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An Ecological Study of the Bear Lake Littoral Zone, Utah-Idaho

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AN ECOLOGICAL STUDY OF THE BEAR LAKE LITTORAL ZONE, UTAH-IDAHO

by

Gar W. Workman

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

of

DOCTOR OF PHILOSOPHY

in

Fishery Biology

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Gar W. Workman

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INTRODUCTION

In the past, several projects have been conducted at Bear Lake, Utah-Idaho, by the Utah State University through the Wildlife Resources Department, in conjunction with the Utah and Idaho fish and game departments, the Fish and Wildlife Service, and the National Science Foundation. These projects have dealt primarily with limnology, limnological techniques, fish life histories, fish movements, and bottom fauna in the pelagic and benthic areas of the lake. Subsequently, a littoral zone project was set up to study some of the ecological aspects of the shallow waters of Bear Lake, and some of the influences that this area may have on the entire lake.

The term "littoral zone" is an artificial subdivision set up to describe a particular zone in a lentic or standing water environment. Ruttner (1953) describes this area as "that portion of the shoreward profile inhabited by autotrophic plants." However, because the shoreline of Bear Lake is regular, the wave action and hence the water movement inhibits plant growth. Under conditions of little or no plant growth, therefore, it becomes necessary to set other limitations on the boundaries of this subdivision. This is usually the area of effective light penetration or a depth limitation. Carpenter (1928), in writing of the littoral zone says that this area may have two main aspects at its margin: on the one hand, the open-washed shores of the "erosion-littoral," and on the other, the gently sloping shore of the "quiet-littoral." In Bear Lake the "erosion-littoral" takes on greater significance than in other lakes with more protected shore lines.

The Bear Lake littoral zone research was concerned with the study of the distribution and abundance of the small non-game fish and net-plankton within the littoral zone. In order to evaluate the littoral zone in general, it was necessary to set up sampling stations to determine the influence of the different bottom types present on the fish of the littoral zone. Other environmental factors such as water temperatures, specific electrical conductance, turbidity, hydrogen-ion concentration, oxygen, total hardness, and stream flow were also studied in relation to the littoral zone fauna.

During the fourth year of the study, emphasis was shifted from the dynamics of the littoral zone in general to more specific ecological problems such as nocturnal and diurnal distribution and depth penetration of the small fish of the littoral zone. A study was also made of the influence of rock size and shape on small fish population levels.

Fish movements, harvest, and life history have been studied in Bear Lake in detail. This includes the study of fish movements by Hassler (1960) and Loo (1960); studies on life histories by Perry (1943), McConnell, et al. (1957), and limited unpublished reports by the Utah Fish and Game Department. However, to date, little or no reference has been made to the distribution and abundance of the fish in shallow water.

One of the principal groups of fish foods, that of the bottom fauna, was studied by Smart (1958). Smart points out that the quantity of the macroscopic bottom fauna in Bear Lake is not high, the average number of total organisms for all bottom types being 675 per square meter or 568 per square yard. This bottom type population is dominated by the aquatic Oligochaeta and the Diptera. He also states that the rocky zone and rooted plant zone produce a large variety of bottom fauna organisms and would possibly be the most productive zones on the lake if they constituted a larger portion of the lake area.

Cycles in plankton populations have not been studied in great detail for Bear Lake. Various investigators, however, have checked on plankton dynamics on limited or extended surveys. This list of investigators includes Kemmerer, et al. (1923), Hazzard (1935), Wright, et al. (1941), Perry (1943), Clark (1956), McConnell, et al. (1957), Smart (1958), Hassler (1960) and Clark, et al. (1961).

A summary of the Bear Lake physical and biological characteristics is given by McConnell, et al. (1957), and further information is discussed by Smart (1958) and Hassler (1960).

The subject of Bear Lake description and history will not be discussed in this thesis because it has been described previously in some detail by Williams, et al. (1962), Smart (1958), Beal (1942), McConnell, et al. (1957), and Thomson (1962).

DESCRIPTION OF THE LITTORAL ZONE STATIONS

When the lake is at its maximum level (5923.65 feet above sea level), approximately 10 per cent of the lake shore has some rock areas. At a lake level 15 feet below maximum the amount of rock areas in the water along the shore line drops to less than 5 per cent. At the minimum water level (5902 feet above sea level), only a trace of the rock bottom type is left in the water on the east side of the lake. Actually, if the lake in general is considered and not just the shore areas, the rock zone in the lake at maximum water level is about 0.001 per cent of the total bottom area (Smart 1958).

For the purposes of the littoral zone study, six stations were chosen for observation (Figure 1). These were picked on the basis of habitat types and exposure on the lake. Inasmuch as the lake is long and narrow it was decided that more stations should be located on the long shorelines than on the ends of the lake. Therefore, two stations were located on each side of the lake and one station was located at each end of the lake. Two of these stations represented a sandy bottom type; two stations represented a sand-rock bottom type with some plant areas; and two stations represented a rock bottom type. As the lake level was raised or lowered the station was moved either inward or outward from its original position. During 1961, the lake level was dropped so drastically that the sand-rock stations eventually came under the sand classification, and one of the rock stations came under the sand-rock classification.

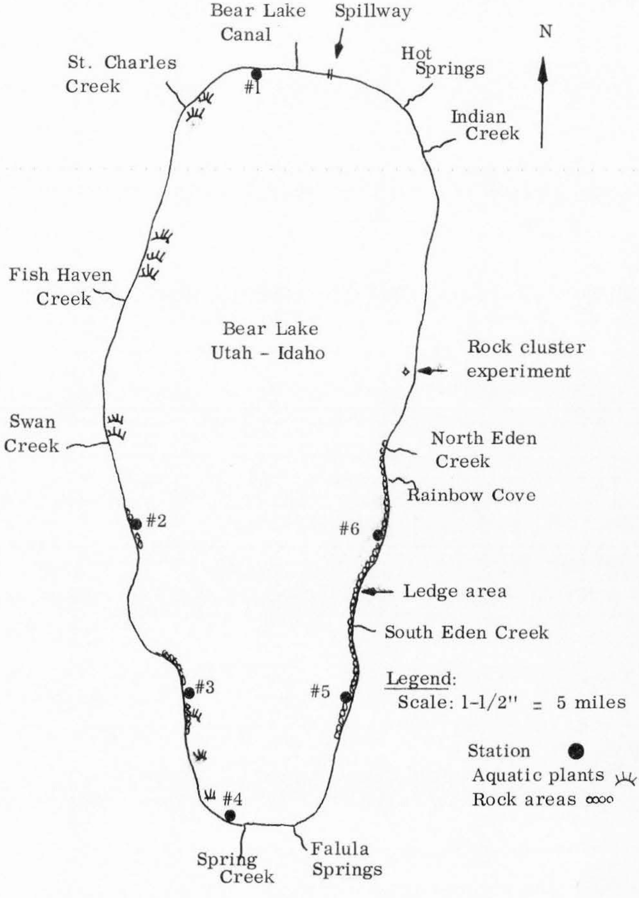

Figure 1. Bear Lake showing the location of sampling stations, rock and aquatic plant areas, inlets and outlet.

The fact that this rocky area is so small in comparison to the sand and marl bottom types of the lake is indeed unfortunate for some of the fauna of Bear Lake. As will be pointed out later in this thesis, the rock area is undoubtedly the most productive area in the lake for many biotic forms.

Station one was located in shallow water at the north end of the lake one mile to the west of the Lifton Pumping Station. The bottom type is sand and the water is very shallow for some distance from shore. The gradient of the bottom here is approximately 1:98.

Station two was located in the shallow water on the west side of the lake near the state boat-launching ramp. The bottom gradient here is 1:13. The bottom type at the beginning of the project was rock and sand with a few plants. However, after the lake level had dropped 10 feet during the summer of 1961, the rocks were out of the water and the bottom type of this station became one of entirely sand.

Station three was located in shallow water just south of the highway cut near Gus Rich's Point on the west side of the lake. The original station had a bottom type of sand and rock with some hard stem bulrush Scirpus acutus areas. When the lake had dropped to a level 10 feet below maximum during the summer, the rocks were out of the water. When the lake reached its lowest level in the fall, all of the plants were eliminated. The bottom gradient is 1:11.

Station four was located in shallow water on the southwest end of the lake. The bottom type is sand with some silt. However, unlike station one on the north end of the lake, more organic debris is present because of winds and water currents, which consequently provides more cover for the fish. The bottom gradient here is about 1:30.

Station five was on the east side of the lake in shallow water, between the first and second points. The bottom type was flat rocks, some of which are covered with a calcium crust. These rocks extend along the bottom to a water depth of about 13 feet from the maximum water level, after which the bottom type makes an abrupt transition to sand. The bottom gradient at this station is approximately 1:29.

Station six was located in shallow water near the boat-launching area to the north of the "Ledges," on the east side of the lake. The bottom type is large mass rock down to about 20 feet in depth from the maximum water level. The bottom gradient is approximately 1:11. There are no aquatic plants in this area.

PHYSICAL AND CHEMICAL FACTORS

In order to understand more completely some of the factors which contribute to the ecological status of the littoral zone, the following physical and chemical factors of the water in this area were studied: temperature, oxygen content, hydrogen-ion concentration, hardness, electrical conductivity, and turbidity. Sampling was conducted on a monthly basis. A limited study on the streams which contribute to the littoral zone was also conducted.

Materials and Methods

Temperature

Surface water temperatures were obtained with a Foxboro potentiometer. Temperature profiles of the deeper water were made utilizing a Wallace Tiernan thermarine recorder or bathythermograph.

Oxygen

Oxygen samples were taken at each station with a three-liter Kemmerer water sampling bottle held horizontally under the surface of the water. The sampler was pushed forward through an undisturbed water area forcing the air bubbles and the original disturbed water column out of the cylinder. The catch was released by hand. The sampler was then lifted from the water and suspended from a vertical holder on the truck. Two samples were collected in 300 ml. BOD bottles and treated according to the unmodified Winkler Method (Welch 1948) as far as the addition of acid. The oxygen determination of the collected sample was made in the laboratory using a Bausch & Lomb Spectronic 20 Colorimeter.

The oxygen saturation values were corrected for altitude as described by Ricker (1934), and the saturation percentages were determined from a nomograph described by Welch (1948) and checked by slide rule. Absolute deficits in p.p.m. (parts per million) can be obtained by subtracting the calculated oxygen concentrations from the saturated oxygen concentrations in Figures 9 through 14.

Oxygen determinations were occasionally conducted using the modified Winkler method (Welch 1948) when the values became too high to read accurately with the colorimeter.

Hydrogen-ion concentration

The hydrogen-ion concentration or pH determinations were made using the colorimeter. The pH is considered to be an indicator of environmental conditions and may be the result of many underlying chemical conditions (Rawson, 1939).

Total hardness

The water hardness was determined by titration using TitraVer (Ethylenediaminetetraacetate - EDTA), and the MonoVer hardness test as outlined by the Hach Chemical Company.

Electrical conductivity

The water conductivities were taken with a type RD, Solu Bridge. In fresh waters, mineral salts exist in a high degree of dissociation. These electrolytes can be separated into anions and cations. Four of the anions (HCO_3^-, SO_4^{--},

Cl^-, and CO_3^{--}) and four of the cations (Ca^{++}, Mg^{++}, K^+, and Na^+) contribute practically all of the electrolytic composition to normal water. Others (Cu^{++}, NO_3^-, etc.) are of relatively little significance (Reimers, et al., 1955). Fresh water lakes are classified according to sulfates (SO_4) or bicarbonates (HCO_3) depending on which one represents the major ion (Clarke, 1924). Bear Lake is therefore a bicarbonate type as HCO_3 is from 352 to 381 p.p.m. (McConnell, et al. 1957); whereas SO_4 is only 71 to 78 p.p.m., which is not high enough to make it a sulfate type.

Conductivity, as stated in this thesis, is expressed in micromhos per centimeter (EC x 10^6). According to Thorne (1951), for waters of low and intermediate salt content, the approximate relationships between conductance, m.e./l. (milligram equivalents per liter) and p.p.m. are as follows:

$$EC \times 10^6 = \frac{\text{m.e./l.}}{0.01} = \frac{\text{p.p.m.}}{0.70}$$

Turbidities

As a general rule the turbidities of Bear Lake had such low values that they were omitted from the collection. However, on occasion after violent wind storms, the turbidity was checked to determine what the maximums encountered in the littoral zone might be. The turbidities were determined using the colorimeter. The calibrated table made by the Hach Chemical Company for this purpose was made from natural water samples using a Jackson Candle Turbidimeter as the standard. The turbidity is expressed in "turbidity units."

Results and Analysis

Littoral zone station limnology

The Bear Lake water levels during this research project are given in Figure 2. It becomes imperative to describe stations on a day-to-day basis because of the frequent water level changes.

Figures 3 through 8 give the limnological data from the six Bear Lake littoral zone stations. The conductivity, hardness and turbidity of the water is extremely variable for all stations. This is attributed mainly to the fact that in the littoral zone the greater the current the higher the conductivity and hardness reading, which in turn is mainly due to the increase in mineral salts with increased agitation of the bottom. That this is the case is borne out by the increase in fluctuation of hardness, conductivity, and turbidity at the shallow water stations over a sand bottom type. The turbidities are not graphed here. The maximum turbidity reached was about 50 at station one during a storm.

The samples on which the data for the last entry on each graph was taken through the ice. Under the ice a micro-habitat is set up almost immediately as the water currents may stop or almost stop and contribution from other areas in the lake become non-existent. At all stations except station three the conductivity of the water dropped under ice cover.

The water temperatures of the littoral zone stations may reach levels too high for some aquatic forms. This is not so true on the east side of the lake (stations five and six) where the bottom gradient is steeper, and hence cooler water is circulated to a greater degree and temperatures are somewhat lower in

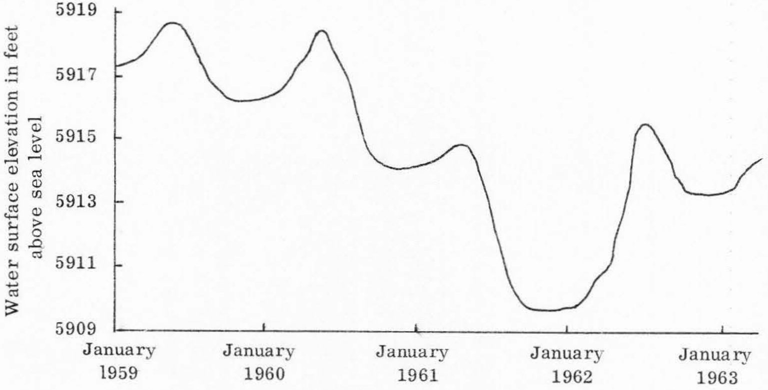

Figure 2. Bear Lake water levels during the littoral zone research project. The data were taken from the records of the Lifton Pumping Plant, Bear Lake, Idaho. The maximum water level for Bear Lake is 5923.65 feet above sea level, while the minimum water level is 5902.00 feet in elevation, or a differential of of 21.65 feet.

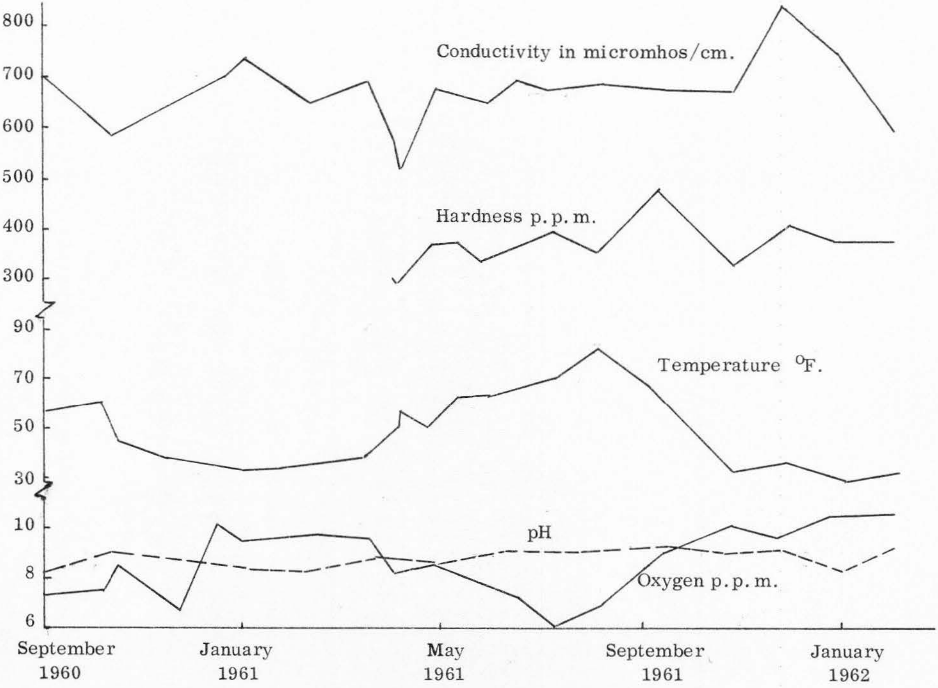

Figure 3. Limnological data from station one of the Bear Lake littoral zone. The last sample recorded was taken under the ice.

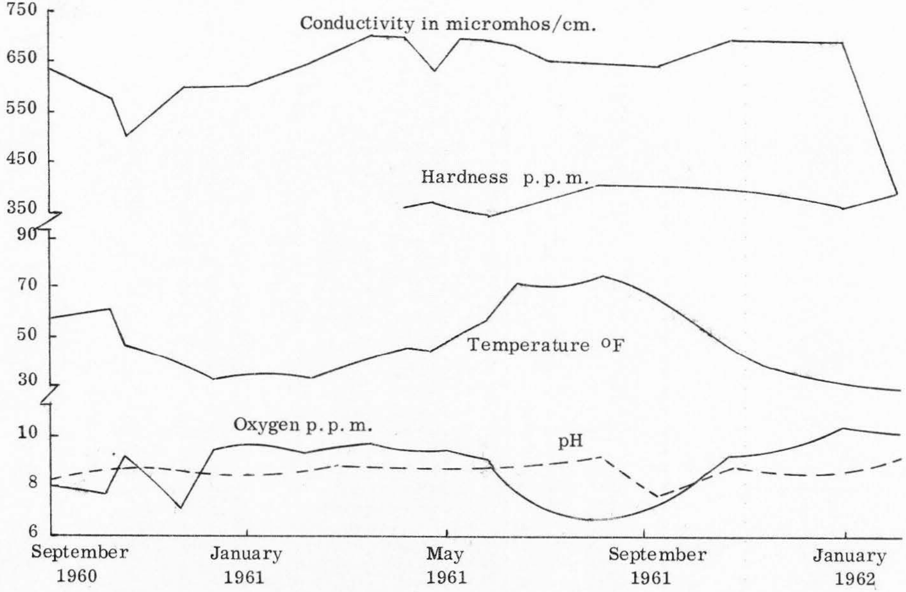

Figure 4. Limnological data from station two of the Bear Lake littoral zone. The last sample recorded was taken under the ice.

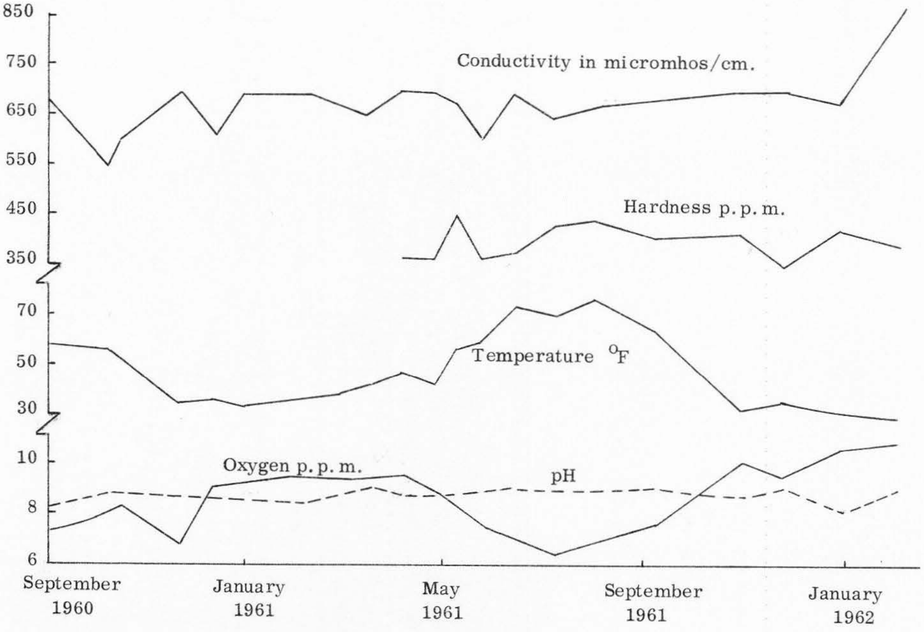

Figure 5. Limnological data from station three of the Bear Lake littoral zone. The last sample recorded was taken under the ice.

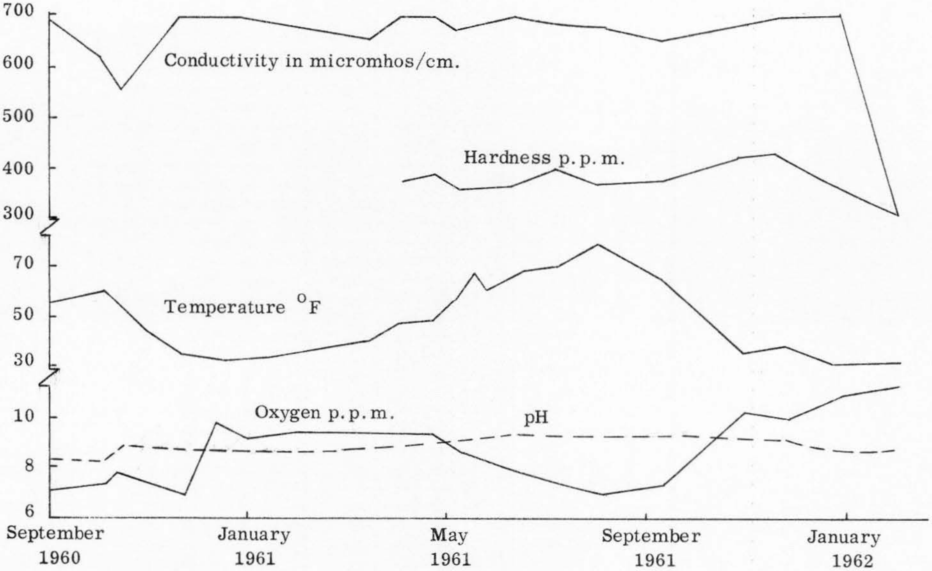

Figure 6. Limnological data from station four of the Bear Lake littoral zone. The last sample recorded was taken under the ice.

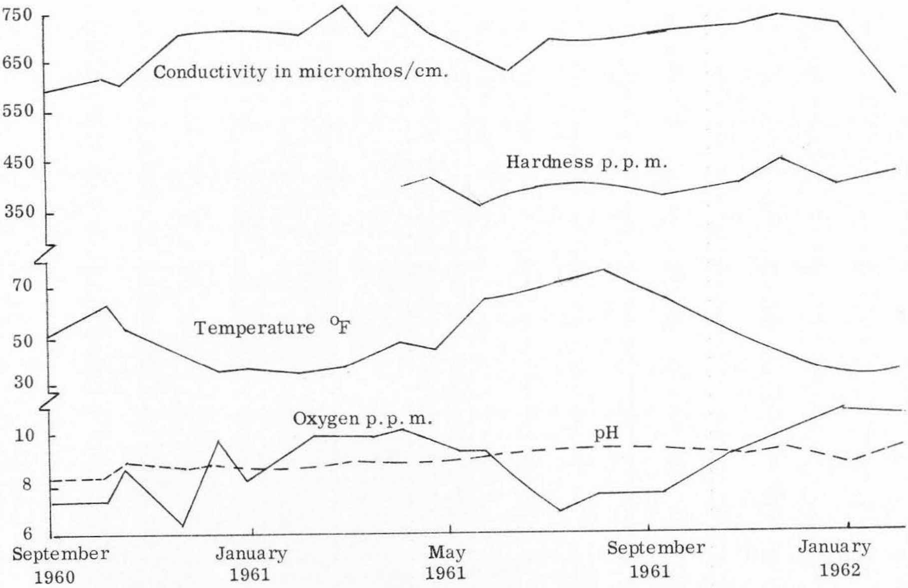

Figure 7. Limnological data from station five of the Bear Lake littoral zone. The last sample recorded was taken under the ice.

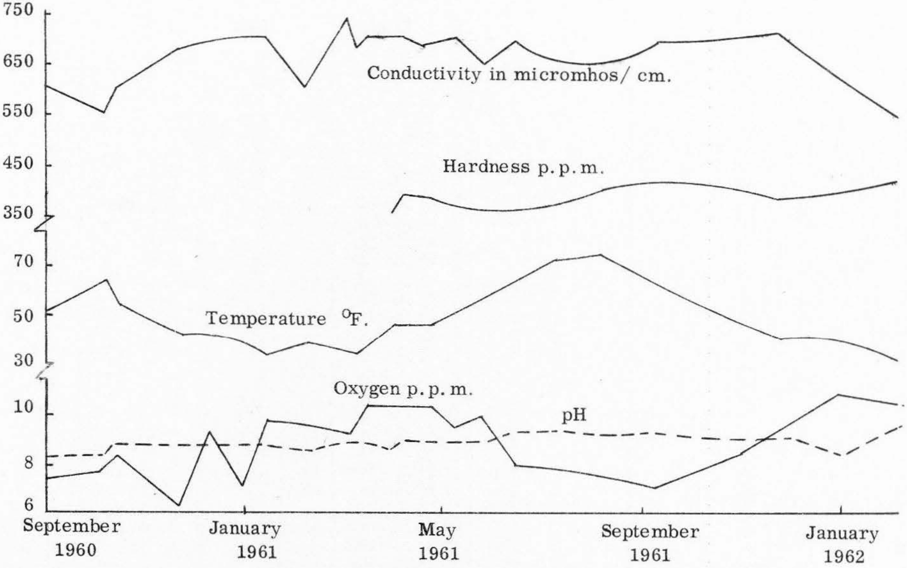

Figure 8. Limnological data from station six of the Bear Lake littoral zone. The last sample recorded was taken under the ice.

the summer. The reverse of this is true in the winter as the extremely shallow water, as on the north end of the lake, freezes over first.

The oxygen has a highly significant inverse relationship to water temperature as is shown in the analysis (correlation coefficients) presented in the gross ecology section of this thesis. The oxygen levels never get to a critical level in relation to Bear Lake fish. The fact that this value remains slightly above or below the saturation value (Figures 9 through 14) for all six Bear Lake littoral zone stations further exemplifies this point.

The pH of the littoral zone is fairly constant from station to station throughout the year. Undoubtedly the pH, oxygen, conductivity, and other limnological dynamics in this area would be quite different if there was a more stable littoral zone environment instead of the constantly changing erosion littoral as we know it.

Stream habitat

The streams (shown in Figure 1) that run into Bear Lake exhibit a variety of limnological conditions. Because these streams empty into the littoral zone of the lake, and actually the "mouths" of these streams are part of the littoral zone, they were studied to see just what variation might occur there. The following conditions represent a superficial study only and are not intended to be all-inclusive in scope.

St. Charles Creek, Idaho. This stream enters Bear Lake near the northwest corner of the lake. Actually, this is only the south fork as there is a division of the creek upstream. This stream is utilized by the cutthroat for spawning in the

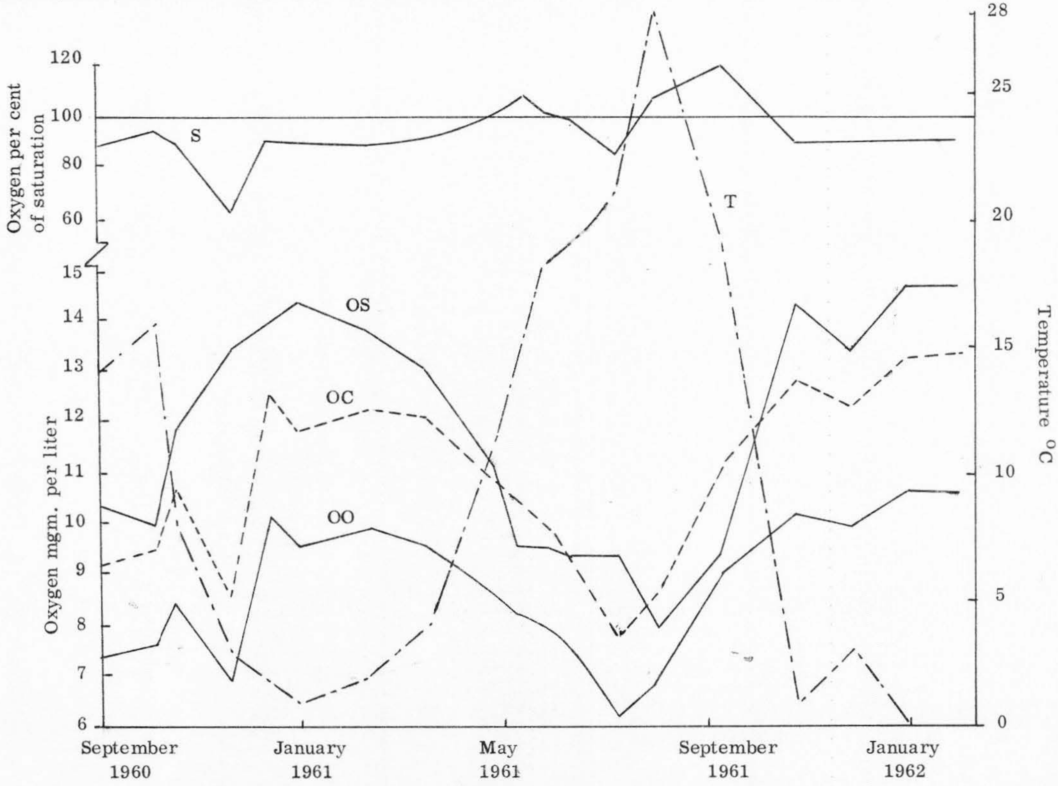

Figure 9. Oxygen dynamics at station one of the Bear Lake littoral zone. Where T = temperature °C; S = per cent of oxygen saturation; OS = oxygen at standard conditions; OC = calculated oxygen concentration; OO = observed oxygen concentration.

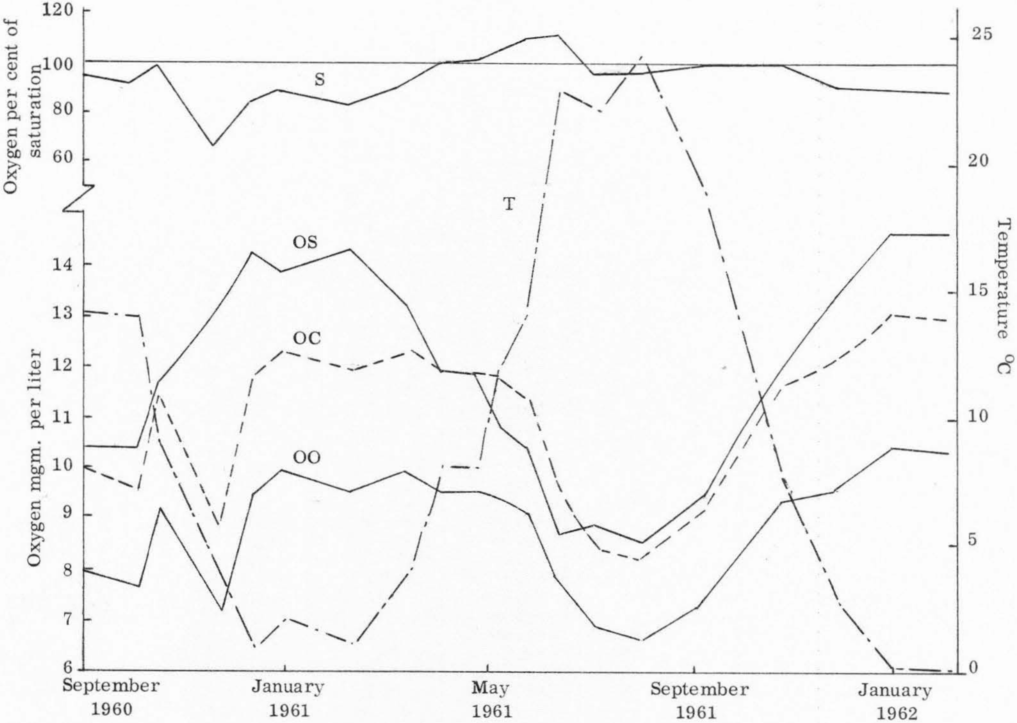

Figure 10. Oxygen dynamics at station two of the Bear Lake littoral zone, where T = temperature °C; S = per cent of oxygen saturation; OS = oxygen at standard conditions; OC = calculated oxygen concentration; OO = observed oxygen concentration.

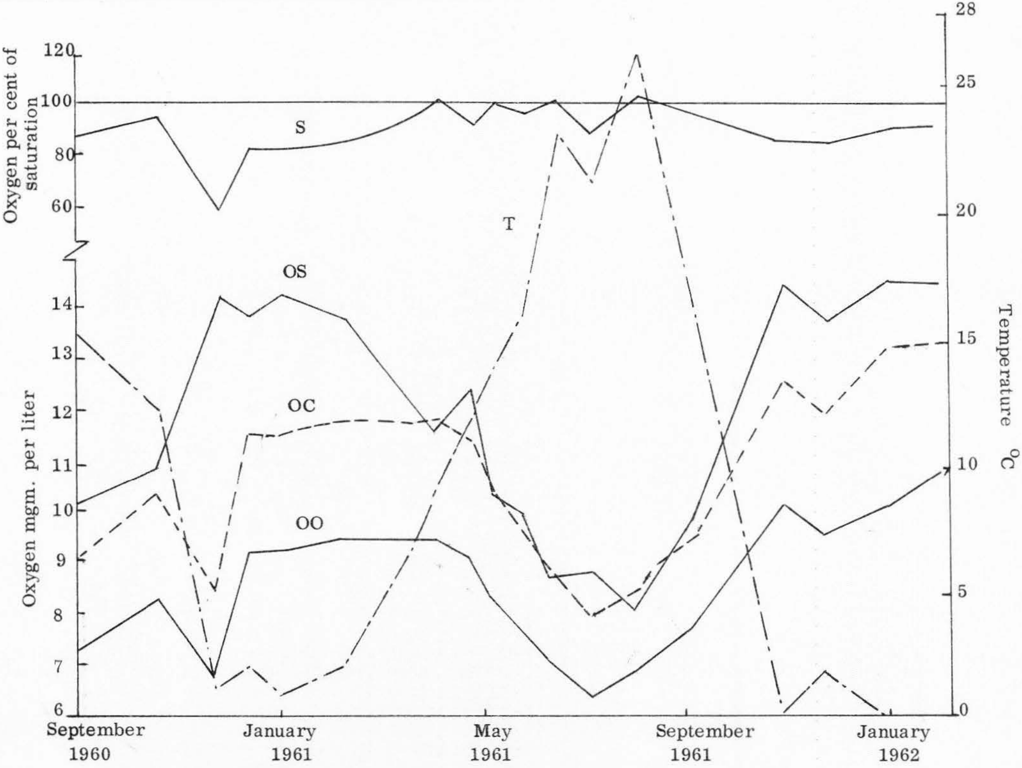

Figure 11. Oxygen dynamics at station three of the Bear Lake littoral zone, where T = temperature °C; S = per cent of oxygen saturation; OS = oxygen at standard conditions; OC = calculated oxygen concentration; OO = observed oxygen concentration.

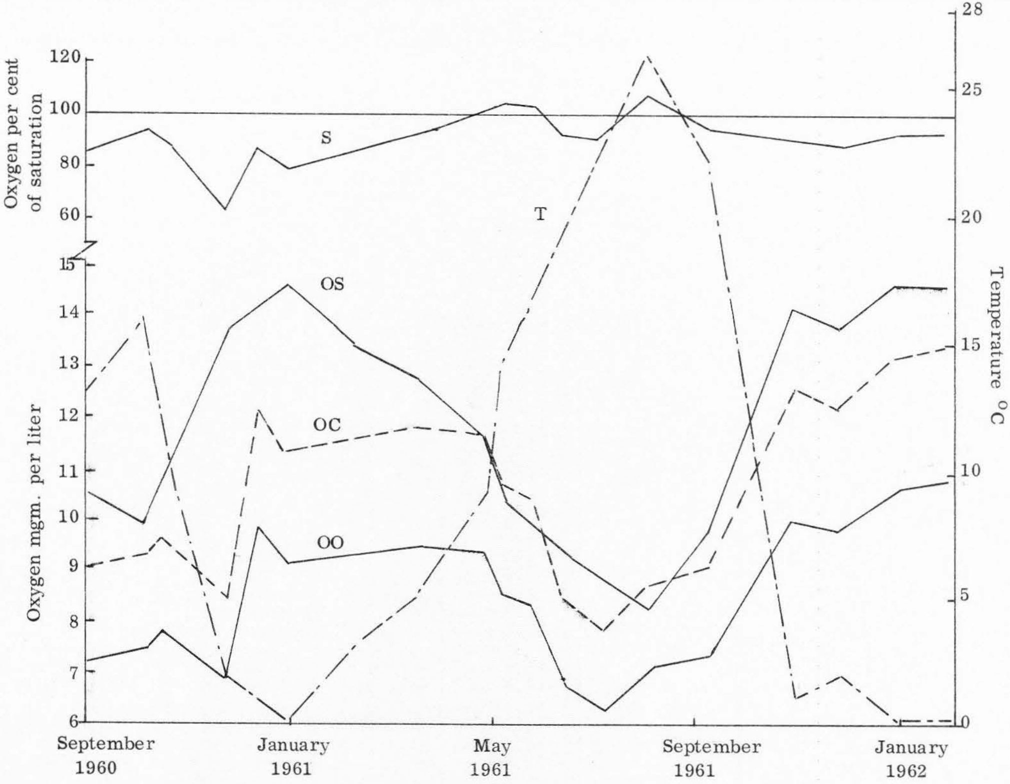

Figure 12. Oxygen dynamics at station four of the Bear Lake littoral zone, where T = temperature °C; S = per cent of oxygen saturation; OS = oxygen at standard conditions; OC = calculated oxygen concentration; OO = observed oxygen concentration.

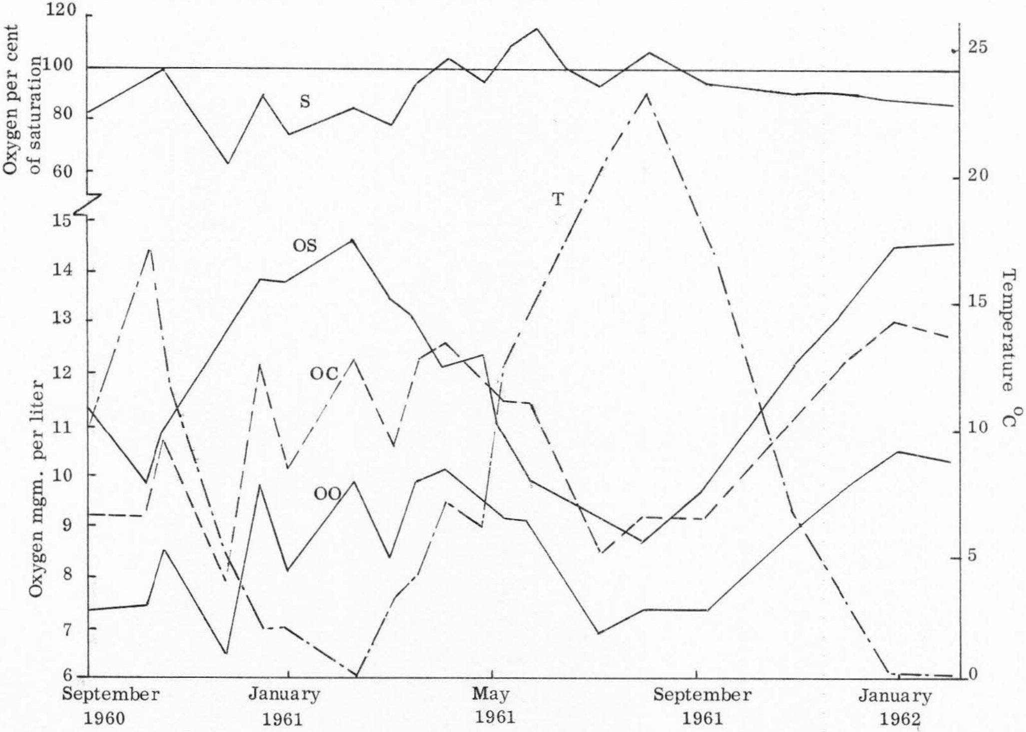

Figure 13. Oxygen dynamics at station five of the Bear Lake littoral zone, where T = temperature °C; S = per cent of oxygen saturation; OS = oxygen at standard conditions; OC = calculated oxygen concentration; OO = observed oxygen concentration.

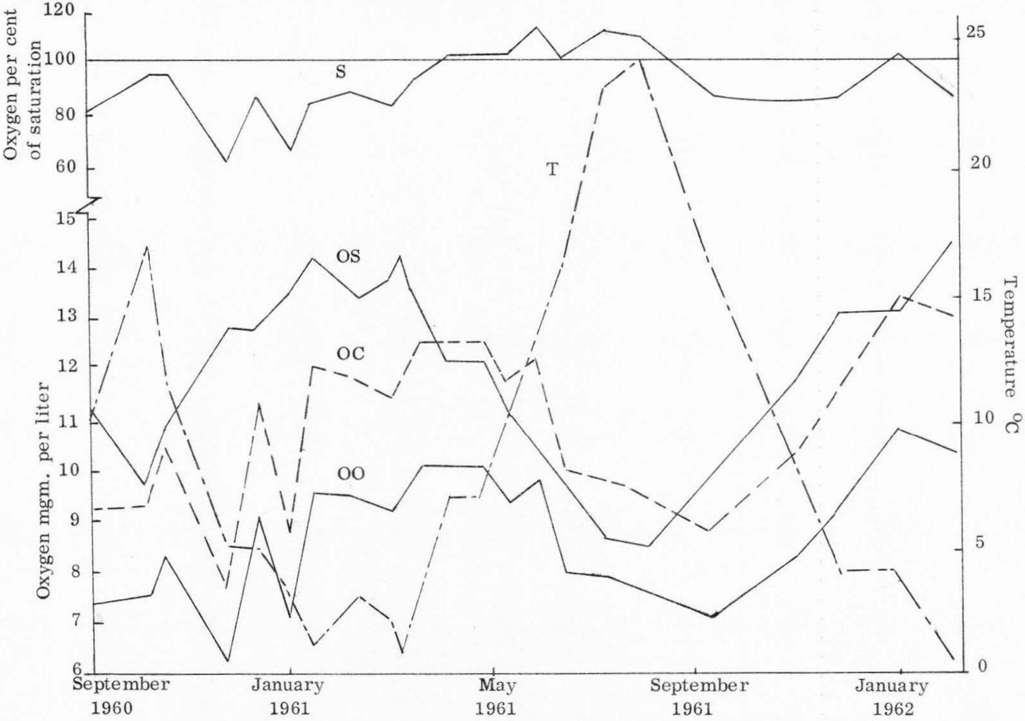

Figure 14. Oxygen dynamics at station six of the Bear Lake littoral zone, where T = temperature $^{\circ}$C; S = per cent of oxygen saturation; OS = oxygen at standard conditions; OC = calculated oxygen concentration; OO = observed oxygen concentration.

spring and is prime carp habitat in the summer. In the winter this stream may freeze over. During the summer months much of the water is diverted out and the stream becomes quite sluggish. At this time the water temperatures may reach 76° F. The pH ranges from 8.3 in the winter to 8.7 in the summer. The winter turbidities are near zero p.p.m., while the summer turbidities may reach 13.0 p.p.m. or more. The electrical conductivity ranges from 185 to 410 micromhos/cm., and the water hardness is from 242 to 318 p.p.m. This is a permanent stream which carries water the year round except under extreme conditions. Summer volumes are approximately four to eight c.f.s.

Fish Haven Creek, Idaho. Fish Haven Creek enters the west side of Bear Lake to the north of the Utah-Idaho State line. This is a small stream of one c.f.s. or less where it enters the lake. During most of the summer and fall, this stream is dry and is subsequently of little value to the littoral zone. When this stream is flowing, the pH varies from 8.3 to 8.5, the temperature from 35 to 50° F., the electrical conductivity from 290 to 300 micromhos/cm., and the water hardness is about 200 p.p.m.

Swan Creek, Utah. This stream enters Bear Lake from the west side, just south of the Utah-Idaho border. Swan Creek acts as a spawning stream for the cutthroat trout in the spring and as a trout nursery and excellent habitat for other cold-water species by summer, irrigation permitting. The pH ranges from 7.7 to 8.7, the turbidity is generally quite close to the zero mark, the temperature ranges from about 43° F. in the winter to 57° F. in the summer. Electrical conductivity ranges from 290 to 330 micromhos/cm. and the total hardness varies from about 180 to 222 p.p.m. The summer volumes may reach four c.f.s. or less , depending on water and irrigation conditions.

Spring Creek, Utah. This creek is one which represents a pond-like habitat as it meanders across the flats before it enters the south end of the lake. The water temperatures may drop to freezing in the winter but reach temperatures as high as 75° F. during the summer. Therefore, this stream is generally considered a warm-water fishery in contrast to Bear Lake and supports large numbers of centrarchids. The pH ranges from 8.2 to 9.4, the turbidity from 5.3 to 26.0 p.p.m. or more. Electrical conductivities range from 325 to 350 micromhos/cm., and the total hardness ranges from about 194 to 286 p.p.m. Stream volumes drop in the summer depending on irrigation requirements and have been known to reach the zero mark below the pond on the lower road.

Falula Springs, Utah. Falula Springs enters Bear Lake on the southeast corner of the lake. It is an intermittent stream depending on irrigation requirements upstream. It supports a variety of fish including trout, sunfish, and spawning red-side shiners when water conditions permit. The pH ranges from 8.2 to about 8.4, and temperatures may vary from freezing in winter to 60° F. or more in the summer. The electrical conductivity is about 400 micromhos/cm., and the total hardness is near 240 p.p.m.

South Eden and North Eden Creeks, Utah. These creeks seldom, if ever, reach Bear Lake any more. However, in years gone by they have been intermittent streams to the east side of Bear Lake.

Indian Creek, Idaho. Indian Creek is a very small stream averaging about 0.25 c.f.s. or less where it enters the lake. It has a winter temperature in the mid-thirties, while summer temperatures may reach 55° F. or more. Electrical conductivity runs as high as 800 micromhos/cm. Indian Creek enters Bear Lake on its northeast corner.

Hot Springs, Idaho. This water may be diverted through a pool into Bear Lake at the northeast corner of the lake. An analysis of the spring water during February of 1961 showed the following analysis: water temperature 118° F., electrical conductivity 1200 micromhos/cm.

Spillway, Idaho. The spillway from Mud Lake allows only seepage to come into Bear Lake. However, this has been found to contain many thousand green sunfish on various occasions on the Bear Lake side of the spillway.

Lifton, Idaho, and the Bear Lake Canal. The water at the pumping plant at Lifton shifts its characteristics depending on whether the water is flowing into or out of Bear Lake. During the winter water flows into Bear Lake from Mud Lake. This water has a temperature from 33° to 50° F. or more. The pH is from 8.1 to 8.3, the electrical conductivity is about 450 micromhos/cm., and the water hardness is about 212 p.p.m. When the water is being pumped out of Bear Lake into Mud Lake during the spring and summer, the water temperatures are from about 60 to 75°F., the pH about 9.0, the electrical conductivity about 650 micromhos/cm., and the total hardness from approximately 368 to 384 p.p.m.

PLANKTON

Introduction

In Bear Lake there are many fluctuations in net-plankton densities during the year and the causes of these fluctuations are numerous. Tressler (1939) states that seasonal (zooplankton) changes seem to be due to many factors, the most important of which are spring and fall overturn. Some of these gross ecological factors are analyzed later in this thesis.

In studying the plankton further, it would seem logical to study the micro-relationships. One such related study is by Tonolli (1958) in which a very sharp correlation has been shown between the numbers of large predator cladocerans and the numbers of all the other crustaceans. Different organisms very often manifest variations in their spatial densities simultaneously, which may be considered as an effect of external forces acting through the water. Some variations, however, appear independently and the perturbating agent is supposed to be a biological one, acting inside a species or a stage.

The bentho-fauna of any lake is dependent on the general characteristics of the benthos along with other environmental factors. Critical times for these species as is indicated by Greze (1960) may exist where more than 60 per cent of the benthos by number and more than 50 per cent by biomass die during the period from the first formation of ice to incipient freezing of the soil. Between the beginning of soil freezing and the spring thaw, the loss of benthos fluctuates between 35 and 70 per cent of the number of animals present when the soil begins to freeze. This may be important in Bear Lake where the lake freezes over quite often and where the more productive area of the limited littoral zone is that area most greatly affected by the formation of ice.

The terrestrial insects may also be very important as food during part of the year on Bear Lake when such species as Gammarus, etc., become rare because of a water drawdown. This is also the case on other lakes as described by Nilsson (1961).

During the past years of research on Bear Lake, investigators have concerned themselves primarily with fish problems. As a result plankton research has been conducted on a very superficial basis with perhaps the exception of those of Clark (1956), whose studies dealt with plankton sampling.

The objectives of this plankton study were to determine the general distribution and abundance of the net-plankton of the Bear Lake littoral zone according to season, bottom type and exposure. Since the plankton were being studied in relation to the fish of the littoral zone, the net-plankton forms were of greatest importance according to our preliminary investigations. A study of the nanno-plankton was considered beyond the scope of this project.

Materials and Methods

Collections were made by suspending a Wisconsin plankton net in a perforated metal cylinder. The cylinder was supported by a metal ring with three legs. Fifty liters of water were poured through in each sample. The sample was fixed in a 1 per cent formaldehyde solution colored with erythrosine. Plankton sampling was conducted on a monthly basis in conjunction with water chemistry.

The plankton net used was made from number 25 silk bolting cloth, which has 40, 000 meshes per square inch, with an aperture size of about 60 microns before wetting and shrinkage. The mesh strands are approximately the same diameter as the mesh apertures.

In considering just which plankton forms should be studied, it was necessary to limit the counting of the planktonic organisms to those having a diameter no smaller than 60 microns. In order to sample the nannoplankton, which are those forms not retained by number 25 bolting cloth, it is necessary to use other filtering devices, as has been pointed out by Clark (1956), McConnell, et al. (1957), and Clark, et al. (1961) for Bear Lake forms.

The following forms are retained for the most part by number 25 silk bolting cloth due to minimum diameter sizes which exceed the maximum aperture sizes. They are: Volvox, Ceratium, Anuraeopsis, Conochilus, Notholca, Polyarthra, Filinia, Difflugia, Keratella, cladocerans (Daphnia, Ceriodaphnia, Moina, Bosmina, Alona, Chydorus), and copepods (Epischura, Cyclops, Canthocamptus).

Counts were made of the individual rotifers contained in the Conochilus colonies. A random sample of 30 such colonies showed a range of 6 to 60 individuals, with an average of 23 individuals per rotifer colony. Such counts were found necessary in converting individual rotifer counts to a colonial rotifer count.

Candona, Gammarus, Hyalella, Hirudinea and the Oligochaeta were omitted from the plankton counts even though they were sometimes collected. The reason for this is that they are mainly bottom inhabiting organisms and as a result are not uniformly collected in the plankton samples taken above the bottom. Another form not included here is Binuclearia, which is normally a periphyton form but may at times become detached and subsequently become part of the planktonic biomass.

The diameters of the net-phytoplankton studied are: Volvox, 60 ; and Ceratium 60μ; and of the net-zooplankton are Anuraeopsis 60μ ; Conochilus individuals 60μ ; Keratella 60μ; Notholca 90μ; Polyarthra 90μ; Filinia 90μ; Difflugia 200μ ; cladocerans 200μ ; and copepods 300μ .

Identification of plankton forms was accomplished with the aid of Smith (1933), Pratt (1951), Pennak (1953), Prescott (1954), Edmondson (1959), and Needham, et al. (1962). The nomenclature of Table 1 is based on the original author reference for that form as long as it is consistent with Edmondson (1959).

The six sampling stations described previously in this thesis were used throughout this part of the study.

Results and Analysis

A tentative list of phytoplankton and zooplankton is given in Table 1. The list represents only those species which have been collected and identified to date. Because many of the Bear Lake plankters are so small, they have been overlook and passed by except as chance residues in plankton-catching gear by

Table 1. A checklist of the phytoplankton, zooplankton and related organisms which have been identified from Bear Lake, Utah-Idaho, by all investigators

Species	Investigator									
	Kemmerer *et al*. (1923)	Hazzard (1935)	Wright & Perry (1941)	Perry (1943)	Clark (1956)	McConnell *et al*. (1957)	Smart (1958)	Hassler (1960)	Clark & Sigler (1961)	Workman
Bacteria										
Pelogloea bacillifera Lauterborn(l, 2)									x	
Myxophyceae, blue green algae										
Coccochloris Sprengal (formerly *Rhabdoderma*)									x	
Anacystis Meneghini (formerly *Microcystis*, *Chroococcus*)		x			x				x	x
Gomphosphaeria Kutzing (formerly *Coelosphaerium*)	x					x				x
Agmenellum Brebisson (formerly*Merismopedia*)									x	
Lyngbya Agardh						x				
L. *circumcreta* G. S. West (2)									x	
L. *contorta* Lemmermann					x					
Algae										
Volvox Linnaeus										x
Blakatothrix gelatinosa Wille (2)									x	
Dictosphaerium Nageli					x	x			x	x
D. *pulchellum* Wood									x	
Chlorella Beijerinck									x	
Ankistrodesmus Corda						x				x
A. *spiralis* (Turner) Lemmermann					x					
A. *falcatus* (Corda) Ralfs					x	x			x	x
A. *falcatus* var. *spirilliformis* West (2)									x	x
Chodatella Lemmermann (formerly Lagerheimia)					x	x			x	

Table 1. (cont'd.)

Species	Investigator									
	(1923)	(1935)	(1941)	(1943)	(1956)	(1957)	(1958)	(1960)	(1961)	Workman
Algae, (cont'd)										
Oocystis Nageli						x			x	x
O. lacustris Chodat (2)									x	
O. marssonii Lemmermann (2)									x	
O. perva West & West (2)					x				x	
O. pusilla Hansgirg (2)					x				x	
O. solitaria Wittrock (2)									x	
Selenastrum Reinsch					x					
S. minutum G. S. West (2)									x	
Dactylococcopsis Hansgirg (3)					x					
D. acicularis Lemmermann (2)									x	
D. rupestris Hansgirg (2)									x	
Crucigenia quadrata Morren (2)									x	
Scenedesmus quadricauda (Turp.) Brebisson (2)									x	x
Staurastrum Meyen		x								x
Binuclearia Wittrock										x
Stichococcus bacillaris Nageli									x	
Dinobryon Ehrenberg					x	x				x
D. sertularia Ehrenberg									x	
D. sociale Ehrenberg (2)									x	
Ceratium Schrank	x					x				x
Bacillariophyceae, diatoms										
Diatom species (general)					x	x			x	x
Fragilaria Lyngbye	x					x				x
Synedra Shrenberg									x	
Asterionella Hassall										x
Cyclotella Brebisson									x	
Rhizopoda										
Difflugia Leclerc										x
Rotifera, rotifers										
Polyarthra Ehrenberg	x	x		x						x
Filinia Bory de St. Vincent (formerly *Triarthra*)		x								x
Anuraeopsis Lauterbora (formerly Anurae)		x		x						x

Table 1 (cont'd)

	Investigator									
	(1923)	(1935)	(1941)	(1943)	(1956)	(1957)	(1958)	(1960)	(1961)	Workman
Keratella Bory de St. Vincent										x
Notholca Gosse		x								x
Conochilus Hlava		x	x	x		x		x		x
Annelida, aquatic earthworms, etc.										
Oligochaeta							x			x
Hirudinea							x			x
Cladocera										x
Daphnia O. F. Muller		x		x			x			
Ceriodaphnia Dana				x						
Moina Baird				x						
Bosmina Baird				x						
Alona Baird				x						
Chydorus Leach				x						
Ostracoda										
Candona Baird							x			x
Copepoda										x
Epischura Forbes	x	x	x	x		x		x		
Cyclops O. F. Muller				x						
Canthocamptus Westwood	x			x						
Malacostraca, fresh-water shrimp										
Hyalella azteca Saussure (formerly *H. knickerbockeri*)							x			x
Gammarus lacustris Sars (formerly *G. limnaeus*)							x			x

(1) Indicates questionable nomenclature.

(2) Clark *et al* (1961), nomenclature.

(3) Clark (1956), nomenclature.

Kemmerer, et al. (1923), Hazzard (1935), Wright, et al. (1941), Perry (1943), Smart (1958), Hassler (1960), as well as this study. The papers by Clark (1956) and Clark, et al. (1961) represent the greatest contribution to the understanding of these smaller forms to date.

Several new forms have been added to the list of Table 1 as a result of the present study. These include the species Keratella, Difflugia, and Volvox. The rest of the identifications made during this study are mainly confirmations of forms already identified as this was not a taxonomic study.

Figures 15 through 20 depict the fluctuations in species numbers throughout the months from April of 1961 through February of 1962 for the six Bear Lake littoral zone stations. Because of the small numbers involved, these figures plus the summary Figure 21, based on total population fluctuations, are expressed in terms of plankters per 50 liter sample. The usual way of expressing such information is based on the diameter of "spherical curves" which correspond to the cube root of the number of individuals per liter, hence to the number of individuals occurring along the diameter of a cylinder of water (or sphere) or along an edge of a cube containing one liter (Ruttner, 1953).

If the Figures 15 through 20 which depict plankton dynamics at each of the six Bear Lake stations are checked systematically against each other, it will be noted that there is a great variation in maximum and minimum "bloom" periods for individual species. The only interpretation which can presently be attributed to this phenomenon is that these planktonic or free-floating forms are constantly being shifted about in this area of the littoral zone. Little if any

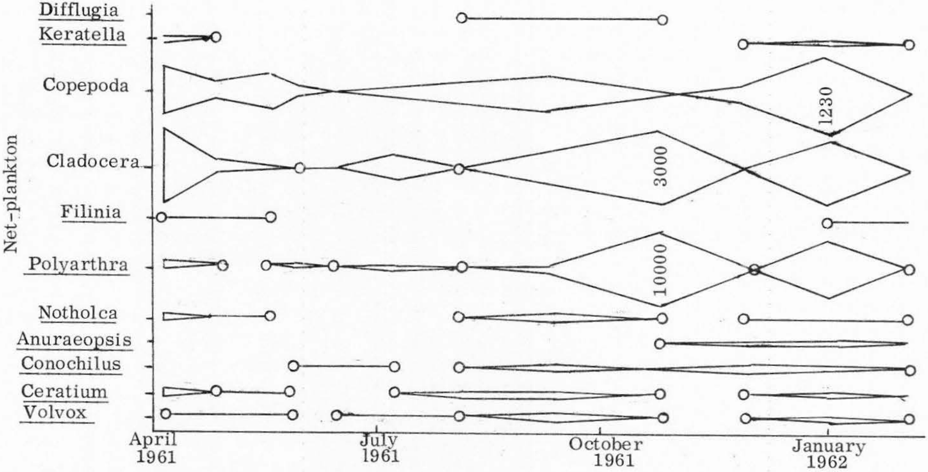

Figure 15. Net-plankton densities during 1961 and 1962 at station one of the Bear Lake littoral zone. One millimeter on the vertical scale is equal to 50 plankters. All results expressed as plankters per 50 liter sample. Circle around point indicates a zero collection.

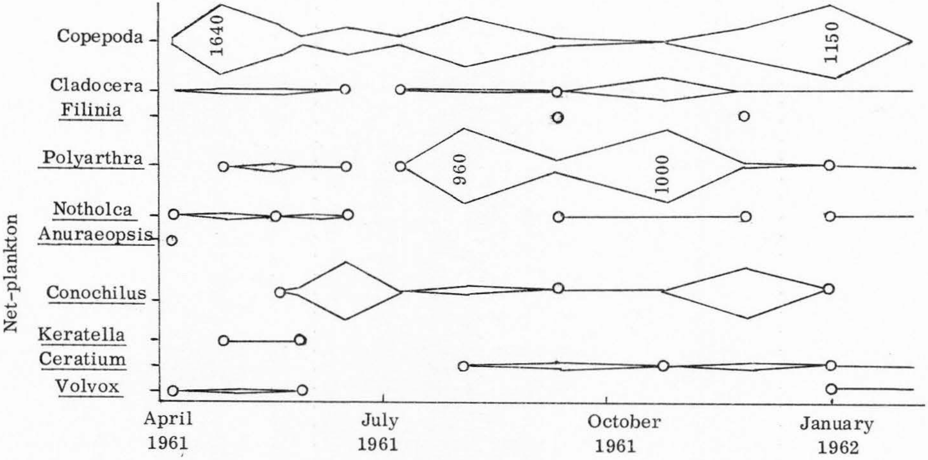

Figure 16. Net-plankton densities during 1961 and 1962 at station two of the Bear Lake littoral zone. One millimeter on the vertical scale is equal to 50 plankters. All results expressed as plankters per 50 liter sample. Circle around point indicates a zero collection.

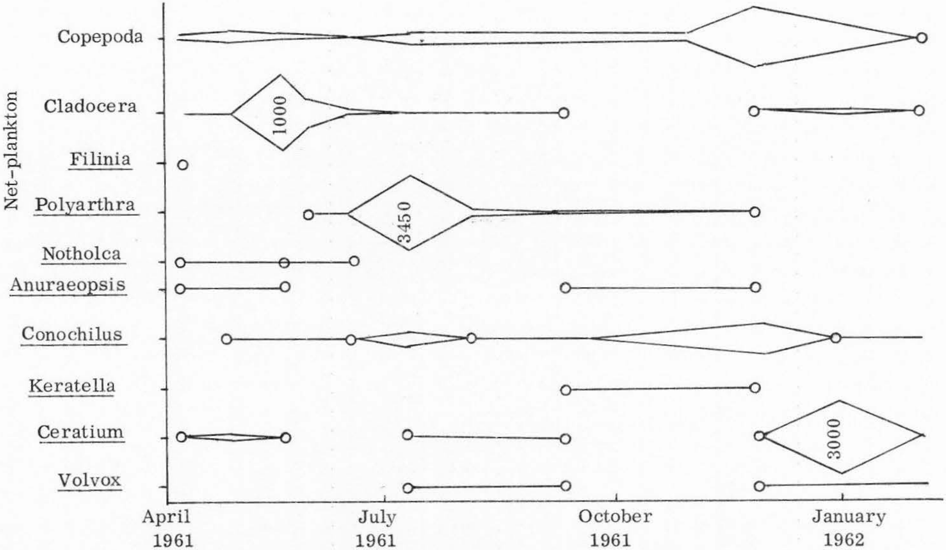

Figure 17. Net-plankton densities during 1961 and 1962 at station three of the Bear Lake littoral zone. One millimeter on the vertical scale is equal to 50 plankters. All results expressed as plankters per 50 liter sample. Circle around point indicates a zero collection.

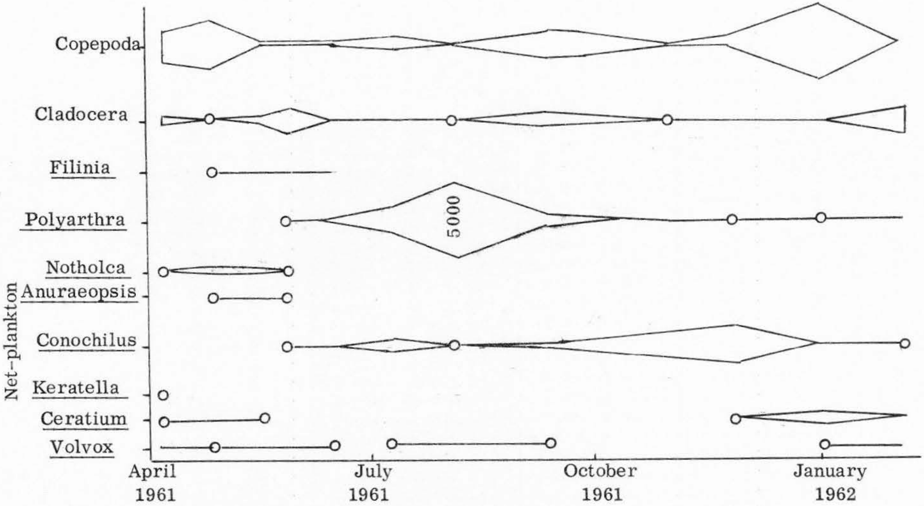

Figure 18. Net-plankton densities during 1961 and 1962 at station four of the Bear Lake littoral zone. One millimeter on the vertical scale is equal to 50 plankters. All results expressed as plankters per 50 liter sample. Circle around point indicates a zero collection.

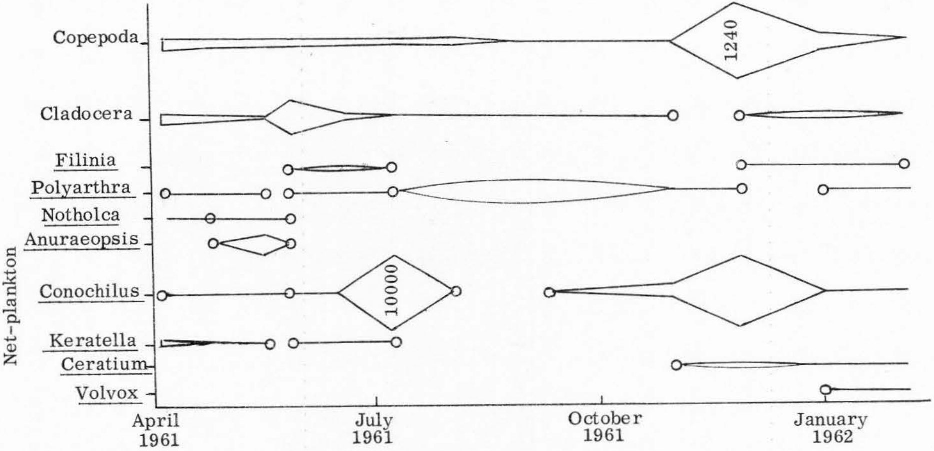

Figure 19. Net-plankton densities during 1961 and 1962 at station five of the Bear Lake littoral zone. One millimeter on the vertical scale is equal to 50 plankters. All results expressed as plankters per 50 liter sample. Circle around point indicates a zero collection.

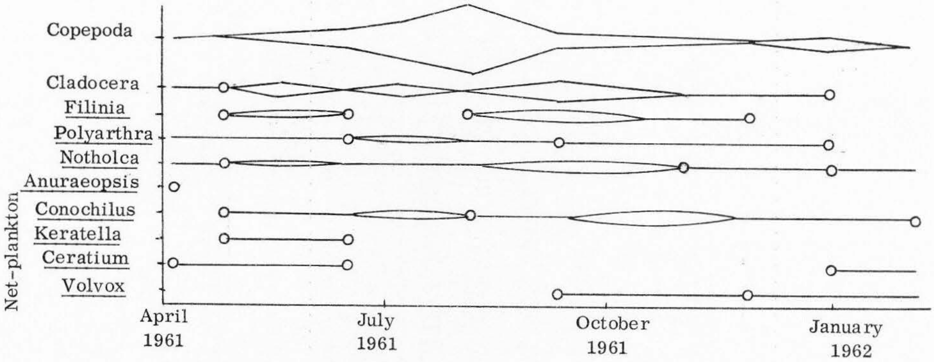

Figure 20. Net-plankton densities during 1961 and 1962 at station six of the Bear Lake littoral zone. One millimeter on the vertical scale is equal to 50 plankters. All results expressed as plankters per 50 liter sample. Circle around point indicates a zero collection.

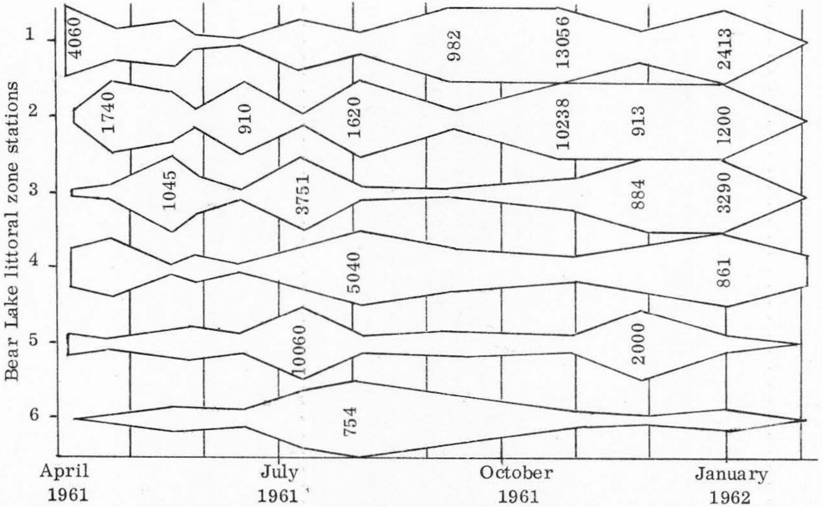

Figure 21. Total net-plankton organisms collected at the six Bear Lake stations during 1961-1962. One millimeter on the vertical scale is equal to 50 organisms. All results expressed as plankters per 50 liter sample.

chance is ever given to a species to establish itself under a constant condition which is so necessary in the establishment of a micro-habitat.

It is therefore assumed that during periods of normal open water conditions, that the littoral zone net-plankton population dynamics are determined by wind-swept water currents which transport these plankters from pelagic and benthic areas of the lake where subsequent "blooming" may be taking place.

Three exceptions to this general moving current lakeshore habitat develop from time to time in Bear Lake The first of these is a temporary condition which may result during an extended period of calm. The second is a more permanent condition which is found in the few sheltered areas along the lakeshore where currents are deflected. These areas may be disrupted, however, by a mere change in wind vectors. The third, and perhaps most important in the establishment of micro-habitat conditions in the littoral zone, is that of ice cover. The last entries (February 1962) of Figures 15 through 21, point out the response of the net-plankters to ice cover and subsequent reduction of water currents. Under such conditions of calm, the plankters are therefore probably more capable of selecting and moving towards a desired depth and subsequently a more optimum habitat.

Since the copepods are considered to be so important in the food chain sequence, and also because of their general consistent abundance, they were checked statistically on a station-to-station basis. The analysis of variance of Table 2 indicates that there is no significant difference between stations in regard to copepod dynmaics.

Table 2. Analysis of variance of copepod densities versus the six Bear Lake littoral zone stations during 1961-1962

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	5	637,952.78	127,590.56	1.26[a]
Within	65	6,621,907.00	101,187.55	
Total	70	6,259,859.78		

[a] Not significant.

Birge and Juday (1922) indicated in their study of copepods in Lake Mendota that the copepods continued in fair abundance throughout the year with a maximum in the spring (April to June) and again in November. The copepods in Chautauqua were reduced to almost zero during the winter and reappeared in fairly large numbers in May. Another maximum occurred in November. The Cladocera in Mendota exhibited spring and fall maxima and in Chautauqua their distribution was similar to that of the Copepoda, although their maxima did not start until June. Rotifers were abundant the year around in Lake Mendota and Chautauqua.

A statistical analysis was also made of the total net-plankton organisms collected at the six Bear Lake littoral zone stations during 1961 and 1962. This analysis of variance, which is given in Table 3, indicates that there is no significant difference between these six stations in regard to population fluctuations.

The inlet at the north end of Bear Lake which lets plankton-bearing water from Mud Lake into Bear Lake during the fall, winter, and spring makes some

Table 3. Analysis of variance of total number of net-plankters versus the six Bear Lake littoral zone stations during 1961-1962

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	5	18, 921, 685. 63	3, 784, 337. 12	. 67[a]
Within	65	368, 190, 471. 07	5, 664, 468. 78	
Total	70	387, 112, 156. 70		

[a] Not significant

contribution to the general plankton of the littoral zone in the immediate area of the north end. Figure 22 indicates an analysis of a water sample collected from Mud Lake water entering Bear Lake. It will be noted that the species of net-plankton collected at this particular time coincide with species already in the lake.

The reverse sample of the above, that of Bear Lake water being pumped into Mud Lake during the summer, is illustrated in Figure 23. At this particular time Conochilus colonies and copepods were being removed from Bear Lake in large quantities.

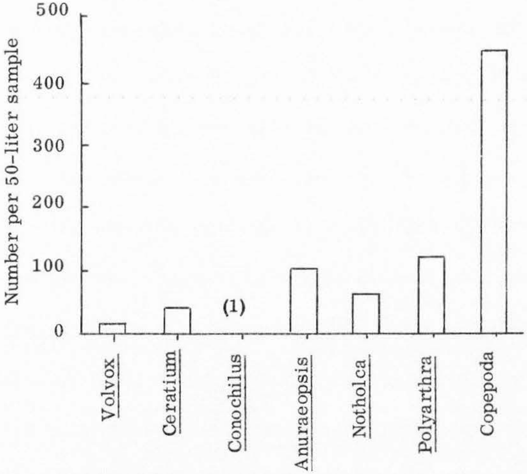

Figure 22. Net-plankters collected from the Mud Lake water entering Bear Lake on the Bear Lake side of the Lifton Pumping Plant on December 3, 1961.

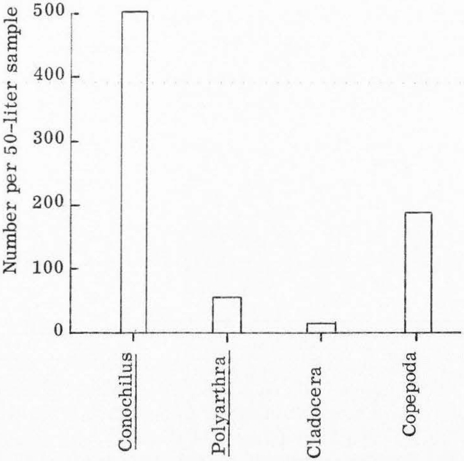

Figure 23. Net-plankters collected from the Bear Lake water being pumped into Mud Lake on the Mud Lake side of the Lifton Pumping Plant on July 8, 1961.

FISH

General Littoral Zone Distribution

Materials and methods

The littoral zone presented several problems in sampling fish. At the beginning of the project, by taking advantage of inshore water currents, rotenone was dispersed from the up-current end of the study station. All the fish within an area 30 feet wide (from the shore out) and 100 feet long (along the shore) were collected as they became sick or died. This soon proved to be unsatisfactory as the area had no fixed boundaries and therefore fish could swim out of the area of their own accord after becoming irritated by the toxicant; water currents could change drastically, thereby washing fish and poison from the sampling area; sculpin swam under rocks and died; often an excessive area was poisoned; and dace swam into deeper water after becoming sick from the toxicant.

The next step was to add a short seine to the down-current end of the collecting station. This net was placed perpendicular to the shoreline. This was also discontinued because the fish could swim around the seine or out of the area; the current could change and would thereby render the net ineffective; sculpin *Cottus sp.* still swam under rocks when sick or dying; and an excessive area was often poisoned.

The methods used for the main collection periods during 1961 and 1962 were as follows: In sand a 100-foot fine mesh seine (1/8 inch mesh) was pulled so as to make a barrier perpendicular to the shore. Then the outside end of the net was drawn in an arc to the shore and was pulled up on the sandy beach; in the rocky areas the seine was placed in an arc, the shore distance of which was about 75 feet. The next step involved securing the lead line in the rocks along the bottom of the area. A direct-current shocker was added to this arrangement, the electrodes being placed on the bottom about 10 feet apart. Fish were then picked up by means of small dip nets between the electrodes. To make the collection complete literally every rock within the area had to be turned over. By employing these methods an estimate was obtained of the number of fish per square foot of the bottom area. However, it should be noted here that these methods were not adequate for the capture of the larger fish or green sunfish _Lepomis cyanellus_. These fish are extremely wary and swim away from the seine and thus from the area. Fish sampling was conducted on a monthly basis.

Results and analysis

The fish sampled during the study included the Utah sucker _Catostomus ardens_, redside shiner _Richardsonius balteatus_, Utah chub _Gila atraria_, speckled dace _Rhinichthys osculus_, sculpin _Cottus_ sp., rainbow trout _Salmo gairdneri_, carp _Cyprinus carpio_, perch _Perca flavescens_ and green sunfish _Lepomis cyanellus_. The fish names listed throughout the thesis are in accordance with Bailey, _et al._ (1960).

The gill netting of larger fish in the littoral zone indicated greater activity of carp, suckers, chub, and rainbow trout at night than in the daytime. The observations with SCUBA (self-contained underwater breathing apparatus) gear indicated lower fish densities during the daytime.

Figures 24 through 29 give the small-fish densities during 1961 at each of the Bear Lake stations. At station one (Figure 24), which was located over a sand bottom, it will be noted that fish populations were at a very low density throughout the year.

Station two (Figure 25) was at a location where ice cover precluded part of the collections from the first and last of the sampling period. In general the fish densities dropped as the lake bottom became one of pure sand. The one-time pulse for shiners and suckers can only be attributed to the springs in this area.

Figure 26, illustrating the small fish densities of station three, shows the typical effect of a poor cover. Such low fish densities are also true of station four (Figure 27), except for one minor pulse for suckers and shiners.

The effect of rock cover at station five (Figure 28) is indicative of more constant fish densities especially in regard to dace and sculpin. However, even at this station the population numbers tended to decline as the quality of the cover was reduced.

Station six (Figure 29) was the only station where the bottom quality remained fairly constant. At this rock station the population levels remained fairly high except during the summer months, when the fish subsequently sought slightly deeper and cooler water where cover was available.

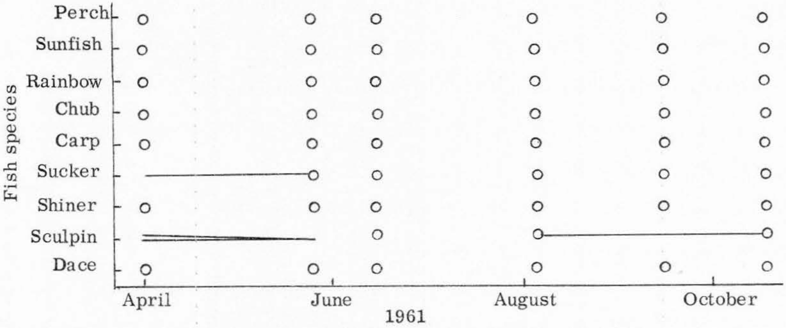

Figure 24. Small-fish densities during 1961 at station one of the Bear Lake littoral zone. One-fourth inch on the vertical scale is equal to 50 fish. All results expressed as fish per 12,000 square foot sample over a sand bottom type. Circle around point indicates a zero collection.

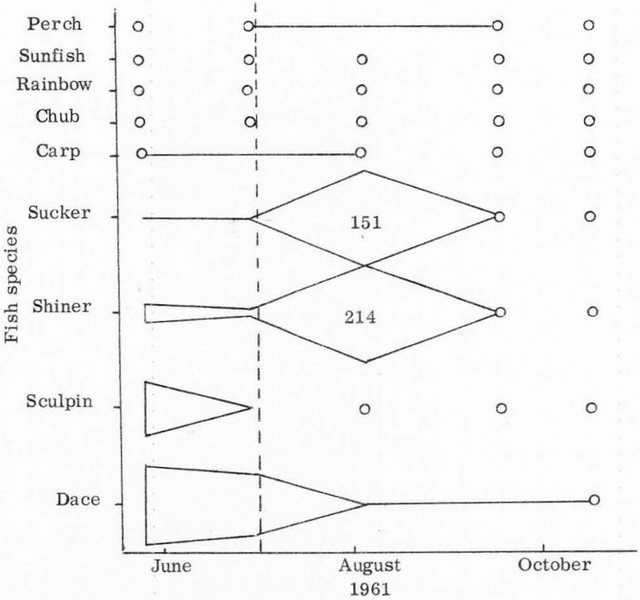

Figure 25. Small-fish densities during 1961 at station two of the Bear Lake littoral zone. One-fourth inch on the vertical scale is equal to 50 fish. Collections on the left of the dotted line indicate 1, 000 square foot samples over a rock-sand bottom type. Those collections on the right of the dotted line indicate 12, 000 square foot samples over sand. Circle around point indicates a zero collection.

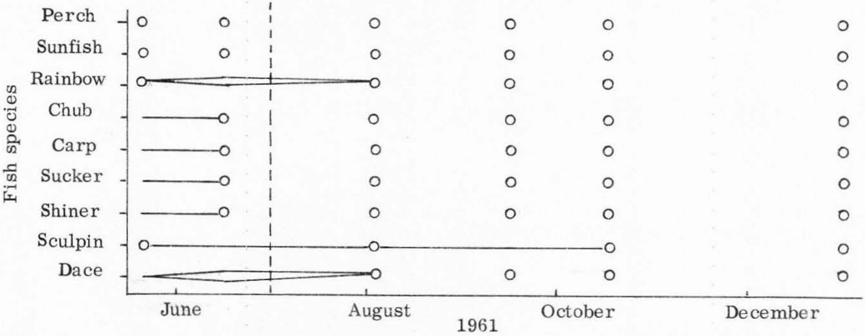

Figure 26. Small-fish densities during 1961 at station three of the Bear Lake littoral zone. One-fourth inch on the vertical scale is equal to 50 fish. Collections on the left of the dotted line indicate 1,000 square foot samples over a rock-sand bottom type. Those collections on the right of the line indicate 12,000 square foot samples over sand. Circle around point indicates a zero collection.

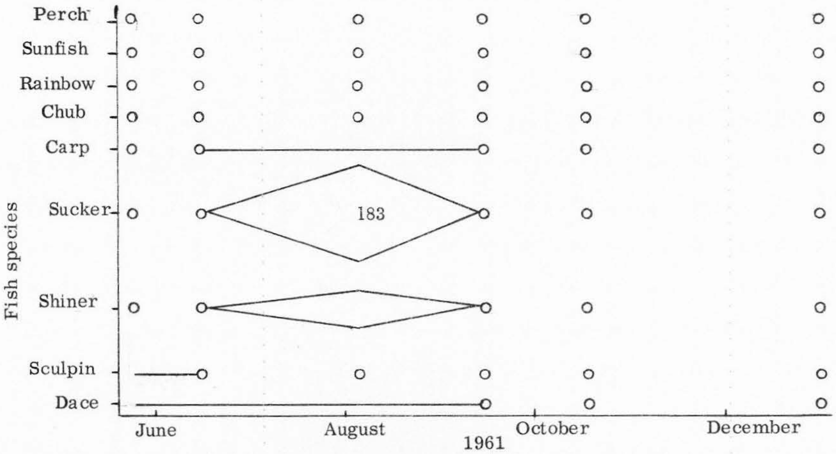

Figure 27. Small-fish densities during 1961 at station four of the Bear Lake littoral zone. One-fourth inch on the vertical scale is equal to 50 fish. All results expressed as fish per 12,000 square foot sample over a sand bottom type. Circle around point indicates a zero collection.

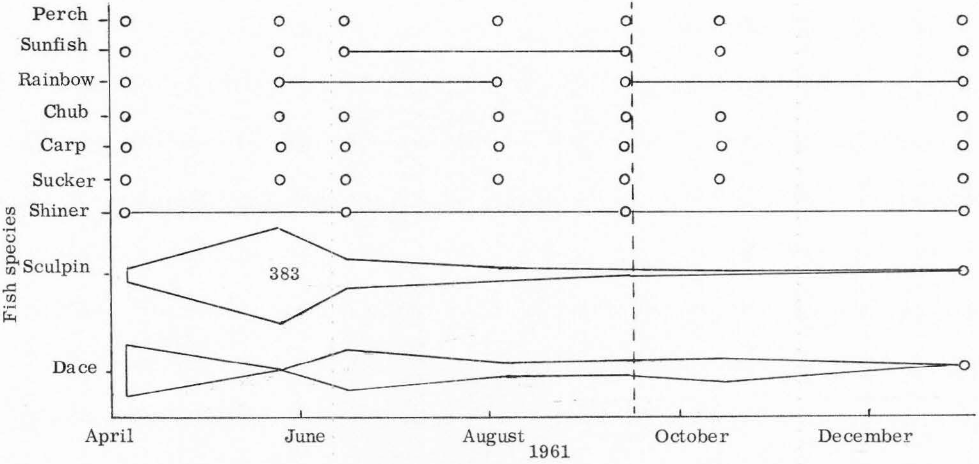

Figure 28. Small-fish densities during 1961 at station five of the Bear Lake littoral zone. One-fourth inch on the vertical scale is equal to 50 fish. Collections on the of the dotted line indicate 1, 000 square foot samples over a rock or rock-sand bottom type. Those collections on the right of the dotted line indicate 12, 000 square foot samples over sand. Circle around point indicates a zero collection.

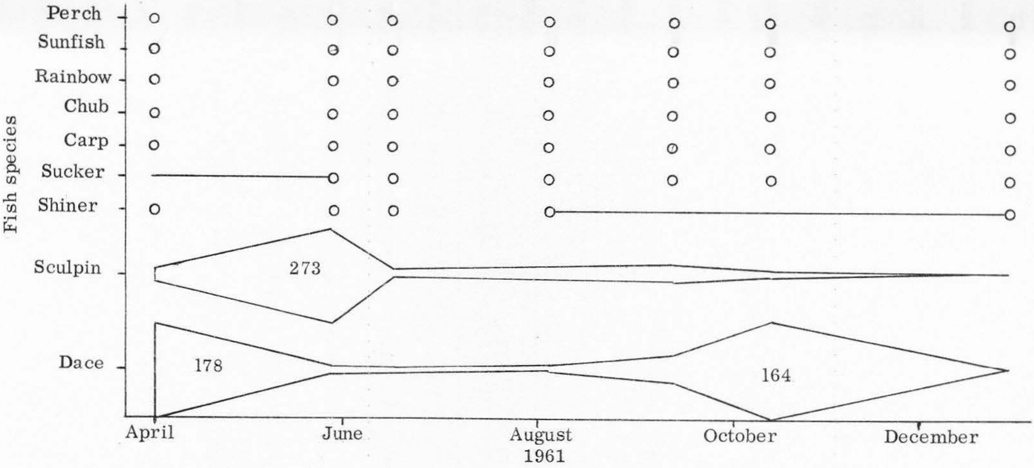

Figure 29. Small-fish densities during 1961 at station six of the Bear Lake littoral zone. One-fourth inch on the vertical scale is equal to 50 fish. All results expressed as fish per 1,000 square foot sample over rock or rock-sand bottom type. Circle around point indicates a zero collection.

The summary Figure 30 points out quite graphically the effect of cover versus no cover for all species combined at each station; the two more consistent stations being five and six, where cover was most available.

The general phenomenon of fish declining in numbers as a station's cover quality is reduced seems to follow a pattern. First, as the cover band along the area of the littoral zone is reduced, the fish become more concentrated. In fact, there is probably a point where their numbers exceed the available cover potential for that area. At such a time the fish and the crayfish are extremely vulnerable to storm action and high water temperatures. When the rocks have been exposed or the remaining areas of cover sanded in, the fish are forced to move along the lakeshore, thereby seeking out other areas of protection. The sculpin is probably at the least disadvantage due to its protective coloration and habits.

When the small fish densities of the Bear Lake littoral zone are expressed as square feet of bottom type per fish as in Table 4, it can readily be ascertained that cover is a very important factor. For dace there is 370 times more area per fish over sand than there is over areas of cover.

For sculpin there is 735 times more area per fish over sand than there is over areas of cover. The author does not feel that this is by any means the complete story on sculpin densities, as they are not limited to the shallow water as are dace. In fact, it is very probable that these fish have a much different water temperature preference and probably seek out the same.

Considering all species combined, there is an increase of 44 times more area

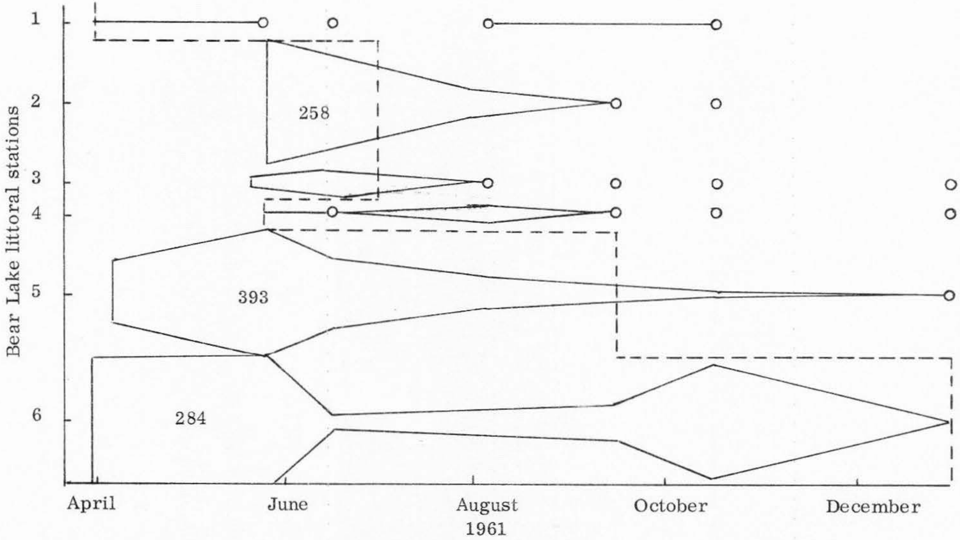

Figure 30. Small-fish densities based on all species during 1961 at the six Bear Lake littoral zone stations. One-fourth inch on the vertical scale is equal to 50 fish. All results expressed as fish per 1,000 square foot sample. Left of the dotted line denotes rocks on the bottom. Right of the dotted line indicates a sand bottom. Circle around point indicates a zero collection.

Table 4. Fish densities of the Bear Lake littoral zone expressed as square feet of bottom per fish

Species	Any cover	Rock	Rock-sand	Sand
Dace	18	15	29	6,667
Sculpin	17	12	278	12,500
All species	8	7	24	355

per fish in sand areas as compared to those areas with cover. Figure 31 shows the decline in small fish numbers with a reduction in cover quality at one of the Bear Lake littoral zone stations.

The analysis of variance of Table 5 for rock, rock-sand, and sand bottom types versus dace densities in the littoral zone was significant at the 99 per cent level of confidence. A separate analysis of variance for cover versus no cover and dace densitities (Table 6) was also highly significant, thereby indicating that the dace densities are very dependent on cover quality.

Sculpin densities versus rock, rock-sand, and sand bottom types are analyzed in Table 7. For this particular analysis of variance, there was a highly significant difference in bottom types versus sculpin densities. However, in the analysis of variance of Table 8, where cover versus no cover is checked against sculpin densities, the significant difference has now dropped to the 95 per cent level of confidence. It is further thought by the author that this may be

Table 5. Analysis of variance of rock, rock-sand, and sand bottom types versus dace densities in the Bear Lake littoral zone, 1961

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	2	33, 199.57	16, 599.78	11.43**
Within	34	49, 369.25	1, 452.04	
Total	36	82, 568.82		

**Significant at the 99 per cent level of confidence.

Table 6. Analysis of variance of cover versus no cover and dace densities in the Bear Lake littoral zone, 1961

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	1	29, 352.30	29, 352.30	19.31**
Within	35	53, 215.92	1, 520.45	
Total	36	82, 568.22		

**Significant at the 99 per cen level of confidence.

Table 7. Analysis of variance of rock, rock-sand, and sand bottom types versus sculpin densities in the Bear Lake littoral zone, 1961

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	2	51, 298. 74	25, 649. 37	5.50**
Within	34	158, 665.35	4, 666. 63	
Total	36	209, 964.09		

**Significant at the 99 per cent level of confidence.

Table 8. Analysis of variance of cover versus no cover and sculpin densities in the Bear Lake littoral zone, 1961

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	1	30, 071. 83	30, 071. 83	5.85*
Within	35	179, 892.26	5, 139.78	
Total	36	209, 964.09		

*Significant at the 95 per cent level of confidence.

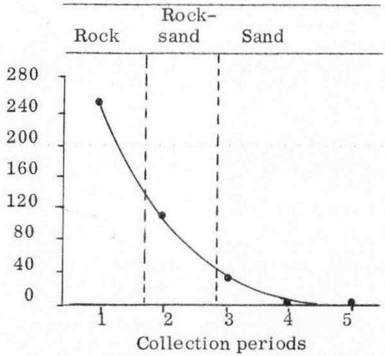

Figure 31. Small fish population dynamics during changes in bottom type at station two of the Bear Lake littoral zone. The data here are expressed as fish per 1000 square-foot sample.

due to the fact that the sculpins are not tied in so closely to the rock areas of the littoral zone as are the dace and other species.

The analysis of variance of rock, rock-sand, and sand bottom types versus total small-fish densities in the littoral zone of Table 9 shows a highly significant difference between types. This is also true for the analysis of variance of Table 10, where the test is made for cover versus no cover and total small fish densities.

The conclusion which is indicated again in this section of the research is that cover is the controlling agent in small fish densities in the Bear Lake littoral zone. The only exception possibly is the sculpin, which is not so specific in its cover requirements as are the other small fish species.

Table 9. Analysis of variance of rock, rock-sand, and sand bottom types versus total small-fish densities in the Bear Lake littoral zone, 1961

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	2	164, 089.60	82, 044.80	18.07**
Within	34	154, 373.29	4, 540.39	
Total	36	318, 462.89		

**Significant at the 99 per cent level of confidence.

Table 10. Analysis of variance of cover versus no cover and total small-fish densities in the Bear Lake littoral zone, 1961

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	1	121, 527.78	121, 527.78	12.71**
Within	35	196, 935.11	9, 562.67	
Total	36	318, 462.89		

**Significant at the 99 per cent level of confidence.

Station Distribution

Materials and methods

During the summer of 1962, an experiment was set up to study the depth penetration of some of the small fish of the littoral zone. Dace were suspected to be limited almost entirely to the rock areas of the lake or to the extremely shallow water. In either of these areas a form of cover was provided.

In order to study this part of the distribution of the Bear Lake fishery, stations were selected where fish were abundant, to see just how far out into the lake these fish might move. Inasmuch as this study was carried out during the summer months, when vacationers, boaters, and swimmers were abundant, any feasible study had to be set up so that no traps or markers were visible on or near the surface of the lake. The experimental stations were located at Rainbow Cove on the east side of the lake, and off the Utah State University breakwater on the west side of the lake.

Standard 18-inch minnow traps were set up on the bottom near the transition area between rock to sand. These traps were tied to a common nylon tether line 20 feet apart and were baited with hay pellets or raw deer meat suspended in a cloth bag inside the trap.

The traps were positioned with SCUBA gear and were checked the same way. In this way, tallies were made without ever bringing the traps to the surface.

Deeper, open water penetration was studied in a similar manner, the only real difference being the fact that the traps were set out on a sand bottom area.

The SCUBA gear was further employed in the visual observation of these fish during diurnal periods, at these and other areas of the lake.

Results and analysis

The underwater observations indicated that while dace were abundant they were also very wary and tended to stay close to cover. On being approached underwater they would dive into the crevices about the roocks and vanish. This was also true of other species such as green sunfish and red-side shiners. Water turbidity seemed to reduce the waryness of all species.

Sculpin exhibited quite a different reaction. They would stay very still unless disturbed, after which they would swim for a short distance and again come to rest on a rock or on the sand bottom. In either case they were extremely well camouflaged.

Observations in the sand areas away from any cover indicated that sculpins were present almost everywhere, although they appeared to be most abundant in the rock areas. On the other hand, dace, red-side shiners, green sunfish, chub, small carp and crayfish appeared to be restricted almost entirely, if not completely, to the rock areas.

The minnow traps are constructed with the trap entrance off the bottom. Subsequently, the sculpin which are bottom "movers" and "feeders" were not captured in these traps unless algae accumulated on the approach screen. However, because sculpin were known by observation to be in the sand areas of intermediate water depths and by gill netting in deeper water, it was not felt that their lack of trapping was a serious limitation.

Minnow traps proved to be adequate for crayfish, dace, red-side shiners, green sunfish, and young suckers. There was a slight bait preference (67 per cent) by fish for the traps baited with hay pellets, while the number of crayfish captured was 45 per cent in those traps baited with hay pellets.

Although the number of fish caught in the traps were quite low, the results were probably quite indicative of the situation. The 135 trap days and nights near rock areas yielded 100 per cent of the fish and crayfish, while 105 trap days and nights over sand did not result in the catch of a single fish. At no time were the traps over sand more than 150 feet from rock cover, yet in this particular experiment fish were not caught in this area. In rock areas, the capturable species were apparently caught as easily during nocturnal periods as during diurnal periods, indicating movement during darkness and light.

Rock-cluster Experiment

Materials and methods

The rock-cluster experiment was set up on the northeast side of the lake, one mile north of the North Eden delta. Rock piles were established over a sand bottom area in shallow water away from any other cover.

The setting up procedure was as follows: Suitable rock were selected in the Rainbow Cove area. They were then transported by boat to a sandy beach area in the cove north of the North Eden delta. This experiment was set up to determine whether there was any difference in fish numbers in the rocks of different qualitative and quantitative arrangements. Therefore, two types of rocks were selected as follows: flat rocks, two to four inches thick and approximately 14 inches in diameter, and rocks with mass, from 10 to 16 inches in diameter.

Three replicates were established under each of the following conditions in 6-foot diameter clusters: mass rocks, one layer; mass rocks, two layers; flat rocks, two layers; and flat rocks, several layers. One other combination, that of flat rocks one layer deep was eliminated at the start of the experiment because of the encroachment of sand into the spaces between the rocks and the subsequent removal of the cover condition to be tested.

These clusters were laid out approximately 25 yards apart in about 3 feet of water. The arrangement as to the rock combination in the line was random.

Results and analysis

The first observations of the rock-clusters were made one week following the establishment of the experiment. It was noted that small fish, mainly dace and sculpin, had begun to concentrate in the clusters. From previous samples it had been determined that small fish were very scarce over a sand bottom area. However, the fact that these fish were moving into the rock-clusters within one week indicated that they were passing through the sand area. One possibility is that they moved through the area under the protection of the shallow water. Other factors which could afford these small fish some temporary protection would be the cover provided by darkness and increased turbidity.

At the end of two and one-half months the experiment was terminated and the fish were collected from the rock-clusters with a 230 volt D. C. shocker. The results of this collection are given in Figure 32.

Three analysis of variance tests were made to determine if there was a significant difference between rock-cluster types and densities for dace, sculpin, and all species in general. Table 11 shows that the difference in rock-cluster quality versus density of species in general is highly significant. Since dace make up most of the species the analysis of variance given in Table 12 would also show a highly significant difference. Sculpin, on the other hand, showed little response to the rock-clusters or to their quality. Subsequently, the analysis of variance of sculpin densities versus rock quality of Table 13 showed that there was no significant difference between types for this species.

The dace showed the greatest response to the two-layered, mass rock clusters, and the least response to the one-layered mass rock. The responsiveness of dace to variable cover is undoubtedly very important in the overall population dynamics of this species in Bear Lake.

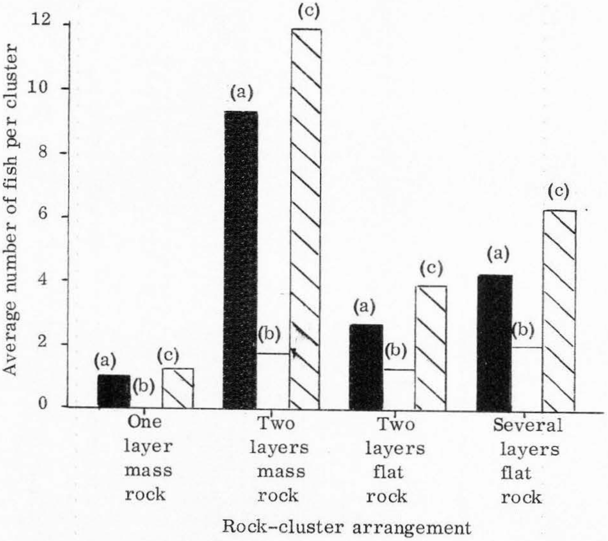

Figure 32. Results of the two and one-half month rock-cluster experiment on the east side of Bear Lake over a sand bottom type. (July 1 to September 14, 1962.) In this figure (a) represents date; (b) represents sculpin; (c) represents all species of fish collected.

Table 11. Analysis of variance of rock-cluster quality versus fish densities in the Bear Lake littoral zone in 1962

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	3	185.58	61.86	10.03**
Within	8	49.34	6.17	
Total	11	234.92		

**Significant at the 99 per cent level of confidence.

Table 12. Analysis of variance of rock-cluster quality versus dace densities in the Bear Lake littoral zone in 1962

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	3	116.66	38.89	12.96**
Within	8	24.01	3.00	
Total	11	140.67		

**Significant at the 99 per cent level of confidence.

Table 13. Analysis of variance of rock-cluster quality versus sculpin densities in the Bear Lake littoral zone in 1962

Source of variation	Degree of freedom	Sum of squares	Mean square	F
Among	3	6.91	2.30	0.73[a]
Within	8	25.34	3.17	
Total	11	32.25		

[a] Not significant.

GROSS ECOLOGY

In attempting to work out some of the relationships which exist in regard to the general ecology of this area, a statistical analysis was set up, where, by means of partial correlation coefficients (r), an attempt was made to measure the degree of linear association between two particular variables after "eliminating" any linear tendency of other variables, to affect jointly the two variables or factors under consideration. If more samples from other years were available for replicates (past or future), then a more complex test could be used to test the interactions which undoubtedly exist. The methods used in the above analysis were taken from Ostle (1956) and Snedecor (1946).

Ordinarily, plankton distribution in the littoral zone includes reactions to depth (light), transportation by water movements, possible dependence on plants and bottom as substratum, and also competition between filter-feeding crustacea (Lindstrom, 1957). However, because Bear Lake has a littoral zone mainly of the "erosion type," it comes under the description given by Welch (1952) where, in general, horizontal distribution of plankton and alterations in it are largely of a mechanical character and are less concerned with profound environmental differences such as are involved in vertical distribution.

On the basis of Table 3 where the analysis of variance indicated that there was no significant difference between stations in regard to plankton dynamics, a second table was subsequently drawn up and the overall mean figure for each category density was set up in regard to net-plankton. From this table of means, Table 14 was then calculated. In this table the gross ecological information in regard to net-plankton from all six stations of the Bear Lake littoral zone during 1961 and 1962 was analyzed by means of partial correlation coefficients (r).

The important relationships which should be obtained from Table 14 are in regard to $X_1 \ldots\ldots X_{10}$ versus $X_{11} \ldots\ldots X_{15}$. However, it should be noted that the (r)-.53 between Ceratium and pH shows the greatest relationship, and even then this is not a significant figure. The significant figures in the table between net-plankters of (r) . 66 for Volvox versus Filinia; (r). 64 for Ceratium versus Copepoda; and (r). 62 for Notholca versus Filinia, probably indicate similar life cycles in the littoral zone area during 1961 and 1962.

The next step in the ecological analysis was to analyze the net-plankton information on a station-to-station basis. Inasmuch as the density figures for the majority of the net-planters were so low, only four of the most consistently appearing forms were checked. In Tables 15 through 20, the partial correlation coefficients (r) were worked out for Conochilus colonies, Polyarthra, cladocerans and the copepods versus the most important of the limnological factors checked, that of water temperature and oxygen concentration of the water. Station one (Table 16) at the north end of the lake has a significant (r)-. 62 for Conochilus versus water temperature. This is the only station of the six checked with such a relationship. However, it should be remembered that the temperature dynamics of this station are somewhat more extreme than at the other stations.

Table 14. Ecological information on net-plankton from all six stations of the Bear Lake littoral zone during 1961 and 1962. Analysis was made on the basis of computed means and is expressed in terms of partial correlation coefficients (r) for plankton per 50-liter sample versus physical and chemical factors.

	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
X_1	.41	-.18	.41	.53	-.16	.66*	.18	-.14	.15	-.15	.18	-.20	-.15	.32
X_2	.	-.13	-.01	.07	-.15	-.06	.51	-.11	.64*	-.41	.43	-.53	.18	-.00
X_3	.	.	-.13	-.03	.05	-.18	-.24	-.16	-.11	.31	-.48	.23	.03	.33
X_4	.	.	.	.01	-.20	.04	.04	.04	.00	-.00	.09	-.16	.17	.02
X_5	.	.	.	.	-.07	.62*	-.07	-.24	.22	.20	-.18	-.14	.19	.25
X_6	.	.	.	.	.	.16	-.32	.47	-.24	-.00	-.14	.11	.19	.44
X_7	.	.	.	.	.	.	-.18	-.11	-.13	.22	-.28	.10	.07	.48
X_8	.	.	.	.	.	.	.	.47	.31	-.24	.38	-.45	.29	-.39
X_9	.	.	.	.	.	.	.	.	-.36	-.21	.26	-.17	.23	-.23
X_{10}	.	.	.	.	.	.	.	.	.	-.09	.15	-.34	.44	.26
X_{11}	.	.	.	.	.	.	.	.	.	.	-.95**	.32	.22	.06
X_{12}	.	.	.	.	.	.	.	.	.	.	.	-.50	-.23	-.26
X_{13}	.	.	.	.	.	.	.	.	.	.	.	.	-.25	.19
X_{14}	.	.	.	.	.	.	.	.	.	.	.	.	.	.19

* Significant at the 95 per cent level of confidence.

** Significant at the 99 per cent level of confidence.

Where:

X_1 is *Volvox*
X_2 is *Ceratium*
X_3 is *Conochilus* colonies
X_4 is *Anuraeopsis*
X_5 is *Notholca*
X_6 is *Polyarthra*
X_7 is *Filinia*
X_8 is *Keratella*
X_9 is Cladocera
X_{10} is Copepoda
X_{11} is water temperature
X_{12} is oxygen concentration
X_{13} is pH
X_{14} is conductivity
X_{15} is hardness

Table 15. Ecological information on net-plankton from station one of the Bear Lake littoral zone during 1961 and 1962. Analysis is expressed in terms of partial correlation coefficients (r) for plankton per 50-liter sample versus oxygen concentration and temperature of the water.

	X_2	X_3	X_4	X_5	X_6
X_1	.20	.02	.24	-.62*	.53
X2		.63*	-.20	-.40	.36
X_3			.06	-.25	.19
X_4				-.22	.25
X_5					-.93**

*Significant at the 95 per cent level of confidence.
**Significant at the 99 per cent level of confidence.

Where:

X_1 represents <u>Conochilus</u> colony numbers
X_2 represents <u>Polyarthra</u> numbers
X_3 represents Cladocera numbers
X_4 represents Copepoda numbers
X_5 represents water temperature

Table 16. Ecological information on net-plankton from station two of the Bear Lake littoral zone during 1961 and 1962. Analysis is expressed in terms of partial correlation coefficients (r) for plankton per 50-liter sample versus oxygen concentration and temperature of the water.

	X_2	X_3	X_4	X_5	X_6
X_1	-.14	-.11	-.11	.19	-.12
X_2		.96**	.24	.21	.07
X_3			-.05	-.36	.20
X_4				-.17	.23
X_5					-.95**

** Significant at the 99 per cent level of confidence.

Where:

X_1 represents Conochilus colony numbers

X_2 represents Polyarthra numbers

X_3 represents Cladocera numbers

X_4 represents Copepoda numbers

X_5 represents water temperature

X_6 represents oxygen concentration of the water

Table 17. Ecological information on net-plankton from station three of the Bear Lake littoral zone during 1961 and 1962. Analysis is expressed in terms of partial correlation coefficients (r) for plankton per 50-liter sample versus oxygen concentration and temperature of the water.

	X_2	X_3	X_4	X_5	X_6
X_1	.24	-.20	.78**	-.30	.15
X_2		-.12	.40	.34	-.47
X_3			-.25	.17	-.15
X_4				-.35	.23
X_5					-.97**

** Significant at the 99 per cent level of confidence.

Where:

X_1 represents Conochilus colony numbers

X_2 represents Polyarthra numbers

X_3 represents Cladocera numbers

X_4 represents Copepoda numbers

X_5 represents water temperature

X_6 represents oxygen concentration of the water

Table 18. Ecological information on net-plankton from station four of the Bear Lake littoral zone during 1961 and 1962. Analysis is expressed in terms of partial correlation coefficients (r) for plankton per 50 liter sample versus oxygen concentration and temperature of the water.

	X_2	X_3	X_4	X_5	X_6
X_1	-.16	-.31	-.26	-.34	.20
X_2		-.22	-.21	.53	-.37
X_3			-.33	-.18	.25
X_4				-.35	.35
X_5					-.94**

**Significant at the 99 per cent level of confidence.

Where:

X_1 represents Conochilus colony numbers

X_2 represents Polyarthra numbers

X_3 represents Cladocera numbers

X_4 represents Copepoda numbers

X_5 represents water temperature

X_6 represents oxygen concentration of the water

Table 19. Ecological information on net-plankton from station five of the Bear Lake littoral zone during 1961 and 1962. Analysis is expressed in terms of partial correlation coefficients (r) for plankton per 50-liter sample versus oxygen concentration and temperature of the water.

	X_2	X_3	X_4	X_5	X_6
X_1	-.17	-.10	-.04	.35	-.52
X_2		-.24	-.19	.41	-.52
X_3			-.17	.13	.18
X_4				-.29	.24
X_5					-.90**

** Significant at the 99 per cent level of confidence.

Where:

X_1 represents Conochilus colony numbers

X_2 represents Polyarthra numbers

X_3 represents Cladocera numbers

X_4 represents Copepoda numbers

X_5 represents water temperature

X_6 represents oxygen concentration of the water

Table 20. Ecological information on net-plankton from station six of the Bear Lake littoral zone during 1961 and 1962. Analysis is expressed in terms of partial correlation coefficients (r) for plankton per 50-liter sample versus oxygen concentration and temperature of the water.

	X_2	X_3	X_4	X_5	X_6
X_1	.42	-.05	.02	.12	-.36
X_2		.06	.63*	.64	-.44
X_3			.15	.37	-.56
X_4				.79**	-.63*
X_5					-.77**

*Significant at the 95 per cent level of confidence.
**Significant at the 99 per cent level of confidence.

Where:

X_1 represents Conochilus colony numbers

X_2 represents Polyarthra numbers

X_3 represents Cladocera numbers

X_4 represents Copepoda numbers

X_5 represents water temperature

X_6 represents oxygen concentration of the water

At station six (Figure 20) on the east side of Bear Lake, a highly significant relationship between copepods and water temperature existed and a significant relationship occurred between copepods and oxygen concentration.

The significant relationships indicated by the correlation coefficients (r) between species having similar dynamics are Polyarthra versus cladocerans at station one; Polyarthra versus cladocerans at station two; Conochilus versus copepods at station three; and Polyarthra versus copepods at station six.

Other relationships between net-plankters and limnology also exist which may guide future research but which do not reach the significant level for this study. Among these are the (r).53 for Conochilus versus oxygen concentration at station one (Figure 16); the (r).53 for Polyarthra versus water temperature at station four (Figure 18); the (r)-.52 for Conochilus versus oxygen concentration and the (r)-.52 for Polyarthra versus oxygen concentration at station five (Figure 19); the (r).64 for Polyarthra versus water temperature; and the (r)-.56 for Cladocera versus oxygen concentration at station six (Figure 20).

The highly significant negative correlation for water temperature versus oxygen concentration in Tables 14 through 20 is a normal phenomenon. As water becomes warmer, it loses its capacity for oxygen retention; therefore, as the water temperature goes up the oxygen concentration of the water goes down and vise versa.

In examining the information on gross ecology with respect to the fish, two species and a total fish category were analyzed in regard to total net-plankton and the littoral zone limnology at two of the Bear Lake littoral zone stations (Tables 21 and 22). Due to the low fish densities at the stations which exhibited poor protection or poor bottom cover, this analysis was limited to stations five and six, the stations with consistently the greatest fish densities.

The important relationships are for the fish and plankton ($X_1 \ldots\ldots X_4$) versus the limnology ($X_5 \ldots\ldots X_9$). As both of these stations represent about the same exposure on the lake, similar bottom types and similar fish populations, there are certainly some relationships expected to be in common. The relationships, however, are vague as the two closest relationships occur between sculpin and water hardness at station five (Table 21) with a highly significant (r)-.79 and for the same relationship at station six (Table 22) with (r)-.41. A similar relationship is found between total fish numbers and water hardness at station five with (r)-.72 and for the same relationship at station six with (r)-.46.

Although these stations are in several ways quite similar, they nevertheless exhibit some very different relationships. Probably the most graphic in relation to Tables 21 and 22 is total net-plankton versus limnology at each of these stations. In fact, the only (r) value similar is for total net-plankters versus water hardness.

The limnology of these stations show significant relationships between water temperature, water pH, and the oxygen concentration of the water.

Table 21. Ecological formation in relation to fish from station five of the Bear Lake littoral zone during 1961. Analysis is expressed in terms of partial correlation coefficients (r).

	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	-.22	.01	-.48	.17	.34	.15	.22	-.02
X_2		.97**	.64*	-.41	-.79**	.26	-.12	.10
X_3			.54	-.39	-.72**	.30	-.07	.98**
X_4				.16	-.66*	-.02	-.20	.16
X_5					.58*	-.58*	-.34	.54
X_6						-.37	-.04	.23
X_7							.92**	-.88**
X_8								-.92**

* Significant at the 95 per cent level of confidence.
**Significant at the 99 per cen level of confidence.

Where:

X_1 represents dace number

X_2 represents sculpin numbers

X_3 represents total fish numbers

X_4 represents total net-plankton numbers

X_5 represents electrical conductivity of the water

X_6 represents water hardness

X_7 represents water temperature

X_8 represents water pH

X_9 represents oxygen concentration of the water

Table 22. Ecological information in relation to fish from station six of the Bear Lake littoral zone during 1961. Analysis is expressed in terms of partial correlation coefficients (r).

	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
X_1	-.27	.48	-.44	.65*	-.12	-.48	-.11	.10
X_2		.72**	-.02	-.29	-.41	.09	-.02	.27
X_3			-.33	.20	-.46	-.27	-.10	.31
X_4				-.14	.58*	.89**	.64*	-.76**
X_5					-.16	.02	.53	-.47
X_6						.21	.33	-.50
X_7							.73**	-.77**
X_8								-.95**

*Significant at the 95 per cent level of confidence.
**Significant at the 99 per cent level of confidence.

Where:

X_1 represents dace number

X_2 represents sculpin number

X_3 represents total fish numbers

X_4 represents total net-plankton numbers

X_5 represents electrical conducitivity of the water

X_6 represents water hardness

X_7 represents water temperature

X_8 represents water pH

X_9 represents oxygen concentration of the water

DISCUSSION

If an attempt is made to characterize the most influential factor of the littoral zone, probably the factor of water motion would be most important. This is not a new idea, as it is discussed in most literature dealing with this particular lake zone. Carpenter (1928) states that the dominant factor in the littoral zone is the motion of the water. This is not a steady flow in any particular direction, but is a dynamic type of flow, back and forth from shore to open water by wave action (this may be direct, indirect, or slanting action), and along the shore in one direction or another according to the influence of the wind action. Another dynamic force in this area is the constant lowering or raising of the lake level, which either puts protected areas in production or take them out of production. These moving forces have a great influence on the limnology of the Bear Lake littoral zone, as well as on the flora and fauna of this area.

It is interesting to speculate as to the effect of high water versus extremely low water levels on the small-fish populations. As pointed out in this thesis, if the water levels approach the minimum drawdown level, virtually all rock or cover areas are exposed. This would leave only a remnant of the populations in such areas as Mud Lake and the various streams which contribute to the Bear Lake water supply, and which also have available protection areas.

The limnology of Bear Lake has been studied from a variety of angles by several investigators. However, it appears that while such factors as the level of electrical conductivity, hardness, pH, oxygen, turbidity, and a number of other such water factors make the environment what it is, the cycles and periodicities which each projects on the flora and fauna of the littoral zone have little to do with the living cycles there. Of all the chemical factors studied in the Bear Lake littoral zone to date, the one exerting the most force on the living organisms of this niche is that of water temperature.

In the event of calm periods, ice cover, or other mechanical obstructions to wind action in the littoral zone, it is possible to get plankton "blooms" and micro-habitat conditions. Under such conditions the turbidity is reduced, the electrical conductivity will drop (unless influenced by spring action), the water hardness and temperature become more stable, and the oxygen and pH become a result of the immediate environment rather than a result of inward movement of pelagic waters.

The net-plankton organisms studied during this project are quite general in their distribution throughout the littoral zone. From a total net-plankton standpoint, therefore, all areas of the littoral zone possess about the same potential for plankton densities. This is, of course, due to the mechanical nature of the water movements into this area carrying plankters from a more uniform and stable environment, that of open water.

Analysis of net-plankton populations in regard to the general ecology of the lake indicates that there is little dependence in the life cycles of these plankters on limnology fluctuations, whereas there are several similar cycles between species, although these relationships are not yet understood.

Fish and crayfish populations are very dependent upon rocks or other cover for protection. Although there are apparently different cover preferences by the different species of fish found in the littoral zone, they are nevertheless all dependent on littoral zone cover protection for survival. The sculpin is apparently the only fish of the small-fish complex that is not so bound to these cover niches. Because of its different behavioral habits and protective coloration, it seems to be able to survive even in the coverless, open areas of the lake over any bottom type. The limnology of the littoral zone exerts little,if any, influence on small-fish populations, the exception being an occasional high water temperature during the summer in shallow or calm water areas.

Although the bulk of this thesis has dealt with limnological factors, small-fish densities and net-plankton densities within the littoral zone, there are still many other processes going on within this niche. During the summer, the littoral zone is often inhabited by large carp and schools of suckers and chubs. As the water cools off in the fall, many of the trout and whitefish move into this area. In January, the cisco Prosopium gemmiferum uses the rocky east side littoral zone as a major spawning bed for approximately two weeks. By eventually studying most of these species, we may arrive at an image of what the ever-changing Bear Lake pyramid of life approaches. However, from the work accomplished in this regard to date, it is apparent that the life-lines are not as clear-cut as we would first have been led to assume.

SUMMARY

1. The most influential factor of the littoral zone limnology in general is that of water motion.

2. Water conductivity and water hardness in the Bear Lake littoral zone is very erratic and is thought to be controlled by wind-swept water currents.

3. The water temperature and oxygen concentration of the water have a high negative relationship.

4. The temperature of the water is not considered a limiting factor for the biota except in regard to an occasional high temperature during the summer in shallow water areas. Even so, temperature exerts a greater influence on the biota than probably any chemical factor.

5. Oxygen content of the water fluctuates about the saturation point and is not a limiting factor for the biota.

6. Net-plankton densities are fairly uniform throughout the littoral zone and are thought to be controlled by wind-swept water currents from the pelagic areas of the lake. There was no significant difference between stations of the littoral zone for the net-plankters or for the separate category of Copepoda versus the littoral zone stations.

7. There are apparently several similar life cycle fluctuations being exhibited by the net-plankters of the littoral zone, although their exact relationships are not known.

8. Dace, shiners, perch, carp, chub, sunfish, and crayfish densities

in Bear Lake are limited in distribution to the few cover areas within the littoral zone and contributing streams which afford some sort of cover. When all these fish plus the sculpin are grouped together, they show a significant difference in densities between bottom types. There were about 7 square feet of bottom per fish over a rock bottom type, 24 square feet per fish in rock-sand areas, and 355 square feet per fish over sand.

9. There was a significant preference by dace for a habitat with more than one layer of mass rock. There were approximately 15 square feet of bottom per dace in a rock habitat as compared to 29 square feet in rock-sand and 6,667 in sand.

10. The sculpin of the littoral zone in general exhibit a significant difference in numbers between bottom types. In rock areas there were 12 square feet of bottom per sculpin compared to 278 in rock-sand and 12,500 in sand. The lack of sculpin in these littoral zone sand areas was thought to be due to warmer temperatures and not so specifically to lack of cover. Of the fish studied, sculpin are the most independent of cover in the lake. This was thought to be due to the difference in their behavior and coloration adaptabilities.

11. Sculpin and dace are the most common year round species in the littoral zone.

12. The small fish of the littoral zone are active during nocturnal periods as well as during diurnal periods.

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