfish	1.20	2.000
Smallmouth bass	5.18	2.736
Largemouth bass	1.32	3.112
Black crappie	4.90	1.814

*The total length of a fish at annulus formation may be estimated by the formula:

$$\text{Total length} = \underline{a} + \underline{b}\ (22)\ (\text{scale radius})$$

where a and b are the appropriate constants selected from the above table, 22 is the magnification of the image, and the scale radius is measured in centimeters from the focus to the given annulus.

employed by Gerking (1962), with the following exceptions. The survival rates (r_s) were obtained in the manner proposed by Robson and Chapman (1961). These were calculated for each species of fish and converted to the instantaneous mortality rates (i), which were then assumed to be constant over all age groups and throughout the year.

The mean back-calculated lengths at annulus formation were converted to the initial mean weights for individuals using the length-weight relationships in Table 14. For those species not appearing in Table 14, the weights were estimated from log-log plots of lengths versus weights. The initial weights for the age 0 fish were assumed to be 10^{-3} grams. These were arbitrarily selected on the basis of the average volume of eggs reported in the Handbook of Biological Data (1956) and their approximate density. The common logarithm of the initial weight was then plotted on the age. The slope of this line at the midpoint between two consecutive ages multiplied by 2.303 constituted the estimate of the instantaneous growth in weight for that year.

May 1 was assumed to be the date of annulus formation and the initial date for the growing season. This was selected on the basis of recommendations made by Beckman (1943) for this part of Michigan. The water temperature of the Red Cedar River on that date agrees very well with the temperature suggested by Beckman as being conducive to annulus formation (about 53°F.). The end of the growing season was taken to be 180 days after May 1, which coincides with the time that the temperature of the Red Cedar River again approximates that at May 1.

Each population estimate was back-calculated to the initial date (May 1) using the estimate of instantaneous mortality rate for that species. The age distribution within the mean estimates of initial population number were taken to be those distributions which were fixed by the maximum observed age of a fish of that species collected from that zone, the Robson-Chapman survival rate estimate, and the mean estimate of initial population number. These were calculated by trial and error. Because the young-of-the-year fish were not vulnerable to the capture method used, it was assumed that the estimates did not include them. Consequently, the initial population number of age 0 fish was estimated from the number of age I fish and the instantaneous mortality rate.

Samples of fish including 4 rock bass, 3 white suckers, and 3 hogsuckers were weighed on a Mettler electrical balance (Model H4) and subsequently dried to constant weight at 55°C. The average percent dry weight was then used to convert the production estimates to dry weight units.

RESULTS

Movement Study

In the summer of 1960, approximately 225 rock bass were marked with flutter tags and released during the population estimate procedures. Of these, only five tags were recovered. The fish bearing the recovered tags had shown no movement from the original release point.

During the June-July collection period in 1961, several species of fish were tagged (Table 4). The results, however, must be viewed with caution due to the method of recapture. A strong bias is introduced by attempting recapture only within about three or four hundred feet of each release site. Funk (1957) points out that this bias results from the decreased likelihood of recapturing strays, which is quite obvious. However, Gerking (1959) points out the less obvious fact that relying on fisherman returns causes a bias toward recording recapture of the stray fish, which is to be avoided for the purposes of this study. It was intended to test the hypothesis that a significant portion of the population does stay in a limited space.

Table 5 was included to show the direction and mean distance moved of the recaptures for the most successfully tagged species, the rock bass, and for the few other returns that occurred. Of course, the data only indicate the apparent movement in that complex and extensive movement could have preceded recapture. It is suspected that such movement did occur more than these data indicate. I observed that a few tagged fish occurred in the vicinity of the downstream block net at the end of the day. Presumably, these fish may have drifted downstream as a result of the stress due to tagging after the block nets were removed. Early attempts at tag recovery (less than two weeks after tagging) were not generally successful. The later attempts seemed to show that the fish had returned to the release point.

Table 4. Summary of the recovery of marked fish in the summer of 1961.

Species	Number Marked	Number Recaptured	Percent Recaptured
Rock bass	166	36	22
Smallmouth	9	2	22
Bullhead	51	5	10
White sucker	23	1	4
Hog sucker	61	3	5
Redhorse	24	1	4
Northern pike	2	1	50
Spotted sucker	6	0	0
Carp	7	0	0
Grass pickerel	1	0	0
Green sunfish	3	0	0
Bluegill	1	0	0

Table 5. Summary for all collections of the direction and mean distance moved by recovered fish tagged in the summer of 1961.

Species	Upstream %	Upstream d	Downstream %	Downstream d	Complex* %	Complex* d	None %	None d
Rock bass	56	90'	30	241'	3	300'	11	0'
Smallmouth			100	350'				
Bullhead			80	1470'			20	0'
White sucker			100	50'				
Hog sucker			67	168'			33	0'
Redhorse	100	150'						
Northern pike	100	5200'						

*Includes those fish captured more than once and only indicates the mean maximum distance moved.

From Table 6, it appears that the emphasis shifts from an early upstream movement to a downstream movement. The October recaptures were made by another group without attempting to recover tags upstream from the release site.

The effects of spawning, which should have been well under way for the rock bass prior to the dates of original marking and releasing, are not known.

I have concluded that there is at least a large segment of the rock bass population which maintains a small range of movement. This observation agrees with those of Funk (1957), Gerking (1953), and Scott (1949). The other species did not appear in our recaptures with sufficient frequency to warrant any conclusions. This may have been due to excessive movement, or, especially in the case of suckers, loss of the tag or mortality due to the tagging procedure. It was noted that in the case of the suckers it was necessary to apply the tag directly in the middle of the anterior portion of the mandible. This often resulted in severing an artery in the lower jaw. Many such fish recovered at least temporarily, but further irritation by the tag could have resulted in extensive delayed mortality. It is also suspected that feeding would be difficult for suckers so tagged.

Gerking (1959) lists the hog sucker as one species which is known to have restricted movement, but does not include the white sucker found in this region (he includes the western white sucker). Funk (1957) did not include the white sucker in his study.

Ball (1947) suggests that the yellow bullhead has a restricted movement pattern in lakes. Gerking (1959) includes this species in the list of fish with restricted movement, and Funk (1957) places it in his "sedentary" classification. Other fishes included in the Red Cedar River study which are believed to have a restricted movement are: bluegill, redhorse, green sunfish, smallmouth bass, and pumpkinseed (Gerking, 1959).

Table 6. Direction and mean distance moved by tagged rock bass by month of recapture in 1961.

	Month of Recapture											
	July			August			September			October		
Type of Movement	d*	n**	%	d	n	%	d	n	%	d	n	%
Upstream	100'	13	62	67'	9	56	67'	3	43		0	0
Downstream	100'	4	19	80'	5	31	117'	3	43	550'	4	100
None		4	19		2	13		1	14		0	0
Absolute***	81'	21	100	63'	16	100	79'	7	100	550'	4	100

*Mean distance moved in feet.

**Number of observations included in associated mean distance.

***Mean distance moved including all observations without respect to direction.

Growth Study

Mean back-calculated total lengths in centimeters for each age, zone, and species were computed (Appendix B). For statistical purposes, the mean back-calculated length for each age group at age II was used because the sample size for age group II was larger than that for older groups. Age I was rejected due to the possibility of strong effects of the time during the previous summer when the eggs hatched. The use of the mean back-calculated length at age II for each of the age-groups also gave a better estimate of internal variation for the several years of the study, thereby increasing the sensitivity of the tests.

One-way analyses of variance, Model I (Dixon and Massey, 1957), were used to examine the significance of the observed differences in the mean back-calculated lengths at age II for the rock bass, white suckers, hog suckers, and redhorse for the four years of the study. The salient features of these analyses are presented in Tables 7, 9, 11, and 12 as recommended by Dixon and Massey (1957). In the case of the rock bass and hog suckers, differences were observed to be significant at least at the 5% level. Therefore, further investigation of the nature of the observed differences was undertaken by means of the Tukey multiple-range test (Snedecor, 1956) with the modification of Kramer (1956) and the modification of Hartley (Snedecor, ibid.). The results of these tests are presented in Tables 8 and 10. For those pairs of zones where the observed growth was significantly different at the 5% level, an X appears in the table.

It may be seen from Table 7 that the rock bass showed very significantly different mean lengths. The individual comparisons revealed that the heterogeneity was due to the differences shown in Table 8. The data indicate that the growth of rock bass is faster,

Table 7. Results of an analysis of variance for the significance of observed differences in the mean length at age II of rock bass in each of the five zones for the years of 1958 through 1961.

Source	Sum of Squares	df	Mean Square	F
Means	8.185	4	2.046	9.789
Within	9.598	46	0.209	
Total	17.783	50		

$F_{.9995}(4, 40) = 6.30$

Table 8. Summary of pairs of zones which showed a significant difference with respect to length of rock bass at age II.

		Zone I	Zone II	Zone III	Zone IV
Zone	II	0*			
Zone	III	X	X		
Zone	IV	X	0	0	
Zone	V	X	0	0	0

*X denotes significant difference at 5% level.
0 denotes no significant difference at 5% level.

Table 9. Results of an analysis of variance for the significance of observed differences in the mean length at age II of hog suckers in each of the five zones for the years 1958 through 1961.

Source	Sum of Squares	df	Mean Square	F
Means	54.296	3	18.099	18.646
Within	21.354	22	0.971	
Total	75.650	25		

$F_{.9995}(3, 20) = 9.20$

Table 10. Summary of pairs of zones which showed a significant difference with respect to length of hog suckers at age II.

		Zone I	Zone II	Zone III	Zone IV
Zone	II	0**			
	III	0	0		
	IV	*	*	*	
	V	X	X	X	*

*No observations from Zone IV.

**X denotes significant difference at 5% level.

0 denotes no signifcant difference at 5% level.

Table 11. Results of an analysis of variance for the significance of observed differences in the mean length at age II of white suckers in each of the five zones for the years 1958 through 1961.

Source	Sum of Squares	df	Mean Square	F
Means	20.978	3	6.993	1.988
Within	87.954	25	3.518	
Total	108.932	28		

$F_{.75}(3, 24) = 1.46$
$F_{.90}(3, 24) = 2.33$

Table 12. Results of an analysis of variance for the significance of observed differences in the mean length at age II of redhorse in each of the five zones for the years 1958 through 1961.

Source	Sum of Squares	df	Mean Square	F
Means	3.570	2	1.785	1.728
Within	27.902	27	1.033	
Total	31.472	29		

$F_{.75}(2, 24) = 1.47$
$F_{.90}(2, 24) = 2.54$

at least through age II, in the three upstream zones than it is in zones I and II. The best growth apparently occurred in zone III, likely the richest zone with respect to allochthonous nutrients, while the poorest growth apparently occurred in zone I.

The hog suckers followed approximately the same pattern, but the difference in their growth above and below the dam between zones III and IV is so pronounced as to appear in error. From Tables 9 and 10, it may be seen that with respect to growth, the three zones below the dam (I, II, III) represent a homogeneous subset. The records for zone V result from the observation of only six back-calculated lengths and must be treated with caution.

No significant difference in growth in the five zones for the white suckers (Table 11) and redhorse (Table 12) were revealed by the above methods. It is obvious that the variation in lengths of age II fish for the four years of the study was great.

The Red Cedar rock bass growth is comparable to the growth in the poorer year--classes reported by Scott (1949) for the Tippecanoe River. It is ~~also~~ slightly lower than that reported by Brown (1960) for Massie Creek and the Little Miami River, both in Ohio. The growth of river-inhabiting rock bass in Kentucky reported by Tompkins and Carter (1951) far outstrips the growth of Red Cedar River rock bass or any other reported growth considered in this paper. At age I, the Kentucky rock bass were more than twice the length of the age I Red Cedar River rock bass. At age VI, the Red Cedar fish had reached approximately the same length as that attained by Kentucky fish at age IV.

A cursory inspection of these results seems to substantiate the claim that, within this species, the northern populations are made up of slower-growing individuals than the southern populations. However, it became obvious during the course of this study that the direct comparison of calculated lengths of fish from one area with those of another area is of little value when based on small, localized samples. The observed growth of fish in the five zones of the Red Cedar River varied enough so that sampling from one station in the river could not be considered even a good representation of this river. The use of these data to extrapolate to all Michigan fishes would be wholly unjustified.

Length-Weight Relationships

The length-weight relationships for rock bass and suckers were calculated by the method described by Rounsefell and Everhart (1953). The data from September collections were pooled over the several years of the study for these purposes. An analysis of covariance revealed a significant difference in the regression lines for two successive years, 1959 and 1960, for rock bass in the same locality, which indicates that, for a given total length, the fish were slightly heavier in one year than in the other. It appears that the young fish were heavier in 1960 than in 1959. Further investigation showed that, although the difference was statistically significant, it was so small as to be unimportant from the standpoint of weight estimation. A comparison of the actual weights of three rock bass and the weights calculated with the 1959 and 1960 formulae as well as the pooled formula is presented in Table 13. Whenever necessary, the weights of fish were calculated with the appropriate mathematical regression formulae as they appear in Table 14, with lengths in centimeters and weights in grams.

Population and Biomass Estimates

The results of the estimation procedures appear in Table 15. The estimates for 1961 in zones II, III, and V are the mean values for the two stations sampled in each case. The population sizes are

Table 13. Actual and calculated weights of three rock bass using three length-weight regression formulas.

Total Length	Actual	Weight 1959 Formula	1960 Formula	Pooled Formula
6.2 cm	5 gm	4.6 gm	5.1 gm	5.0 gm
12.4	38	37.1	37.6	37.2
19.0	133	128	124	129

Table 14. Observed values of the constants log c and n for length-weight regression* formulas for several species of fish.

Species	log c*	n*	Sample Size
Hog sucker	-2.054	3.047	62
Redhorse	-2.071	3.059	62
White sucker	-2.212	3.158	62
Rock bass			
Zone I	-1.6107	2.9090	230
Zone II	-2.1426	3.3825	205
Zone III	-1.8204	3.0768	110
Zone IV	-1.5828	2.8649	91
Zone V	-1.6407	2.9459	61

*The weight of a fish in grams may be estimated from the total length using the regression formula:

common log of weight = log c + n (common log of length)

where the weight is expressed in grams, log c and n are the appropriate constants selected from the table above, and the length is expressed in centimeters.

Table 15. Summary of population and biomass estimates of fish in each zone of the Red Cedar River during the 1959, summer of 1960, fall of 1960, and summer of 1961 collection periods in terms of numbers per acre, numbers per mile, and pounds per acre.

Year	Zone	Rock bass			Total suckers			Bullheads			All Others			Totals		
		No.**		Mass*	No.**		Mass*	No.**		Mass*	No.**		Mass*	No.**		Mass*
1959	I	3880	402*+	28	1720	178	34	570	59	10	500	52	8	6670	690	80
	II	3840	484	42	1990	251	64	840	106	22	610	77	4	7280	918	132
	III	2767	366	28	2670	353	91	780	103	6	1490	197	213	7707	1019	338
	IV	1093	148	10	1010	137	24	700	95	10	1130	153	73	3933	533	117
	V	558	132	26	158	38	27	60	14	3	390	94	15	1166	280	71
1960s	I	4011	415	44	72	8	1	767	79	16	516	53	4	5366	556	65
	II	2286	288	26	1293	163	32	173	22	5	69	9	3	3821	481	66
	III	1484	196	28	497	66	26	439	58	12	351	46	3	2771	366	69
	IV	690	94	15	47	6	7	366	50	7	1207	164	15	2310	313	44
	V	585	141	13	262	63	25	26	6	1	225	54	1	1098	264	40
1960f	I	5110	529	38	1541	160	12	944	98	17	1298	134	12	8893	921	79
	II	6557	826	56	5944	749	58	362	46	6	621	78	18	13484	1698	138
	III	2282	302	27	439	58	9	161	21	4	512	68	3	3394	449	43
	IV	3011	408	34	1166	158	141	685	93	9	5245	711	43	10107	1369	227
	V	1739	418	45	624	150	56	328	79	6	1146	276	57	3837	923	164
1961s	I	2816	292	10	1267	131	7	70	7	2	53	6	1	4206	435	20
	II	3424	431	22	1303	164	39	27	3	1	141	18	6	4895	617	68
	III	1083	143	16	1189	157	60	651	86	27	1602	212	22	4525	598	125
	IV	299	41	5	844	114	19	475	64	6	282	38	88	1900	257	118
	V	0	0	0	141	34	9	141	34	8	44	11	1	326	78	18

*In pounds per acre
**Number per river mile
*+Number per acre

expressed as number per acre and number per river mile and the standing crop of biomass is expressed as pounds per acre.

An evaluation of the estimation procedures was attempted in August of 1962 by conducting population estimates using the electrofishing technique (with the Petersen method) and subsequently poisoning the fish with rotenone. The site (in Zone II) selected for the study included four pools and was bounded at either end by shallow riffles. The station was 530 feet long and comprised 0.59 acres. Block nets were employed both times in the manner described for the previous population estimates. The combination of low stream discharge (40 to 50 cfs) and low turbidity provided excellent conditions for the operations. Rainfall caused a delay in the poisoning, so that a week elapsed between the two estimates, which made possible the movement of some fishes into and out of the study section. A comparison of the results of the two estimates is presented in Table 16. The data from the poisoning are used as a base for percent error in each case.

Friedman two-way analyses of variance (Siegel, 1956) were employed to investigate the significance of the observed differences in the biomass estimates and in the population estimates for the five zones. No significant differences were found between the zones in the case of the total biomass, but the population estimates (number of fish per acre) were found to be significantly different at the 10% level. This suggests that the numbers of fish per acre and the age distributions may be different in the five zones and compensatory in such a manner that the biomass per acre is similar. That is, a large proportion of young fish in one zone would tend to yield a biomass estimate comparable to one for a zone having a smaller number of fish, but with a larger proportion of older ones. Another interpretation is possible. The biomass estimate is the number of fish per acre multiplied by the mean weight of fish in the sample from which the population estimate

Table 16. Comparison of the numbers and weights of fish estimated by the Petersen method with the numbers and weights of fish recovered after poisoning the same area with rotenone.

Species	Rotenone Sample		Petersen Estimate		Percent Error	
	Number	Weight*	Number	Weight*	Number	Weight
Rock bass	204	13.38	252	12.67	+24	-5
Smallmouth	116	10.99	72	5.58	-38	-49
White sucker	194	13.57	208	10.33	+7	-24
Hog sucker	141	18.84	165	10.85	+17	-42
Redhorse	87	10.28	26	2.88	-70	-72
Total suckers	422	42.69	399	24.06	-5	-44

*Pounds per acre.

was made. This results in a multiplicative operation on the sample variances. Therefore, the biomass estimates would have a much greater "within variance" than the population estimates have, which could obscure the differences between the zones in the case of the biomass estimates. That is, if repeated population and biomass estimates were run on the same population of fish, the biomass estimates would be more variable than the population estimates.

The non-parametric tests were selected for the following reasons. The testing of parametric analyses of variance requires certain assumptions which these population and biomass estimates fail to satisfy. These assumptions are: (1) homogeneity of variance, (2) normality of distribution, and (3) lack of interaction. The heterogeneity of variances was tested with Bartlett's test (Dixon and Massey, 1957) in the case of the biomass estimates and was found to be significant at the 0.0005 level, which indicates that the assumption of homogeneity of variances is not valid.

The assumption of normality of distribution of the biomass estimates may be shown to be unjustified in the following manner. The distribution of individual weights of fish in a population is strongly skewed. The distribution of the mean weights in small samples, though having a tendency toward normality of distribution, will then be skewed. Consequently, the distribution of the biomass estimates, which are based on the mean weights of the fish in the samples, will also be skewed. It may be seen in Table 16 that although the population estimates both over- and underestimate the results from the poisoning, the biomass estimates all fall below the biomass recovered after poisoning. This substantiates the claim that the biomass estimates are drawn from a skewed distribution.

The third assumption, that of linearity, is important when it may not be tested, which is the case when only one replication appears in each cell of the matrix of observations. If replications are used, they must consist of the estimates obtained in the various sampling periods. But if these estimates from the various sampling periods constitute the replications, the estimate of internal variation (or "within variance") is so large that it obscures the difference that may exist between zones. If the parametric three-way analysis of variance is used, the main effects of the sampling periods may be tested, but it is then necessary to assume that no interactions exist. This is probably not true with respect to the relationship between the various habitats and the abundance of the fish species present. It is generally accepted that certain environments are more favorable for a given species of organism. This effect has been reduced by using the total biomass of suckers instead of the biomass of individual species, but the same consideration applies, to a lesser extent, to taxonomic families of organisms. Hence, the assumption of no interaction is invalid.

Cooper and Lagler (1956) have shown that the use of total numbers over all age groups in the Petersen estimate tends to underestimate the total population size. They suggest that the sum of the age-group estimates is less subject to the bias found in the other method. This is attributed to the fact that the efficiency of capture by any known method is dependent on the size of the individuals or some function of the size of the individuals. I suggest that a reason for this effect, at least in the estimates based on small samples, may be that there exists a minimum proportion of the population (here used in a statistical sense) which must be captured in order to provide an unbiased estimate of the population. Though the underlying distribution of estimates is continuous, i.e., one may estimate that a part of a fish occurs within a given area, the number of fish handled follows a discrete distribution. Assuming that no correction factors were used (i.e., C + 1 or R + 1), then at least one recapture must be recorded, or the population estimate will be zero or infinity, if

$$\hat{T} = \frac{MC}{R}$$

where: $\hat{T}$ = estimate of population number, T,

M = number of marked fish,

C = number of fish captured on census run,

and R = number of recaptures.

Since the number of recaptures follows a discrete distribution, the minimum value (other than zero) will be one. If a one is obtained, then the product MC will equal or exceed the total population number only if the maximum of the two values equals or exceeds the square root of the total population number. The product will equal the total population number if $M = C = \sqrt{T}$, in which case the efficiency is equal to $\sqrt{T}/T$.

It was found that M and C were not extremely divergent within the estimates in the experimental data reported in this paper. This tends to support the claim that a real and somewhat consistent efficiency of capture exists. In order to have an unbiased estimate of a parameter, it is necessary that the expected value of the statistic ($\hat{T}$ in this case) agrees with the parameter. This will be realized in the Petersen estimate only if the efficiency is sufficiently great to ensure that R is large enough so that the effect of the discrete measurement is negligible.

Under good conditions, the efficiency of collection for small rock bass is about 10%. Table 17 has been included to show the effects of selected efficiencies on population estimates in hypothetical populations. It may be seen that the bias is important at realistic levels of estimation. It is suggested that the minimum value of R which should be accepted for calculation of a valid estimate of T be 5. If this condition

Table 17. Population estimates by the Petersen and Bailey formulae for several hypothetical populations under various conditions of capture efficiency.

T*	E* (percent)	M(=C)*	R*	$\hat{T}_1$*	Percent Error	$\hat{T}_2$*	Percent Error
50	5	3	1	6	88	9	82
	10	5	1	15	70	25	50
	15	8	1	36	28	64	28
	25	13	3	46	8	56	12
100	5	5	1	15	85	25	75
	10	10	1	55	45	100	0
	15	15	2	80	20	113	13
	25	25	6	93	7	104	4
1000	5	50	3	638	36	833	17
	10	100	10	918	8	1000	0
	15	150	23	944	6	978	2
	25	250	63	980	2	992	1

*Explanation of symbols:

T = number of fish in the population
E = hypothetical efficiency of capture
M = number of fish marked
C = number of fish captured on census run (includes recaptures and non-recaptures)
$\hat{T}_1$ = estimated number of fish in the population using the Bailey equation: $\hat{T}_1 = \frac{M\ (C+1)}{R+1}$
$\hat{T}_2$ = estimated number of fish in the population using the Petersen equation: $\hat{T}_2 = \frac{MC}{R}$

holds, it is also apparent that the bias introduced by the correction factor is unnecessary and the factor may be eliminated.

The same argument may be applied to the estimation of age-classes because the term "population" was used in a statistical sense. Furthermore, it is contended that this condition exists with respect to the age-classes even though the data are lumped over all ages. That is, even though the value of R exceeds 5 in the overall estimate, if those portions of R which correspond to the ages for which E is small are less than 5, the estimate will be biased. A means of reducing the effect of this bias is to increase T to the point where the collection efficiency results in an R value greater than 5. This, of course, is done by increasing the sampling area.

A comparison of the biomass of fishes in the Red Cedar River with the biomass reported for several other rivers is presented in Table 18. The species of fish making up the categories entitled "suckers" and "bullheads" vary with location, but are all included in the families Catostomidae and Ictaluridae. The total biomass reported by the several authors has been adjusted to comparable values by subtracting the biomass of those groups not considered in the present study, i.e., minnows, darters, mudminnows, etc.

Larimore (1961) provides a discussion of the difficulties encountered in the comparison of biomass estimates and measurements. Probably the most important consideration should be the methods employed by the authors. Charles (1957) used rotenone in his sampling, though he occasionally preceded it with electric seine sampling. Larimore, working on a small stream, was able to pump most of the flow of the river onto adjacent fields. He followed this with the employment of an electric seine and subsequent poisoning with rotenone. Gerking depended on seining short sections with minnow seines in an attempt to remove all of the fish. A subjective self-evaluation is

Table 18. Comparison of the estimated fish biomass in three taxonomic categories and the total biomass for the Red Cedar River and that reported for eight other streams.

		Biomass						
Stream and		Rock bass		Suckers		Bullheads		Total
reference	Station	lbs/a	(%)	lbs/a	(%)	lbs/a	(%)	lbs/a
Paw Paw Creek (Gerking, 1949)	(average)							58
	1	13	(16)	49	(60)	5	(6)	81
	2	5	(15)	22	(65)	0	(0)	34
Little Blue River (Gerking, 1949)	(average)							239
	1	0	(0)	21	(42)	10	(20)	50
	2	0	(0)	377	(88)	5	(1)	428
Whitewater River (Gerking, 1949)	-	0.4	(4)	6	(60)	0	(0)	10
Simon Creek (Gerking, 1949)	-	0.4	(2)	14	(82)	0	(0)	17
Jordan Creek (Larimore, 1961)	-	3	(3)	12	(13)	28	(30)	93
North Fork (Charles, 1957)	-	0	(0)	84	(57)	17	(11)	148
Whippoorwill Creek (Charles, 1957)	-	2	(15)	10	(77)	0.2	(2)	13
Floyd's Fork Creek (Charles, 1957)	-	0.1	(0.1)	28	(42)	3	(4)	67
Red Cedar River (present study)	(average)							101
	I	30	(49)	14	(23)	11	(18)	61
	II	36	(36)	48	(48)	9	(9)	101
	III	25	(17)	46	(32)	12	(8)	144
	IV	16	(13)	48	(38)	8	(6)	126
	V	21	(29)	29	(40)	5	(7)	73

included in his paper. Therefore, the results of all of the above authors may be looked upon as the minima for biomass in the section being studied. Extrapolation from the study area to the entire river is, of course, dependent on the variation introduced by subjectivity or randomness in site selection. Petersen estimates, on the other hand, may be higher or lower than the actual population and are subject to the bias discussed above.

Of the streams considered in Table 18, it may be seen that the average total biomass of the Red Cedar River was exceeded by that of only two streams: North Fork in Kentucky and Little Blue River in Indiana. Larimore (1961) quoted the results of total biomass estimates by several other workers, but the contribution of the various species were not reported. Assuming the proportion of the total biomass which consists of minnows and darters is the same in the Red Cedar River as that reported by Larimore (1961), the total biomass for the present study would be multiplied by 1.74, or the mean total biomass would be 176 lbs/acre. Of those twenty-five streams reported by Larimore which are not considered in Table 18, eight were estimated to have a total biomass exceeding 176 lbs/acre.

The distribution and abundance of the components of the sucker group is reported in Table 19 in terms of number per mile of stream. Of particular interest is the observation that the average number of white suckers per mile of stream is fairly consistent for the five zones. Therefore, the apparent increase of importance (percent of total) in succeeding upstream zones is primarily a function of the decrease in numbers of the other suckers. The hog suckers, on the other hand, appear with greater frequency in the lower parts of the river and reach their greatest abundance in Zone II. The habitat in Zone II agrees with those which Scott (1954) and Hubbs and Lagler (1955) report as

Table 19. Distribution and estimated abundance of the various sucker species in number per mile of stream for the Red Cedar River in 1959, 1960 summer and fall, and 1961.

	Zone I	%	Zone II	%	Zone III	%	Zone IV	%	Zone V	%
1959										
White sucker	190	11	550	28	724	27	422	42	143	91
Northern hog sucker	240	14	720	36	38	1	0	0	15	9
Spotted sucker	20	1	0	0	23	1	588	58	0	0
Redhorse	1270	74	720	36	1885	71	0	0	0	0
Total	1720		1990		2670		1010		158	
1960 summer										
White sucker	29	40	172	13	22	4	12	26	258	98
Northern hog sucker	7	10	759	59	219	44	0	0	4	2
Spotted sucker	7	10	0	0	0	0	35	74	0	0
Redhorse	29	40	362	28	256	52	0	0	0	0
Total	72		1293		497		47		262	
1960 fall										
White sucker	111	7	621	10	22	5	1056	91	547	88
Northern hog sucker	22	1	4141	70	256	58	6	1	77	12
Spotted sucker	15	1	9	0	15	3	104	9	0	0
Redhorse	1393	90	1173	20	146	33	0	0	0	0
Total	1541		5944		439		1166		624	
1961										
White sucker	0	0	70	5	493	42	774	92	141	100
Northern hog sucker	1267	100	1118	86	264	22	0	0	0	0
Spotted sucker	0	0	0	0	52	4	70	8	0	0
Redhorse	0	0	115	9	378	32	0	0	0	0
Total	1267		1303		1187		844		141	
Mean for all collection periods										
White sucker	83	7	353	13	315	26	566	74	272	92
Northern hog sucker	384	33	1685	64	194	16	2	0	24	8
Spotted sucker	11	1	2	0	23	2	199	26	0	0
Redhorse	673	58	592	22	666	56	0	0	0	0
Total	1151		2632		1198		767		296	

being suitable for hog suckers in this region. Redhorse did not appear in any collection made on the river upstream from the dam at Williamston.

The most abundant fish (other than minnows and darters) in the Red Cedar River is the rock bass. It may be seen (Table 15) that there is a general tendency for the numbers of rock bass to diminish in an upstream direction. Zone II most consistently displays the highest number per acre and the largest standing crop of rock bass.

Bullheads were widely distributed, but their contribution to the total biomass was generally small and displayed no consistent rank in the zones.

Production Estimates

Net production was estimated for the centrarchid and catostomid fishes in the five zones. The figures represent net production in the Ivlev sense, i.e., the total elaboration of biomass, whether or not it reaches the end of the period for which the estimate was made. The results, in dry weight units, are presented in Table 20 for all the species considered. Dry weight was found to equal 0.242 x wet weight for these species. Table 21 includes these same estimates separated into the contributions made by each of the major groups.

The Robson-Chapman estimate presupposes that the recruitment is similar in subsequent years, so that there is no effect of strong or weak year-classes. For that reason, the survival estimates were made by combining the data for the four years of the study. Although this will reduce the year-class effect, it precludes the possibility of replicating the estimates. Consequently, only one mortality estimate may be made for each species. This was assumed to be constant, though it is likely that a considerable error is introduced into the production estimates. It is believed that the mortality is greater in

Table 20. Estimated dry weight* production for several species of fish in the Red Cedar River (units are milligrams dry weight per square meter per day).

Species	Zone I	II	III	IV	V
White sucker	0.66	1.35	2.90	6.86	4.40
Northern hog sucker	1.03	6.22	5.15	0.18	0.39
Redhorse	3.06	2.33	5.43	0.00	0.00
Spotted sucker	0.02	0.03	0.96	4.42	0.00
Rock bass	2.92	3.89	2.86	1.60	1.75
Smallmouth bass	0.07	4.47	0.55	0.16	0.06
Green sunfish	0.00	0.14	0.06	0.06	0.00+
Bluegill	0.00+	0.00	0.31	0.00+	0.04
Longear sunfish	0.00	0.00	0.00+	0.00	0.00
Black crappie	0.00	0.00	0.00	0.18	0.00
Pumpkinseed	0.05	0.01	0.43	1.33	0.72
Largemouth bass	0.01	0.00	0.00	0.00+	0.00
Warmouth	0.00+	0.00+	0.00	0.01	0.00
Total	7.83	18.45	18.65	14.81	7.36

*Wet weight = 4.13 x dry weight

Table 21. Estimated dry weight* production for the two major families of fishes considered in the Red Cedar River (units are milligrams dry weight per square meter per day).

Family	Zone I	II	III	IV	V	Mean
Centrarchidae	3.06	8.51	4.23	3.36	2.58	4.35
Catostomidae	4.76	9.93	14.45	11.46	4.79	9.08
Total	7.82	18.44	18.68	14.82	7.37	13.43

*Wet weight = 4.13 x dry weight

the early periods of life. This implies that the production estimates would probably be increased if the true mortality could be applied.

An error of unknown extent is introduced by the back-calculation of the population estimates to May 1 using the estimate of instantaneous mortality rate. However, I believe that this error is small in relation to the error component in the variance of the Petersen estimate of population size. The effect in this case is likely to be one of reducing the estimate. This would result from using an annual mortality rate for that period from May 1 to some time during the summer or early fall. The actual mortality during this period is probably lower than that during the more harsh seasons of the year, which would also be reflected in the estimate of annual mortality.

The error component in the estimate of instantaneous growth rate for individuals is small and the bias, if any, is probably quite small.

The average biomass which represents an intermediate step in these calculations is not comparable to the average biomass estimates reported above, although the two are not independent in the sense that some of the same basic data were used in both calculations. Those reported above are arithmetic means of a set of simple estimates, while those which appear in the production estimate calculations are a geometric mean of the biomass over the year.

Since only one estimate of the net production of each species in each zone is obtained, and because of the bias in the estimates, they are not amenable to a rigorous statistical analysis. In fact, due to the bias, even descriptive confidence intervals are meaningless. Therefore, these estimates may be considered as minimum absolute estimates of the true net production for the species considered.

DISCUSSION

This study indicates that the Red Cedar River fish populations do not comprise one homogeneous community, but rather make up several incompletely separated communities in which the populations differ both in relative quantity and in certain qualitative characteristics, such as growth rate of individuals and productivity of the populations. Table 22 is a summary of the salient features of the fish populations and certain physical and biological characteristics of the study zones.

Near the upstream end of Zone V, the river receives the effluent from a metal plating plant and organic enrichment from the Fowlerville urban area. The major part of this study was confined to the lower reaches of the zone where the fish populations are recovering from the effects of these effluents. Those sampling stations which fell further upstream, nearer the plating plant and sewage outfall, supported extremely low populations. In the spring of 1961, an extensive fish kill occurred in Zone V as a result of an accidental release of toxic materials from the metal plating plant. The influence of this kill could be recognized in the decreased fish populations as far downstream as Stow Road, about 6 miles downstream from the plating plant, in the summer sampling period.

Zone V includes the widest variety of major habitat types of any of the study zones. They range from the slow-flowing, deeper, silty, dredged portions which make up the greater part of the zone to the shallow, gravel-bottom riffles and runs found in the vicinity of Webberville Road and Highway M47. The low gradient and subsequently slow flow of the river in most of this zone coupled with its small width (mean width: 34.3 feet) are conducive to the retention and accumulation of fallen trees and brush. These, with the overhanging brush on the banks, provide excellent cover for larger rock bass and northern pike.

Regardless of the organic enrichment from the Fowlerville area and the variety of the habitat types, fish production is low (see Table 22)

Table 22. Summary of the estimates of population number, biomass, and production of fish compared with several other physical and biological characteristics of the five zones of the Red Cedar River.

Zone	Gradient* (ft./mile)	Discharge** (ft^3/year) ($\times 10^{-6}$)	Primary* Production (gm cal/m^2 per day)	Inorganic* Sedimentation Rate (mg/m^2/day)	Fish: Species	No./Mile	Biomass (lbs/acre)	Production (mg/m^2/day)
I	3.98	2981	768	318.8	Rock bass	3954	30.0	2.92
					Suckers	1150	13.5	4.76
					Total	6284	61.0	7.83
II	2.73	3244	1156	461.1	Rock bass	4027	36.5	3.89
					Suckers	2632	48.2	9.93
					Total	7370	101.0	18.45
III	1.44	2194	903	762.8	Rock bass	1904	24.8	2.86
					Suckers	1199	46.5	14.45
					Total	4599	143.8	18.65
IV	1.56	2388	1253	942.6	Rock bass	1273	16.0	1.60
					Suckers	767	47.8	11.46
					Total	4563	126.5	14.81
V	0.62	1213	1452	524.0	Rock bass	721	21.0	1.75
					Suckers	296	29.3	4.79
					Total	1607	73.3	7.36

*Data from King (1964, Ph. D. thesis)

**Data from Vannote (1961, M. S. thesis) and the species composition is rather limited. The dominant catostomid in Zone V is the white sucker, although it is less abundant here than in three of the four downstream stations (Table 19). This results from the fact that neither the redhorse nor the spotted sucker are found here and the hog sucker is present in only limited numbers. The absence of the redhorse from this zone and from Zone IV is not readily explained. It seems unlikely that the dam between Zones III and IV would provide a completely effective barrier for so many years against the invasion of the upper parts of the system. It is quite likely, though not necessary, that redhorse were present in the stream prior to the construction of the dam. The spotted sucker seems to prefer the more lacustrine type of environment found in the reservoir proper, which is the only part of the river where it is abundant.

The habitats described above favor the rock bass, which is quite abundant in the lower part of the zone. But it appears that the domestic and industrial pollution from Fowlerville exerts a strong depressing effect on their abundance in the upper portion of this zone. The mean of the weight of individual rock bass is higher in this zone than in any of the other zones. This reflects the age distribution of the population more than an increased growth rate of individuals. Zone V supports a larger proportion of older rock bass. This could be due to any one or a combination of the following reasons. The habitat provides relatively more extensive cover for older fish than is found in the other zones. This situation could also be indicative of a senile and degenerating population with poor recruitment. Or it might represent the results of sampling from an unexploited population which is compared with the rather heavily fished populations in the downstream zones. A similar age distribution might result from a high vulnerability of young fish to some predator with a reduction in vulnerability as age increases. Northern pike are quite common in this zone. An age distribution similar to this one would be observed when sampling the preferred spawning areas of a population during the spawning period. However, the latter does not appear likely in view of the fact that rock bass spawn in the late spring and early summer, whereas these data were collected from June through September. It seems likely that the observed effect results from all of the above factors except for that of sampling from spawning grounds.

Zone IV does not receive directly any extensive sewage or industrial pollution throughout most of its length. The extreme lower end of this zone lies within the city of Williamston, from which it receives a limited amount of organic pollution, but the outfall of the Williamston sewage treatment plant enters the stream in Zone III about one mile below the end of Zone IV. Squaw Creek and Doan Creek both empty into the main stream in this zone. Neither of these tributaries drain urban or industrial areas, although the runoff from this intensively cultivated area would contain some agricultural chemicals.

The reservoir proper comprises approximately half of Zone IV and its influence extends throughout the length. The flow is very slow and the bottom consists largely of mud and silt with occasional shallow sand flats in the upper half mile. The reservoir occupies a rather narrow and sinuous basin with a maximum depth of approximately 10 feet. Only the upper half (about two miles) of this zone was sampled for the fish study. The north side of the channel is quite steep through much of this portion, providing a run four to five feet deep immediately adjacent to the bank. Numerous logs with accumulated debris furnish cover for the larger pike and rock bass, while the deeper runs and pools are occupied by white suckers and spotted suckers. Extensive beds of several macrophytes (primarily *Sagittaria* sp.) offer protection for young fish of most of the species present.

In Zone IV, the dominant catostomid is the white sucker, which reaches its peak abundance here (see Table 19). The spotted sucker is also most abundant in this zone. The production of rock bass is lower in Zone IV than in any other, though the total production by centrarchids occupies a median position for the five zones (Table 21). This is due primarily to the presence of a large population of pumpkinseeds, which contributed 40% of the total centrarchid production (see Table 20). Pumpkinseeds, like the white sucker and spotted sucker, reach their greatest population density in this zone. It is believed that these species are numerous here due to the more lacustrine nature of the habitat. The scarcity of hog suckers may be attributed to a lack of the shallow sand flats and riffles that they occupy in other zones. On the other hand, the presence of largemouth bass and black crappies is a further indication of the lentic nature of the environment in this zone.

Zone III receives the effluent of the sewage treatment plant in Williamston as well as direct seepage from the septic tanks and tile fields of the residences adjacent to the river. The latter problem is in the process of being corrected by extending the sewer facilities of the city. The sewage disposal plant applies excellent primary treatment so that the effect on the river is one of organic enrichment rather than foul pollution. The result is an extensive production of heterotrophic aufwuchs (King, 1964, Ph. D. thesis). Deer Creek drains into the main stream near the upper end of Zone III and contributes greatly to the turbidity of the river during periods of high water. The nutrients introduced into the main stream from this source remain low except during heavy rainfall and rapid runoff. However, the rise in nutrient levels during rapid runoff accompanies high water conditions when these nutrients are not efficiently utilized by the biota (Brehmer, 1958, Ph. D. thesis). Consequently, the main source of allochthonous nutrients is supplied by the sewage treatment plant, which empties about 2.5 metric tons of phosphorus into the river annually (Brehmer, ibid.).

The gradient in Zone III is slight and the bottom is relatively uniform with occasional deep pools. The bottom materials consist mainly of sand and cobbles with some silt and detritus. A few riffles are present near the lower end of the zone. Concealment for fishes is provided by extensive beds of rooted macrophytes (*Vallisneria* and *Sagittaria* spp.), but there are fewer accumulations of logs and other cover than in the upstream zones.

The biomass and production of fish in Zone III are higher than in any other zone of the river. This may seem incongruous with the rate of primary production unless the amount of allochthonous nutrients is considered. King (1964, Ph. D. thesis) describes the unusual conditions found here. He estimates that the production of heterotrophic aufwuchs in this zone is 885 g-cal/m^2/day, which is more than 3.5 times as much production as occurs in Zone V, which most nearly equals it.

In Zone III, redhorse are the most important species with respect to the standing crop of biomass and rate of production. This zone seems to provide the most nearly optimum conditions for catostomids to be found in the Red Cedar River; they reach their greatest abundance and production here. This situation is especially true for the redhorse and hog suckers, although white suckers may also be found here in large numbers. The standing crop and production of centrarchids are high in this zone, but are not as great here as in Zone II. This could be due to the reduced availability of suitable cover, which prevents them from making full use of the abundant food. Rock bass are the dominant centrarchid and the pumpkinseed, though present, is relegated to a minor position.

Zone II is the cleanest of the five study zones. It receives almost no organic or industrial pollution except for the influence of Okemos in the last half mile before entering Zone I. The bottom consists of sand, boulders, and gravel with a large number of riffle-pool combinations. Extensive sand flats occur in the lower end of the zone, but the gradient is high and provides a current sufficiently swift to prevent much silt deposition. Valisneria sp. appears to be invading the area from Zone III and may be found in thick beds through much of the upstream end of the zone. Runoff from the construction sites of a major highway in the southern portion of the Red Cedar River drainage system in the summer of 1961 introduced a considerable amount of sand and clay into the main stream. This has most noticeably affected Zone II where it is responsible for the filling of many pools. In the subsequent low water years, this material has been somewhat stabilized and may represent a permanent alteration of the environment.

The dominant catostomid in Zone II is the hog sucker, which is abundant throughout the zone. Redhorse and white suckers are present in fewer numbers, but contribute a significant part of the biomass. The greatest production of centrarchids occurs here, representing the highest proportion of the total production to be found in any part of the river. Of particular importance is the status of the smallmouth bass. This is the only zone where its production exceeds that of the rock bass; indeed, the only zone where it contributes a significant part of the total production. Vannote (1963, Ph. D. thesis) presents an excellent treatise on the ecology of the smallmouth bass in a part of Zone II. He notes that in the recent past the Red Cedar River was considered to be an excellent smallmouth bass stream. However, the stream has now reached a stage of degradation where only this part of the river maintains a semblance of its former stature. He also indicates the importance of a high density of riffle-pool combinations for the maintenance of a highly productive smallmouth bass population. It is likely that the destruction of some of the pools in this zone by the transport of sand and clay from the highway construction site to the main stream has resulted in permanent damage to the smallmouth bass population. However, this zone still represents the most desirable part of the river from the standpoint of the sport fisherman.

Zone I receives organic and some small industrial pollution from Okemos at the upper end as well as seepage and raw sewage from the urban development near and in East Lansing at the lower end. The high gradient (Table 22) is obscured by the presence of the dam just below the downstream boundary of the zone. Since the river is wide in this section and the effective gradient is low, the current is slow. In the upstream end of the zone, the bottom is largely sand and rubble which gives way to mud and silt in the middle portion. The figure for inorganic sedimentation rate for Zone I in Table 22 is likely to be an underestimate due to sampling problems (Darrell King, personal communication). In a river system, the transport of nutrients and other materials is unilateral, with some few exceptions, though the rate of transport may be very low in the case of some biologically utilized materials. It would seem likely, then, that the cumulative effects of all the allochthonous energy would eventually be evident in that zone which is furthest downstream. However, it is necessary to consider that any toxic materials added to any part of the stream would also eventually reach the downstream zone provided they were not degraded or removed biologically or became unavailable in the bottom sediments. If the cumulative effects described above result in an already marginal water quality, then the addition of even a slight amount of pollution may be sufficient to make the waters unsuitable for fish populations.

This appears to be the case in Zone I of the Red Cedar River. It may be seen from Table 22 that the primary production in this zone is the lowest in the river. King (1964, Ph. D. thesis) reports that insect production is also lower in Zone I than in any other part of the river.

It may be expected that heterotrophic production would offset the low primary production, but he shows that this is not the case. Therefore, it is not surprising to find that the production of fish is also very low in this zone. Early in the study, the biotic community included fairly large populations of rock bass and several species of suckers. Later (in 1961) a sharp reduction in the rock bass population was observed as well as a noticeable downward trend in the sucker populations. Subsequent observations indicate that this trend has not reversed.

The natural eutrophication of a river proceeds in an upstream direction. It is believed that in the Red Cedar River, this eutrophication has been accelerated by the activities of man and is resulting in the rapid degradation of the stream as a productive community. Continued urban development in the watershed seems certain, but additional impairment of the water quality is likely to render the river unsuitable for the support of fish populations.

SUMMARY

1. The fish populations in the Red Cedar River, a warm-water stream in central Michigan, were investigated to determine any differences which might exist between five selected zones in a 30-mile study section of the river.

2. A movement study involving tagged fish demonstrated that at least a large portion of the rock bass population exhibits limited movement.

3. Comparative studies included growth rates, standing crop in numbers and weights, and production of the major fish populations in the five zones.

4. Age determinations were made for approximately 3100 fish from scale samples using the acetate impression method.

5. A significant difference in the growth rates of rock bass and hog suckers for the five zones was demonstrated. Both species showed better growth in the upstream zones. No significant differences in the growth rates of the white suckers and redhorse were demonstrated.

6. Population numbers and biomass were estimated by the Petersen method and the mean weight of fish in the samples using an electro-fishing technique.

7. Non-parametric statistical analyses indicated a significant difference in the numbers of fish per acre but not in the standing crops of biomass. The mean standing crop of biomass for the five zones was estimated to be 101 lbs./acre with the individual estimates ranging from 18 lbs./acre to 338 lbs./acre.

8. A source of bias in the Petersen estimate using small samples was shown to be the effect of estimating a continuous distribution with a discrete distribution.

9. Net production of the major fish populations was estimated by the technique of Ricker with some modifications.

10. The total mean net production of the major fishes in the Red Cedar River was estimated to be 13.43 mg dry weight/m^2/day in the growing season with a range of 7.37 mg dry weight/m^2/day to 18.68 mg dry weight/m^2/day.

LITERATURE CITED

Ball, R. C. 1947. A tagging experiment on the fish population of Third Sister Lake, Michigan. Trans. Am. Fisheries Soc., 74: 360-369.

Beckman, W. C. 1943. Annulus formation on the scales of certain Michigan game fishes. Papers Mich. Acad. Sci. A. L., 28: 281-312.

Brehmer, M. L. 1956. A biological and chemical survey of the Red Cedar River in the vicinity of Williamston, Michigan. Unpub. Master's thesis, Mich. State Univ. Lib., 51 pp.

________. 1958. A study of nutrient accrual, uptake, and regeneration as related to primary production in a warm-water stream. Unpub. Doctor's thesis, Mich. State Univ. Lib., 97 pp.

Brown, E. H. 1960. Little Miami River headwater-stream investigations. Ohio Dept. Nat. Res., 143 pp.

Charles, J. R. 1957. Final report on population manipulation studies in three Kentucky streams. Fish. Bull. 22, Kentucky Dept. Fish and Wildl. Res., 45 pp.

Cooper, G. P. and K. F. Lagler. 1956. Appraisal of methods of fish population study - Part III: the measurement of fish population size. Trans. 21st N. A. Wildl. Conf., 281-297.

Dixon, W. J. and F. J. Massey, Jr. 1957. Introduction to statistical analysis. 2d Ed. McGraw-Hill Book Co., Inc., New York, 488 pp.

Funk, J. L. 1957. Movement of stream fishes in Missouri. Trans. Am. Fisheries Soc., 85: 39-57.

Gerking, S. D. 1953. Evidence for the concept of home range and territory in stream fishes. Ecology, 34: 347-365.

________. 1959. The restricted movement of fish populations. Biol. Reviews, 34: 221-242.

________. 1962. Production and food utilization in a population of bluegill sunfish. Ecol. Monogr., 32: 31-78.

Grzenda, A. R. 1960. Primary production, energetics and nutrient utilization in a warm-water stream. Unpub. Doctor's thesis, Mich. State Univ. Lib., 99 pp.

Handbook of biological data. 1956. W. B. Saunders Co., Philadelphia. 584 pp.

Hile, R. O. 1941. Age and growth of the rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Trans. Wisconsin Acad. Sci. A. L., 33: 189-337.

Hubbs, C. L. and K. F. Lagler. 1958. Fishes of the Great Lakes region. (Rev. ed.) Bull. No. 26, Cranbrook Inst. Sci. 213 pp.

King, D. L. 1962. Distribution and biomass studies of the aquatic invertebrates of a warm-water stream. Unpub. Master's thesis, Mich. State Univ. Lib., 96 pp.

________. 1964. An ecological and pollution-related study of a warm-water stream. Unpub. Doctor's thesis, Mich. State Univ. Lib., 154 pp.

Kramer, C. Y. 1956. Extension of multiple range tests to group means with unequal numbers of replications. Biometrics, 12: 307-310.

Larimore, R. W. 1961. Fish population and electrofishing success in a warm-water stream. J. Wildl. Mgmt., 25: 1-12.

Rawstron, R. R. 1961. A study of primary production on artificial substrates in a riffle and pool area of the Red Cedar River. Unpub. Master's thesis, Michigan State Univ. Lib., 73 pp.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Bd. Canada. Bull. No. 119: 1-300.

Robson, D. S. and D. G. Chapman. 1961. Catch curves and mortality rates. Trans. Am. Fisheries Soc., 90: 181-189.

Rounsfell, G. A. and W. H. Everhart. 1953. Fishery Science: its methods and applications. John Wiley and Sons, Inc., New York. 444 pp.

Scott, D. C. 1949. A study of a stream population of rock bass, Ambloplites rupestris. Invest. Indiana Lakes and Streams, 3: 169-234.

Scott, W. B. 1954. Fresh-water fishes of eastern Canada. Univ. of Toronto Press, Toronto. 128 pp.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Co., Inc., New York. 312 pp.

Smith, S. H. 1954. Method of producing plastic impressions of fish scales without using heat. .Prog. Fish Culturist, 16: 75-78.

Snedecor, G. W. 1956. Statistical methods. Iowa State Univ. Press, Ames, Iowa. 534 pp.

Tompkins, W. A. and B. T. Carter. 1951. The growth rates of some Kentucky fishes. Kentucky Div. Game and Fish, Fish. Bull. No. 6. 9 pp.

Vannote, R. L. 1961. Chemical and hydrological investigations of the Red Cedar River watershed. Unpub. Master's thesis, Mich. State Univ. Lib., 126 pp.

________. 1963. Community productivity and energy flow in an enriched warm-water stream. Unpub. Doctor's thesis, Mich. State Univ. Lib., 156 pp.

APPENDICES

APPENDIX A

List of names* of fishes encountered in the Red Cedar River during the course of this study.

Scientific name	Common name
Esocidae	
Esox americanus vermiculatus LeSueur	Grass pickerel
E. lucius Linnaeus	Northern pike
Cyprinidae	
Cyprinus carpio Linnaeus	Carp
Catostomidae	
Catostomus commersoni (Lacepede)	White sucker
Hypentelium nigricans (LeSueur)	Northern hog sucker
Minytrema melanops (Rafinesque)	Spotted sucker
Moxostoma spp.	Redhorse
Ictaluridae	
Ictalurus melas (Rafinesque)	Black bullhead
I. natalis (LeSueur)	Yellow bullhead
Centrarchidae	
Ambloplites rupestris (Rafinesque)	Rock bass
Chaenobryttus gulosus (Cuvier)	Warmouth
Lepomis cyanellus Rafinesque	Green sunfish
L. gibbosus (Linnaeus)	Pumpkinseed
L. macrochirus Rafinesque	Bluegill
L. megalotis (Rafinesque)	Longear sunfish
Micropterus dolomieui Lacepede	Smallmouth bass
M. salmoides (Lacepede)	Largemouth bass
Pomoxis nigromaculatus (LeSueur)	Black crappie

*American Fisheries Society. 1960. A list of common and scientific names of fishes from the United States and Canada. Special Publ. No. 2. 101 pp.

APPENDIX B

Mean back-calculated lengths (in centimeters) at annulus formation for thirteen species of fish in the five zones of the Red Cedar River.

Species	Annulus number	Zone I	II	III	IV	V
Rock bass	I	3.91 (406)*	4.09 (641)	4.31 (290)	4.22 (194)	4.05 (114)
	II	6.61 (251)	7.13 (413)	7.80 (213)	7.45 (129)	7.32 (91)
	III	10.72 (103)	10.97 (139)	11.55 (128)	12.26 (74)	11.82 (67)
	IV	14.67 (49)	14.49 (70)	15.19 (73)	15.99 (25)	15.40 (19)
	V	17.34 (11)	16.63 (21)	17.45 (21)	18.74 (8)	17.56 (11)
	VI	20.3 (1)	16.0 (1)	20.23 (4)	20.35 (2)	18.90 (4)
	VII			22.0 (1)		20.45 (2)
	VIII					22.0 (1)
White sucker	I	11.02 (16)	10.55 (41)	11.09 (54)	11.08 (114)	11.21 (100)
	II	18.80 (4)	16.70 (22)	16.83 (35)	19.25 (84)	18.61 (75)
	III	24.1 (1)	20.70 (5)	23.99 (19)	28.96 (62)	26.91 (37)
	IV		18.9 (1)	31.42 (5)	34.86 (21)	29.92 (9)
	V		25.0 (1)		35.35 (2)	30.90 (2)
Redhorse	I	6.02 (121)	6.33 (88)	6.36 (149)		
	II	10.26 (63)	11.30 (63)	11.60 (139)		
	III	17.59 (26)	17.97 (47)	18.94 (123)		
	IV	23.81 (12)	24.32 (37)	25.99 (93)		
	V	27.72 (6)	28.71 (16)	31.25 (64)		
	VI	31.00 (4)	33.35 (10)	34.90 (29)		
	VII	35.9 (1)	34.90 (2)	39.35 (11)		

*Figures in parentheses are the numbers of fish in the samples from which the mean was calculated.

Appendix B - Continued

Species	Annulus number	Zone I	II	III	IV	V
Spotted sucker	I	7.55 (2)	7.95 (2)	8.20 (13)	8.38 (38)	
	II		11.4 (1)	14.60 (7)	15.90 (35)	
	III		14.8 (1)	22.77 (6)	25.37 (27)	
	IV		24.3 (1)	29.75 (4)	32.31 (19)	
	V			42.7 (1)	38.09 (13)	
	VI				41.17 (6)	
	VII				42.5 (1)	
Smallmouth bass	I	8.79 (15)	8.55 (18)	8.80 (16)	8.60 (3)	8.60 (3)
	II	16.0 (1)	14.34 (12)	13.73 (13)	12.70 (2)	11.75 (2)
	III		21.24 (8)	18.95 (12)	18.80 (2)	16.30 (2)
	IV		33.1 (1)		23.6 (1)	
Green sunfish	I	2.7 (1)	3.17 (6)	3.36 (9)	2.48 (5)	4.10 (2)
	II	7.7 (1)	8.65 (2)	7.73 (6)	5.10 (2)	
Bluegill	I	4.40 (2)		4.23 (12)	3.05 (4)	3.7 (1)
	II	7.00 (2)		8.86 (10)		9.2 (1)
	III	10.5 (1)		10.5 (1)		
Longear sunfish	I			3.35 (2)		
	II			6.50 (2)		
Black crappie	I	6.75 (2)			7.1 (1)	
	II	10.75 (2)			11.4 (1)	
	III	16.85 (2)				
	IV	20.6 (1)				

Appendix B - Continued

Species	Annulus number	Zone I	II	III	IV	V
Warmouth	I	6.55	6.1		6.6	
		(2)	(1)		(1)	
	II	9.00	7.3		9.0	
		(2)	(1)		(1)	
	III	10.10	10.2			
		(2)	(1)			
	IV	11.75				
		(2)				
Largemouth bass	I	8.1			4.68	
		(1)			(4)	
	II	19.7				
		(1)				
Pumpkinseed	I	5.36	6.4	5.42	5.40	5.55
		(7)	(1)	(80)	(70)	(15)
	II	7.0	8.4	8.19	8.14	9.37
		(1)	(1)	(76)	(20)	(3)
	III			10.00	10.45	14.0
				(7)	(4)	(1)
	IV				12.35	
					(2)	
Northern hog sucker	I	8.43	8.74	9.20	5.53	9.45
		(114)	(236)	(92)	(2)	(10)
	II	13.07	13.72	15.04	18.0	17.99
		(85)	(163)	(61)	(1)	(10)
	III	18.86	19.65	21.52	28.4	25.26
		(70)	(110)	(47)	(1)	(5)
	IV	24.54	24.61	26.30		31.15
		(34)	(31)	(11)		(4)
	V	29.02	28.50	29.03		
		(6)	(9)	(4)		
	VI	31.95	29.25			
		(4)	(2)			
	VII	34.95				
		(2)				