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RELATIONSHIP OF CERTAIN ENVIRONMENTAL FACTORS TO BENTHIC FISH DENSITIES IN BEAR LAKE, IDAHO-UTAH

by

Thomas J. Hassler

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Fishery Biology

Approved:

UTAH STATE UNIVERSITY
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TABLE OF CONTENTS

Page

Introduction 1

Review of literature 2

Bear Lake 6

Materials and methods 7

Selection of sampling stations 7
Sampling procedure 7
Water temperatures 8
Specific conductance 8
Zooplankton densities 8
Fish densities 9
Statistical analysis 10

Results 11

Water temperatures 11
Specific conductance 13
Zooplankton densities 15
Fish densities 18

Relationships 20

General aspects 20
Fish density as determined by bottom set experimental gill nets 20

Fish density and conductivity 20
Fish density and temperature 20
Fish density and depth 21
Fish density and zooplankton density 21

Fish density as determined by bottom set Japanese gill nets . 21

Fish density and conductivity 21
Fish density and temperature 23
Fish density and depth 25
Fish density and zooplankton density 25

Summary and conclusions 34

Literature cited 36

LIST OF TABLES

Table		Page
1.	Thermal conditions in Bear Lake at station 5	12
2.	Conductivity changes in relation to thermal stratification	14
3.	Benthic zooplankton density at each station	16
4.	Fish captured and percentage of total capture, by species, in experimental gill nets and in Japanese gill nets	19
5.	Analysis of variance of benthic fish densities determined by experimental gill nets, and mean bottom conductivities	29
6.	Analysis of variance of benthic fish densities determined by experimental gill nets, and mean bottom temperatures	29
7.	Analysis of variance of benthic fish densities determined by experimental gill nets, and depths	30
8.	Analysis of variance of benthic fish densities determined by experimental gill nets, and mean benthic zooplankton densities	30
9.	Analysis of variance of benthic fish densities determined by Japanese gill nets, and mean bottom conductivities	31
10.	Analysis of variance of benthic fish densities determined by Japanese gill nets, and mean bottom temperatures	31
11.	Analysis of variance of benthic fish densities determined by Japanese gill nets, and depths	32
12.	Analysis of variance of benthic fish densities determined by Japanese gill nets, and mean benthic zooplankton densities	33

LIST OF FIGURES

Figure		Page
1.	Fish density-depth relationship. Fish captured in experimental gill nets	22
2.	Fish density-temperature relationship. Fish captured in Japanese gill nets	24
3.	Fish density-depth relationship. Fish captured in Japanese gill nets	26
4.	Fish density-zooplankton density relationship. Fish captured in Japanese gill nets	27

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Thomas J. Hassler

INTRODUCTION

The project was initiated in June of 1958 and financed by the National Science Foundation and the Wildlife Management Department of Utah State University.

The broad aspects of the study were to determine if a relationship exists between certain physical and biological factors and benthic fish densities. The project was divided into two parts: (1) to determine the time and extent of thermal stratification, zooplankton densities, conductivity changes within the lake and conductivity differences between the lake and its tributaries; (2) to determine if a relationship exists between benthic fish densities, temperatures, depths, conductivities and benthic zooplankton densities. The data were analyzed statistically and a separate regression analysis was run on each factor to determine the degree of relationship between that factor and benthic fish densities.

It is believed that the present research program will contribute to the basic knowledge of benthic fish populations in Oligotrophic lakes.

REVIEW OF LITERATURE

The thermal properties of water exert great influences on all types of aquatic life. Welch (1952) states that the thermal conditions in a lake have such a profound influence on the biology of a lake that it should be the basis for any study involving limnology and aquatic biology.

The first attempt to demonstrate the thermal properties of lakes was by De Saussure in 1779, when he noted that low temperatures prevailed at the bottom of many deep Swiss lakes. According to Hutchinson (1957), the first series of vertical temperature determinations were made in 1812-1814 by Jardine and that the first published contributions demonstrating thermal stratification were those of De la Beche in 1819-1820. Since that time, the concept of thermal stratification has become well established.

Conductivity of lake water is a measurement of the total electrolytes present in lake water. Several workers have studied lake conductivities (Juday and Birge, 1933; Edmondson, 1956), but only in relation to the conductivity differences between lakes and within lakes. They did not try to relate conductivity changes to fish densities. The conductivity of natural waters may be an indication of the biological productivity of a body of water.

Zooplankton densities occurring in lakes at any moment are highly variable and greatly dependent on other factors. Pennak (1942) states that the expected periodicity of a species of zooplankton present in a lake is often greatly modified, exaggerated or even eliminated by the

combined effects of the physical, chemical and biological conditions operating at a particular time in the body of water. Rawson (1953) found that seasonal fluctuation in zooplankton density is perhaps the greatest obstacle in measurement and interpretation of the plankton crop. Zooplankton densities not only change with the season but also with depth and the type of lake being sampled. Langford (1953) found zooplankton densities differ at different depths and Rawson (1953) found that zooplankton densities decreased as the depth sampled increased. Raymond (1936) found lakes whose bottoms contain a large amount of marl, have a scarcity of free carbon dioxide and possess few rooted aquatic plants, tend to have low zooplankton densities. Pennak (1946) found that large size, regular shape, and great depth in lakes are all factors which tend to discourage the development of large zooplankton populations.

Kemmerer, Bovard and Boorman (1923), in their studies on Bear Lake, found two copepods, Epischura, found at all depths, and Canthocamptus, found only in the 50-55 M. stratum. The rotifer, Polyarthra, was found in limited numbers in the 5-15 M. stratum. Perry (1943), in his study on Bear Lake, listed 12 genera of zooplankton, Epischura and Conochilus being the dominant forms collected. Epischura was present at all depths in the lake and was present during all seasons of the year. Conochilus was found at varying depths from the surface to 125 feet. McConnell, Clark and Sigler (1957) also found Epischura and Conochilus to be the dominant forms of zooplankton present in Bear Lake.

Temperature and depth in relation to fish distribution have been studied for some time, and certain relationships have been noted. Cady (1945), in his studies on Norris Reservoir, found depth to be an important factor in determining fish distribution. However, there is

some question as to just what effect depth has on fish distribution. Rawson (1952) suggests that depth has an indirect effect on fish distribution because of the depth-temperature relationship, and that extreme depth may actually tend to limit fish distribution to the shallower portions of deep lakes. Dency (1946), in his studies on Norris Reservoir, found temperature exerts the most significant influence on fish distribution. Further studies by Dendy (1945) suggest that a close relationship exists between temperature and the distribution of the middle 50 percent of the fish captured by gill nets in Norris Reservoir for an eight-month period in 1943.

Under laboratory conditions, fish show definite temperature preferences. Several investigators have noted that when fish are introduced into artificial tanks with a large temperature gradient, the fish chose a certain temperature zone to occupy (Doudoroff, 1938; Gibson and Fry, 1954; Pitt, Garside and Hepburn, 1956; Garside and Tait, 1958).

Fish distribution patterns due to temperature tend to change from time to time, not because the temperature changes but because the selective preference of the fish changes. Sullivan and Fisher (1953), in their work with brook trout, Salvelinus fontinalis (Mitchill), under laboratory conditions, found that brook trout tend to occupy a certain temperature zone, but their temperature preference changes with the time of year. Hackey (1952) found that the temperature selected by an organism, while characteristic of it to a degree, is capable of considerable modification as the physiological state of the organism changes.

Temperature may further influence fish densities by its effect on the reproductive success of certain species of fish. Very favorable

temperatures during the breeding season and the period immediately following the breeding season increase the reproductive success and consequently raise population levels. Doan (1942) found that increases in the average temperatures during the spawning season of the blue pike, Stigostedion vitreum glaicum (Mitchill) was followed by increased catches of this species in the Ohio waters of Lake Erie, two years later.

The type of food taken and the feeding habits of fish greatly influence their densities. Perry (1943) found evidence indicating a correlation between the plankton of Bear Lake and peaknose cisco, Leucichthys gemmifer (Snyder) densities. Smith and Swingle (1938) found a direct relationship between the average production of plankton and the production of blue gill bream, Heliperca machrochira (Rafinesque) in experimental ponds. Hourston (1959) in his work with juvenile herring in Barkley Sound, found that habitats frequented by juvenile herring contained lower concentrations of the smaller zooplankton on which these fish feed than most other localities in the Sound. This difference in the abundance of the food supply could result from predation by the herring.

BEAR LAKE

Bear Lake is a large Oligotrophic lake, lying half in southeast Idaho and half in northeast Utah. The maximum lake elevation is 5,923 feet above sea level. The lake is almost rectangular in surface outline; 20 miles long and 4 to 8 miles wide. When full, the lake has a surface area of about 110 square miles and a 48-mile shore line. The lake is deepest along the east side and more than half the lake is deeper than 100 feet.

At present, the lake is used as a storage reservoir. Excess water from the flow of Bear River is diverted into Bear Lake and later returned to Bear River by pumping from the lake. It is physically possible to lower the lake 21 feet by pumping from the maximum surface elevation of 5,923 feet. The change in water level in any one year is usually only 3 to 4 feet according to McConnell, Clark and Sigler (1957).

In the late summer the surface temperature is about 70° F. This extends down about 30 to 50 feet and the water below 150 feet rarely exceeds 42° F. A thermocline forms in early June and persists until November. During the summer the epilimnion increases in thickness, reaching a depth of 70 to 80 feet just before the fall overturn.

MATERIALS AND METHODS

Selection of sampling stations

Eight permanent sampling stations were established at five depths on the lake. These depths were 15, 50, 100, 125, and 150 feet. The depths selected were weighted by area and depth. The number of stations located at the 50-, 100-, 125-, and 150-foot depths were selected according to the percentage of the total lake area having that depth. The stations located at the 15-foot depth were not selected according to the percentage of the total lake area occupied by that depth, but because of their proximity to shore. The stations were located on a straight line, transecting the depth contours, between Lakota Resort on the west side of the lake and North Eden Canyon on the east side. The stations were numbered 1 through 8 and followed that sequence across the lake, station 1 being located on the west side of the lake and station 8 on the east side. Anchored float cans served as station markers.

Station locations according to depth were:

Station	Depth in feet
1	15
2	50
3	100
4	125
5	150
6	100
7	50
8	15

Sampling procedure

Weekly samples were taken at each station during November and December of 1958 and during April through October of 1959. Samples were

not taken during January through March of 1959 because of adverse weather conditions and partial ice cover of the lake.

Water temperatures

Temperature profiles were taken at stations 2, 5 and 6 weekly with a Thermarine Recorder (bathythermograph). Bottom temperatures at the remaining 5 stations were taken weekly with a pocket thermometer. A Kemmerer water bottle was lowered to the bottom and filled with water. The water bottle was immediately brought to the surface and the water temperature was taken with the pocket thermometer. Temperature measurements taken with the pocket thermometer were adjusted to coincide with temperatures taken by the bathythermograph. All temperatures are expressed in degrees Fahrenheit (F.).

Specific conductance

Conductivity measurements were taken *in situ* with a portable Solu Bridge having a cell constant of 2.0 and a reference temperature of 18° C. The unit of measurement was micromho/centimeter cubed. Bottom conductivity measurements were taken weekly at all stations and conductivity profiles were taken monthly from June through October at station 5. Conductivity measurements of the major tributaries were also taken monthly from April through October.

Zooplankton densities

Benthic zooplankton densities were sampled weekly at each station with a Clark-Bumpus plankton sampler. This is the most satisfactory closing-net type of quantitative plankton sampler yet produced (Welch, 1948). However, this type of instrument must be properly calibrated

before quantitative zooplankton estimates are made. Calibration determined that 7 liters of water were filtered per revolution of the propeller. The propeller-counter mechanism registered the number of revolutions of the propeller for each 5-minute haul and the number of revolutions multiplied by 7 equaled the amount of water sampled, in liters, for that particular haul. A detailed description of this instrument is presented in Limnological Methods (Welch, 1948). Five-minute zooplankton hauls were made weekly at each station. The zooplankton were preserved in .01 percent formalin. At the laboratory, the volume of zooplankton obtained at each station was determined by the use of a graduated centrifuge tube. Benthic zooplankton densities are expressed in milliliters (ml.) of zooplankton captured per 1,000 liters (L.) of water sampled.

Fish densities

Benthic fish densities were estimated with two types of bottom set nylon gill nets. Experimental gill nets were used to estimate the densities of fish larger than 7 inches, and Japanese gill nets were used to estimate the densities of fish smaller than 7 inches. Fish densities are expressed in numbers of fish caught per 100-foot gill net hour. The experimental gill nets were 125 feet long, 5 feet deep and composed of five 25-foot panels, each panel of a different size mesh. The mesh sizes by bar measure were three-fourths, 1, $1\frac{1}{4}$, $1\frac{1}{2}$ and 2 inches. The Japanese gill nets were 100 feet long by 6 feet deep. The entire net was three-eighths inch bar measure mesh. One net was set at each station, for an overnight period, averageing 15 hours, for the duration of the study. The type of net set and direction of set at a particular station was chosen on a random basis.

Since gill nets were used to estimate benthic fish densities, a certain amount of error was present in the estimated fish density. The degree of movement of a species largely determines its rate of capture by gill nets and since some species are more active than others, their rate of capture is greater. As an example, the sculpin, Cottis species (undescribed), which is one of the most abundant benthic fish in Bear Lake (McConnell, Clark and Sigler, 1957), was seldom caught in gill nets. Also, because of the high rate of capture of lake trout, Salvelinus namaycush (Walbaum) in the Japanese nets, it is believed that further bias was introduced into the estimate of benthic fish density. It was assumed that this high rate of capture of lake trout can be attributed to the baiting effect that the Japanese nets have on lake trout. Small fish, already caught in the net, served as bait for lake trout.

Statistical analysis

Bottom fish densities, conductivities, temperatures and zooplankton densities were sampled weekly at 8 sampling stations for 9 months. The data were analyzed using the curvilinear regression analysis described by Snedecor (1946) and the non-linear regression analysis described by Goulden (1956) to determine the relationships between benthic fish densities, depths, bottom conductivities, bottom temperatures and benthic zooplankton densities. The results obtained from the analysis of variance were estimated at the 95 and 99 percent levels of confidence. Benthic fish densities as estimated by experimental gill nets and their probable relationships with other factors were analyzed separately from benthic fish densities, as estimated by Japanese gill nets and their probable relationships with other factors.

RESULTS

Water temperatures

When field work began on November 1, 1958, the surface temperature of the lake was 52° F. A thermocline was evident extending from 90 to 92 feet in depth. By November 29, the thermocline had disappeared and the lake surface cooled to 42° F. The lake continued to cool until January 18, 1959. At that time, the lake was isothermous at 35° F. The lake remained isothermous at 35° F. during February and March (Table 1). On April 21, the lake was isothermous at 40° F.; from then on the entire lake continued to warm. The maximum surface temperature recorded during 1959 was 72° F. on August 4.

In 1959, a thermocline formed in early June and was still present when the project terminated October 21 (Table 1). On June 2, the thermocline extended from 1 to 10 feet in depth with a drop in temperature of 7° F. During the remainder of June and the first week in July, the upper limit of the thermocline was depressed to a depth of 33 feet (Table 1). However, a rise in temperature of 6° F. in the first 20 feet of the epilimnion from July 7 to July 21 caused the upper limit of the thermocline to rise to a depth of 20 feet (Table 1). During the remainder of July, August, September and October, the thermocline was continually depressed. On October 21, the thermocline extended from 70 to 80 feet in depth with a drop in temperature of 6° F. The maximum fluctuation of bottom temperature at station 5 during the project was from 35° F. to 43° F. (Table 1).

Table 1. Thermal conditions in Bear Lake at station 5

Date	Temperature (F.) Surface	Temperature (F.) Bottom	Epilimnion Thickness (ft.)	Epilimnion Fall in temperature (F.)	Thermocline Limits (ft.)	Thermocline Upper limit (F.)	Thermocline Lower limit (F.)	Hypolimnion Thickness (ft.)	Hypolimnion Fall in temperature (F.)
11-8-58	50	40	90	2	90-92	48	46	58	6
11-29-58	42	42			No stratification				
12-20-58	40	40			"	"			
1-18-59	35	35							
2-6-59	35	35							
3-7-59	35	35							
4-3-59	39	39							
4-21-59	40	40							
5-5-59	43	42							
5-19-59	48	42							
6-2-59	57	42	1	0	1-10	57	50	140	8
6-30-59	61	42	32	1	32-60	60	48	90	6
7-7-59	64	42	33	2	33-50	62	50	100	8
7-21-59	70	42	20	2	20-40	68	52	110	10
8-4-59	72	42	22	1	22-43	71	52	107	10
8-18-59	70	42	28	0	28-50	70	50	100	8
9-2-59	65	42	40	0	40-60	65	49	90	7
9-23-59	62	42	50	0	50-72	62	47	78	5
10-6-59	56	42.5	60	1	50-90	55	45	60	2.5
10-21-59	53	43	70	1	70-80	52	46	70	3

Specific conductance

Bottom conductivity measurements were taken in situ weekly at each station for the duration of the study. Changes in bottom conductivity from week to week at each station were slight.

The maximum conductivity recorded during the study was 760 micromhos/cm. and the minimum was 600 micromhos/cm. The maximum average conductivity difference between any two stations during the study was 26 micromhos/cm. The average conductivity at the two stations located at the 15-foot depth, stations 1 and 8, was the lowest recorded. The average conductivity at station 1 was 655 micromhos/cm. and at station eight, 658 micromhos/cm. The average variation in conductivity at the remaining stations was between 668 and 675 micromhos/cm.

Conductivity profiles were taken monthly after the lake had stratified to determine the effect thermal stratification had on conductivity. All profiles were taken at station 5. Variations in conductivity between the surface and bottom were slight (Table 2), and it was felt that thermal stratification had no great effect on conductivity.

Conductivity differences between the lake and its major tributaries were measured in situ, to show the extent of the effect that the tributary had on the lake. Conductivity measurements were taken in the tributaries and the flow of the tributary water was followed into the lake by conductivity measurements until it became too dilute to distinguish it from lake water. Swan Creek, Fish Haven Creek, Saint Charles Creek and the inlet canal at the pumping station were the tributaries sampled. The average conductivity from April to October in Swan Creek, Fish Haven Creek, and Saint Charles Creek was 257, 307 and 350 micromhos/cm. respectively. It was only possible to follow the stream water into the lake, by

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Table 2. Conductivity changes in relation to thermal stratification on Bear Lake from June through October of 1959 at station 5

Month	Conductivity (in micromhos/cm.)				
	Surface	Above thermocline	In thermocline	Below thermocline	Bottom
June	640	640	660	660	650
July	640	640	640	640	640
August	610	650	650	650	645
September	620	620	630	630	640
October	630	630	630	630	630

conductivity measurements, about 100 yards. On May 11, the water entering Bear Lake through the pumping station had a conductivity of 525 micromhos/cm. Due to the relatively larger volume of water entering the lake through the pumping station, it was possible to follow its flow, with conductivity measurements, into the lake about one-half mile.

It seems very unlikely that the tributaries would bring about any major conductivity changes in the lake. The conductivities of Swan Creek, Fish Haven Creek and Saint Charles Creek are considerably lower than that in the lake, and over a period of years these streams may decrease the conductivity of the lake water in the general area of their entrance into the lake. The water entering the lake through the pumping station has about the same conductivity as does the lake water and would cause only slight conductivity changes, where it enters the lake.

Zooplankton densities

Benthic zooplankton densities were estimated weekly at each station for the duration of the study. Zooplankton densities are expressed in ml. of zooplankton per 1,000 L. of water sampled. It was not the purpose of this study to determine the abundance of each species of zooplankton present in each sample, but only to determine the amount of zooplankton present. However, the dominant forms in the collections were noted.

The month in which the maximum and minimum zooplankton density occurred at each station varied between stations (Table 3). The maximum densities occurred in the late summer and early fall while the minimum densities occurred in the winter and spring (Table 3). However,

Table 3. Benthic zooplankton density at each station on Bear Lake during November and December of 1958 and during April through October of 1959

Station	Maximum zooplankton density*	Date collected	Minimum zooplankton density	Date collected
1	1.592	7-14-59	.006	4-9-59
2	2.964	10-21-59	.043	6-23-59
3	2.321	7-28-59	.041	4-28-59
4	1.242	9-30-59	.004	12-6-59
5	2.817	9-2-59	.000	10-12-59
6	1.975	8-18-59	.008	5-5-59
7	2.456	7-28-59	.040	5-26-59
8	2.381	6-24-59	.023	4-3-59

*Zooplankton densities are expressed in ml. of zooplankton per 1,000 L. of water sampled.

the minimum density at station 5 occurred in the fall. The average monthly zooplankton density at each station varied less from month to month between each station than it did from month to month at the same station. Zooplankton densities were highest in the 50- to 100-foot depths and as the depth sampled increased, the zooplankton densities decreased. Light intensity, temperature and available food were probably more favorable for zooplankton production in depths of 50 and 100 feet.

The dominant forms collected during the present study were the Copepod Epischura and the rotifer Conochilus. Epischura and Conochilus were also the dominant forms collected by Perry (1943) and McConnell, Clark, and Sigler (1957) in Bear Lake. Epischura was present in all the samples taken at each station except in the collection made at station 5 on October 12, 1959, when no zooplankton of any type was present. Kemmerer, Bovard, and Boorman (1923) and Perry (1943) also found Epischura to be present at all depths in Bear Lake. Conochilus was present in most samples taken at depths of less than 125 feet. Perry (1943) found Conochilus present at varying depths from the surface to 125 feet.

The amount of zooplankton in Bear Lake is low when compared to that in other large deep lakes (McConnell, Clark, and Sigler, 1957). Bear Lake is a large lake having a very regular shape, a maximum depth of 200 feet, very little if any free carbon dioxide, few rooted aquatic plants, and the bottom below 25 feet is predominately marl. All of the above physical, chemical and biological factors may tend to discourage the development of large zooplankton populations in Bear Lake. Raymond (1936) found lakes whose bottoms contain a large amount of marl, have a scarcity of free carbon dioxide, and possess few rooted aquatic plants

tend to have low zooplankton densities. Pennak (1946) states that large size, regular shape, and great depth in lakes tend to discourage the development of large zooplankton populations.

Fish densities

Benthic fish densities were estimated weekly at each station during the study with two types of bottom set nylon gill nets. A total of 2,367 fish were captured in 5,000 one hundred-foot gill net hours. The rate of capture per 100-foot net hour in Japanese nets was twice that in experimental nets. There were 1,178 fish captured in 1,694 one hundred-foot Japanese gill net hours and 1,189 fish captured in 3,306 one hundred-foot experimental gill net hours.

Twelve different species of fish were captured: cutthroat trout Salmo clarki (Richardson), peaknose cisco Coregonus gemmifer (Snyder), Bonneville whitefish Prosopium spilonotus (Snyder), Bear Lake whitefish Prosopium abyssicola (Snyder), Utah sucker Catostomus ardens (Jordan and Gilbert), Utah chub Gila atraria (Girard), sculpin Cottus species (undescribed), rainbow trout Salmo gairdneri (Gibbons), lake trout Salvelinus namaycush (Walbaum), carp Cyprinus carpio (Linnaeus), yellow perch Perca flavenscens (Mitchell), speckled dace Rhinichthys osculus (Girard).

The peaknose cisco was the most abundant fish captured. It represented 38.2 percent of the total catch. The Utah sucker, the second most abundant fish, represented 23.3 percent of the total catch. Of the total fish captured in the Japanese nets, the peaknose cisco represented 60.3 percent. In the experimental net catches it represented only 16.1 percent of the total catch. The Utah sucker represented 47.9 percent

of the total catch in the experimental nets, but it represented only 20.5 percent of the total catch in the Japanese nets.

Table 4. Fish captured and percentage of total capture, by species, in the experimental gill nets and in the Japanese gill nets in Bear Lake during November and December of 1958 and during April through October of 1959

Species	Total captured in J.G.N.[a]	Percentage of total capture	Total captured in E.G.N.[b]	Percentage of total capture	Total captured
Cutthroat trout	4	25	12	75	16
Peaknose cisco	713	79	192	21	905
White fishes	302	61	193	39	495
Utah sucker	17	3	533	97	550
Utah chub	50	2	192	98	242
Sculpin	30	91	3	9	33
Rainbow trout	3	23	10	77	13
Lake trout	49	73	18	27	67
Carp	6	25	18	75	24
Perch	3	14	18	86	21
Dace	1	100	0	0	1

[a]Japanese gill nets

[b]Experimental gill nets

RELATIONSHIPS

General aspects

The data were analyzed using the regression analysis. Benthic fish densities, estimated by experimental gill nets, and their relationship to physical and biological factors were analyzed separately from benthic fish densities, estimated by Japanese gill nets, and their relationship to physical and biological factors.

Bottom conductivities, bottom temperatures and benthic zooplankton densities were each divided into four groups and the group means were determined. Thus, the actual analysis was between benthic fish densities and the four mean bottom conductivities, the four mean bottom temperatures and the four mean benthic zooplankton densities. Due to the similarity of bottom temperatures, bottom types and fish densities at the 125- and 150-foot depths, the data were combined. Therefore, the analysis was between benthic fish densities and depths of 15, 50, 100 and 150 feet. Fish density was the dependent variable in all cases.

Fish density as determined by bottom set experimental gill nets

Fish density and conductivity.--In the analysis of variance there was no significant relationship between benthic fish densities and mean bottom conductivities (Table 5).

Fish density and temperature.--In the analysis of variance there was no significant relationship between benthic fish densities and mean bottom temperatures (Table 6).

Fish density and depth.--In this analysis of variance, there was a linear relationship between benthic fish densities and depths, significant at the 99 percent level of confidence (Table 7). Differences between computed and empirical fish densities were slight. Fish density was highest at the 15-foot depth and as the depth increased, fish density decreased (Figure 1). McConnell, Clark and Sigler (1957), in their work on Bear Lake, found depth to be an important factor governing fish distribution in the lake. Cady (1945) found depth to be an important factor in determining fish distribution in Norris Reservoir. Rawson (1952) indicates depth has an indirect effect on fish distribution due to the depth-temperature relationship. However, in this case, depth was the primary factor determining fish density because temperature had no effect on fish density (Table 6). Rawson further states that depth may tend to limit fish distribution to the shallower portions of deep lakes. This seems to apply here because fish density was highest in the shallow depths and decreased with depth (Figure 1).

Fish density and zooplankton density.--There was no significant relationship between benthic fish densities and mean benthic zooplankton densities indicated by the analysis of variance (Table 8). This is to be expected because only 16.1 percent of the total fish captured in experimental nets was peaknose cisco which is the predominant zooplankton feeding fish in Bear Lake (McConnel, Clark and Sigler, 1957).

Fish density as determined by bottom set Japanese gill nets

Fish density and conductivity.--In the analysis of variance there was no significant relationship between benthic fish densities and mean bottom conductivities (Table 9). It appears that bottom conductivity changes within the lake had no direct effect on benthic fish densities.

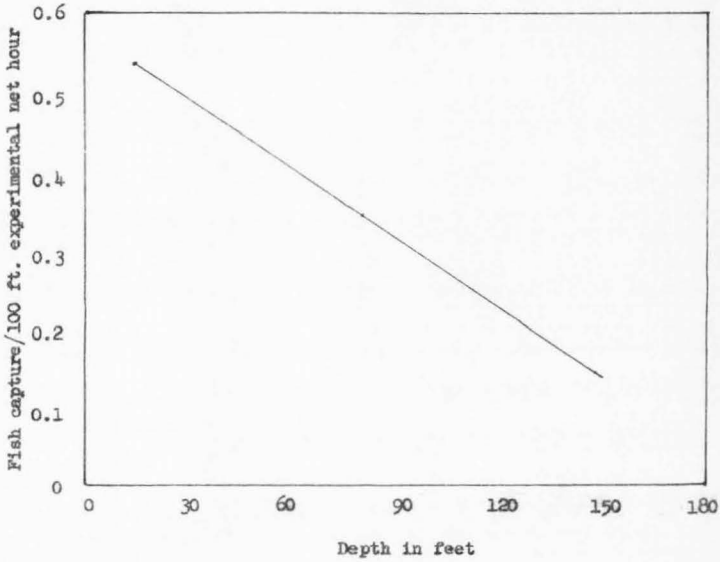

Figure 1. Fish density-depth relationship. Fish captured in bottom set experimental gill nets on Bear Lake during November and December of 1958 and during June through October of 1959. $Y = .5812-.00286X$

In both analyses of variance there was no relationship between benthic fish densities and mean bottom conductivities (Tables 5 and 9). Conductivity may have an indirect effect on fish densities, operating through the biological productivity of natural waters. Conductivity is a measurement of the total electrolyte content of a body of water and the richer a body of water is in electrolytes, other factors being equal, the greater the productivity (Welch, 1952).

Fish density and temperature.--In the analysis of variance there was a quadratic relationship between benthic fish densities and mean bottom temperatures, significant at the 99 percent level of confidence (Table 10). Differences between computed and empirical fish densities were slight. Fish density was low in the 41.4° F. water and as the water temperature increased, up to 54.7° F., fish density also increased, but as the water temperature further increased, fish density decreased (Figure 2). Dendy (1945, 1946) and Rawson (1952) state that temperature has a great effect in determining fish distribution.

The difference in the relationship between benthic fish density and temperature (no relationship between fish density estimated by experimental nets and temperature, and a quadratic relationship between fish density estimated by Japanese nets and temperature) may be due to differences in age and specie composition of the fish captured in the two types of nets. Many of the fish caught in the Japanese nets were young fish while most of the fish captured in the experimental nets were older fish. The younger fish may select temperatures quite different from the temperatures selected by older fish. Hackey (1952) points out that the temperatures selected by an organism may change as the physiological state of the organism changes. The peaknose cisco which is known to be

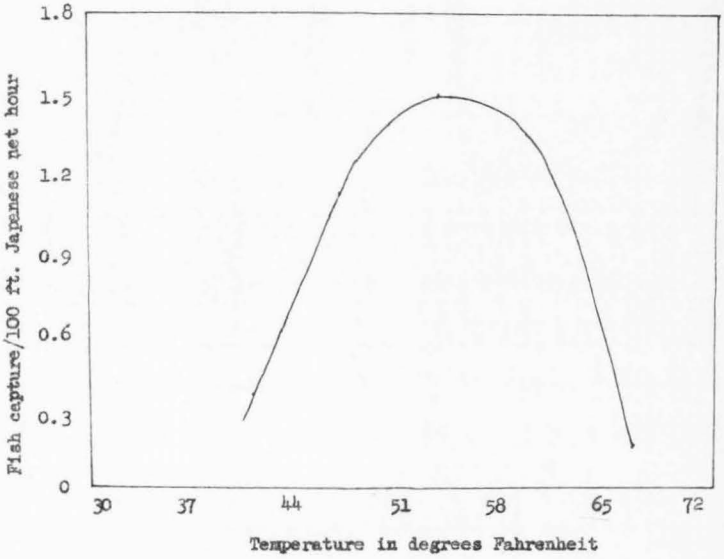

Figure 2. Fish density-temperature relationship. Fish captured in bottom set Japanese gill nets on Bear Lake during November and December of 1958 and during June through October of 1959. $Y = -21.411305 + .856046X - .008002X^2$

influenced by temperature (Perry, 1943) accounted for 60.5 percent of the total catch in Japanese nets and only 16.1 percent of the total catch in experimental nets. This difference in the number of peaknose cisco captured by the two types of nets may account for the difference in fish density and temperature relationship between the two types of nets. Also, 45 percent of the total fish captured in experimental nets was Utah sucker, which is a bottom feeding fish, and its distribution would be more influenced by available food than by temperature.

Fish density and depth.--In the analysis of variance there was a quadratic relationship between benthic fish densities and depths, significant at the 99 percent level confidence (Table 11). Differences between computed and empirical fish densities were slight. Fish density was low at the 15-foot depth but as depth increased up to 50 feet, fish density also increased. As the depth increased from 50 to 100 feet, fish density remained about the same but as depth increased beyond 100 feet, fish density decreased (Figure 3). The relationship between fish density and depth was not a response to depth alone but was also influenced by zooplankton density. Fish density and zooplankton density were both highest in depths of 50 and 100 feet and in the analysis of the fish density--zooplankton density data, fish density increased as zooplankton density increased (Figure 4). Also, 60.5 percent of the fish captured in Japanese nets was peaknose cisco, which is the predominate zooplankton feeding fish in Bear Lake (McConnell, Clark and Sigler, 1957).

Fish density and zooplankton density.--In the analysis of variance there was a linear relationship between benthic fish densities and mean benthic zooplankton densities, significant at the 99 percent level

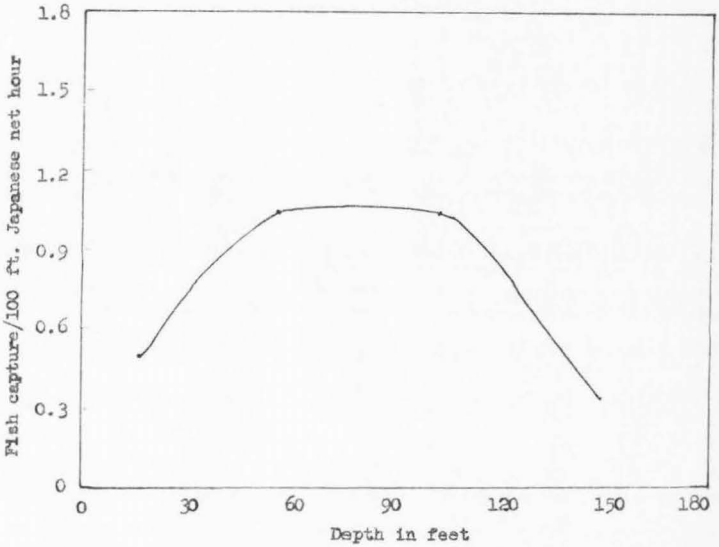

Figure 3. Fish density-depth relationship. Fish captured in bottom set Japanese gill nets on Bear Lake during November and December of 1958 and during June through October of 1959. $Y = .157864 + .024253 - .000153X^2$

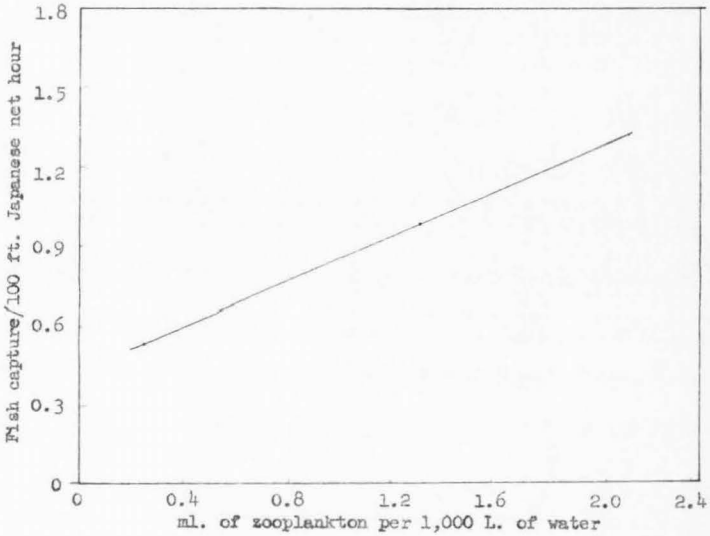

Figure 4. Fish density-zooplankton density relationship. Fish captured in bottom set Japanese gill nets on Bear Lake during November and December of 1958 and during June through October of 1959. $Y = .4697 + .4357X$

of confidence (Table 12). Differences between computed and empirical fish densities were slight. Fish density increased as zooplankton density increased (Figure 4). This is to be expected because 60.5 percent of the total number of fish captured in Japanese nets was peaknose cisco which is the predominate zooplankton feeding fish in Bear Lake (McConnell, Clark and Sigler, 1957). Perry (1943) indicated that there was a correlation between the plankton of Bear Lake and peaknose cisco densities. Smith and Swingle (1938) found a direct relationship between the average production of blue gill bream and the average production of plankton in experimental ponds.

Table 5. Analysis of variance of benthic fish densities expressed in numbers of fish captured per 100-foot experimental net hour and mean bottom conductivities expressed in micromhos/cm.

Source	Degree of freedom	Sum of squares	Mean square	F ratio
Due to regression	3	.2818	.0939	.6230
Error	154	23.2141	.1507	
Total	157	23.4959		

Table 6. Analysis of variance of benthic fish densities expressed in numbers of fish captured per 100-foot experimental net hour and bottom temperatures expressed in degrees Fahrenheit

Source	Degree of freedom	Sum of squares	Mean square	F. ratio
Due to regression	3	.8609	.28697	1.9524
Error	154	22.6350	.14698	
Total	157	23.4959		

Table 7. Analysis of variance of benthic fish densities expressed in numbers of fish captured per 100-foot experimental net hour and depths in feet

Source	Degree of freedom	Sum of squares	Mean square	F ratio
Linear regression	1	3.3821	3.3821	26.0162**
Deviation from linear	2	.0916	.0458	.3523
Error	154	20.0222	.1300	
Total	157	23.4959		

**Significant at the 99 percent level of confidence

Table 8. Analysis of variance of benthic fish densities expressed in numbers of fish captured per 100-foot experimental net hour and mean benthic zooplankton densities expressed in ml. of zooplankton captured per 1,000 L. of water

Source	Degree of freedom	Sum of squares	Mean square	F ratio
Due to regression	3	.1309	.0436	.2874
Error	154	23.3650	.1517	
Total	157	23.4959		

Table 9. Analysis of variance of benthic fish densities expressed in numbers of fish captured per 100-foot Japanese net hour and mean bottom conductivities expressed in micromhos/cm.

Source	Degree of freedom	Sum of squares	Mean square	F ratio
Due to regression	3	1.9934	.6645	.6049
Error	111	122.4147	1.1028	
Total	114	124.4081		

Table 10. Analysis of variance of benthic fish densities expressed in numbers of fish captured per 100-foot Japanese net hour and mean bottom temperatures expressed in degrees Fahrenheit

Source	Degree of freedom	Sum of squares	Mean square	F ratio
Linear regression	1	1.0529	1.0528	1.0628
Excess due to quadratic	1	12.6798	12.6798	12.8001**
Excess due to cubic	1	.7153	.7153	.0722
Error	111	109.9601	.9906	
Total	114	124.4081		

**Significant at the 99 percent level of confidence

Table 11. Analysis of variance of benthic fish densities expressed in numbers of fish captured per 100-foot Japanese net hour and mean depths in feet

Source	Degree of freedom	Sum of squares	Mean square	F ratio
Linear regression	1	.535749	.535749	.0526
Excess due to quadratic	1	10.089779	10.089779	9.9141**
Excess due to cubic	1	.815872	.815872	.0802
Error	111	112.966700	1.017720	
Total	114	124.408100		

**Significant at the 99 percent level of confidence

Table 12. Analysis of variance of benthic fish densities expressed in numbers of fish captured per 100-foot Japanese net hour and mean benthic zooplankton densities expressed in ml. of zooplankton per 1,000 L. of water

Source	Degree of freedom	Sum of squares	Mean square	F ratio
Linear regression	1	7.7456	7.7456	7.4996**
Deviation from linear	2	2.0175	1.0088	.9768
Error	111	114.645	1.0328	
Total	114	124.4081		

**Significant at the 99 percent level of confidence

SUMMARY AND CONCLUSIONS

1. Certain physical and biological factors were sampled weekly in Bear Lake during November and December of 1958 and during April through October of 1959.

2. Temperature profiles were taken weekly throughout the study. The lake showed typical thermal stratification.

3. Bottom conductivity measurements were taken weekly for the duration of the study. Conductivity profiles were taken monthly after the lake had stratified and conductivity differences between the lakes and its major tributaries were noted during April through October of 1959. The maximum bottom conductivity was 760 micromhos/cm. and the minimum was 600 micromhos/cm. Thermal stratification had little effect on conductivity changes within the lake. Tributaries had very little effect on the lake as far as causing any major conductivity changes to occur in the lake.

4. Benthic zooplankton densities were sampled weekly during the study. Maximum densities occurred in the late summer and early fall, while minimum densities occurred in the winter and spring. Zooplankton densities were highest in depths of 50 and 100 feet. The dominant forms collected were the copepod Epischura and the rotifer Conochilus.

5. Benthic fish densities were sampled weekly at each station with two types of bottom set nylon gill nets. A total of 2,367 fish were captured in 5,000 one hundred-foot gill net hours. The rate of capture per 100-foot net hour in Japanese nets was twice that in experimental nets.

6. There were no relationships between benthic fish densities, estimated by bottom set experimental gill nets, and mean bottom conductivities, mean bottom temperatures, and mean benthic zooplankton densities.

7. There was a linear relationship between benthic fish densities, estimated by bottom set experimental gill nets and depths. Fish density was highest at the 15-foot depth and as the depth sampled increased, fish density decreased.

8. There was no relationship between benthic fish densities, estimated by bottom set Japanese gill nets and mean bottom conductivities.

9. There was a quadratic relationship between benthic fish densities, estimated by bottom set Japanese gill nets and mean bottom temperatures. Fish density was low in the 41.4° F. water and as water temperature increased, up to 54.7° F., fish density also increased, but as water temperature further increased, fish density decreased.

10. There was a quadratic relationship between benthic fish densities, estimated by bottom set Japanese gill nets and depths. Fish density was low at the 15-foot depth but as depth increased up to 50 feet, fish density also increased. As the depth increased from 50 to 100 feet, fish density remained about the same but as depth increased beyond 100 feet, fish density decreased. The relationship between fish density and depth was not a response to depth alone but was also influenced by zooplankton density.

11. There was a linear relationship between fish densities, estimated by bottom set Japanese gill nets and mean benthic zooplankton densities. Fish density increased as zooplankton density increased.

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