THE EFFECT OF WATER QUALITY ALTERATION ON THE GROWTH RATE OF WHITE SUCKER

By JOHN V. ROLAND and KENNETH B. CUMMING

Division of Forestry and Wildlife Sciences of Va. Polytechnic Institute
Virginia Cooperative Fishery Unit
Bureau of Sport Fisheries and Wildlife
Fish and Wildlife Service
U. S. Department of the Interior
Blacksburg, Virginia

INTRODUCTION

PURPOSE AND SCOPE OF STUDY

The relationships between fish production and physicochemical factors in lake environments have been of considerable interest to aquatic biologists for some years. A knowledge of the effect of these environmental factors on fish production would be of great benefit to fishery workers. It would permit management personnel to more accurately predict the optimum fishery resources that a lake could support. Much of the research along these lines has been done by associating various concentrations of alkalinity to fish productivity. Ball (1945), Moyle (1946), Rawson (1951), Carlander (1955), Northcote and Larkin (1956), Hayes and Anthony (1964), and Ryder (1965) have been the principal workers in this area of research. The purpose of this type of study is to try and find some index or classification that can be given to a lake or lakes in terms of its relative productiveness. This type of classification would be of high value to fishery biologists as well as all aquatic biologists.

Rawson (1951) found that fish production was determined by three principal factors: morphometry of the basin, dissolved nutrients and climatic factors. Most studies up to the present time have involved a comparison of lakes which varied in all three factors.

In the present study at Carvin Cove Reservoir, variation due to two of the factors (morphometric and climatic) were minimized. In November, 1966, the Water Department of the City of Roanoke built a tunnel through Tinker Mountain and diverted Tinker Creek, a hard water, nutrient-rich stream, into the nutrient-poor, soft water of Carvin Cove Reservoir. This provided an ideal situation in which a study could be undertaken on hardness-fish production relationships where the usual complicating morphometric and climatic factors could be largely ignored.

The objective of this research was to study some of the physicochemical and biological changes that occurred in the reservoir during the first two years following the hard water introduction. To do this, physical and chemical records taken by the Roanoke Water Department during 1965 and 1966 (the two years prior to the hard water introduction) were compared with similar data collected in 1967 and 1968 (the two years following hard water introduction). Physical and chemical conditions were also measured in the reservoir during 1968 to see what effects Tinker Creek had on the water quality of different areas of the reservoir.

Biological studies included examination of the distribution and abundance of fish populations and bottom fauna in the reservoir during 1968, and an age and growth study on the white sucker, before and after the Tinker Creek introduction.

Location and Description of the Reservoir

Carvin Cove Reservoir is an impoundment on the Carvin Creek watershed. It was built by the City of Roanoke in 1930 for use as a public water supply reservoir. The dam impounds approximately 638 acres of water in Botetourt and Roanoke Counties, Virginia. The dam site is located at 37°22′ north longitude, 79°58.5′ west latitude (Fig. 1).

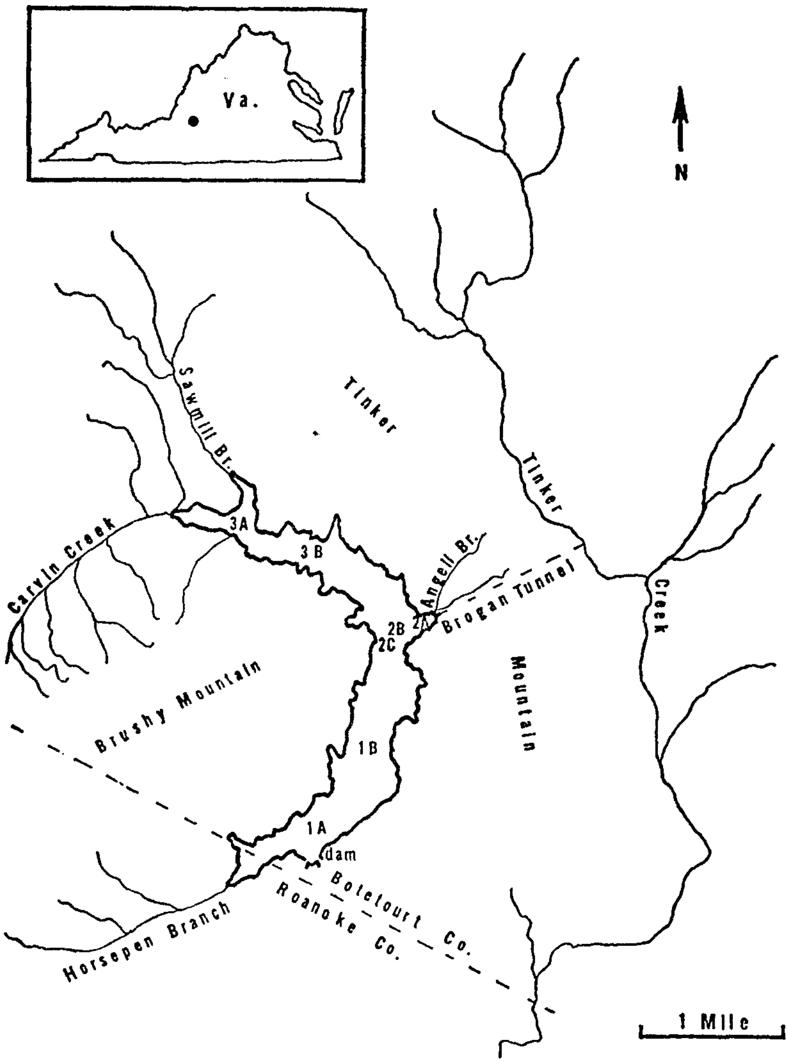

Figure 1. Geographic location of Carvin Cove Reservoir and sampling stations.

In the fall of 1966, a 6500 ft. tunnel, named the Brogan Tunnel, was built through Tinker Mountain to divert part of the Tinker Creek watershed into the reservoir. The stream was diverted in order to help meet the City of Roanoke's increasing water demand. An average rate of about 5 million gallons per day of Tinker Creek water flows into the reservoir. A minimum flow of 1 cubic foot per second must be allowed to bypass the diversion.

The lake was divided into three areas: area 1 composed the lower, deep-water end of the lake near the dam; area 2 included the long cove in the vicinity of the Tinker Creek inflow, and area 3 was confined to the upper, shallow end of the lake. The station locations in each area are represented by A, B and C and those on the tributaries are located just above the point where the stream enters the reservoir. The five streams investigated included: Tinker Creek, Carvin Creek, Sawmill Branch, Horsepen Branch and Angell Branch.

Geology of the Study Area

Carvin Cove Reservoir and its original drainage are located in an area composed primarily of shales and sandstone, mostly of Devonian age. Devonian formations include Braillier shale, Chemung sandstone and Romney shale. The Clinch sandstone of Silurian age and the Martinsburg shale of Ordovician age are the other formations present in the drainage (Butts 1933).

The Tinker Creek, on the other hand, flows through a fertile limestone and dolomite valley. These rocks are primarily Cambrian and Ordovician in age. Major formations include Elbrook and Copper Ridge dolomites in the headwaters region, and Beekmantown, Athens and Lenoir limestones farther downstream (Butts 1933).

Rawson (1951) found that water in a drainage which is characterized by soft rocks, such as dolomites and limestones, had a much higher mineral content than that passing over hard, resistant rocks such as the sandstones, granites and shales.

METHODS AND MATERIALS

Physical and Chemical Measurements

Water chemistry data were collected from December, 1967 to November, 1968. The monthly measurements included; alkalinity, total hardness, calcium hardness, pH, dissolved oxygen and air and water temperatures taken at each open water station and in each of the five major tributaries. Only selected portions of these data will be used in the present paper. Alkalinity was measured by using an Engineer's Hach Water Analysis Kit. Total hardness and calcium hardness were determined by the EDTA method (as mg/1, $CaCO_3$).

The Roanoke Water Department also made monthly water analyses at the dam site in area 1. These records were utilized for this study from January, 1965 through December, 1968. Measurements taken were alkalinity, total hardness, pH, dissolved oxygen, carbon dioxide, iron, manganese, and water temperature. Water samples were taken at 10 foot depth intervals and were analyzed at the water treatment plant.

The Water Department used The Winkler method for dissolved oxygen concentrations and the EDTA titrimetric method to measure total hardness. Total alkalinity was determined by the methyl orange indicator method and carbon dioxide by the phenolphthalein indicator titration. Total iron was determined using the colorimetric thiocyanate method, and manganese by the colorimetric persulfate method. A Taylor water analyzer was used for making the color comparisons for total iron and manganese. The pH and temperature were monitored with a Hellige comparator and a meter reading thermistor.

Bottom Fauna

Benthic samples were collected with a 21.6 cm^2 Ekman dredge. After washing the sample in No. 10 and No. 40 standard sieves, the contents were transferred to a white porcelain pan where the organisms were picked out with forceps and preserved in 70% isopropyl alcohol. Collections were made in all three sampling areas on May 17, 1968, July 17, 1968 and July 30, 1968. All samples were taken at a depth of ten meters. The organisms were sorted and identified to family and subfamily in the laboratory. Counts were made of each sample and wet weights were taken to the nearest 0.01 gm.

Fish Collections

Fish collections were made by using three sampling methods: gill nets, hoop nets, and electrofishing gear. Experimental gill nets were set each month from March, 1968 until July, 1968 in each of the three sampling areas. The experimental gill nets were left out from 12-14 hours during each sampling period. The nets were 125 ft. long by 6 ft. deep. They were made up of five 25 ft. sections, ranging in mesh size from 3/4, 1, 1 1/4, 1 1/2 to 2 in. square measure. In all cases, the nets were tied to shore with an anchor line, set perpendicular to the shore, and anchored with weights at the terminal end, keeping the net close to the bottom. As a result, the depth of the set corresponds to the depth contour of the lake at the point of collection.

Hoop nets were employed during the month of August, 1968. During the week of August 3-August 7, three hoop nets were set, using a single lead, in about four ft. of water. One net was set at the mouth of the hard water stream, Tinker Creek, and nets were set at the mouth of Carvin Creek and Sawmill Branch, the two main sources of soft water to the reservoir. These nets were operated for five days; the fish were removed about 7:00 a. m. each morning. On August 20, 1968, one hoop net was set in each lake area and fished for three days. All sets were made in about 4 ft. of water, close to the shore with a lead running from the net, perpendicular to the shore. The nets were checked each morning at 7:00 a. m. as before.

On October 9, 1968, a final collection was made in the lake using a shocker boat rigged with electrodes for sampling in the shallow water close to shore. The electrofishing was done at night in areas 1 and 2. Unfortunately, area 3 was not sampled due to an equipment malfunction. Actual shocking time was 40 minutes in each area as recorded with a timing device installed on the electronics package. Alternating current was used with 250 volts at 3 amps.

Length and Weight Determinations

All fish collected were individually measured and weighed before being preserved. Fish collected during gill net sampling in March, April and May, 1968 were measured to the nearest 0.25 in. and weighed to the nearest 0.1 lb. In all subsequent collections, fish were measured to the nearest 0.5 cm. and weighed to the nearest gm. Total length measurements were obtained with a metric measuring board. Previous measurements in inches and pounds were converted to metric measure.

Age and Growth

An age and growth study was conducted on the white sucker, *Catostomus commersoni* using data from 79 fish. The scales were scrubbed with soap and water and rinsed before being mounted dry between glass microscope slides. Four to six scales were taken from the left side of the fish, about midway between the base of the dorsal fin and the lateral line (Spoor 1938). Scales were projected at a magnification of 43x on an Eberbach scale projector. Length of fish in millimeters and length of scale from the center of the focus to the anterior edge of the scale in millimeters were measured for each fish. The body length-scale length relationship was then calculated by using a computer program for a weighted linear regression analysis. Lee (1920) studied the body length-scale length relationship of herrings, and she found that the growth increment of the scale was a constant proportion of the growth increment of the fish. For this reason, the Lee formula, $L = a + cS$ (Lee

1920) where L is the length in millimeters, a and c are constants and S is the anterior scale radius, was used to estimate the body length-scale length relationship. The regression equations were also utilized for back calculations of lengths at earlier ages in the white sucker.

Back calculations of lengths at earlier ages were computed using the formula $L_n - c = \frac{S_n}{S}(L - c)$ as described by Tesch (1968) where L_n = length of fish at annulus n, L = length of fish at time scale sample was obtained, S_n = radius of annulus n (at length n), S = total scale radius and c is the intercept of the body scale regression line with the abscissa. All length measurements were taken in millimeters. Back calculations were obtained using a computer program designed by Dahlberg (personal communication) and executed on an IBM 360/50 computer.

RESULTS AND DISCUSSION

Physicochemical Conditions

Roanoke Water Department Water Chemistry Analysis

Monthly chemical analyses of Carvin Cove water have been made by the Roanoke Water Department for a number of years. Yearly means of their findings were taken for 1965, 1966, 1967 and 1968. These data gave a good indication of the chemical and physical changes brought about by the introduction of Tinker Creek water in November, 1966.

Fig. 2a shows yearly means of total hardness for the four year period. In 1965 and 1966 mean total hardness values ranged from 12-16 ppm. During 1967, or the first year after the hard water was piped in, mean total hardness increased to around 48 ppm at the surface and 35-40 ppm near the bottom. Mean total hardness for 1968 shows a further increase up to 56 ppm. Thus, total hardness in the reservoir had tripled by the end of 1967 and had increased in 1968 by almost four times the 1966 level.

Changes in alkalinity followed the same general pattern as hardness (Fig. 2b). Carvin Cove water, before the addition of Tinker Creek, had total alkalinities of from 10-12 ppm which increased to about 37 ppm during 1967 and 50 ppm in 1968. Mean total alkalinities measured slightly less than mean total hardness each year. Hutchinson (1957) distinguishes two kinds of hardness, temporary or carbnoate hardness and permanent or non-carbonate hardness. Carbonate hardness in Carvin Cove Reservoir should closely approximate the value for total alkalinity. Since total hardness in the reservoir exceeds alkalinity each year by 5-10 ppm, this excess or non-carbonate hardness would be due primarily to sulfate and chloride (Ruttner 1953).

The change in alkalinity and hardness as shown from these records is very significant. Using Moyle's (1946) classification, Carvin Cove Reservoir changed from a very soft water lake in 1966 to a medium to medium-hard water lake in 1968.

Hydrogen ion concentration prior to November, 1966 was slightly acidic at about 6.7 to 6.8 (Fig. 2c). In 1967, hydrogen ion concentrations were slightly alkaline, around 7.2 to 7.4. By 1968, pH had increased to about 7.6.

Reid (1961) states that at increased levels of pH, alkalinity, and hardness, the amount of bound carbon dioxide increases. Fig. 2d demonstrates this as CO_2 changed from less than 1 ppm under soft water conditions in 1966 to about 2 ppm in 1967 and 3 to 4 ppm in 1968.

Iron concentrations in the reservoir seemed to be affected very little by the hard water introduction. Mean total iron levels remained fairly constant over the four year period (Fig. 3a).

Fig. 3b shows that manganese levels have decreased in the epilimnion since the hard water was introduced. Manganese in 1965 and 1966

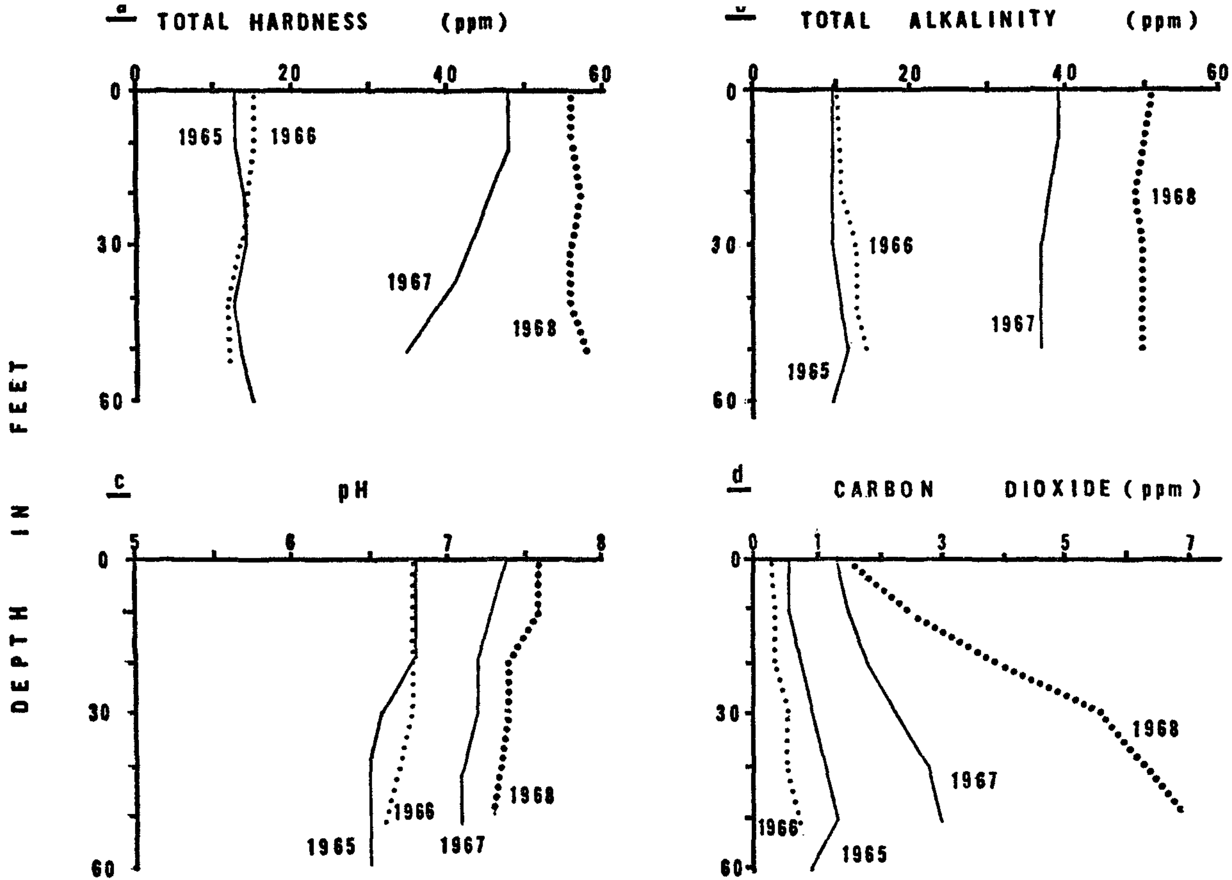

Figure 2. Yearly means for a - total hardness, b - total alkalinity, c - pH, and d - carbon dioxide measurements taken by the Roanoke City Water Department at Carvin Cove Reservoir, 1965 - 1968.

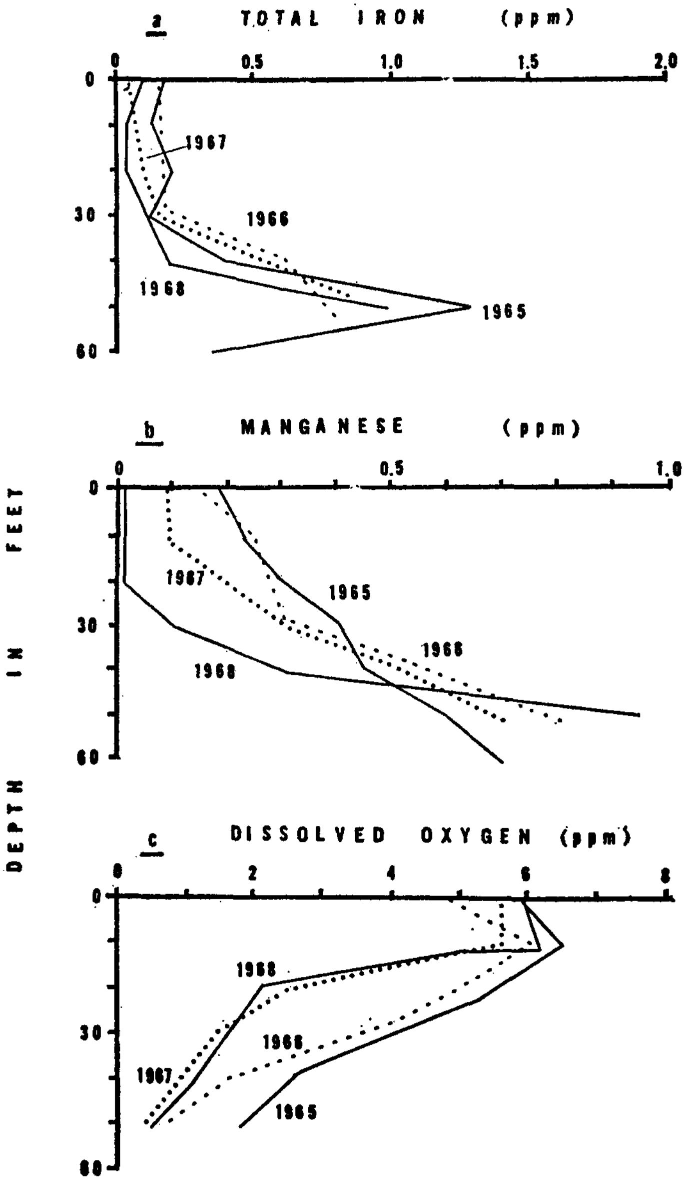

Figure 3. Yearly means of a - total iron, b - manganese, and c - dissolved oxygen measurements taken by the Roanoke City Water Department at Carvin Cove Reservoir, 1965 - 1968.

averaged about 0.2 ppm. In 1967, average manganese concentrations lowered to less than 0.1 ppm, and only a trace remained in the epilimnion during 1968. These data agree with Mackereth (1963) who stated that manganese is more apt to remain in solution in acid waters. Conditions were more acidic in the reservoir in 1965 and 1966 (Fig. 2c). He also points out that manganese is found in higher concentrations in the anaerobic zone of lakes. This would explain the slight increase in manganese in the bottom waters as the hypolimnion is seen to become more anaerobic following the hard water inrtoduction (Fig. 3c).

Dissolved oxygen and temperature were also recorded monthly by the Roanoke Water Department. Summer means for the months of July, August and September of dissolved oxygen for 1965, 1966, 1967 and 1968 were analyzed. Dissolved oxygen was not measured in August, 1968, so the summer mean for that year includes only the months of July and September.

Dissolved oxygen in the hypolimnion at Carvin Cove Reservoir decreased by almost one-half below the 20 ft. level after the hard water was introduced (Fig. 3c). The metalimnion was located between 10 and 20 ft. below the surface during the summer of all four years (Table I).

TABLE I. Temperature measurements (°C) taken by the Roanoke Water Department at Carvin Cove Reservoir, 1965-1968

Depth (Ft.)	1965 Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
sf.	6	6	8	12	22	24	26	26	24	17	13	7
10	6	5	7	11	20	23	21	25	23	16	13	8
20	6	4	6.5	9	15	18	17	24.5	17	16	12.5	8
30	6	6	6	9	13	16	15	18	14	13	12	7
40	6	4.5	7	8.5	13	15	15	15	14	13	11	7
50	6	4.5	6	8	12	14	15	15	14	13	10	6
60	.	.	6	8	12	13	15	15	..	..	..	.

Depth (Ft.)	1966 Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
sf.	7	3	6	11	19	25	27	26	20	15	10.5	7
10	6	3	6	11	18	20	26	25	20	15	10	6
20	6	3	6	10	13	16	18	19	19	14	10	6
30	6	3	5	10	13	14	15	17	13	14	10	6
40	6	4	5	10	12	14	14	16	13	13	10	6
50	6	5	5	10	12	13	14	16	13	12	10	6

Depth (Ft.)	1967 Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
sf.	5	5	6	15	16	24	26	26	22	16	12	7
20	5	5	6	15	15	20	21	23	21.5	16	12	7
20	5	5	6	12	14	17	18	19	18	15	12	7
30	5	5	6	10	12	15	15	16	15	13	11	7
40	5.5	5	6	10	12	14	13	14	14	12	10	7
50	5.5	5	6	9	11	14	13	14	14	12	10	7

Depth (Ft.)	1968 Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
sf.	.	4	7	14	19	14	28	..	23	18	15	5
10	.	4	6	12	16	20	22	..	22	18	15	5
20	.	4	6	12	13	15	16	..	17	17	15	5
30	.	4	6	10	12	13	15	..	14	14	13	5
40	.	4	6	10	12	13	14	..	14	13	12	5
50	.	4	6	10	11	12	14	..	14	12	12	5

Ruttner (1953) states that the hypolimnetic oxygen deficit is based on the idea that the rate of oxygen utilization is proportional to the amount of organic matter raining into the hypolimnion from the trophogenic zone above. In other words, the productivity of a reservoir influences hypolimnetic oxygen concentrations, with the more eutrophic lakes having less oxygen and vice versa for oligotrophic lakes. The relative productiveness of the lakes relates back to the amount of nutrients in usable form present in the lake.

Tributraies

Before November, 1966, Carvin Cove Reservoir was supplied with water mainly by four streams: Carvin Creek, Sawmill Branch, Horsepen Branch and Angell Branch. In addition to these streams, there are many small, intermittent, wet weather creeks that flow only during the early spring and after periods of heavy rainfall. Tinker Creek water was turned into the reservoir in November, 1966 and contributed substantially to the amount of water entering the reservoir. As an example, Tinker Creek contributed 37% of the inflow as measured on November 17, 1968 (Table II).

Physicochemical stations were set up on Tinker Creek, Carvin Creek, Sawmill Branch, Horsepen Branch and Angell Branch just above where the streams enter the reservoir. Chemical and physical measurements were taken monthly; only the alkalinity and total hardness will be presented here.

Total Hardness and Alkalinity. Total alkalinity in a stream is dependent largely on the geology of the region (Lagler 1956). It is the buffering system in fresh waters and, as such, helps determine the amount of bound carbon dioxide present and the degree of acidity of the water (Reid 1961). Moyle (1946) has demonstrated the significance of alkalinity concentrations in the basic productivity of the water. Hardness values are closely associated with alkalinity readings (American Public Health Service 1965) and can also be used as an index to measure productivity. Table III demonstrates the differences between the chemical properties of the waters from the original drainage (Sawmill Branch, Carvin Creek, Horsepen Branch and Angell Branch) of

TABLE II. Calculated volume of flow in cubic feet per second (c.f.s.) of the five major tributaries of Carvin Cove Reservoir on November 17, 1968

Stream	Inflow c.f.s.	Percent Total
Tinker Creek	5.24	37
Carvin Creek	4.51	32
Sawmill Branch	3.24	23
Horsepen Branch	0.80	6
Angell Branch	0.22	2
Total	14.01	100

TABLE III. Total hardness and total alkalinity in parts per million at stream stations in 1967-1968 at Carvin Cove Reservoir

Test	Date	Tinker Creek	Carvin Creek	Station Sawmill Branch	Horsepen Branch	Angell Branch
Hardness Total						
	12/14	...	..	..	..	..
	1/25	160	..	..	..	..
	3/19	220	24	12	12	24
	4/17	236	16	16	12	16
	5/29	256	24	16	16	20
	6/26	248	20	34	16	24
	7/27	244	24	30	16	32
	8/22	256	24	28	24	..
	9/26	240	16	24	28	48
	10/27	236	20	28	24	48
	11/24	244	28	16	20	16
Average		234	22	23	19	28

Test	Date	Tinker Creek	Carvin Creek	Station Sawmill Branch	Horsepen Branch	Angell Branch
Alkalinity Total						
	12/14	...	..	..	..	..
	1/25	130	..	..	..	10
	3/19	150	20	20	20	16
	4/17	240	20	18	24	40
	5/29	280	18	20	18	32
	6/26	265	20	30	38	40
	7/27	260	18	30	30	38
	8/22	180	20	22	26	..
	9/26	180	18	18	20	20
	10/27	200	16	16	13	18
	11/24	180	14	9	12	8
Average		206	18	20	22	25

the reservoir and Tinker Creek. Alkalinity and hardness values for the four streams in the original drainage ranged from 18-28 ppm, whereas in Tinker Creek, the average total alkalinity was 206 ppm and the average total hardness, 234 ppm. According to Moyle's (1946) classification, the four streams making up Carvin Cove's original drainage would be considered very soft. Tinker Creek, on the other hand, would be classified a very hard water stream.

Reservoir

Water chemistry and physical measurements were taken from December, 1967 through November, 1968 in different areas of the lake; only total hardness will be discussed here. Stations were set up so that the reservoir could be sampled to measure the effects the Tinker Creek introduction had upon water quality in different parts of the lake.

Total Hardness. Hardness is frequently used to express the total alkaline earth content that can produce insoluble soaps (Hutchinson 1957). Total hardness was measured at each station (1A, 1B, 2A, 2B, 2C, 3A, and 3B) once a month beginning in March, 1968 and ending in November, 1968. Means of at least six measurements were then calculated for each area with depth. Total hardness values in the reservoir ranged from approximately 60 ppm in March to around 70 ppm in November. This represents about 10 ppm incerase in hardness over a period of nine months.

Total hardness readings varied slightly between the three areas. Area 2 showed somewhat higher values than area 1 and 3. Area 3 had hardness values slightly lower than area 1 and averaged 5 ppm lower than area 2.

Area 2 and area 3 were found to contain higher values of total hardness in the epilimnion than were found in the hypolimnion during the late summer and early fall. Fig. 4 shows the mean values for the vertical distribution for the months of July, August, September and October at stations 2A, 2B, 2C, 1B and 1A. These data give an indication of the total hardness concentrations at various distances from the Tinker Creek inflow. At station 2A, close to the hard water inflow, the hard water is seen to sink with 72 ppm at the surface and 100 ppm near the bottom at 10 feet. The trend continues at stations farther down Tinker Creek but the difference becomes less pronounced. Eley, Carter and Davis (1967) found that salt heavy waters, being more dense, will sink to the bottom where, if high enough in dissolved solids, they will form what Reid (1961) calls a monimolimnion with density gradient, the chemocline. Such a lake is called meromictic lake. Eley, Carter and Davis (1967) found a situation much like Carvin Cove Reservoir where a river, which was much higher in dissolved solids than the reservoir into which it flowed (Keystone Reservoir), formed a density current and settled to the bottom of the reservoir where it became chemically stratified.

Tinker Creek water apparently has not reacted in this manner although it is considerably higher in dissolved solids than the water in the reservoir. The hard water from Tinker Creek seems to remain in the upper stratum of the lake during the summer and fall and does not become vertically uniform in concentration until the fall circulation in November. A comparison of the water temperatures in the reservoir during the summer and fall and the water temperatures of Tinker Creek (data not presented here) indicates that Tinker Creek water is flowing into the reservoir along the top of the metalimnion and does not intermix with the hypolimnion. Other data (not reported here) also show that the difference in the total hardness concentration of the epilimnion and hypolimnion is becoming less pronounced each year. It may be that, as time progresses, a condition will result that is similar to that found in Eley, Carter and Davis' (1967) study in Keystone Reservoir.

Bottom Fauna

Three macroscopic bottom fauna collections were taken during the spring and summer of 1968. Several samples were taken in each area to determine the distribution of the benthic food organisms in the lake after the introduction of Tinker Creek water. Hayes (1957) found that concentrations of bottom organisms varied with depth, although there was no set pattern to this variation. With this in mind, all collections were made at a depth of 10 meters to try and reduce some of the variation caused by different depth distributions of the organism.

A total of 12 samples were taken in area 1, 6 in area 2 and 8 in area 3. Each sample represented the bottom organisms found in 21.6 cm^2 of bottom sediment. The mean number of organisms and weights for the three sampling periods in each area were computed (Fig. 5).

Area 2 far surpassed areas 1 and 3 in both number of organisms present and wet weight per sample of bottom sediment. Reid (1961) states that the nature of the sediments has a strong influence on the population density and species composition of the bottom fauna. Since benthos depend on the organic content of the ooze for their nourishment (Ruttner 1953), eutrophic lakes can generally support a larger

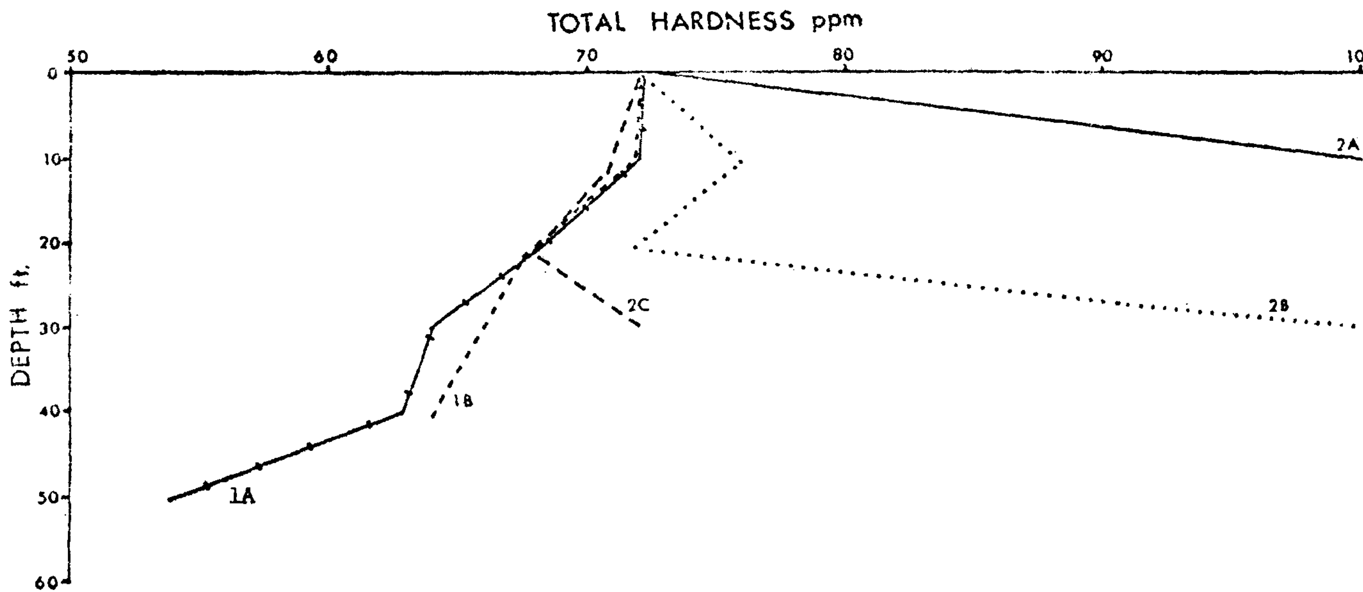

Figure 4. Mean summer total hardness concentrations in different areas of Carvin Cove Reservoir in 1968.

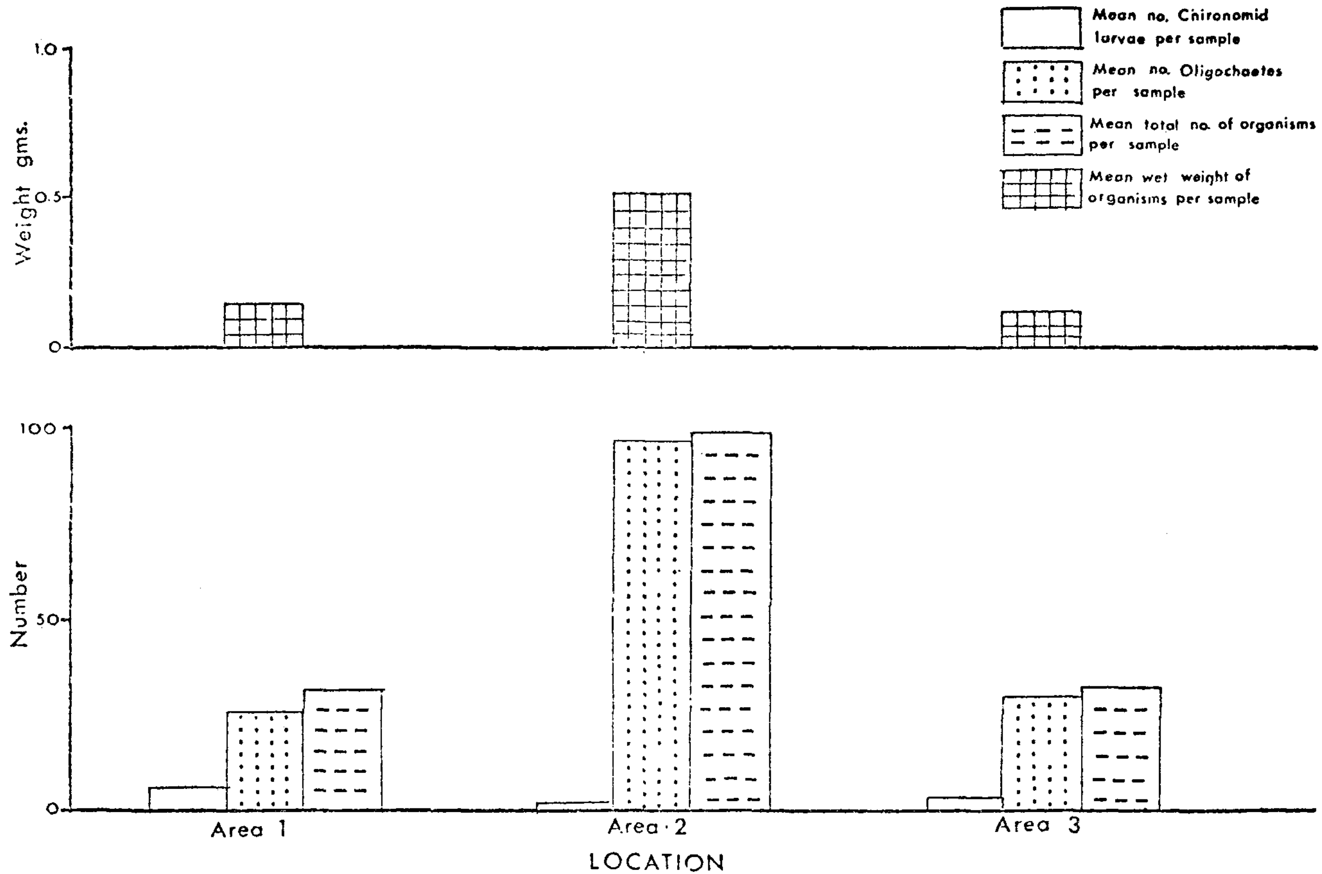

Figure 5. Mean numbers and wet weights per 21.6 cm^2 bottom sample at Carvin Cove Reservoir in 1968.

number of organisms, although there may be fewer species represented. Reid (1961) found that oligotrophic lakes supported a greater variety of different bottom organisms, but a smaller total yield.

It would seem that Tinker Creek supplied area 2 with a considerable amount of organic material, resulting in the higher yield of organisms per unit area. This agrees with Ruttner (1953) who found that allochthonous material supplied by tributaries plays a considerable role in the composition of the sediments. Northcote and Larkin (1956) found that lakes low in total dissolved solids (below 60 ppm) had sparse bottom faunas. Lakes with total dissolved solids above 120 ppm were rich in bottom organisms. It may be that the rich supply of nutrients being brought in by Tinker Creek is an important factor in the high density of the benthos in area 2 of Carvin Cove Reservoir.

It is difficult to draw any definite conclusions about bottom fauna yields. In addition to the very marked seasonal changes that take place in the bottom fauna (Welch 1935), temperature, transparency, dissolved oxygen, water currents, lake basin morphology, drainage, and climatic factors play a considerable role in bottom fauna production (Reid 1961).

Fish Population Investigations

Fish collections in Carvin Cove Reservoir were made from March, 1968 until November, 1968 using gill nets, hoop nets and an electrofishing boat. The population of fishes was studied in order to measure the effects of Tinker Creek water on the distribution relative abundance and species composition of fish in different areas of the reservoir, and to determine what changes have taken place in growth rates and productivity since November, 1966.

Distribution and Abundance

Area 2, near the hard water inflow, yielded both the largest number of fish and the highest total weight of fish (Figs. 6a and 6b). Gill nets were set in area 2 from March to July catching an average of 23.67 fish and 13.90 lbs. per gill net. Area 3 was next with an average of 22.3 fish and 11.02 lbs per gill net. Using gill nets, area 1 was by far the least productive of the three areas in the reservoir, yielding only 13.2 fish and 7.80 lbs. per gill net.

The species composition of fish collected by gill netting was seen to vary between sampling areas. Area 2, near the Tinker Creek inflow, yielded a considerably higher percentage of gizzard shad and white suckers. The white sucker and gizzard shad have similar feeding habits. Both species subsist primarily on aquatic organisms and plant material found in the bottom ooze (McClane 1965). The high concentration of bottom organisms found in area 2 (Fig. 5) may partly explain the greater abundance of white suckers and gizzard shad in this area.

Age and Growth of the White Sucker

An age and growth study was conducted to determine what effects the Tinker Creek introduction had upon growth rates of fish in Carvin Cove Reservoir. The white sucker, *Catastomus commersoni*, was chosen for this study primarily because it was present in reasonably large numbers in the reservoir, and the population was represented by a number of older age group fish. The white sucker is not sought by anglers in the reservoir which reduces any influences of angling pressure on calculated growth rates.

By back calculating lengths at earlier ages in the manner described by Tesch (1968), growth increments of suckers from different year classes could be determined for years prior to the introduction of Tinker Creek water in November, 1966. The fish were collected in 1968, so in essence, growth of white suckers during 1967 and 1968 would be compared with calculated growth rates from years prior to November, 1966.

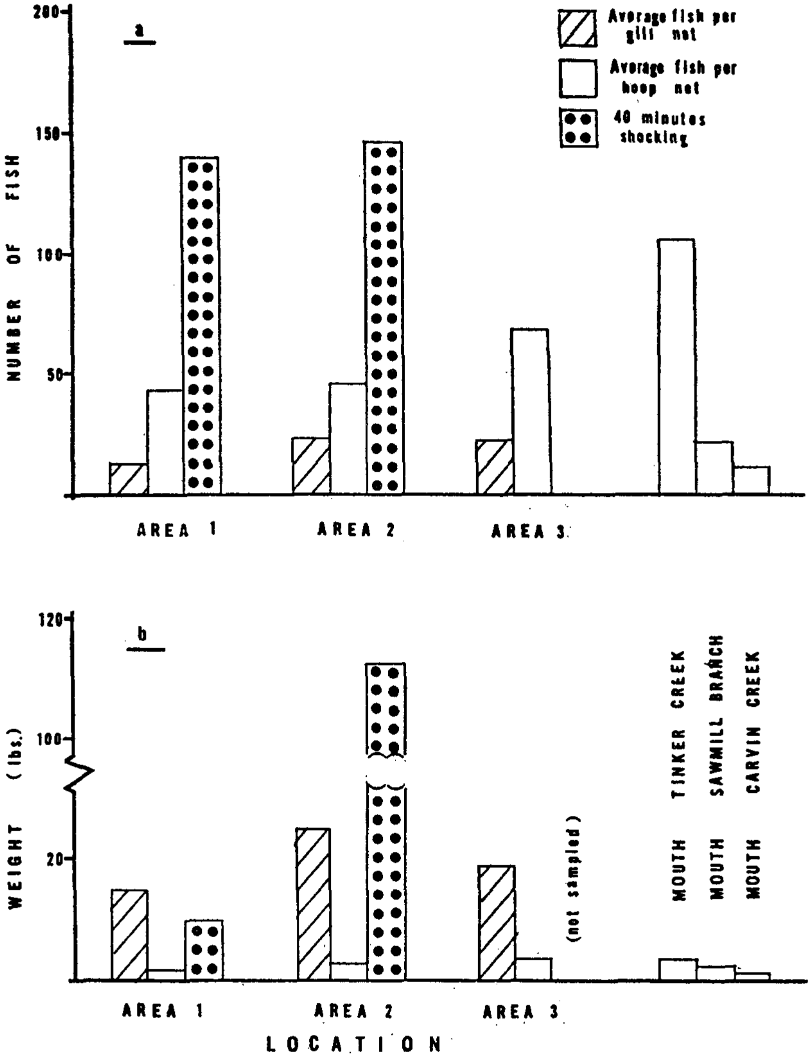

Figure 6. Average number, a, and average weight, b, of fish collected per unit effort at sampling locations at Carvin Cove Reservoir in 1968.

Body-Scale Relationship. The body length-scale length relationship of the white sucker is described by $S = -21.92351 + .53049L$, where $L =$ total length in mm and $S =$ scale length in mm. The regression equation is represented in Fig. 7. The value of the abscissa intercept, + 41.3269, was used for the calculation of length at earlier ages as described by Tesch.

Annulus Formation. White suckers were collected for March, 1968—October, 1968. Some of the fish from March and April collections did not show the winter, 1967–1968 annulus. For these fish, the anterior

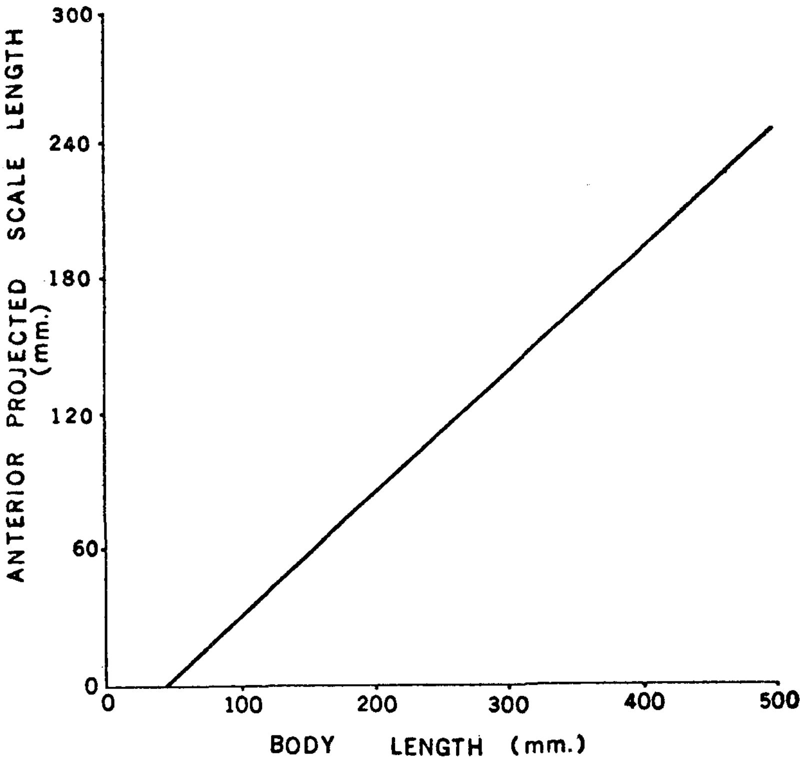

Figure 7. Body length-scale length relationship ($S = -21.92351 + 0.53049L$) for 79 white suckers at Carvin Cove Reservoir in 1968.

margin of the scale was considered to be this annulus. No new annulus had appeared on any of the suckers collected in October or any previous collections. Spoor (1938) found that the growing season for white suckers in Muskellunge Lake, Wisconsin began around the middle of May. In this same study, Spoor also found that white suckers consistently laid down an annulus each year. Raney and Webster (1942) were also able to age suckers by the scale method. Beamish and Harvey (1969) found the scale method of aging white suckers to be valid up to five years.

Most authors agree that annulus formation on scales in older age suckers was somewhat inconsistent. This proved to be the case in the present study as well. Annulus formation in age I to age V suckers was consistent, but scales from older fish often appeared to have one or more annului absent.

Age Composition. Seventy-nine white suckers aged by the scale method were utilized in this study. Forty-six of these were in age groups I—V (Table IV). The remaining 33 suckers belonged to age groups VI, VII and VIII. Average total lengths at time of capture ranged from 109 mm. at age class 0 to 427.5 mm. at age VIII. Raney and Webster (1942) found about the same average lengths at time capture for the same age groups.

Calculated Length and Growth Increments. The average calculated lengths of *Catostomus commersoni* captured during the study period is shown in Table V. Average calculated lengths at annuli that were laid down after the hard water introduction were significantly higher. The average calculated growth increments for white sucker growth in Carvin Cove Reservoir after Tinker Creek was introduced were considerably higher than growth increments attained before the hard water introduction (Fig. 8). Growth increments more than doubled during the growing season following the Tinker Creek introduction in almost all year classes. Fig. 9 demonstrates this increased growth rate in age-groups O, I, II, III and IV. The position of the first annulus in age-class I fish is more distant from the focus of the scale (Fig. 9b). In older age groups, the first annulus was closer to the focus of the scale (Figs. 9c, 9d and 9e). The last year's growth as represented on scales from age class II, III and IV fish also showed a substantial increase in growth rate. The average calculated length of one year old white suckers demonstrates a highly significant change in growth rate between age class I fish (post-hard water introduction growth) and age class II and older fish (first year growth in soft water before the Tinker Creek introduction). The average calculated length after one year's growth in age I fish was 160.3 mm. whereas the average calculated length at the first annulus of older age groups was 85 mm. or less. Two age-class O fish collected in the summer of 1968 averaged 109.0 mm. Raney and Webster (1942) found first year growth in white suckers to be around 61 mm., measuring total lengths. Spoor (1938) found the average calculated length of white suckers at the first annulus to be 72 mm. is standard length. Spoor also found that Lee's phenomenon (Lee 1920), where calculated lengths to earlier ages were smaller in older age fish, was a factor in back calculations of length to earlier age in the white sucker at Muskellunge Lake, Wisconsin. Lee's phonomenon was also seen in back calculated lengths of the white sucker in Carvin Cove Reservoir.

Figure 8 shows a large calculated growth increment between the third and sixth annuli. Raney and Webster (1942) found that much of the growth in the white sucker occurred between the ages of two and four years. Spoor (1938) using standard lengths, found slightly faster growth rates in the white sucker during the first three years of life.

TABLE IV. Age composition and lengths of 79 white suckers from Carvin Cove Reservoir

Age group	Number of fish	Total lengths		
		Minimum	Average	Maximum
O	2	88.0	109.0	130.0
I	14	165.0	271.8	345.0
II	2	255.0	277.5	300.0
III	6	220.0	323.3	375.0
IV	12	240.0	363.8	435.0
V	10	325.0	373.0	405.0
VI	15	370.0	406.3	425.0
VII	14	335.0	418.9	455.0
VIII	4	405.0	427.5	445.0

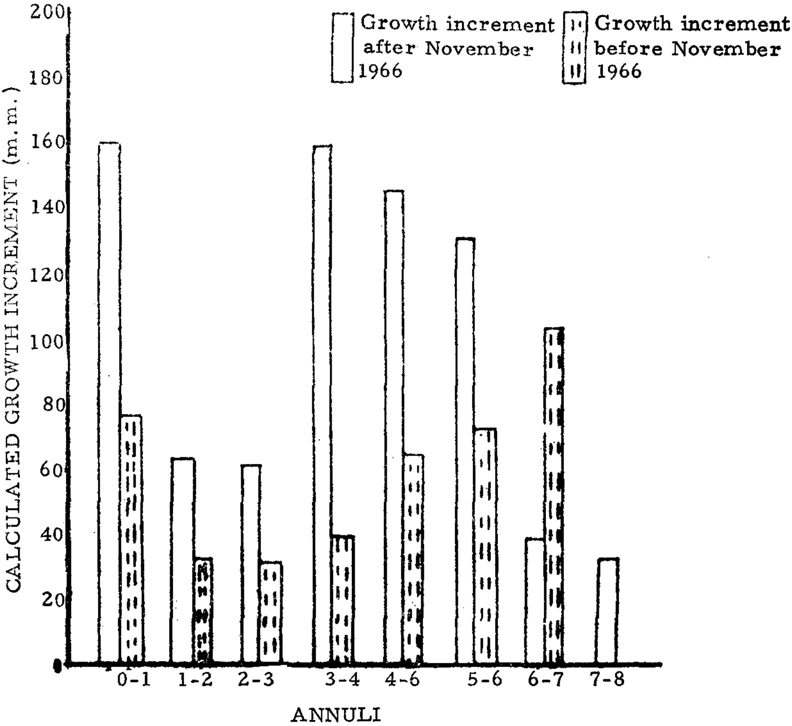

FIG. 8 shows a large observed growth increment between the third and sixth annuli. Raney and Webster (1942) found that much of the growth in the white sucker occurred between the ages of two and four years. Spoor (1938) using standard lengths, found slightly faster growth rates in the white sucker during the first three years of life

SUMMARY AND CONCLUSIONS

1. The introduction of Tinker Creek water in November, 1966 changed Carvin Cove Reservoir from a soft water lake to a medium-hard water lake by the end of 1968.

2. Tinker Creek was found to be extremely high in dissolved nutrients, resulting in much higher pH, alkalinity and hardness values than were found in the other major streams entering the reservoir.

3. Water quality in different areas of the lake in 1968 was changed somewhat as a result of the hard water flowing into the reservoir from Tinker Creek. Dissolved nutrients were denied access to the hypolimnion during the summer months, and pH, alkalinity and hardness were generally higher in the area near the Tinker Creek inflow.

4. Bottom fauna was found in higher concentrations in the area of the reservoir close to the hard water inflow.

5. High concentrations of fish were found in the vicinity of the Tinker Creek inflow. Gizzard shad and white suckers seemed to be more abundant in this area.

6. Growth rates in the white sucker increased significantly after Tinker Creek water was added.

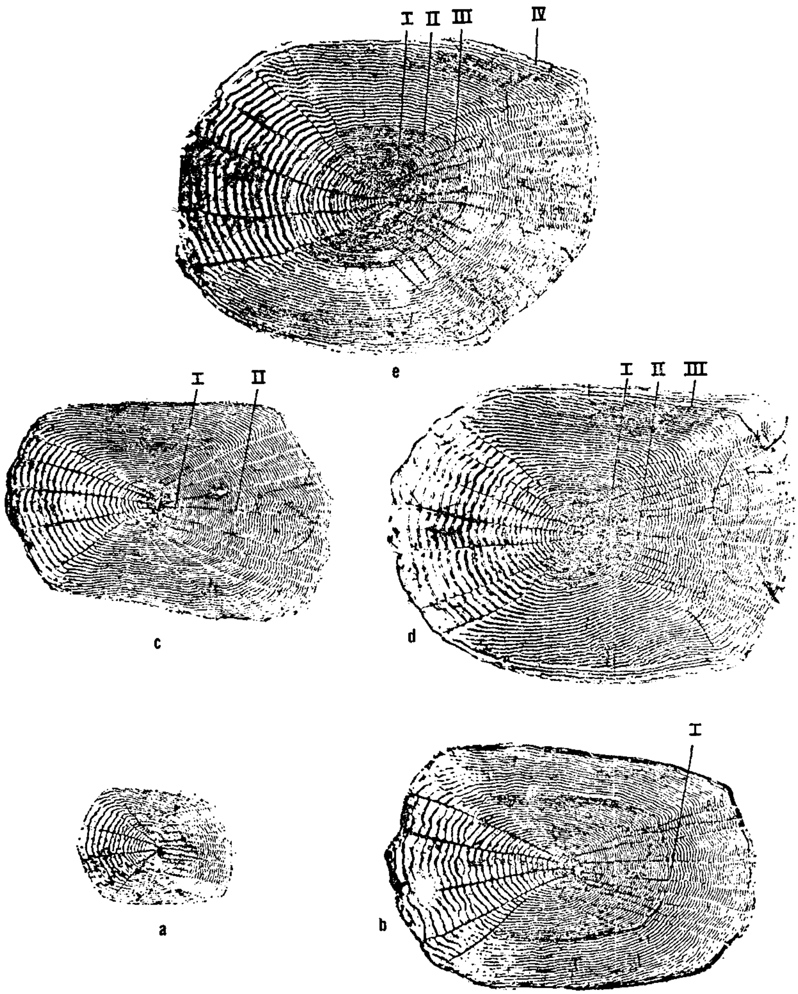

Figure 9. Scales from white suckers of 0-group, a, showing no annulus; I-group, b, showing one annulus; II-group, c, showing two annuli; III-group, d, showing three annuli; IV-group, e, showing four annuli. Enlargement is not the same for all specimens, but the relative size of growth increments is easily seen.

TABLE V. Average total length calculated for 79 white suckers from Carvin Cove Reservoir in 1968

Age class	Number of fish	Average length at capture (mm)	Average calculated standard length at each annulus							
			1	2	3	4	5	6	7	8
O	2	(109.0)								
I	14	271.8	(160.3)*							
II	2	277.5	79.2	(142.2)						
III	6	323.3	85.0	126.1	(187.6)					
IV	12	363.8	84.0	127.3	166.8	(326.5)				
V	10	373.0	76.6	108.9	144.8	192.1	(337.2)			
VI	15	406.3	73.7	101.3	138.1	184.7	252.8	(383.7)		
VII	14	418.9	79.2	99.6	139.9	202.1	281.6	367.4	(406.8)	
VIII	4	427.5	67.0	91.6	137.6	184.8	233.0	291.0	394.4	(427.5)
Average			87.0	113.8	152.5	218.0	251.2	347.4	400.6	427.5
Total	79									

* Numbers enclosed in parentheses represent calculated length attained from growth after the Tinker Creek introduction.

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