SOME FACTORS AFFECTING FISH FORAGE PRODUCTION IN FOUR ARIZONA LAKES

by

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ABSTRACT

In an attempt to gain a better understanding of the low rate of fish production in Parker Canyon Lake, several factors influencing fish forage production were measured and compared in Parker Canyon, Woods Canyon, Pena Blanca, and Becker lakes between September 1967 and September 1968. These factors included: standing crops of phytoplankton chlorophyll, planktonic, benthic, and littoral fish forage organisms, plant nutrient import; heavy metal and essential nutrient content of the lake water and the major vascular aquatic plants; fish food habits and growth and temperature stratification.

High correlations were found between inflow nitrate concentrations and standing crops of planktonic (r = .993), benthic (r = .929), and littoral (r = .950) fish forage organisms. Fish forage organisms appeared to be supported primarily by phytoplankton. Data suggest that the forage value of phytoplankton is influenced by nitrate import. Heavy and trace metal concentrations were not believed to be limiting to invertebrate production. Temperature and oxygen stratification limited benthic invertebrate production and restricted access of the fish to deep benthic invertebrate communities. The low turnover rate of aquatic plant biomass in Parker Canyon Lake may limit the trophic contribution of these plants to the invertebrate food chains. The low productivity of Parker Canyon Lake was attributed to low nitrate import.

INTRODUCTION

Fish production and harvest in Parker Canyon Lake have failed to attain desirable levels commensurate with sport fishing demands in the region. An earlier study of Parker Canyon Lake by Glucksman (1965) revealed slow trout growth and low fish condition factor (K_{sl}) during the summer months caused by unfavorable temperature and oxygen stratification and turbidity. It was hoped that in subsequent years after the lake had filled, water conditions in the summer would become more favorable for trout well-being and growth, and harvest would increase. Since filling, turbidity in the lake has decreased substantially. Endress (1967) reports maximum summer water temperatures slightly less than was found by Glucksman (1965). Fish growth and harvest, however, have remained low.

Largemouth bass believed to have been spawned in 1965 (Endress 1967) averaged slightly less than six inches in total length after four growing seasons.

Rainbow trout also exhibit poor growth in Parker Canyon Lake. The majority of 50,000 four-inch rainbow trout fingerlings stocked in April 1965 averaged only eight inches in length one year later.[1] For a lake at its latitude and subject to its temperature regime, fish growth in Parker Canyon Lake is extremely poor. This study was initiated to investigate possible reasons for this unexpected low rate of growth.

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1. Unpublished creel census reports, Arizona Game and Fish Department.

Many workers have investigated various factors influencing the basis of game fish production in lakes. Standing crops of fish food organisms, primary producers, and chlorophyll have often been used as indices of lake productivity. The role of biogenic salts and other essential plant nutrients have also been investigated. Early work by Deevey (1940) showed a correlation between phosphate and alkalinity, and phytoplankton productivity. Kemmerer (1965) discussed the effects of basin morphometry on lake productivity and how it can be important in modifying the effects of inflow phosphate and alkalinity. Kemmerer et al. (1968) suggested that inflow nitrate concentrations may influence the quality of phytoplankton as invertebrate forage.

The effects of trace amounts of essential nutrients on lake productivity have been shown by several investigators (Bradford, Blair, and Hunsaker 1968, Goldman 1966). Hutchinson (1957) discussed the role of several essential trace metals in lake productivity.

Early work by Schuette and Alder (1929) and more recently by Gerloff and Krombholz (1966) on the chemical composition of aquatic plants indicates that the nitrate and phosphate content of the plants may be reliable indicators of the availability of these nutrients in the plants' environment.

To gain a better understanding of game fish production in Parker Canyon Lake, the following factors were periodically measured and compared in Woods Canyon, Becker, Pena Blanca, and Parker Canyon lakes between September 1967 and September 1968:

1. Standing crop of phytoplankton chlorophyll.
2. Standing crops of planktonic, benthic, and littoral fish food organisms.
3. Alkalinity, nitrate, and phosphate of inflow waters.
4. Selected heavy and trace metals in the lake water.
5. Selected metal and organic nitrogen content of the major aquatic plants.
6. Fish food habits.
7. Temperature stratification.

DESCRIPTION OF STUDY AREA

Parker Canyon Lake

Parker Canyon is a warm, monomictic lake located in southeastern Arizona on the western slopes of the Huachuca Mountains, approximately 35 miles east of Nogales and 6 miles north of the U.S.-Mexico border. Oak-juniper woodland is the dominant vegetation type on the 9-square-mile watershed.

Mean summer precipitation (May-September) in the lake vicinity over a 30-year period has averaged 12 inches; mean winter precipitation (October-April) averages 8 inches. Due to the seasonal nature of the precipitation pattern, the three major inflows--Parker Canyon, Collins Canyon, and Merritt Canyon creeks--are intermittent.

At spillway height, the shoreline of the lake is 8.25 miles, mean depth 33 feet, maximum depth 85 feet, surface area 182 acres, with a shoreline development factor of 4.4.

The lake first filled in August 1966. The period of thermal stratification extended from April to October.

Parker Canyon Lake was first stocked in November 1962 with fingerling rainbow trout *Salmo gairdneri* Richardson and has continued to receive fall and winter plants of fry, fingerlings, and catchable trout. Largemouth bass *Micropterus salmoides* (Lacepede) were surreptitiously introduced into the lake, probably early in 1965, and were successful in spawning that spring. Fingerling channel catfish *Ictalurus punctatus* (Rafinesque) have been stocked in the lake on an annual basis since 1965. Unauthorized introductions of bluegill *Lepomis macrochirus* Rafinesque and redear sunfish *Lepomis microlophus* (Gunther) were made in the lake prior to 1968 and have since become relatively abundant.

Red shiners *Notropis lutrensis* (Baird and Girard) were stocked in the lake by the Arizona Game and Fish Department in August 1967 as a forage species but have not been observed since their introduction.

Pena Blanca Lake

Pena Blanca Lake is a moderately productive, warm monomictic impoundment located at 3800 feet in the Pajarito Mountains, Santa Cruz County, Arizona. The lake lies approximately 14 miles northwest of Nogales on the U.S.-Mexico border.

Summer precipitation averages 10 inches; winter precipitation averages about 8 inches. Winter precipitation in 1967-68 probably exceeded this value by several inches. The lake's watershed covers approximately 15 square miles with about two square miles lying in Sonora, Mexico. Oak woodland and open grassland constitute the predominant vegetation types on the moderately steep watershed.

Average depth of the lake is 20 feet; maximum depth is 57 feet; surface area at spillway level is 49 acres; the shoreline development factor is 2.7. Intermittent Pena Blanca Creek is the only major inflow entering the lake.

Water was first impounded in the lake in 1958 and stocked immediately with largemouth bass, channel catfish, and black crappie *Pomoxis nigromaculatus* (LeSueur). The threadfin shad *Dorosoma petenense*

(Gunther) was also introduced at that time as a forage species. Bluegills *Lepomis macrochirus* Rafinesque, green sunfish *Lepomis cyanellus* Rafinesque, brown bullheads *Ictalurus nebulosus* (LeSueur), and mosquitofish *Gambusia affinis* (Baird and Girard) have also been introduced into the lake. Fish growth and production in Pena Blanca is moderately high. McConnell (1963) reports a mean annual centrarchid (bass and crappie) harvest of 138 pounds per acre.

Becker Lake

This lake, owned by the Becker Lake Corporation, is located in Apache County, 2 miles northwest of Springerville, Arizona.

Summer precipitation in the vicinity of the lake averages 9 inches; winter precipitation averages 4 inches. The lake has no outlet. From October to March, evaporation losses and minor irrigation withdrawals are periodically replaced with water from the Little Colorado River through a ditch entering the east side of the lake.

The Little Colorado River at Springerville has a drainage area of about 400 square miles with vegetation varying from Engleman spruce on the upper watershed to gently sloping grasslands surrounding the lake. Lake elevation is 7100 feet. The lake has a mean depth of 10 feet; maximum depth is 20 feet; surface area of 110 acres and a shoreline development factor of 1.3.

Due to frequent high winds in the lake basin and its shallow depth, Becker Lake seldom stratifies. Becker Lake is an extremely fertile and productive lake. Rainbow trout fingerlings planted in October each year have been known to average 16 inches in total length one year later (Stewart 1967). Total trout production is about 300 pounds per acre. This is in addition to an apparently large population of an undetermined species of sucker present in the lake.

Woods Canyon Lake

This dimictic lake is located atop the Mogollon Rim 20 miles southwest of the town of Heber, Coconino County, Arizona.

Precipitation at the lake averages about 12 inches in the summer months and 20 inches during the winter. Vegetation on the lake's 9.5 square mile watershed is predominantly ponderosa pine (*Pinus ponderosa*). Elevation at the lake site is 7500 feet.

The lake has a mean depth of 20 feet; maximum depth of 36 feet, surface area of 51 acres, and a shoreline development factor of 2.6.

During the spring runoff numerous inflows cause strong flushing of the lake. Only two of these, Woods Canyon Creek and an unnamed creek entering the lake from the northwest, continue to flow after the snow cover has melted. Both streams, however, become intermittent during the drier periods of the year. Thermal stratification in the lake usually sets in during April and continues into September.

The lake first filled in 1957 and was stocked with fingerling rainbow trout. Poor growth and survival attributed to the low productivity of the lake and high stocking densities made the stocking of fry and fingerling trout unfeasible. The lake currently receives weekly plants of catchable rainbow trout throughout the summer months. Brown trout *Salmo trutta fario* Linnaeus and brook trout *Salvelinus fontinales*

(Mitchill) have also been introduced into the lake. Golden shiners *Notemigonus crysoleucas* (Mitchill) are extremely abundant in the lake.

MATERIALS AND METHODS

Although the interpretation of standing crops of fish forage organisms as an index of lake productivity has been questioned on the basis that the time interval required to produce the standing is unknown (Odum and Smalley 1959), they appear to be valid indices of potential fish production when fish are abundant and are used as such in this report.

Zooplankton Standing Crop

Zooplankton samples were collected with a metering tow net (#2 mesh), towed at a constant speed for several hundred yards over the long axis of the lake. Although labeled #2 mesh, this net was found to be somewhat larger, probably closer to a #1 mesh net. While being towed horizontally, the net was raised and lowered within the mixing zone which extended to the bottom during turnover. By following this procedure, errors from horizontal and vertical differences in plankton density in the lake should have been minimized.

Plankton samples were transported to the laboratory in 10% formalin and concentrated on tared bolting cloth, dried at 60 C for 24 hours, and weighed to the nearest 0.1 mg after being allowed to cool. Results are presented as mg/m^3.

A homogeneous portion of each plankton sample was examined with a dissecting microscope under low power to determine the relative abundance of specific organisms.

Standing Crop of Benthic Organisms

Benthic invertebrates were collected with an Ekman dredge. Because of the limitations of the dredge and the narrow littoral regions of three of the study lakes, samples were collected only in the deeper mud and silt-covered bottom areas. Generally, six samples were collected during each visit to the lake. Each sample was placed in a sieve-bottomed wash bucket (30 mesh brass wire screen) and rinsed prior to preservation in 10% formalin.

A sugar flotation technique was used for sorting bottom organisms (Anderson 1959) which were identified using keys from Pennak (1953). Sorted organisms were dried at 60 C for 24 hours and weighed to the nearest 0.1 mg on a Mettler balance. Values are expressed as gm/m^2.

Standing Crop of Littoral Weed Organisms

Only weed bed inhabiting invertebrate organisms were collected from the littoral regions of the lakes. Samples were collected with a long handled dip net with razor blades attached around the net hoop. The razor blades cut the plant material which then remained in the net along with any invertebrates associated with it. By making numerous rapid sweeping movements with the net through the weed beds, it was possible to obtain a relatively large quantity of plant material in a short time. Samples were collected at various depths from the predominant weed beds throughout the lakes. The one-gallon glass jars used to transport the plants and live invertebrates were half-filled with water and placed on ice while returning to the laboratory. All invertebrates were separated from the plant material by hand (usually within 24 hours) and were identified using keys of Pennak (1953). Absorbent paper was used to remove excess water from the invertebrates and plant material prior to drying at 60 C for 24 hours. The dried plant material was weighed on a torsion balance to the nearest 0.01 gram. Invertebrates were weighed on a Mettler balance. Invertebrate weight/plant weight ratios were expressed as grams of organisms per kilogram of dried plant material. All plant species were identified by personnel of The University of Arizona Herbarium staff.

Standing Crop of Chlorophyll

Water samples for chlorophyll content determination were collected from the euphotic zone only. The depth of this zone was considered to be the depth at which 1% of the light entering the lake surface remained and was measured with an Ocean Research Equipment submarine photometer connected to a multirange milliameter. Measurements were taken between 11:00 A.M. and 1:30 P.M. When the euphotic depths were less than 4 meters, water samples were collected with a large capacity syringe sampler having an 8-foot extension handle which enabled rapid sampling in the shallower depths. When deeper euphotic depths occurred, water samples were collected with a larger syring which was raised and lowered within the euphotic zone while filling in the manner described by Kemmerer (1968). Pooled 1-liter samples usually collected between 11:00 A.M. and 4:00 P.M. from several areas of the lake were placed on ice within one-half hour and transported to the laboratory in darkness where the water was filtered through "AA" 0.8 μ "Millipore" membrane filters. The filter plus the filtered material was placed in cold 90-95% acetone and allowed to stand in darkness for 24 hours. Optical density of the extracted material was measured at 664 mu with a Bausch and Lomb "Spectronic 20." Chlorophyll concentrations were calculated after the method of Odum, McConnell, and Abbott (1958) and were expressed as mg/m^3.

Trace Metals

Lake water samples for metal analysis were collected in a manner similar to that described for the chlorophyll samples. Samples from the hypolimnion were collected with a three-liter capacity Kemmerer bottle. Pooled water samples were placed on ice in one-liter amber glass bottles soon after collection and transported to the laboratory where all samples were prefiltered through "AA" 0.8 μ "Millipore" membrane filters.

Prior to analysis of selected metals, the following were routinely determined for all water samples by The University of Arizona Soil and Water Testing Laboratory: soluble salts, conductivity, Ca, Mg, Na, Cl, SO_4, CO_3, HCO_3, Fl, B, K, SiO_2, Li, and pH (see Appendix, Table A-8). Heavy and trace metal analyses conducted by the Arizona Soil and Water Testing Laboratory on an atomic absorption spectrophotometer included: Fe, Mn, Cr, Ni, Cu, Pb, Cd, Co, and Sr. Upon return to the laboratory, water samples used for metal analysis were acidified and placed in acid-rinsed 500-ml polyethylene bottles. Efco Laboratories in Tucson conducted trace metal analyses early in the study. They also conducted all analyses for molybdenum using a modified USGS colorimetric method (Clark 1958). Because of the low molybdenum concentrations in the study lakes, a rotary vacuum evaporator was used to concentrate 500 to 1000 ml of sample water to dryness in order to bring the molybdenum content of the sample within the detectable limits of this method.

Three of the four metal analyses of inflow waters entering Parker Canyon Lake and one from Woods Canyon Lake were made by Efco Laboratories. All other inflow metal analyses were made by The University of Arizona Soil and Water Testing Laboratory.

Alkalinity, Nitrate, and Phosphate of Inflow Waters

Samples were collected in one-liter amber glass bottles, prerinsed with the water to be sampled. Rainwater and Thatcher (1960) do not recommend this type of bottle for water collection because of possible ion exchange; however, Kemmerer (1965) was unable to find any serious errors caused by the use of this type of bottle for collecting water to be analyzed for alkalinity, nitrate, and phosphate.

Inflow water was taken as close to the lake as possible without contaminating the sample with water from the lake basin. Samples were collected during interflood periods only. Only flowing water was sampled. All inflows were ephemeral with the exception of the regulated ditch entering Becker Lake from the nearby Little Colorado River. This ditch flowed continuously from October to March.

Alkalinity of inflow waters expressed as mg/l $CaCO_3$ was determined by the method described by American Public Health Association and others (1965). Sulfuric acid (0.02N) supplied by the Hach Chemical Company was used for titration.

Nitrate, orthophosphate, and total phosphate were determined colorimetrically using a Bausch and Lomb "Spectronic 20." The methods were those of APHA (1965) as modified by the Hach Chemical Company. Ortho and total phosphates were determined by the Stannous Chloride Method; nitrate was determined by the Cadmium Reduction Method.

Aquatic Plant Tissue Analysis

Aquatic plants analyzed for organic nitrogen and metal content were collected by hand or with the previously described littoral invertebrate sampler. Only fresh new growth was used for analytical purposes. Fresh plant material from which all invertebrates had been removed was rinsed in tap water to remove attached detritus. Excess moisture was removed from the plants with absorbent paper prior to drying at 60-80 C. Dried petiole samples were powdered in a Waring blender. Organic nitrogen analysis (semimicro-Kjeldahl Method) of the dried samples were made by The University of Arizona Soil and Water Testing Laboratory. Metal analyses of the plant tissues were made by Efco Feed Company Laboratories, Tucson.

Temperature Stratification

Water temperatures were measured at one-foot intervals with a Yellow Springs Instrument Company electric telethermometer. This instrument was occasionally checked for accuracy with a pocket mercury thermometer. Temperatures were usually recorded in the deepest parts of the lakes.

Fish Food Habits

Fish examined for food habits and growth were collected at bi-monthly intervals with two 150-foot nylon gill nets (bar mesh 1-1/16 inches to 1-7/8 inches) set at various depths depending on the temperature regime of the lake and the fish species desired at the time of sampling.

During the winter months, nets were usually set overnight. As the lake water warmed, nets were checked frequently after setting and pulled when the desired sample size was captured, usually 10-20 fish. The abdominal cavities of fish over six inches were slit before placing them in a 10% formalin solution.

Only the contents of the anterior portion of the foregut of each fish was examined with a dissecting microscope. Components of the food found further back in the digestive tract were usually unrecognizable; however, the contents of the anterior portion of the intestines were occasionally examined for the presence of annelid chaetae.

Visual estimates were made of the relative volumes (%) of each group of organisms occurring in the fish stomachs. Total settled volume of the food ingested was determined by placing the stomach contents in a graduated centrifuge tube and allowing it to settle for about five minutes. This also allowed a check of the visual estimates. The organisms were divided into ten or eleven classifications (see Appendix, Table A-5). Plant material included bark and twigs and occasionally fresh aquatic plants. Miscellaneous items included organisms which occurred only occasionally or in very small quantities.

RESULTS

A summary of the mean values of selected factors influencing fish forage production in the four study lakes is presented in Table 1.

Zooplankton Standing Crop

Zooplankton standing crop data are presented in Table 2. Mean zooplankton densities in Becker and Pena Blanca lakes were 700.6 mg/m^3 and 336.7 mg/m^3, respectively. Both of these lakes showed spring and fall peaks in zooplankton standing crops while Parker Canyon Lake, which produced a mean crop of 149.9 mg/m^3, exhibited maximum standing crops during early summer and mid-winter. No zooplankton was found in a water sample collected from Woods Canyon Lake toward the end of the long ice cover period which ended in early April. Mean zooplankton standing crop in Woods Canyon Lake was 81.8 mg/m^3.

Daphnia dominated the zooplankton in all four study lakes throughout the year. Copepods became moderately abundant in Becker Lake during the winter months but were not used heavily as food by the trout.

Chaoborus, a dipteran not previously reported in Becker Lake, accounted for a small portion of the zooplankton standing crop in the lake during late summer and early fall of 1968. *Chaoborus* larvae and *Daphnia* were the predominant zooplankton in Woods Canyon Lake with copepods occurring only occasionally. Copepods were never abundant in Pena Blanca while *Chaoborus* was abundant only during late summer.

Table 1. Mean values of selected factors[a] influencing fish forage production in Parker Canyon, Becker, Pena Blanca, and Woods Canyon lakes.

		Parker Canyon	Becker	Pena Blanca	Woods Canyon
Standing Crops					
Zooplankton	(mg/m^3)	149.9	700.6	336.7	81.8
Benthic invertebrates	(gm/m^2)	0.26	3.34	0.66	0.27
Littoral weed organisms	(gm/kg)	4.10	13.71	10.78	2.45
Phytoplankton chlorophyll	(mg/m^3)	7.12	26.79	29.99	8.44
Inflow Chemistry					
Methyl orange alkalinity	(mg/l)	156.0	84.0	88.4	16.6
Nitrate	(mg/l)	0.063	0.412	0.23	0.036
Orthophosphate	(mg/l)	0.072	0.162	0.082	0.033
Total phosphate	(mg/l)	0.415	0.308	0.40	0.122

a. See Table 8 for means of trace elements and metals in the lake water.

Table 2. Zooplankton standing crop measurements for Parker Canyon, Becker, Pena Blanca, and Woods Canyon lakes, expressed as mg/m^3.

Date	Parker Canyon	Becker	Pena Blanca	Woods Canyon
Sept. 1967	143.3[a]	-	-	-
Oct. 1967	142.8	-	-	-
Nov. 1967	226.3[b]	825.5	-	-
Dec. 1967	-	-	889.6	-[c]
Jan. 1968	266.2[b]	75.2[c]	40.8	-[c]
Feb. 1968	163.5	1243.4	266.8[b]	0.0[c]
Mar. 1968	116.6	1364.4	892.7	-[d]
Apr. 1968	122.0	-	237.1	-
May 1968	-	977.7	-	1.3
June 1968	228.7	466.8	376.5	22.2
July 1968	49.0	448.4	135.8	109.7
Aug. 1968	90.7	614.4	83.2	111.1
Sept. 1968	94.3	292.1	108.5	164.7
Mean	149.9	700.6	336.7	81.8

Tukey's-w = 579.0, 95% confidence interval (Steel and Torrie 1960)

a. Not included in calculations of annual mean

b. Mean of two samples taken during the month

c. Collected through ice

d. Lake not accessible due to heavy snow cover

A highly significant correlation (r = .993) existed between interflood inflows of nitrate and mean zooplankton standing crops. The correlation (r = .890) between an index based on interflood inflows of alkalinity, phosphate, and nitrate (APN index of Kemmerer et al. 1968) and zooplankton standing crops was not significant. Tukey's-w procedure, also called the honestly significant difference (hsd) was chosen for statistical treatment of zooplankton data. The 5% significance level was used for all calculations. Using this very stringent test, the mean zooplankton standing crop in Becker Lake was significantly higher than zooplankton crops in Parker Canyon and Woods Canyon lakes. Differences between Becker Lake and Pena Blanca Lake approached significance. The seasonal variations in the zooplankton standing crops were of necessity accepted as experimental error. Therefore, although the differences in zooplankton standing crops between Woods Canyon, Parker Canyon, and Pena Blanca lakes were not statistically significant, this same relative order of ranking was evident in previous studies (McConnell 1963, Glucksman 1965, Stewart 1967), and it is believed that the differences which occurred are probably real and persistent.

Standing Crop of Benthic Fish Food Organisms

Estimates of standing crops of benthic organisms are presented in Table 3 (see Appendix, Table A-1, for total benthic standing crop including Annelida). Annelid worms, although present in all four lakes and often comprising a large portion of some samples, were excluded from calculations when determining correlations of benthic fish food

Table 3. Standing crops of benthic fish food organisms in Parker Canyon, Becker, Pena Blanca, and Woods Canyon lakes, expressed as gm/m^2.

Date	Parker Canyon	Becker	Pena Blanca	Woods Canyon
1968				
Feb.	-	5.25	-	- [a]
Mar.	0.73	3.20	0.71	- [a]
Apr.	0.21	-	0.61	-
May	-	3.03	-	0.51
June	0.15	0.57	1.20	0.34
July	0.17	1.34	0.52	0.18
Aug.	-	5.68	0.51	0.03
Sept.	0.04	4.37	0.43	0.32
Mean	0.26	3.34	0.66	0.27

Tukey's-w = .923, 95% confidence interval (Steel and Torrie 1960)

a. No samples collected due to heavy snow and ice cover production to other parameters of the lakes. This was done because annelid chaetae were not seen in any of the fish stomachs examined from Becker Lake, Woods Canyon Lake, or Parker Canyon Lake, and they were never found in the diets of centrarchids in Pena Blanca Lake (Biggins 1968). The absence of annelids in the diets of the fish is probably due to the burrowing nature of the organisms and its elimination from the fishes' food chain during long periods of stratification. Rejection of the organism by the fish is also possible (Hayne and Ball 1956). A steady decline in the size of standing crops of benthic organisms was apparent with the onset of summer stratification in Woods Canyon, Parker Canyon, and Pena Blanca lakes. The decrease which occurred in Becker Lake during the early summer months was probably the result of the emergence of larval forms. Large numbers of adult dipterans were noted at this time in the immediate vicinity of the lake.

The correlation between inflow nitrate and standing crops of benthic organisms ($r = .929$) approached significance.

Standing crops of benthic organisms in Becker Lake were found to be significantly greater than those in the other three lakes. No significant differences were found between the other study lakes. The same significance was found with and without the annelid worms being included in the calculations.

Standing Crop of Littoral
Weed Organisms

Standing crops of littoral weed organisms expressed as grams of dry weight of organisms per kilogram dry weight of plant material are presented in Table 4. Figure 1 shows the major vascular aquatic plant species present in the lakes.

In each lake only one plant species was dominant throughout the sampling period. All samples were collected from these plants. *Aufwuchs* which developed on the plants in the summer appeared to have little effect on the macroinvertebrate fauna associated with the plants. The densities of littoral invertebrates did not appear to be directly related to the standing crops of aquatic plants or the particular species present in the lake. The large population of golden shiners in Woods Canyon Lake may have complicated this relationship somewhat by greatly reducing the invertebrate crops in the *Potamogeton* beds in this lake.

Marl accretions on the plants in Parker Canyon Lake became moderately heavy late in the summer and resulted in a small undetermined weight of inorganic material being included in the total weight of dried plant material. The "organism/weed" ratio should therefore be considered minimal in this lake.

A significant correlation (r = .950) was found between inflow nitrate and the mean standing crops of weed organisms in the four study lakes. Differences in the weed organisms standing crops in the four study lakes failed to approach significance. Fluctuations in the number of organisms per gram dry weight of the predominant aquatic plants are shown in the Appendix, Table A-2.

Amphipods (tentatively identified as *Gammarus*) were abundant in the *Myriophyllum* beds in Parker Canyon Lake during the early spring

Table 4. Littoral weed organism standing crops in Parker Canyon, Becker, Pena Blanca, and Woods Canyon lakes, expressed as gms invertebrate/kg dry weight of plant material.

Date	Parker Canyon	Becker	Pena Blanca	Woods Canyon
1968				
April	4.71	-	40.59	-
May	-	12.22	-	-
June	4.47	33.42	10.20	-
July	5.02[a]	8.35	1.48	2.73
August	1.87[a]	7.37	0.68	2.61
September	4.45	7.91	1.02	2.03
Mean	4.10	13.71	10.78	2.45

Tukey's-w = 29.8, 95% confidence interval (Steel and Torrie 1960)

a. Mean of two samples taken during the month

	Parker Canyon	Becker	Pena Blanca	Woods Canyon
Typha sp.	x	x	x	x
Paspalum dicticum	x			
Potamogeton berchtoldii	x			
Myriophyllum exalbescens	x[a]	x[a]		
Scirpus sp.	x	x		
Potamogeton pectinatus	x	x	x[b]	
Potamogeton latifolius		x		
Potamogeton pusillus		x		
Potamogeton richardsonii		x		
Polygonum amphibium		x		
Ceratophyllum demersum		x	x[a]	
Potamogeton sp.			x	
Najas quadalupensis			x	
Hydrodicton sp.			x	
Potamogeton gramineus				x[a]
Nitella sp.				x

Figure 1. Major vascular plant species present in Parker Canyon, Becker, Pena Blanca, and Woods Canyon lakes.

a. Predominant plant in lake

b. Tentative identification

months but declined sharply during the summer. This decline was probably due to the high summer water temperatures. Ball (1949) reports the critical maximum temperature for Gammarus fascinatus at 60 to 65 F. Ephemeroptera showed a similar decline and were absent from samples after April. Zygoptera nymphs and gastropods fluctuated in abundance throughout the sampling period, while Trichoptera nymphs increased steadily.

Zygoptera nymphs and gastropods predominated in the littoral fauna in both Pena Blanca and Becker lakes and in both lakes their numbers fluctuated considerably from one sampling to the next. Zygoptera nymphs constituted the major fish food organism present in the Potamogeton beds at Woods Canyon Lake.

Standing Crop of Chlorophyll

Phytoplankton chlorophyll standing crops in the four study lakes are presented in Table 5.

Both Woods Canyon Lake and Becker Lake exhibited summer peaks in chlorophyll standing crops with an additional peak occurring in Becker Lake in late fall. Parker Canyon and Pena Blanca lakes exhibited mid-winter peaks. The winter peaks, particularly in Pena Blanca Lake, were undoubtedly influenced by the abnormally heavy rains which occurred over most of southern Arizona during the winter of 1967-1968. During the peak storm period of mid-December, Pena Blanca Lake had in excess of 3½ feet of water flowing over the spillway. The highly turbid water entering the lake resulted in photic depths of less than 0.5 meters. The large quantities of nutrients brought into the lake

Table 5. Standing crops of chlorophyll in Parker Canyon, Becker, Pena Blanca, and Woods Canyon lakes, expressed as mg/m^3.

Date	Parker Canyon	Becker	Pena Blanca	Woods Canyon
1967				
September	3.48[a]	-	-	-
October	6.30	-	-	-
November	5.02[b]	43.00	-	-
December	-	-	5.70	-[c]
1968				
January	11.37[b]	19.65	71.40	-[c]
February	12.28	26.90	212.00[a]	4.35
March	7.50	21.32	39.08	-[c]
April	5.40	-	27.60	-
May	-	23.00	-	22.00
June	3.15	38.20	31.00	9.00
July	4.00	31.00	32.10	4.00
August	8.00	19.00	17.50	5.90
September	8.20	19.00	15.60	5.40
Mean	7.12	26.79	29.99	8.44

a. Not included in calculating annual mean

b. Mean of two samples collected during the month

c. Lake inaccessible due to heavy snows

during this storm caused an immediate increase in phytoplankton chlorophyll production. The February 1968 value of 212 mg/m^3 was the highest ever recorded in the lake. By April chlorophyll concentrations had subsided considerably but continued to remain above the pre-winter rainy season values for at least nine months and above a three-year mean of 25 mg/m^3 (McConnell 1963) for almost seven months.

Mean chlorophyll standing crop in Becker Lake is essentially the same as was found by Stewart (1967). Chlorophyll crops in Parker Canyon Lake and Woods Canyon Lake were both considerably lower than during previous investigations. Glucksman (1965) found a mean chlorophyll crop of 18.8 mg/m^3 in Parker Canyon Lake immediately following its construction. During 1965-1966, the mean chlorophyll standing crop in Woods Canyon Lake was 15.6 mg/m^3 (Stewart 1967). This was almost twice the concentration found during the current study.

Volvox sp. was abundant during the winter months at Pena Blanca Lake. Becker Lake exhibited a large bloom of diatoms during the early spring. The dinoflagelate *Ceratium* sp. became extremely abundant during late spring and early summer and frequently gave the water a reddish brown cast. A large colonial filamentous blue-green alga, probably *Anabaena*, was abundant during the summer months. At Woods Canyon Lake, blue-greens were only incidental in the phytoplankton with diatoms or *Chlorophyta* predominating during most of the year (Stewart 1967). *Chlorophyta* predominated in the phytoplankton in Parker Canyon Lake.

Inflow Chemistry

The range and mean of alkalinity, nitrate, and phosphate entering the four lakes through tributary streams are presented in Table 6.

The large range of inflow alkalinity at Parker Canyon Lake was caused primarily by the low values recorded in Collins Canyon Creek. The geology of this drainage differs from Parker Canyon and Merritt Canyon in that igneous, rather than sedimentary rocks, make up most of the formations, thus accounting for the low alkalinities recorded (Kemmerer 1965). The high mean alkalinity entering Parker Canyon Lake should be noted however.

In general, alkalinity in the inflow varied inversely with flow rate. Ruttner (1963) discusses the effects of both slow percolation of water through soil and rapid surface runoff on the alkalinity of inflow waters. Nitrate content of the inflows varied directly with flow rate. Kemmerer (1965) and Stewart (1967) reported similar findings.

Eight flood water samples, collected during successive stages of a mid-summer flashflood in Pena Blanca Creek (Table A-4), contained only moderate amounts of phosphate. Ground water samples collected two days after the flood contained considerably greater quantities of phosphate, indicating the importance of the period of contact of ground water with underlying rock strata in determining the phosphate content of inflow waters. The usual gentle rain showers occurring during the winter months, which allow slow runoff and long periods of percolation through underlying rock, would therefore favor high phosphate concentrations in the inflows. This is in contrast to the flashflood-producing summer

Table 6. Inflow concentrations of alkalinity, nitrate, and phosphate entering Becker, Pena Blanca, Parker Canyon, and Woods Canyon lakes, expressed as mg/l. Only interflood flows of 2.0 cfs or less are included.

	Sample Size	Maximum	Minimum	Mean[a]
Becker Lake				
Phenolphthalein alkalinity	5	0.0	0.0	0.0
Methyl orange alkalinity	5	102.00	48.0	84.0
NO_3	5	0.7	0.1	0.412
Ortho PO_4	5	0.18	0.12	0.162
Total PO_4	5	0.48	0.21	0.308
Pena Blanca Lake				
Phenolphthalein alkalinity	11	0.0	0.0	0.0
Methyl orange alkalinity	10	184.0	65.0	88.4
NO_3	9	1.1	0.1	0.23
Ortho PO_4	9	0.21	0.02	0.082
Total PO_4	9	0.50	0.19	0.40
Parker Canyon Lake				
Phenolphthalein alkalinity	34	0.0	0.0	0.0
Methyl orange alkalinity	34	241.0	21.0	156.0
NO_3	34	0.39	0.00	0.063
Ortho PO_4	34	0.22	0.01	0.072
Total PO_4	34	0.83	0.17	0.415
Woods Canyon Lake				
Phenolphthalein alkalinity	14	0.0	0.0	0.0
Methyl orange alkalinity	14	30.0	10.0	16.6
NO_3	14	0.05	0.00	0.036
Ortho PO_4	12	0.11	0.02	0.033
Total PO_4	12	0.44	0.10	0.122

a. Means are combined weighted values from this study (Table A-3) and from Kemmerer (1965) and Stewart (1968).

rainstorms which, due to their watershed scouring nature, would tend to remove relatively large quantities of organic material from the watershed and thus favor high nitrate concentrations in the inflows.

Metal analyses of three inflows entering Parker Canyon Lake and one entering Woods Canyon Lake are presented in Table 7. Kemmerer (1965) presents results of qualitative spectrographic analyses of ground water inflows for Woods Canyon, Parker Canyon, and Pena Blanca lakes.

Metal Content of Lake Water

The concentrations of trace elements and metals in the epilimnetic waters of Becker, Woods Canyon, Pena Blanca, and Parker Canyon lakes are presented in Table 8. Concentrations of selected chemical factors determined prior to trace metal analyses are presented in Table A-8 (see Appendix).

Ruttner (1963) emphasizes the importance of trace elements in the productivity of waters and accounts for differences in apparently similar waters on the presence or absence of essential trace elements. Devlin (1967) lists five trace elements as being essential for normal growth and development of most plants. These include: manganese, zinc, boron, copper, and molybdenum. In addition to these, Hutchinson (1967) includes iron, silica sodium, cobalt, and vanadium. Other elements such as aluminum and gallium have been shown to be essential for growth of certain plants; however, evidence of their essential requirement for growth in the majority of plants is lacking and they were not considered in this study. Vanadium content of the lake water was not

Table 7. Atomic absorption analyses[a] of selected metals in three inflows entering Parker Canyon Lake (5 Jan. 1968) and an unnamed inflow entering Woods Canyon Lake (30 March 1968), expressed as mg/l.

Metal	Parker Canyon Creek	Merritt Canyon Creek	Collins Canyon Creek	Unnamed Creek Woods Canyon Lake
Magnesium	2.70	5.04	1.69	0.388
Potassium	1.31	0.99	2.58	0.483
Sodium	6.03	13.4	6.03	4.56
Cobalt	<0.1[b]	<0.1[b]	<0.1[b]	<0.1[b]
Copper	<0.1[b]	<0.1[b]	<0.1[b]	<0.1[b]
Iron	<0.1[b]	<0.1[b]	<0.1[b]	0.154
Manganese	<0.04[b]	<0.04[b]	<0.04[b]	0.013
Zinc	<0.02[b]	<0.02[b]	<0.02[b]	0.017
Chromium	<0.05	<0.05	<0.05	<0.05
Nickel	<0.3[b]	<0.3[b]	<0.3[b]	<0.3[b]
Lead	<0.2[b]	<0.2[b]	<0.2[b]	<0.2[b]
Lithium	<0.05[b]	<0.05[b]	<0.05[b]	<0.05[b]
Molybdenum	<2.5[b]	<2.5[b]	<2.5[b]	0.30

a. Analyses conducted by EFCO Laboratories, Tucson, Arizona.

b. Detection limit of analytical procedure used.

Table 8. Concentrations of trace elements and metals[a] in the epilimnetic waters of Becker, Woods Canyon, Pena Blanca, and Parker Canyon lakes, expressed as mg/l.

	Becker Lake		Woods Canyon Lake	
	Mean and Range	Sample Size	Mean and Range	Sample Size
B	0.16 (0.12-0.20)	5	0.052 (0.00-0.08)	5
Fe	0.023 (0.009-0.047)	5	0.140 (0.075-0.188)	5
Mn	0.007 (0.003-0.018)	5	0.007 (0.002-0.019)	5
Cr	0.00 (0)	5	0.00 (0)	5
Ni	0.00 (0)	5	0.00 (0)	5
Cu	0.013 (0.005-0.034)	5	0.038 (0.001-0.130)	5
Zn	0.0136 (0.009-0.024	6	0.024 (0.013-0.035)	5
Pb	0.004 (0.0-0.021)	5	0.012 (0.0-0.038)	5
Cd	0.000 (0.0-0.003)	5	0.002 (0.0-0.003)	5
Co	0.00 (0)	5	0.001 (0.0-0.007)	5
Sr	0.763 (0.342-2.033)	5	0.275 (0.0-0.961)	5
Mo[b]	0.006 (0.002-0.013)	3	0.003 (0.001-0.007)	3

Table 8.--Continued

	Pena Blanca Lake		Parker Canyon Lake	
	Mean and Range	Sample Size	Mean and Range	Sample Size
B	0.304 (0.06-1.00)	5	0.05 (0.0-0.08)	5
Fe	0.225 (0.022-0.390)	6	0.026 (0.0-0.70)	5
Mn	0.155 (0.002-0.392	6	0.011 (0.004-0.023)	5
Cr	0.00 (0)	5	0.00 (0)	5
Ni	0.001 (0.00-0.005)	5	0.00 (0)	5
Cu	0.013 (0.006-0.029)	5	0.017 (0.08-0.034)	5
Zn	0.012 (0.006-0.021)	5	0.013 (0.007-0.022)	5
Pb	0.043 (0.00-0.096)	5	0.032 (0.00-0.115)	5
Cd	0.002 (0.00-0.006)	5	0.001 (0.00-0.004)	5
Co	0.00 (0)	5	0.00 (0)	5
Sr	0.161 (0.00-0.352)	5	0.229 (0.00-0.760)	5
Mo[b]	0.0101 (0.0032-0.0200)	3	0.0044 (0.0029-0.0070)	4

a. Detection limits: Fe, Mn, Ni, Cu, and Co, 0.01 mg/l; Cr and Pb, 0.05 mg/l; Zn, 0.005 mg/l; Mn, 0.001 mg/l and less, Cd, 0.004 mg/l; Sr, 0.2 mg/l.

b. Molybdenum concentration determined by EFCO Laboratories, Tucson, Arizona, using a modified USGS colorimetric method (Clark 1958).

c. See Appendix, Table A-7, for specific concentrations.

determined. Some trace elements were not always found in the study lakes. During June, four of the nine essential metals were absent from the epilimnetic waters of Parker Canyon Lake. Cobalt only occurred in one sample. This sample was collected from Woods Canyon Lake in May 1968. Hutchinson (1957) found values of .00002-.00004 mg/l cobalt in a Connecticut pond, all apparently sestonic. The prefiltering of the water samples prior to metal analysis would have removed all sestonic forms had they been present in the sample; however, cobalt concentration of this magnitude would not have been detected with the analytical procedures used in this study.

Molybdenum concentrations found in the lakes were higher than those levels considered to be limiting in several high Sierra lakes in California (Goldman 1966, Bradford et al. 1968). Metal concentrations in the lake water samples may be somewhat below actual levels due to the absorption of metal ions on the walls of the sample bottles. The high copper and zinc concentrations found in the hypolimnion (Table A-7) were in contrast to the uniform levels reported throughout a stratified pond by Hutchinson (1957) and may have been due to contamination from the walls of the brass Kemmerer bottle.

Aquatic Plant Tissue Analysis

Organic nitrogen and atomic absorption spectrophotometric analyses of petiole samples from selected aquatic plant species in the study lakes are presented in Tables 9 through 12.

Because of environmental differences in the study lakes, it was not always possible to obtain identical species from all four lakes,

Table 9. Kjeldahl nitrogen and metal concentrations in *Myriophyllum exalbescens* petiole samples from Parker Canyon and Becker lakes, expressed as ppm.

Date	Co	Cu	Fe	Mg	Mn	Zn	Cr	Ni	Pb	Mo	% Kj-N
Parker Canyon Lake											
Myriophyllum exalbescens											
19 Oct. 1967	1.2	7.3	54	-	154	22	<1.3	<3	<5	.17	1.13
16 Mar. 1968	3.1	7.0	732	2540	182	42	3	7	<2	1.30	2.24
6 June 1968	1.7	13.3	468	1990	479	62	<4	<3	<2	-	1.89
11 July 1968	1.1	10.1	247	1900	264	253	<4	<3	<2	.30	2.97
7 Aug. 1968	2.0	8.9	189	1200	191	436	<5	<3	<2	2.10	3.03
Becker Lake											
Myriophyllum exalbescens											
10 Nov. 1967	1.1	6.5	556	-	186	14	<1.3	<3	5	.7	1.83
19 June 1968	3.0	.7	412	4190	96	26	3	7	5	2.4	3.04
23 July 1968	2.0	5.9	289	4730	147	151	<4	<3	2	2.8	1.75
18 Aug. 1968	<1	9.0	214	4340	151	56	<5	<3	2	.87	1.67

Table 10. Kjeldahl nitrogen and metal concentrations in <u>Ceratophyllum demersum</u> petiole samples from Pena Blanca and Becker lakes, expressed as ppm.

Date	Co	Cu	Fe	Mg	Mn	Zn	Cr	Ni	Pb	Mo	% Kj-N
Pena Blanca Lake											
<u>Ceratophyllum demersum</u>											
19 April 1966	7.1	11	467	3950	138	77	1	5	<2	.7	-
5 June 1968	2.5	12.6	275	2830	883	124	<4	<3	<2	1.4	4.55
9 July 1968	3.4	12.2	505	3790	3670	72	<4	<3	<2	.3	3.46
6 Aug. 1968	6.8	7.3	379	3370	579	374	<5	<3	<2	1.0	3.06
14 Sept. 1968	-	-	-	-	-	-	-	-	-	-	2.21
Becker Lake											
<u>Ceratophyllum demersum</u>											
19 June 1968	10	17	866	9380	484	34	7	17	24	1.6	3.89

Table 11. Kjeldahl nitrogen and metal concentrations in *Potamogeton pectinatus* petiole samples from Parker Canyon, Becker, and Pena Blanca lakes, expressed as ppm.

Date	Co	Cu	Fe	Mg	Mn	Zn	Cr	Ni	Pb	Mo	% Kj-N
Parker Canyon Lake											
P. pectinatus											
6 June 1968	4.5	8.1	411	2130	773	478	4	3	2	.3	-
Becker Lake											
P. pectinatus[a]											
23 July 1968	4.5	4.5	326	9360	141	27	4	3	2	3.0	1.42
Pena Blanca Lake											
P. pectinatus[a]											
14 September 1968	-	-	-	-	-	-	-	-	-	-	2.03

a. Tentative identification

Table 12. Kjeldahl nitrogen and metal concentrations in selected plant petiole samples from Woods Canyon, Pena Blanca, and Parker Canyon lakes, expressed as ppm.

Date	Co	Cu	Fe	Mg	Mn	Zn	Cr	Ni	Pb	Mo	% Kj-N
Woods Canyon Lake											
Potamogeton gramineus											
20 June 1968	3.0	14.0	619	6080	237	64	3	4	< 5	0.2	3.74
25 July 1968	1.4	8.8	36.4	6520	158	172	< 4	< 3	< 2	0.3	2.56
18 Aug. 1968	< 1.0	12.0	350	3590	193	133	< 5	< 3	< 2	1.4	1.87
Nitella sp.											
3 May 1968	8.1	19.0	5560	4060	4100	61	2	9	< 2	0.4	4.39
20 June 1968	5.0	0.9	2958	5790	1128	347	9	14	21	1.6	2.94
25 July 1968	6.9	13.8	2268	5860	3020	58	4	< 3	< 2	0.3	2.68
18 Aug. 1968	9.0	20.0	3710	5570	917	356	14	17	< 2	1.4	3.37
Pena Blanca Lake											
Hydrodicton sp.											
5 June 1968	-	-	-	-	-	-	-	-	-	-	2.03
Parker Canyon Lake											
Potamogeton berchtoldii											
6 June 1968	-	-	-	-	-	-	-	-	-	.4	2.24

Myriophyllum exalbescens was the predominant species in both Becker and Parker Canyon lakes. The dominant plant in Pena Blanca Lake, *Ceratophyllum demersum*, was found only once in Becker Lake, making comparisons based on this species difficult. Although *Potomogeton pectinatus* was found in all lakes except Woods Canyon, positive identification was possible only in Parker Canyon Lake. No other positively identified species common to at least two lakes were found in sufficient quantity to warrant comparative analyses.

In comparing *M. exalbescens* in Becker and Parker Canyon lakes, the two most apparent differences occurred in the magnesium and zinc concentrations. The mean magnesium content of the plants in Parker Canyon Lake was less than half the mean value found in the plants in Becker Lake. This might be expected considering the higher mean magnesium concentration in Becker Lake, which was seven times greater than in Parker Canyon Lake.

Zinc concentrations were considerably higher in the *Myriophyllum* in Parker Canyon Lake than in Becker Lake despite lower zinc levels in Parker Canyon Lake water. The presence or absence of another element which might inhibit the absorption of zinc in Becker Lake plants might account for this inconsistency (Devlin 1967).

The mean nitrogen content of *M. exalbescens* in Becker and Parker Canyon lakes was not significantly different. The mean nitrogen content of *C. demersum* in Pena Blanca Lake was slightly higher than the one sample of this species collected in Becker Lake. The relatively small differences in the intra- and interspecific nitrogen contents of the plants analyzed probably reflect differences in growth habit and ability to accumulate nitrogen rather than indicating the availability of nitrogen compounds in plants' environment. Mean nitrogen content of *Nitella* sp. in Woods Canyon, the lake with the lowest inflow nitrate concentration, was higher than any other mean value determined for plants from the other three lakes.

Temperature Stratification

Vertical temperature gradients for Becker, Parker Canyon, Pena Blanca, and Woods Canyon lakes are shown in Figures 2 through 5.

Thermal stratification existed in Parker Canyon Lake for seven months beginning in March. The period of stratification in Pena Blanca Lake was somewhat longer and considerably more extreme than in the other lakes. Zisbell (1969) discusses the fishery implications of the extended period of stratification in Pena Blanca Lake. The shallow thermocline in Pena Blanca Lake during July was probably the result of the five-foot drawdown in the lake level during the construction of a boat launching facility.

Fish Food Habits

The annual relative mean volume of organisms consumed by the fish from the major fish food producing communities is shown in Figure 6.

Zooplankton provided the most important part of the trout diet in Becker Lake during the winter and spring months with chironomid larvae and pupae being ingested in greatest quantities in the late spring

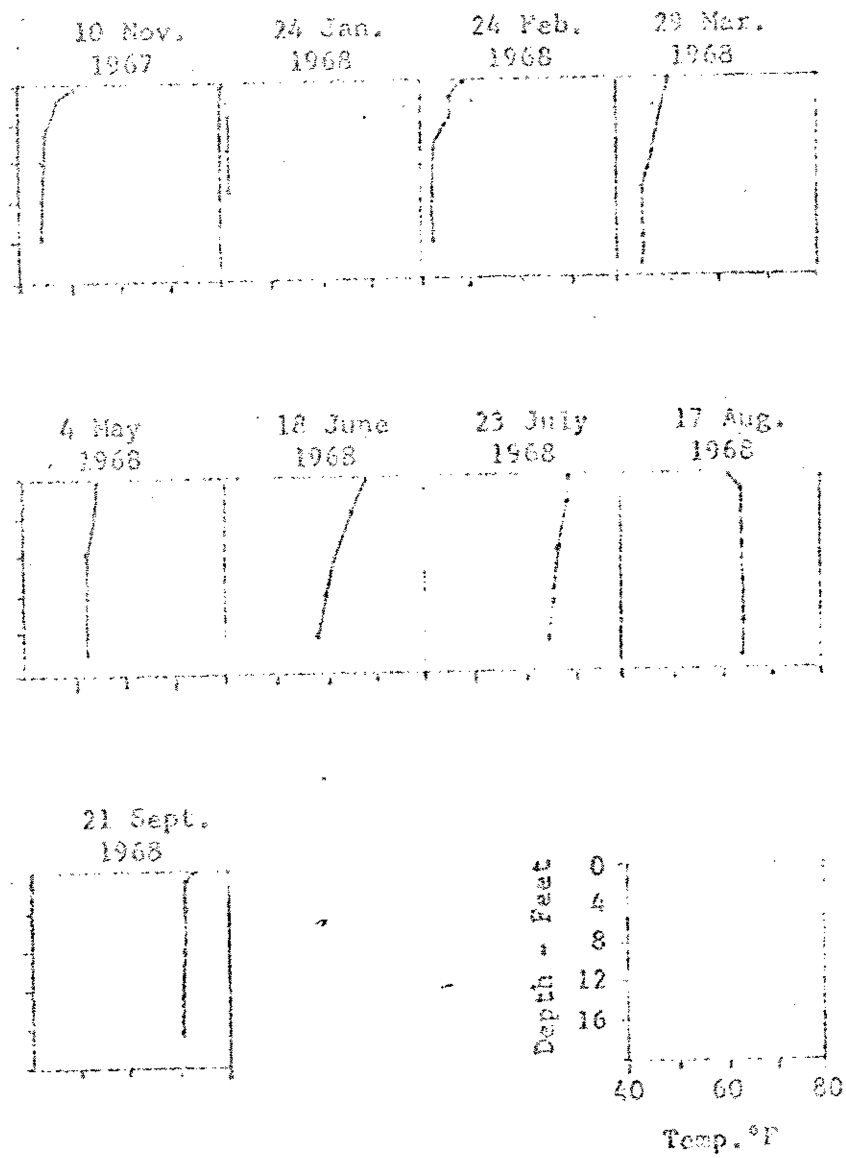

Figure 2. Temperature gradients at Becker Lake.

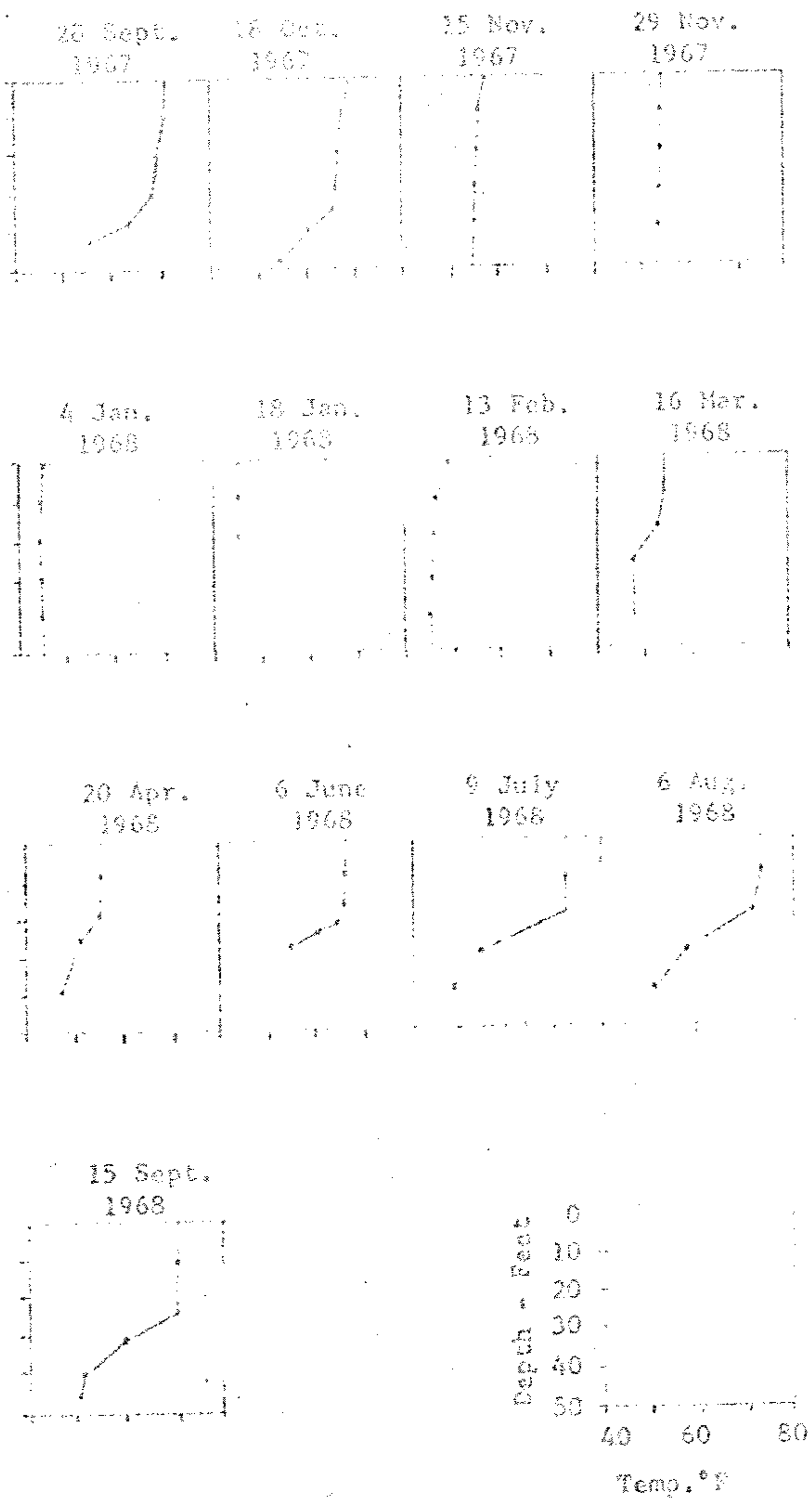

Figure 3. Temperature gradients at Parker Canyon Lake.

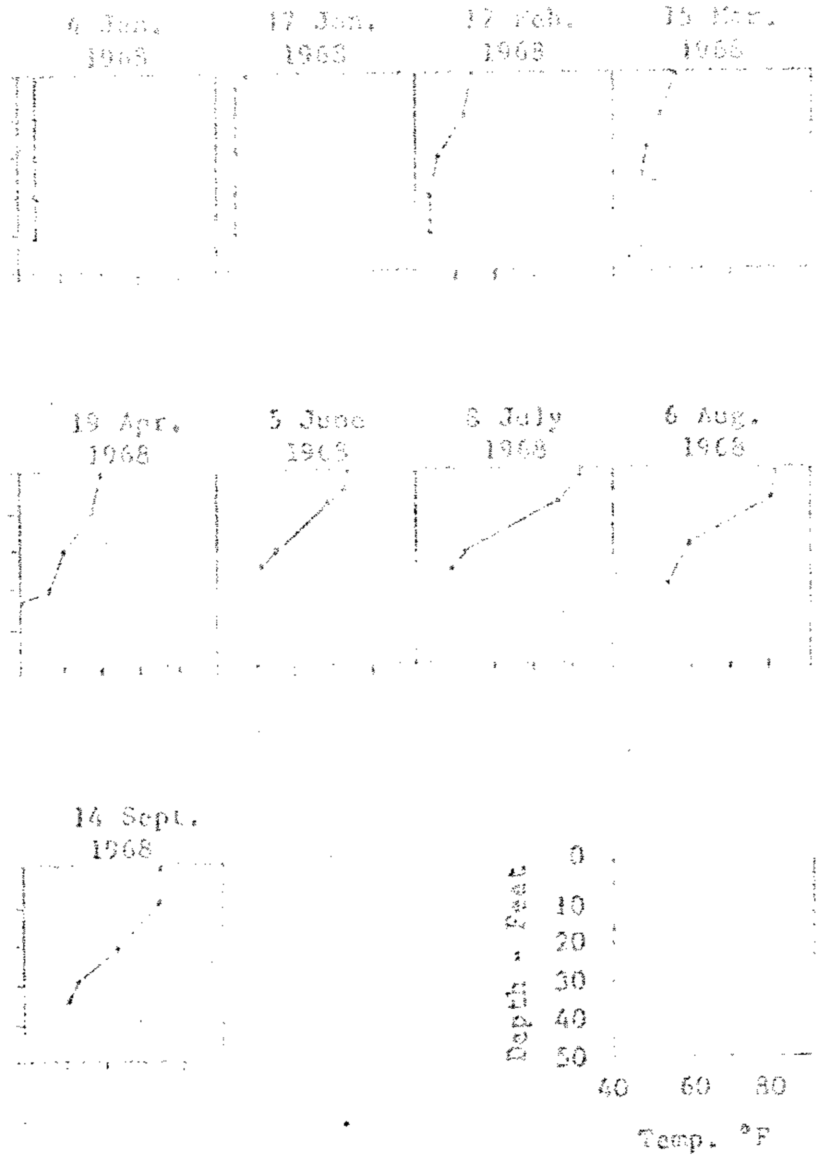

Figure 4. Temperature gradients at Pena Blanca Lake.

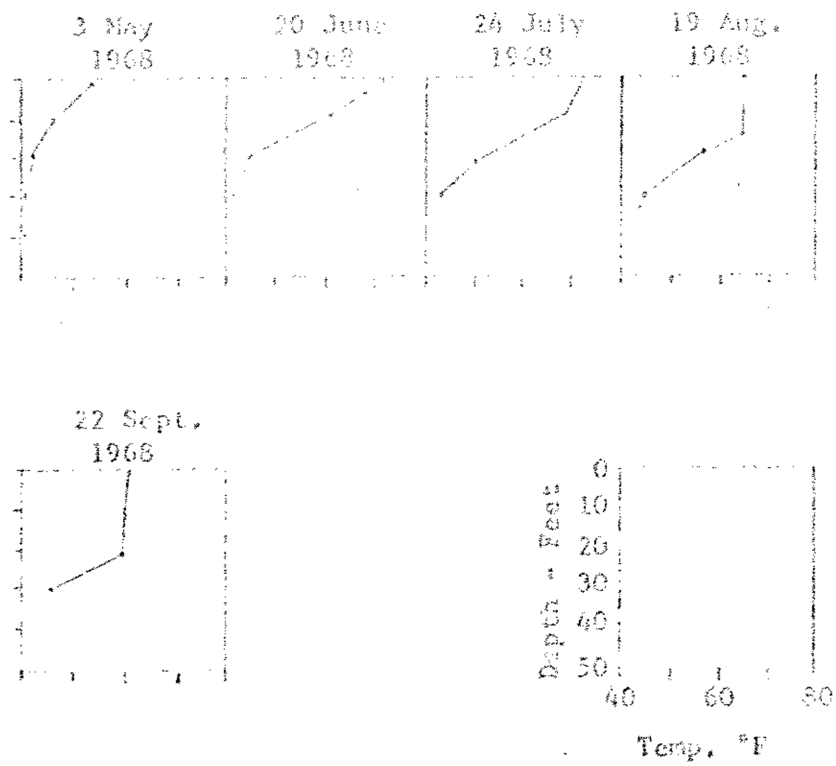

Figure 5. Temperature gradients at Woods Canyon Lake.

Figure 6. The annual relative mean volume (%) of organisms consumed from the major fish food producing communities of Parker Canyon, Woods Canyon, Becker, and Pena Blanca Lakes.

Zooplankton includes Cladocera, Copepoda, and Diptera (Chaoborus); Benthic organisms include chironomid larvae, pupae, and adults; Littoral organisms include Amphipoda, Mollusca, Odonata, Ephemeroptera, Trichoptera, plant material, and miscellaneous organisms; Terrestrial organisms include beetles, flies, bees, wasps, leafhoppers, and grasshoppers. Pena Blanca data are from Biggins (1968). See Table A-5 for specific volumes and percent occurrence.

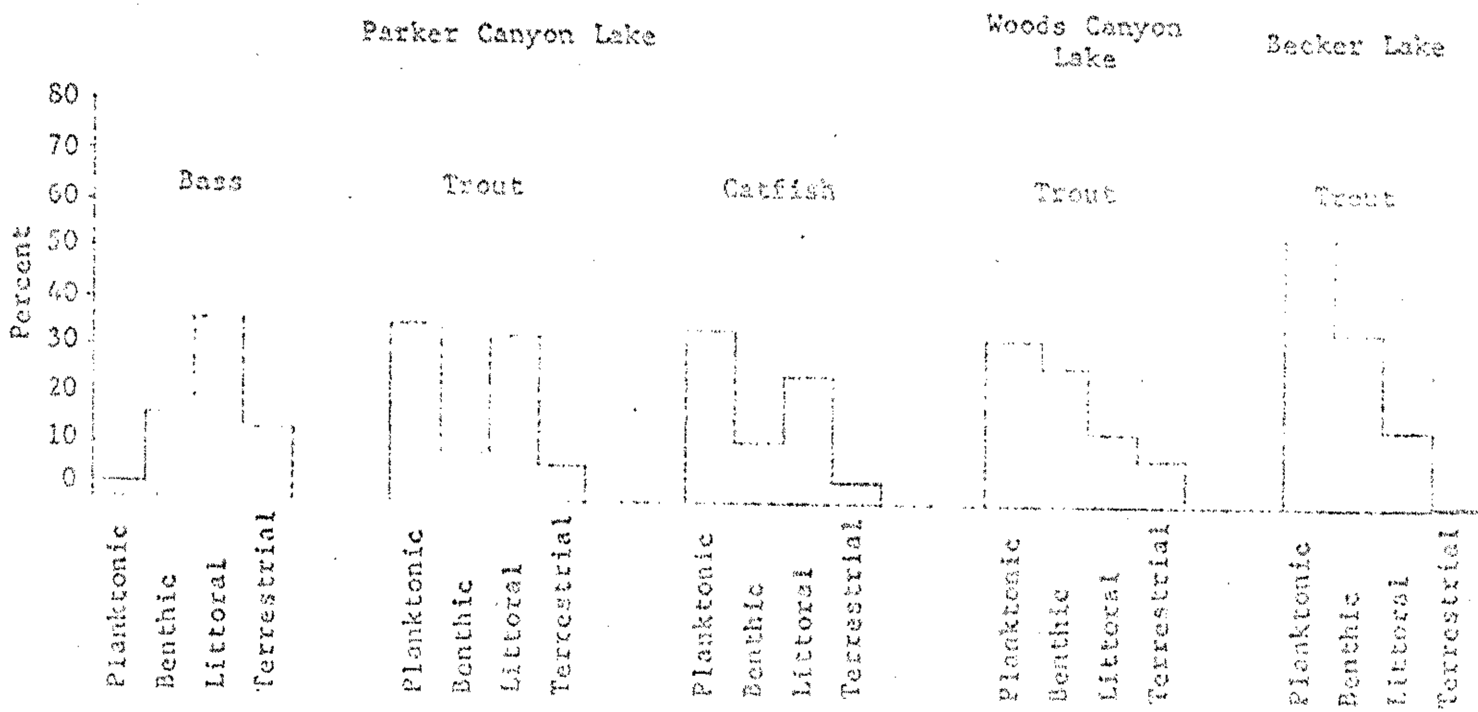

Figure 6. The annual relative mean volume (%) of organisms consumed from the major fish food producing communities of Parker Canyon, Woods Canyon, Becker, and Pena Blanca lakes.

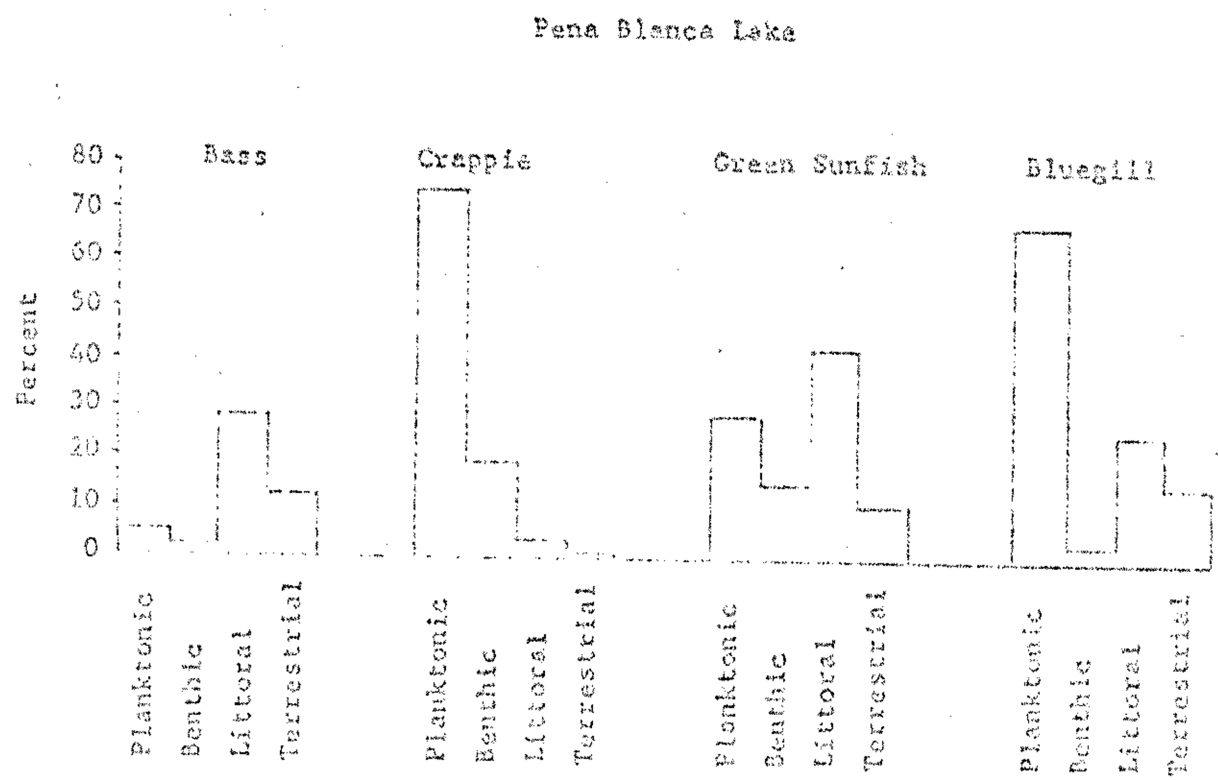

Figure 6.--Continued

and summer months. Plant material, most likely passively ingested while gleaning other food organisms, made up a significant portion of the fishes' diet during June.

In Woods Canyon Lake, ingestion of zooplankton by the trout appeared to increase proportionately with increases in zooplankton production. During May, chironomids were the predominant food organism ingested by the trout. By the end of July, zooplankton became the major food item ingested. This shift was attributed to the decrease in benthic organisms, in part due to stratification and the gradual increase in zooplankton during the summer months. What effect the large population of golden shiners in Woods Canyon Lake had on the feeding habits of the trout is unknown; however, it is suspected that a certain amount of competition for food existed, particularly for the smaller fish forage organisms.

The recent natural establishment of amphipods in Parker Canyon Lake appears to have provided a relatively important winter food source for the trout and bass and to a lesser degree the catfish; however, zooplankton was the major fish food throughout the winter months.

Bass in Parker Canyon Lake consumed minor amounts of zooplankton only during the fall. Terrestrial insects became moderately important during August; however, bass relied most heavily on littoral organisms for their major food supply.

Cladocerans in Pena Blanca Lake were heavily utilized throughout the year as a food source by black crappie, bluegills, and green sunfish (Biggins 1968). Largemouth bass consumed small quantities of cladocera only during the winter months. The majority of the bass which consumed cladocera were less than 180 mm in length. For somewhat larger bass (150-300 mm), Biggins (1968) found heavy utilization of aquatic insects during the winter months. Green sunfish consumed moderate amounts of aquatic insects throughout the year while black crappie ingested relatively large amounts during the summer.

Fish Growth

The growth rate of the 1965 year class of largemouth bass in Parker Canyon Lake from December 1966 to August 1968 is shown in Figure 7. The first two samples shown in this figure were collected with gill nets and electrofishing gear during limnological investigations conducted at the lake by the Arizona Game and Fish Department (see report of Statewide Fishery Investigations, Arizona Game and Fish Department, 1966 and 1967).

During the electrofishing survey in July 1967, no fry or fingerling bass were seen; however, approximately 3500 five to six inch bass were observed (Endress 1967). During the present study no fry or fingerling bass were observed; thus it appears that the 1965 year class has completely dominated the bass population since its formation, and it was assumed that the bass collected in this study were from that year class. Bass between six and seven inches began entering the catch in May of 1966, further substantiating the assumption that these fish were spawned the previous spring.

Except for initial plantings of rainbow trout in Parker Canyon Lake, trout growth has remained well below expected levels. Because of

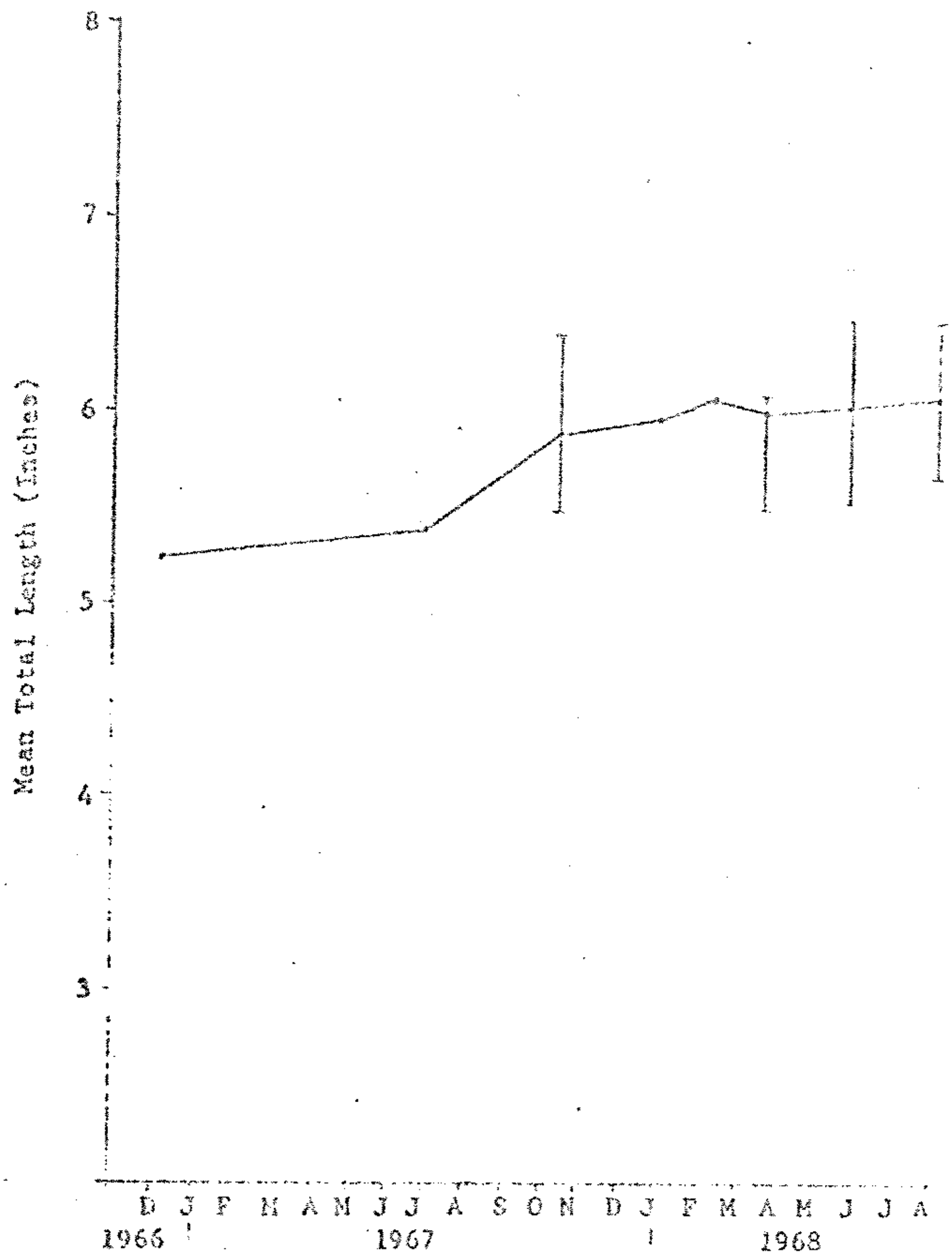

Figure 7. Growth rate of largemouth bass in Parker Canyon Lake from December 1966 to August 1968.

Vertical lines indicate size range within each sample.

multiple plantings of various sized fish in the lake during 1967 and 1968, it was impossible to accurately determine the growth rate of a cohort of fish from any one planting. It was possible however to estimate the growth rate of 50,000 four-inch fish planted in April 1965 by following peaks in the modes of the length frequency distributions of the fish harvested from this plant from July 1965 through July 1966 (unpublished creel census reports Arizona Game and Fish Department). Fish from this plant which were averaging six inches in July 1966 were averaging only nine inches in total length twelve months later.

The growth of trout planted in October 1967 in Becker Lake is shown in Figure 8. Five to six-inch fingerlings planted in October each year have been known to average 16 inches one year later. John K. Anderson, U. S. Bureau of Sport Fisheries and Wildlife, has conducted creel census at Becker Lake and estimates fish production at 300 lbs per acre.

Trout growth rates in Woods Canyon Lake were impossible to determine due to weekly stockings of various sized fish throughout the summer. However, Foster (1958) reported poor fish growth in the lake and attributed it to sterile lake conditions and heavy initial stocking densities. Kemmerer (1966) reported somewhat higher growth rates of fish stocked following renovation of the lake.

Growth rates of fish in Pena Blanca Lake were not determined during this study; however, McConnell (1963) found that bass in Pena Blanca Lake between 1959 and 1961 were slightly less than nine inches in length after two growing seasons. More recently Biggins (1968)

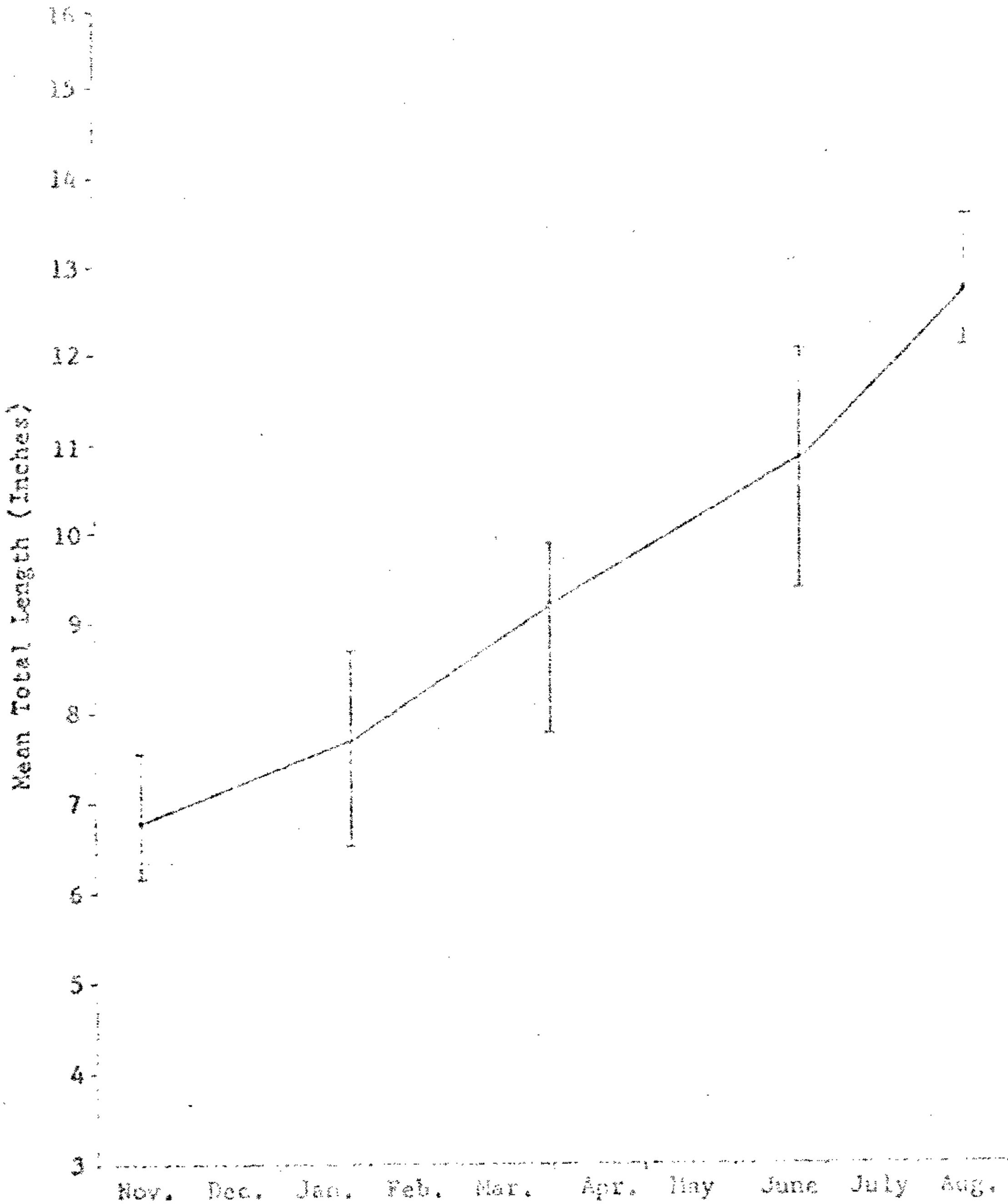

Figure 8. Growth rate of October 1967 plant of rainbow trout in Becker Lake.

Vertical lines indicate size range within each sample.

found that the growth rate of bass in Pena Blanca Lake may be somewhat better than in previous years. He also reports high condition factors (K_{sl}) for the green sunfish, bluegills, and black crappie. McConnell (1963) reports the annual average harvest of bass and crappie in Pena Blanca Lake over a three-year period as 138 pounds per acre.

DISCUSSION

The low rate of fish growth in Parker Canyon Lake appears to be consistent with the low primary and secondary productivity of the lake. Zooplankton crops continue to remain extremely low and have changed little since the lake first started to fill. It is tempting to account for the present low zooplankton crops entirely on the basis of low primary productivity; however, when the previously low crops are considered, which were produced during the period of initial high primary productivity, this does not seem to be the case. Although inflow chemistry was essentially the same as it is now, high phytoplankton production and chlorophyll levels shortly after the lake started to fill were apparently stimulated by the release of nutrients from decaying organic matter in the lake basin and the continuous influx of nutrients washed into the lake by wave action as the lake slowly filled for the first time. Considering the high chlorophyll concentrations found during this period, it is unlikely that a nitrogen deficiency existed in the lake in spite of low concentrations entering through the inflows.

Kemmerer et al. (1968) suggested that inflow nitrate may be important in determining the forage value of phytoplankton for zooplankton. Low nitrogen availability has been shown to cause a decrease in protein synthesis in phytoplankton which subsequently caused a decrease in cell division and cell size (Devlin 1967). Spoehr and Milner (1949) and Wassink (1954) clearly demonstrated this phenomenon by altering the nitrate concentrations of the media in mass culture experiments with chlorella.

The high correlations between inflow nitrate and invertebrate standing crops suggest that inflow nitrate influenced the forage value of the phytoplankton in all four study lakes. The consistency of this relationship in the study lakes would discount the possibility of the presence of a toxic substance limiting invertebrate production in Parker Canyon Lake although it would not explain why large zooplankton crops failed to materialize during Parker Canyon's initial highly productive period when nitrate was apparently abundant.

Beyond establishing the forage quality of phytoplankton for invertebrates, nitrate availability may also affect the amount of phytoplankton present although it is likely this would vary with the plankton species.

The critical level of nitrogen in four vascular aquatic plants was established by Gerloff and Krombholz (1966) at approximately 1.3%, the critical level being the minimum amount of nitrogen which is necessary for maximum growth. In the synthetic nutrient culture experiments used to establish this critical nitrogen level, they were able to show a positive correlation between the nitrogen content of the plant tissue and the nitrogen content of the media. Under natural conditions this would be difficult to demonstrate due to differences in plant densities, the physiological age of the plants, and nutrient availability.

Only one of the 25 samples (eight vasculars and two species of algae) analyzed for nitrogen content was below the established critical level of 1.3%. This occurred at Parker Canyon Lake in October 1967. Mean values for the individual lakes were always above the critical nitrogen level. No correlation was found between nitrogen availability in the lakes (inflow nitrate) and the nitrogen content of the vascular aquatic plants. Intense phytoplankton blooms in Becker and Pena Blanca lakes probably reduced the availability of nitrogen in these lakes to below levels which could be reflected by the vascular plants. Had entire plants been analyzed rather than just the fresh new growth, nitrogen concentrations would probably have been lower and perhaps a more significant relationship would have appeared.

The persistently low zooplankton crops in the lake during periods of high and low phytoplankton production suggests the presence of substances directly toxic to zooplankton. It could be suspected that excessive concentrations of heavy metals might account for the limited zooplankton crops. Of the metal determinations made in this study, none appeared to be in excess or limiting concentrations in any of the study lakes, although copper concentrations which have been reported as being toxic to cladocera and other aquatic invertebrates (Hutchinson 1957) were found occasionally in the epilimnion in Becker, Woods Canyon, and Parker Canyon lakes. Highest copper concentrations (.130 mg/l) were found in Woods Canyon Lake during August. High levels in the lake waters generally occurred with corresponding low levels of copper in the aquatic plants. They were also coincidental with the summer rains which cooled the lake surface waters and may have stimulated the release of copper from the aquatic vegetation. In light of Kemmerer's

(1968) in situ fertilization experiments at Woods Canyon Lake in which primary productivity and zooplankton crops were significantly increased with only the addition of nitrate and phosphate, it would appear that the low trophic status of the lake can be accounted for on the basis of limiting amounts of these two biogenic salts, and that copper, in spite of its high levels, is not limiting to phytoplankton or zooplankton production in this lake. The possibility remains, however, that a toxic substance not tested for in this study is restricting invertebrate production in Parker Canyon Lake.

Although little evidence exists that pesticides may be limiting invertebrate production in Parker Canyon Lake, there have been unofficial reports of an unknown insecticide (used for grasshopper control) and the herbicide 2-4-5-T being used in the vicinity of the lake (personal communication with Coronado National Forest representatives). Whether these substances were actually used on the lake's watershed was not known. Although unlikely, the possibility of toxic concentrations of pesticides in the lake must not be ignored as another possible factor limiting invertebrate production in Parker Canyon Lake.

The specific role of vascular aquatic plants in the trophic structure of the study lakes is unknown; however, they appear to provide little more than physical support and cover for invertebrate organisms. In Becker and Parker Canyon lakes the relative forage values of Myriophyllum exalbescens, based on organic nitrogen content, are essentially alike; yet littoral invertebrate standing crops per unit plant material are three times greater in Becker Lake than in Parker

Canyon Lake. It would appear from this that invertebrates are not able to utilize the growing plant material directly as a food source. In addition to being a poor source of food, rooted vasculars in Parker Canyon Lake may compete directly with phytoplankton for available nutrients. Bennett (1965), in extensive farm pond investigations, found that rooted vegetation was often able to suppress the growth of algae by trapping essential plant nutrients. This may be especially critical in Parker Canyon Lake where the vascular plants appear to be in a dynamic state of growth and decomposition with growth exceeding attrition. In effect this would limit the total annual turnover of plant biomass which would have a two-fold effect on the overall contribution of the vascular plants to the invertebrate food chains by trapping nutrients which would otherwise be available to phytoplankton and by limiting the amount of decomposing particulate plant matter available to invertebrates as a potential food source.

In the dimictic lakes such as Becker and Woods Canyon where the aquatic plants are subject to extensive winter die-offs and decomposition, the delayed entry of decayed plant material into the invertebrate and ultimately the fish food chains must be considered (Odum and Smalley 1959). This may be particularly important in Becker Lake which seldom stratifies, thus allowing sestonic material to remain available to the planktonic, littoral, and benthic communities for long periods of time.

The four study lakes can be ranked essentially in the same order according to planktonic, littoral, and benthic invertebrate standing crops. In decreasing order of productivity the lakes can be ranked as follows: Becker Lake, Pena Blanca Lake, Parker Canyon Lake, and Woods Canyon Lake. Although objective supporting data are lacking, general observations of the fisheries indicate that the lakes can also be ranked in this same order based on fish growth and production.

I assumed that the relative value of a specific invertebrate community as a food source for the fish population would be reflected in the occurrence of representative food organisms ingested by the fish. The annual relative mean volume of organisms consumed from the major food producing communities (Figure 6) gives an insight into the probable trophic structure of the study lakes and in general reflected the relative abundance of the particular organisms in the lakes.

Although the trout primarily used the planktonic community as its major food source in Parker Canyon Lake, littoral invertebrates also provided a substantial portion of their diet. After the trout reached about 10 inches in length, there seemed to be a shift in feeding habits with more emphasis on use of the larger benthic and littoral invertebrates. This shift was also quite evident in Becker Lake. In Parker Canyon Lake this shift in food habits appeared to be coincidental with a cessation in growth. Glucksman (1965) observed this phenomenon in Parker Canyon Lake and referred to it as "topping out." He accounted for it on the basis of a breakdown in the growth rate-food density relationship. Ivlev (1961) presented a thorough discussion of this relationship.

Littoral invertebrates predominated in the diets of the bass in Parker Canyon and Pena Blanca lakes. Terrestrial insects also made up a substantial portion of their diet during the summer months. Although fry and fingerlings were not examined, they were undoubtedly dependent primarily on planktonic organisms for their growth and survival. In several California lakes, largemouth bass fry fed exclusively on Cyclops and Daphnia and other small crustaceans (Emig 1966). When they begin feeding on larger littoral organisms, bass in Pena Blanca Lake would appear to have a decided advantage over those in Parker Canyon Lake based only on the density of the littoral invertebrates present. Densities in Pena Blanca Lake were almost three times those in Parker Canyon Lake. This lack of a food item of suitable size at a critical period of growth seems a likely cause of the poor growth rate exhibited by the bass in Parker Canyon Lake and may also contribute to the relatively poor trout growth in this lake.

An apparent inverse relationship exists between mean lake depth and standing crops of littoral, benthic, and planktonic fish food organisms in the four study lakes; however, when zooplankton densities and mean depths of Hawley Lake and Fool Hollow Lake (Kemmerer et al. 1968) are compared to those of the study lakes, this relationship no longer holds true. That the two study lakes with the largest mean depths, Parker Canyon and Woods Canyon Lake, were also the least productive is probably only coincidental when the extremely deep mean depth (18.5 m) of highly productive Fool Hollow Lake is considered. Because of the consistent relationship between planktonic, benthic, and littoral invertebrate standing crops in the four study lakes (i.e., relatively high standing crops of each in the more productive lakes and low crops in the less productive lakes), this relationship probably also holds true in Hawley Lake and Fool Hollow Lake, in which case the relationship between mean depth and benthic and littoral invertebrate standing crops would become untenable as it did in the case of zooplankton standing crops.

Benthic invertebrate production in the four study lakes appears to be dependent primarily on the extent of autochthonously produced bottom muck deposits. In the past, import of allochthonous matter has been important in forming organic bottom deposits in Pena Blanca Lake (McConnell 1963). Import does not appear to be important in the other three study lakes (Seawell 1966, Gluckaman 1965).

Muck deposits in Parker Canyon Lake are limited to the deeper portions of the lake and along the old stream beds. This reduces the availability of suitable habitat for benthic organisms and may be particularly critical during long periods of stratification. Pena Blanca and Becker lakes have well-developed organic bottom deposits. Benthic production in Pena Blanca is, however, limited by long periods of stratification during the summer months. Ziebell (1969) estimated that 60% of the lake bottom was eliminated as habitat for aerobic organisms by late summer due to the absence of dissolved oxygen and toxic levels of hydrogen sulfide in the hypolimnion. Bottom deposits in Woods Canyon Lake consist of decaying organic detritus composed primarily of pine needles over a thin layer of clay. Here, too, the long periods of stratification and cold bottom waters probably limited benthic invertebrate production. The adverse effects of long periods of stratification on benthic organisms are particularly evident when the relative changes in standing crops in the stratified lakes are compared with those in Becker Lake (Table 2), which never stratifies. Standing crops in these lakes steadily declined as the period of summer stratification continued while those in Becker Lake rapidly returned to above springtime densities after an early summer decline probably due primarily to insect emergences.

Because of the limiting conditions imposed by long periods of oxygen stratification and, as in Pena Blanca Lake, toxic concentrations of hydrogen sulfide in the hypolimnion, the deep benthic communities were only slightly utilized as a food source in those study lakes other than Becker Lake which never stratified.

Terrestrial insects provided a small but in some cases substantial portion of the fish food supply in all of the lakes except Becker Lake. The utilization of a particular food item by the fish appears to be based on its relative abundance with respect to other available food sources. Thus in Becker Lake where planktonic, littoral, and benthic organisms are very abundant and readily available, the contribution made by terrestrial insects would be expected to be low.

CONCLUSIONS

Primary and secondary productivity in Parker Canyon Lake is considerably lower than would be expected despite high import levels of alkalinity and phosphate. Although low nitrogen income is indicated as the probable cause of the low productivity in the lake, invertebrate production may possibly be limited by the presence of substances directly toxic to the invertebrate communities (e.g., an uncommon toxic metal or pesticide).

Comparisons of the water chemistry and micronutrients of vascular aquatic plants in Parker Cañyon Lake with the other study lakes failed to indicate the presence of limiting concentrations of heavy metals or essential nutrients in the lake.

The long period of temperature stratification during the summer months in Parker Canyon Lake apparently suppressed benthic invertebrate production and limited access of the fish to the benthic forage communities.

I suspect the low turnover rate of vascular aquatic plant biomass in Parker Canyon Lake limits the trophic contribution of these plants to the invertebrate food chains. The vascular plants may also trap relatively large quantities of essential nutrients which would otherwise be available to the phytoplankton community.

Fish growth in Parker Canyon Lake appears to be restricted by the limited production of fish forage invertebrates. The data suggest that phytoplankton is the major food source for invertebrate organisms.

Fish food habits indicated that abundance and, in the case of benthic organisms, accessibility were the most important factors determining the degree of utilization of a particular invertebrate forage community by the fish population.

APPENDIX

RAW TABULAR DATA FOR SPECIFIC MEASUREMENTS

Table A-1. Standing crop of benthic organisms including annelid worms, expressed as gm/m^2.

Month	Parker Canyon 30 Ekman Samples	Becker 44 Ekman Samples	Pena Blanca 40 Ekman Samples	Woods Canyon 27 Ekman Samples
1968				
February	-	10.44	-	-
March	1.87	4.59	.76	-
April	.21	-	.63	-
May	-	3.03	-	.51
June	.15	8.72	1.76	.34
July	.17	16.27	.52	.18
August	-	8.15	.51	.03
September	1.27	7.43	.43	.37
Mean gm/m^2	.734	8.37	.768	.286

Table A-2. Fluctuations in the numbers of organisms per gram of dried plant materials in Parker Canyon, Becker, Pena Blanca, and Woods Canyon lakes.

	March	April	May	June	July	August	September
Parker Canyon (*Myriophyllum*)							
Amphipods	3.75	1.32	-	.19	.09	.07	.52
Mayflies	1.73	.20	-	0	0	0	0
Damsel	1.58	.71	-	1.54	.36	.22	.68
Caddis	.07	1.19	-	1.80	2.16	3.66	4.75
Snails	2.99	.76	-	.64	2.25	.22	1.04
Becker Lake (*Myriophyllum*)							
Amphipods	-	-	3.69	.05	.48	.22	2.50
Mayflies	-	-	.60	.70	.35	.05	.25
Damsel	-	-	2.55	8.26	.99	2.32	2.72
Dipteran larvae	-	-	.23	0	0	0	0
Snails	-	-	2.84	2.40	5.00	14.10	7.00
Caddis	-	-	-	.85	.17	.19	.14
Water boatman	-	-	-	-	.07	-	.03
Pena Blanca (*Ceratophyllum*)							
Caddis	-	3.95	-	.30	0	0	0
Damsel	-	2.49	-	1.02	.22	.34	.34
Snails	-	16.00	-	24.40	5.40	2.64	5.23

Table A-2.--<u>Continued</u>

	March	April	May	June	July	August	September
Woods Canyon (*G. greniucus*)							
Snails	-	-	-	-	.19	.43	.01
Damsel	-	-	-	-	.60	.20	.84
Mayflies	-	-	-	-	.03	0	0
Dipteran larvae	-	-	-	-	.03	0	0
Water bug	-	-	-	-	0	.01	0
Dragonfly	-	-	-	-	0	0	.03

Table A-3. Concentrations of selected chemical factors from inflow entering Becker, Pena Blanca, Parker Canyon, and Woods Canyon lakes.

(Becker and Pena Blanca lakes)

	Becker Lake Inflow Ditch 29 March 1968	Pena Blanca Creek 19 April 1968	Pena Blanca Creek 6 August 1968	Inflow Between Pena Blanca Cr. & Lodge 6 August 1968	$\bar{X}$
Estimated inflow (cfs)	.147	.2	.15	<.1	
Phenolphthalein alkalinity	-	-	-	-	
Methyl orange alkalinity	96	83	-	-	83
$NO_3 + NO_2$	-	.5	1.11	-	
NO_3	.1	-	1.1	.11	
Ortho PO_4	.17	.11	.21	.66	.217
Total PO_4	.26	.50	.50	.69	.525

Table A-3.--Continued

(Parker Lake)

	Collins Canyon 6 August 1968	Merritt Canyon 20 April 1968	Merritt Canyon 6 August 1968	Parker Canyon 6 August 1968	Weighted Mean for All Inflows
Estimated inflow (cfs)	1.13	.2	.3	.4	
Phenolphthalein alkalinity	0	-	0	0	
Methyl orange alkalinity	24	205	142	90	72.[illegible]
$NO_2 + NO_3$	-	.7	-	-	
NO_3	.1		.09	.08	.094
Ortho PO_4	.05	.06	.07	.12	.073
Total PO_4	.17	.32	.34	.36	.247

Table A-3.--Continued

(Woods Canyon Lake)

	Surface Inflow 1 30 March	Ground: Inflow 1 3 May	Ground: Woods Canyon Creek 3 May	Ground: Woods Canyon Creek 19 August	Surface Inflow 3 3 May	Ground: Inflow 3 19 Aug.	Ground: Inflow 3 22 Sept.
Estimated flow	2	< .1	.3	< .1	3	< .1	< .1
Phenolphthalein alkalinity	-	-	-	-	-	-	0
Methyl orange alkalinity	16.0	14.4	17.0	13	10	11	15
$NO_3 + NO_2$	-	<.1	.6	.11	.5	.1	.03
NO_3	.3	-	-	-	-	-	.02
Ortho PO_4	.14	.09	.06	-	.02	-	.05
Total PO_4	.21	.14	.10	-	.17	-	.12

Table A-4. Concentrations (mg/l) of nitrate and phosphate in Pena Blanca Creek during successive stages of a flash flood 4 August 1968.

Sample Number	NO_3	Ortho PO_4	Metal PO_4	Total PO_4
1	.18	.32	.02	.34
2	.18	.09	.27	.36
3	.17	.14	--	--
4	.18	.11	.29	.40
5	.18	.15	.15	.30
6	.19	.17	.20	.37
7	.21	.14	.26	.40
8	.16	.16	.21	.37
9	.16	.09	.19	.28
Pena Blanca Creek 6 August 1968				
1	1.11	.21	.29	.50

Table A-5. Relative volume of specific food items ingested by rainbow trout, largemouth bass, and channel cat in Becker, Woods Canyon and Parker Canyon lakes, expressed as a percentage of total stomach content.

Date of Capture	Number of Fish Examined	Amphipoda	Clacodera	Copepoda	Chironomid Larvae	Chironomid Pupae	Chironomid Adult
			Rainbow Trout - Becker Lake				
1967							
November 9	18	0.22	89.2	0.11	3.94	0.0	0.0
1968							
January 29	32	0.72	88.6	0.47	0.59	0.0	0.0
March 29	18	T	92.7	T	0.55	1.72	0.11
June 19	13	T	0.0	0.0	76.6	2.0	0.0
August 17	7	T	0.0	0.0	7.8	80.7	0.0

Date of Capture	Number of Fish Examined	Plant Material	Mollusca (Snails)	Zygoptera Larvae	Ephemeroptera and Tricoptera Larvae	Amorphous Matter	Misc.
1967							
November 9	18	0.50	0.66	0.61	0.11	1.5	2.83
1968							
January 29	32	2.84	1.87	1.87	0.0	1.09	0.0
March 29	18	1.72	0.11	0.11	T	0.61	2.44
June 19	13	40.7	3.23	1.3	6.15	3.7	2.54
August 17	7	0.7	7.1	.14	1.4	2.14	0.14

Table A-5.--Continued

Date of Capture	Number of Fish Examined	Cladocera	Copepoda	Chironomus Larvae	Chironomus Pupae	Chaoborus Larvae	Chaoborus Pupae
1968			Rainbow Trout - Woods Canyon Lake				
May 3	14	T	T	15.5	58.2	T	0
July 23	12	12.5	0.0	5.4	7.5	14.6	31.3
September 23	16	20.9	0.0	0.3	T	15.0	5.8

Date of Capture	Number of Fish Examined	Tricoptera, Orthoptera and Odonata	Plant Matter	Terrestrial Insects	Fish	Amorphous and Miscellaneous
1968						
May 3	14	2.2	7.6	6.8	0.0	10.0
July 23	12	0.4	10.4	8.8	0.0	10.4
September 23	16	13.7	10.9	11.7	6.2	11.6

Table A-5.--Continued

Date of Capture	Number of Fish Examined	Amphipoda	Cladocera	Copepoda	Chironomid Larvae	Chironomid Pupae	Chaoborus Larvae
1968			Rainbow Trout - Parker Canyon Lake				
January 4	17	22.3	31.1	T	1.53	0	26.1
February 13	25	16.4	44.6	T	0.88[a]	-	2.4
March 15	10	0.0	73.3	0.0	T[a]	-	4.7
June 6	6	0.0	0.0	0.0	0.0	7.5	0.0
August 7	9	0.0	T	0.0	34.5	0.0	3.8

Date of Capture	Number of Fish Examined	Plant Material	Mollusca (Snails)	Tricoptera Ephemeroptera and Odonata Larvae	Terrestrial Insects	Amorphous Matter	Misc.
1968							
January 4	17	7.07	0.17	5.2	0.0	6.85	0.0
February 13	25	13.5	0.0	9.7	0.0	8.4	0.0
March 15	10	3.2	0.0	5.5	2.7	3.5	4.2
June 6	6	16.6	0.0	31.6	5.0	39.1	0.0
August 7	9	3.8	T	14.7	29.4	8.7	8.9

a. Larvae and pupae

Table A-5. -- Continued

Date of Capture	Number of Fish Examined	Amphipods	Cladocera	Ostracods	Chironomid Larvae	Chironomid Pupae	Chaoborus
			Largemouth Bass - Parker Canyon Lake				
1967							
October 18	18	27.1	6.0	0.33	0.73	5.4	5.4
1968							
January 4	1 empty	-	-	-	-	-	-
February 14	1 empty	-	-	-	-	-	-
March 15	8	38.9	0.0	0.0	0.0	0.0	0.0
June 6	4	0.0	0.0	0.0	0.0	25.0	0.0
August 7	6	0.0	0.0	10.8	11.6	12.5	T

Date of Capture	Number of Fish Examined	Terrestrial Insects	Plant Material	Zygoptera and Ephemeroptera Larvae	Amorphous Matter	Miscellaneous
1967						
October 18	18	0.0	6.0	6.0	22.8	18.45
1968						
January 4	1 empty	-	-	-	-	-
February 14	1 empty	-	-	-	-	-
March 15	8	0.0	0.0	21.9	T	2.5
June 6	4	0.0	0.0	0.0	0.0	26.2
August 7	6	58.3	0.0	0.0	7.5	0.0

Table A-5.--Continued

Date of Capture	Number of Fish Examined	Amphipoda	Cladocera	Chironomus Larvae	Chironomus Pupae	Chaoborus	Plant Material
1968			Channel Catfish - Parker Canyon Lake				
13 February	1	0.0	100.0	0.0	0.0	0.0	0.0
6 June	2	0.0	0.0	17.5	0.0	0.0	45.0
7 August	7	2.5	0.0	12.8	0.0	0.28	15.5

Date of Capture	Number of Fish Examined	Tricoptera Larvae	Terrestrial Insects	Ostracoda	Amorphous Matter	Miscellaneous
1968						
13 February	1	0.0	0.0	0.0	0.0	0.0
6 June	2	0.0	0.0	0.0	35.0	2.5
7 August	7	10.7	14.0	2.15	1.0	0.43

Table A-6. Percent occurrence of food items in the stomachs of rainbow trout, largemouth bass, and channel catfish in Becker, Woods Canyon, and Parker Canyon lakes.

Date of Capture	Number of Fish Examined	Amphipoda	Cladocera	Copepoda	Chironomid Larvae	Chironomid Pupae	Chironomid Adult
			Rainbow Trout - Becker Lake				
1967							
November 9	18	44.5	100	83.5	50	0	0
1968							
29 January	32	21.2	100	100	18.7	0	0
29 March	18	11	100	100	72	50	22.2
19 June	13	7.7	0	0	92.5	85	0
17 August	7	57	0	0	100	100	0

Date of Capture	Number of Fish Examined	Plant Material	Mollusca (Snails)	Zygoptera Larvae	Ephemeroptera and Tricoptera Larvae	Amorphous Matter	Misc.
1967							
9 November	18	22.2	33.3	16.7	16.7	78	27.8
1968							
29 January	32	34.4	9.4	15.6	0	28.1	0
29 March	18	27.8	11	50	5.5	33.3	55
19 June	13	69	23	38.5	38.5	61.5	46
17 August	7	57	14.3	28.6	43	57	43

Table A-6.--Continued

Date of Capture	Number of Fish Examined	Cladocera	Copepoda	Chironomus Larvae	Chironomus Pupae	Chaoborus Larvae	Chaoborus Pupae
1968			Rainbow Trout - Woods Canyon Lake				
3 May	14	29	21	100	100	7.1	0
25 July	12	25	0	33	83	58	75
23 September	16	44	0	12.5	6.2	37.5	50

Date of Capture	Number of Fish Examined	Tricoptera, Orthoptera and Odonata	Plant Matter	Terrestrial Insects	Fish	Amorphous and Miscellaneous
1968						
3 May	14	71	79	93	0	50
25 July	12	16.7	66	66	0	75
23 September	16	25	31	31	6.2	56

Table A-5.--Continued

Date of Capture	Number of Fish Examined	Amphipoda	Cladocera	Copepoda	Chironomid Larvae	Chironomid Pupae	Chaoborus Larvae
1968			Rainbow Trout - Parker Canyon Lake				
4 January	17	53	82.5	11.7	41.1	0	53
13 January	25	72	68	4	60	-	32
15 March	10	0	100	0	30	-	90
6 June	6	0	0	0	0	50	0
7 August	9	0	11.1	0.	89	0	11.1

Date of Capture	Number of Fish Examined	Plant Material	Mollusca (Snails)	Tricoptera Ephemaroptera and Odonata Larvae	Terrestrial Insects	Amorphous Matter	Misc.
1968							
4 January	17	17.6	5.9	47	0	59	0
13 February	25	72	0	48	0	52	0
15 March	10	40	0	50	7.7	40	16.7
6 June	6	83.5	0	.33	33	66	0
7 August	9	33	11.1	60	44.5	78	33

Table A-6.--Continued

Date of Capture	Number of Fish Examined	Amphipods	Cladocera	Ostracods	Chironomid Larvae	Chironomid Pupae	Chaoborus
			Largemouth Bass - Parker Canyon Lake				
1967							
18 October	18	61	5.5	5.5	16.7	39	39
1968							
4 January	1 empty	-	-	-	-	-	-
14 February	1 empty	-	-	-	-	-	-
15 March	8	75	0	0	0	0	0
6 June	4	0	0	0	0	25	0
7 August	6	0	0	50	66	50	16.7

Date of Capture	Number of Fish Examined	Terrestrial Insects	Plant Material	Zygoptera and Ephemeroptera Larvae	Amorphous Matter	Miscellaneous
1967						
18 October	18	0	5.5	61	50	
1968						
4 January	1 empty	-	-	-	-	-
14 February	1 empty	-	-	-	-	-
15 March	8	0	0	62	12.5	12.5
6 June	4	0	0	0	0	50
7 August	6	83	0	0	66	0

Table A-6.--Continued

Date of Capture	Number of Fish Examined	Amphipoda	Cladocera	Chironomus Larvae	Chironomus Pupae	Chaoborus	Plant Material
			Channel Catfish - Parker Canyon Lake				
1968							
13 February	1	0	100	0	0	0	0
6 June	2	0	0	100	0	0	100
7 August	7	14.3	0	14.3	0	14.3	28.6

Date of Capture	Number of Fish Examined	Tricoptera Larvae	Terrestrial Insects	Ostracoda	Amorphous Matter	Miscellaneous
1968						
13 February	1	0	0	0	0	0
6 June	2	0	0	0	100	50
7 August	7	14.3	14.3	28.6	28.6	14.3

Table A-7. Metal content of the epilimnion and hypolimnion of Becker, Woods Canyon, Pena Blanca, and Parker Canyon lakes.

Date	B	Fe	Mn	Cr	Ni	Cu	Zn	Pb	Cd	Co	Sr	Mo
1968 - Becker Lake												
29 March	-	-	-	<.500	<.300	<.100	.024	<.200	-	<.100	-	-
4 May	.15	.047	.018	.000	.000	.034	.011	.000	.000	.000	2.033	-
19 June	.20	.016	.005	.000	.000	.005	.009	.000	.003	.000	.342	.002
23 July	.18	.033	.006	.000	.000	.012	.009	.012	.000	.000	.391	.013
13 August	.12	.012	.003	.000	.000	.007	.016	.000	.000	.000	.447	.003
21 September	.14	.009	.003	.000	.000	.008	.013	.000	.000	.000	.494	-
1968 - Woods Canyon Lake												
4 May	.03	.141	.003	.000	.000	.010	.013	.000	.000	.007	.961	<.02
20 June	.00	.075	.005	.000	.000	.001	.018	.000	.003	.008	.017	.001
25 July	.06	.183	.002	.000	.000	.032	.035	.021	.003	.000	.307	.007
25 July Hypolimnion	.06	3.782	.947	.005	.009	.060	.106	.043	.000	.000	.030	.009
19 August	.06	.160	.007	.000	.000	.130	.034	.000	.003	.000	.089	.002
21 September	.06	.138	.015	.000	.000	.015	.020	.038	.002	.000	.009	-

Table A-7.--Continued

Date	B	Fe	Mn	Cr	Ni	Cu	Zn	Pb	Cd	Co	Sr	Mo
1968 - Pena Blanca Lake												
15 March	.00	.390	.170	-	-	-	-	-	-	<.040	-	-
19 April	.12	.147	.228	.000	.009	.009	.011	.043	.000	.000	.000	-
5 June	.18	.144	.283	.000	.006	.006	.006	.000	.003	.003	.352	.007
8 July	1.00	.296	.392	.000	.009	.009	.015	.076	.000	.000	.141	-
8 July Hypolimnion	.10	1.163	1.969	.000	.029	.029	.058	.032	.000	.000	.093	.0036
6 August	.06	.350	.002	.000	.029	.029	.021	.096	.006	.000	.051	.0200
14 September	.16	.022	.005	.000	.009	.009	.008	.000	.003	.000	.250	.0052
1968 Pena Blanca Creek												
19 April	.11	.126	.189	.000	.000	.007	.007	.000	.000	.000	.357	
1968 - Parker Canyon Lake												
16 March	-	-	<.010	-	-	-	-	-	-	<.040	-	-
20 April	.06	.021	.017	.000	.000	.015	.009	.000	.000	.000	.153	-
7 June	.00	.000	.023	.000	.000	.008	.007	.000	.004	.000	.760	.007
10 July	.08	.070	.006	.000	.000	.014	.008	.043	.000	.000	.117	.0038
7 August	.05	.020	.004	.000	.000	.013	.022	.115	.003	.000	.113	.0040
7 August Hypolimnion	.05	.062	.767	.000	.000	.012	.016	.000	.003	.000	.079	.0150
15 September	.06	.020	.005	.000	.000	.034	.020	.000	.000	.000	.000	.0029

g/l) of selected chemical factors determined prior to trace metal

	Mg	Na	Cl	SO_4	Fl	NO_3	K	pH	Li	CO_3	HCO_3
)											
	2.68	-	-	-	-	-	-	-	-	-	-
	5.0	7	10	16	0.3	1.3	3.3	8.0	.002	0	24
	3.0	6	8	20	0.8	1.0	3.5	7.4	-	0	93
	4.0	7	8	16	0.2	1.0	3.6	8.2	-	0	88
	2.4	7	6	14	0.2	0.2	3.4	8.2	0	0	88
	0.96	6	4	12	0.2	0.2	3.4	7.5	0	0	97
	4.9	7	4	19	0.0	0.3	3.6	8.1	0	0	88
	5.04	13.4	-	-	-	-	.99	-	<.05	-	-
	8.00	35.0	15	24	0.3	0.1	1.7	7.7	.001	-	220
	.69	6.03	-	-	-	-	2.58	-	<.05	-	-
	.70	6.03	-	-	-	-	1.31	-	<.05	-	-

Table A-8.--Continued

Date	Solvable Salts	Ca	Mg	Na	Cl	SO_4	Fl	NO_3	K	pH	Li	CO_3	HCO_3
Becker Lake													
29 Mar. 1968[a]	-	-	15.1	51.3	-	-	-	-	4.14	-	-	-	-
4 May	396	22	25	46	20	10	0.0	0.4	4.3	7.8	.004	6	262
19 June	364	20	28	52	16	20	0.5	1.0	5.3	8.7	-	0	230
23 July	301	15	29	54	-	8	0.7	0.3	5.7	-	-	-	-
18 Aug.	396	15	28	54	20	6	0.0	0.2	5.1	7.1	.011	10	246
21 Sept.	341	16	24	54	20	8	0.4	0.2	4.5	9.4	.010	24	160
Woods Canyon Lake													
4 May 1968	31	5	0.0	2	5	5	0.3	0.3	0.5	6.6	0	0	12
20 June	35	4	0.5	1	4	10	0.1	0.1	0.5	6.8	-	0	15
25 July	43	3	3.0	2	8	10	0.2	0.2	1.4	7.3	-	0	17
Hypolimnion	24	2	2.0	1	4	4	0.2	1.0	0.8	6.8	-	0	10
19 Aug.	16	2.6	0.49	1	3	6	0.4	0.2	0.8	9.4	0	0	2
21 Sept.	27	4	1.8	1	4	5	0.0	0.2	0.6	8.1	0	0	10
Inflow #1													
30 Mar. 1968	-	-	.388	4.56	-	-	-	-	.483	-	<.05	-	0

Table A-8--Continued

Date	Solvable Salts	Ca	Mg	Na	Cl	SO_4	Fl	NO_3	K	pH	Li	CO_3	HCO_3
Bear Springs Lake													
13 Mar. 1968[a]	-	14.1	2.15	-	-	-	-	-	-	-	-	-	-
19 Apr.	112	14.0	1.0	9	10	14	0.3	0.2	2.4	7.9	.002	0	61
5 Jun.	120	3.0	11.0	9	12	20	0.8	0.1	2.6	7.2	-	0	64
8 July	124	13.0	15.0	10	8	4	0.8	1.0	5.1	7.6	-	0	73
Spillwater[illegible]	104	16.0	0.0	8	8	6	0.3	1.0	2.9	7.1	-	0	56
6 Aug.	131	18.8	3.1	10	6	12	0.3	0.3	3.0	7.3	0	0	78
14 Sept.	146	24.0	3.6	10	6	19	0.0	0.2	3.0	6.[illegible]	.010	0	81
Bear Wallow Creek													
16 Apr. 1968	152	22	2	12	15	14	0.1	0.2	2.5	7.6	.001	0	32

a. Analyses made by ESCO Laboratories, Tucson, Arizona. All others made by University of Arizona Soil and Water Testing Laboratory.

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