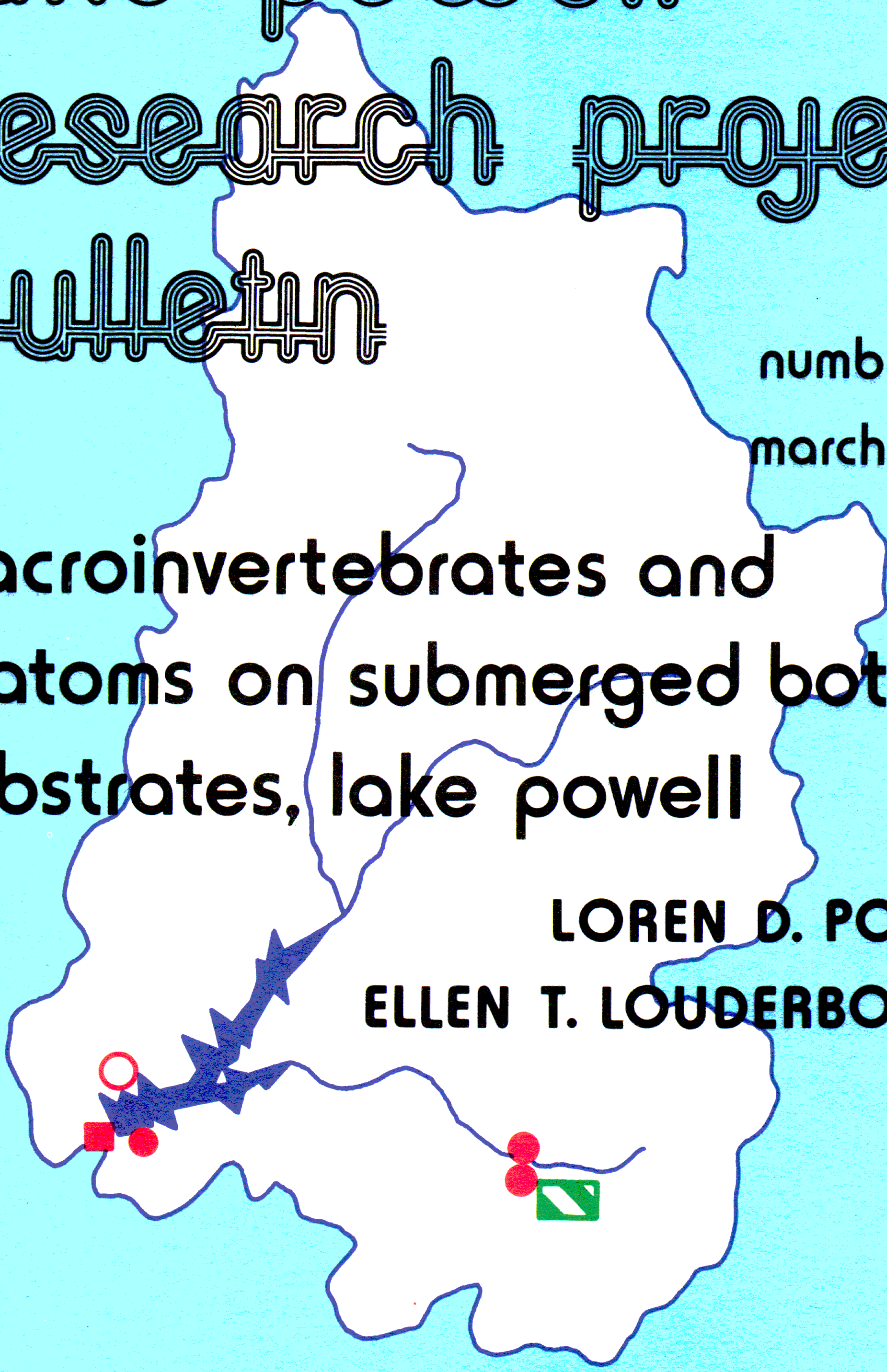
lake powell research project bulletin

number 37
march 1977

macroinvertebrates and diatoms on submerged bottom substrates, lake powell

LOREN D. POTTER
ELLEN T. LOUDERBOUGH



National Science Foundation
Applied to National Needs

LAKE POWELL RESEARCH PROJECT BULLETIN

BULLETIN EDITORS
Jeni M. Varady and Orson L. Anderson

a publication of the research project

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

funded by

Research Applied to National Needs
National Science Foundation

Funded Institutions

Columbia University
Dartmouth College
John Muir Institute
University of Arizona
University of California, Los Angeles
University of California, Santa Barbara
University of New Mexico
University of Rochester
Utah State University

Copies obtainable from:

Jan Langer
Lake Powell Research Project Bulletins
Institute of Geophysics and Planetary Physics
University of California
Los Angeles, California 90024

Price: $2.50, Payable to the Regents of the University of California

MACROINVERTEBRATES AND DIATOMS ON SUBMERGED BOTTOM SUBSTRATES, LAKE POWELL

Loren D. Potter
and
Ellen T. Louderbough

Department of Biology
University of New Mexico
Albuquerque, New Mexico 87131

March 1977

LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (formally known as Collaborative Research on Assessment of Man's Activities in the Lake Powell Region) is a consortium of university groups funded by the Division of Advanced Environmental Research and Technology in RANN (Research Applied to National Needs) in the National Science Foundation.

Researchers in the consortium bring a wide range of expertise in natural and social sciences to bear on the general problem of the effects and ramifications of water resource management in the Lake Powell region. The region currently is experiencing converging demands for water and energy resource development, preservation of nationally unique scenic features, expansion of recreation facilities, and economic growth and modernization in previously isolated rural areas.

The Project comprises interdisciplinary studies centered on the following topics: (1) level and distribution of income and wealth generated by resources development; (2) institutional framework for environmental assessment and planning; (3) institutional decision-making and resource allocation; (4) implications for federal Indian policies of accelerated economic development of the Navajo Indian Reservation; (5) impact of development on demographic structure; (6) consumptive water use in the Upper Colorado River Basin; (7) prediction of future significant changes in the Lake Powell ecosystem; (8) recreational carrying capacity and utilization of the Glen Canyon National Recreational Area; (9) impact of energy development around Lake Powell; and (10) consequences of variability in the lake level of Lake Powell.

One of the major missions of RANN projects is to communicate research results directly to user groups of the region, which include government agencies, Native American Tribes, legislative bodies, and interested civic groups. The Lake Powell Research Project Bulletins are intended to make timely research results readily accessible to user groups. The Bulletins supplement technical articles published by Project members in scholarly journals.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

To collect and examine the organisms associated with newly inundated terrestrial vegetation in Lake Powell, small plastic Christmas trees were "planted" along a sloping sandy bottom at depths of 2, 3, 4.5, 6, 8, and 10 meters (6.6 to 32.8 feet). For the 17 months from July 1973 through October 1974, the trees were harvested and replanted by SCUBA divers at 4- and 12-week intervals. The macroinvertebrate and diatom components of the periphytic community associated with each tree were collected and evaluated to determine the number of individuals per unit area (density) and species composition. A diversity index was computed for the diatom portion of each sample. The changes in composition and density patterns of the periphytic organisms were related to depth and time as is described for natural aquatic situations and for other newly inundated impoundments subject to fluctuating water levels. Data from Lake Powell indicate the organisms associated with inundated vegetation make up an important part of the available fish food in the littoral zone of the lake. In addition, snails of the genus *Physa* were found to concentrate around trees submerged for 12 weeks. These snails can function as hosts for schistosome-dermatitis-producing cercariae, and therefore may present a potential problem in the recreational use of the lake, especially as the shoreline biomass favoring snail populations increases.

INTRODUCTION

Studies of freshwater littoral zones generally have focused on the biological, physical, and chemical activities of one portion of the living community. Planktonic algae may be studied to measure productivity. The composition of the benthic macroinvertebrate communities is often determined to establish the potential fish food supply or as a biological indication of water quality. Collection and quantification of all organisms in a littoral zone habitat have been limited due to problems associated with the process of physically separating species from their substrate and the silt which has accumulated around them. Yet the littoral zone is where the algal and macroinvertebrate associations meet and interact. A factor which affects or alters the availability of utilizable habitat to the organismal associations in the littoral zone would have a potential role in the course of development and maturation of the aquatic system.

A development which has heightened interest in the shallow-water community is the attempt by some researchers to determine key species, or groups of species, which can be accurate indicators of the stability of their freshwater environment (Goodnight 1973; Gaufin and Tarzwell 1956). These researchers generally have concluded there are no "indicator" species as such. However, Round (1964) and Patrick (1964) reporting on diatoms, and Fillion (1967) researching macroinvertebrates, found that algal and macroinvertebrate communities on a variety of substrates follow patterns of density and diversity which change naturally in some respects over time and change in other respects only under some form of environmental stress. An historical documentation of long-time eutrophication, using diatoms, has been reported by Bradbury and Winter (1976).

Another facet of freshwater exploration was stimulated by the construction of man-made multiple-use reservoirs. Studies of species composition and density reveal information on carrying capacity in non-typical aquatic environments. They contribute also to an understanding of adaptation and succession in an almost instantly created and ever-fluctuating environment (Nursall 1952; Fillion 1967). Much of the developmental potential of a lake is determined by the nutrient supply available to it through weathering of surrounding geological material; by the input from its watershed (Hutchinson 1974); and, as in Lake Powell, by input drainage of its major tributaries, the Colorado, San Juan, and Escalante rivers.

The Lake Powell Research Project (LPRP) was established in 1971, with support from the National Science Foundation (Research Applied to National Needs-RANN), to study interactions taking place in and around a reservoir in an arid region. One subproject of the LPRP has been a study of the shoreline ecology of the lake since 1971 (Potter and Pattison 1976), including the terrestrial vegetation which, due to fluctuating water levels in the lake, became available substrate for aquatic organisms in the littoral zone. During the study of the decomposition of submerged vegetation in the lake, it was noted that the inundated plants quickly provided a substrate for algal growth. In addition, benthic algae appeared to form a flocculated association with sand and silt particles on the bottom. The results of the observations prompted a study of the potential role of inundated terrestrial vegetation as a substrate in the lake. If it functions as a habitat with an established periphytic community in the littoral zone of the lake, the presence of terrestrial vegetation will contribute to community structure in Lake Powell.

The purposes of the present study were, first, to establish procedures to collect, process, and quantify organisms physically associated with inundated vegetation in the littoral zone of Lake Powell; second, within this community of organisms, to determine baseline data for species composition, diversity, and density, and to establish the variability of these factors with season and depth; and third, to estimate the potential effects, if any, on the future development or use of the reservoir of species utilizing inundated terrestrial vegetation.

MATERIALS AND METHODS

The field site was located near a small sandy island south of Gunsight Butte, about 18 river-miles (29 kilometers) (km) from Glen Canyon Dam and was seldom disturbed by boaters. This area featured a sloping sandy bottom which provided safe entry and exit for SCUBA divers and allowed for upright positioning of artificial trees along a transect.

To provide a standardized substrate and to prevent loss of substrate to foraging fish, plastic Christmas trees 57 centimeters (cm) (22.4 inches)(in) tall were used. The trees were constructed of identical numbers of molded parts with a total surface area of approximately 1 square meter (m^2) (10.9 square feet)(ft^2). (Area was determined by measurement of all the component parts.) Trees were chosen over glass slides because it was felt they provided substrate which would more nearly simulate the natural growth form of shrubs and would attract the same community of organisms as would a bush. Since the inundated vegetation first observed as substrate in Lake Powell was not able to survive submergence, the periphytic organisms associated with it could not have been dependent on interaction with living substrate.

Samples of periphyton taken from submerged vegetation and compared to samples of flocculated benthic algae (metaphyton) confirmed the above supposition. The same species were present in both periphyton and metaphyton; the distribution of species varied with depth. With the exception of two species, all taxa identified were present on the artificial trees. The diatoms, therefore, displayed no aversion to the artificial substrate. Tests of comparative composition of inundated versus artificial substrate were not conducted throughout the duration of the experiment once it was realized that the artificial trees were serving as a successful substrate.

Four groups of trees with three replicates for each depth were positioned throughout the year at depths of 2, 3, 4.5, 6, 8, and 10 meters (m) (6.6 to 32.8 feet)(ft). One group, consisting of three trees at each depth, was collected every 4 weeks. The organisms were removed in the field and the trees were immediately replanted. The other three groups of trees were collected on a rotating schedule, and each group was harvested after having been submerged for 12 weeks. Collections of 4-week samples were made over a 17-month period. Twelve-week trees were collected 12 times.

Colored tags were used to identify depth and date of retrieval. To collect the samples, divers carefully approached the transect area to minimize disruption of the benthos and substrate, and slowly lowered a large plastic bag over each tree. The open end of the bag was worked downward as the base of the tree was freed from the sand. The tree was pushed upward, the bag was pulled sharply down and immediately a small amount of air was exhaled into the bag, after which the end was securely fastened. Each bag ascended to the surface and remained there until all were gathered and brought to shore by a surface swimmer.

On shore, each bag was opened and the tree inside was agitated to loosen attached organisms and silt. The tree was removed from the bag and was relabeled. The material within the bag was poured through a Wisconsin #20 mesh plankton net, and the retained portion was put in a plastic twirly bag and preserved with 10-percent formalin. The trees were replanted at the appropriate depths along the transect for another 4- or 12-week interval.

In the laboratory the contents of each twirly bag were poured into a pan. Macroinvertebrates were removed by hand and were preserved for later identification and counting. The liquid portion was poured into a 250-milliliter (ml) graduated cylinder and was left to stand for 2 hours, during which time the organic matter and most of the silt settled out. The liquid was decanted into another graduated cylinder and the microorganisms were left to settle for 2 weeks. At that time, most of the liquid was siphoned off, leaving the microorganisms concentrated in 50 ml of liquid. Aliquots were prepared as permanent mounts in Hyrax for diatom analysis.

Chironomid larvae were separated from other macroinvertebrates and were boiled in 10-percent potassium hydroxide (KOH) solution for 60 to 90 minutes; this yielded the sclerotized larval sheaths to be used for identification. The sheaths were rinsed in water and identified in a microscope under low power. The first 40 larvae counted in each sample were identified as to genera using the taxonomic key of Mason (1973); the remainder were only counted.

Macroinvertebrates other than chironomid larvae were counted and keyed to species whenever possible, using the keys of Usinger (1971) and Pennak (1953).

One diatom slide was prepared from the periphyton of each tree. In counting, at least one strip of each 22-square-millimeter (mm^2) coverslip was viewed under oil immersion. The number of diatoms per strip was recorded for density determination. Total numbers of diatoms given in charts and tables are based on the numbers of individuals per strip. To obtain total density per tree, each number would have to be multiplied by the number of strips per slide (x 242) and the dilution factor (x 125). The first 350 individuals seen per slide were identified for species composition (Patrick and Reimer 1966; Weber 1971; Hansmann 1973). Species area curves were drawn for chironomid larvae and for diatoms to determine the number of individuals to be keyed.

All replicates of the 4-week macroinvertebrate samples for the 2-, 3-, and 4.5-m (6.6 to 14.8 ft) depths were counted, but only one was counted for 6-, 8-, and 10-m depths. Three replicates for 12-week samples for the 2-, 3-, and 4.5-m depths were counted to determine the number of macroinvertebrates present. Gastropods only were counted in all replicates of the 12-week samples at depths of 6, 8, and 10 m. One diatom slide for the 4-week samples was examined for depths of 2, 3, 4.5, 6, and 8 m (6.6 to 26.2 ft).

Levels of significance for variables of depth and time were obtained using the Kruskal-Wallis test for non-parametrically distributed data. Sample size and number of replicates at each depth varied due to loss of trees. Correlation coefficients for changes in density over depth were obtained using Spearman's rank correlation procedure for non-parametric data. Throughout the study, depth of submergence was a relative term. Water level fluctuation in the lake, though minimal during this time, did occur. A tree "planted" in 4.5 m (14.8 ft) of water might have been retrieved in 4 or 5 m of water. Its position relative to trees at the other depths remained steady, but its depth was not absolute.

RESULTS

All samples were quantified in terms of species composition and numbers per area (density). Species diversity indices were calculated for diatom samples using estimated H' modified from Shannon and Weaver (Pielou 1966).

Chironomid Larvae

Of the macroinvertebrate portion of each sample, 95 percent were chironomid larvae of which 95 percent were in the genus Dicrotendipes (Table 1). Chironomid density of the 4-week samples peaked in the autumn coincident with warm water, decreased through winter and spring, and increased in mid or late summer to peak again in the fall. Samples submerged for 12 weeks showed somewhat greater larval density, but followed essentially the same pattern (Figure 1). Chironomid density for both sampling intervals decreased with increased depth.

Other Macroinvertebrates

Other macroinvertebrates in the samples are listed in Table 2. Combining the collections from all dates, greatest density occurred at 6 m (19.7 ft), probably due to large numbers of Hydra found there at only one collection date. Excluding Hydra, the greatest numbers of macroinvertebrates occurred at 3 m (9.8 ft), followed by 2 m (6.6 ft), then decreased with depth. Snails of the genus Physa were found most often at 10 m (32.8 ft), their numbers decreasing with depth from 10 to 4.5 m, then increasing again to 2 m. Odonata nymphs were located more frequently at 2 m, their numbers decreased rapidly with depth.

Table 1: Species composition and occurrence of chironomid taxa.

Taxa	Total	Relative Composition (percent)	Occurrence (percent)[a]
4-week samples[b]			
Dicrotendipes	3880	95	98
Glyptotendipes	130	3	51
Tribe Pentaneurini	4	<.1	3
Procladius	37	1	17
Parachironomus	5	.12	3
Cryptochironomus	6	.14	5
Ablabesmyia	2	<.1	1.6
Tanypodinae	1	<.1	.8
Chironomus	2	<.1	1.6
Paratendipes	1	<.1	.8
Tribelos	1	<.1	.8
12-week samples[c]			
Dicrotendipes	2692	95	100
Glyptotendipes	112	4	60
Procladius	14	<.1	12
Crictopus	5	<.1	4
Eukiefferiella	1	<.1	1

[a] Percent occurrence represents the relative number of the 124 4-week samples or the 83 12-week samples in which the taxa occurred.

[b] Number of samples = 124; total individuals = 21,333; all dates; 2-, 3-, 4.5-, 6-, and 8-meter depths; generic representation based on classification of first 40 individuals per sample, total of 4,069 individuals.

[c] Number of samples = 83; total individuals = 25,448; all dates; 2-, 3-, and 4.5-meter depths; generic representation based on first 40 individuals per sample, total of 2,824 individuals.

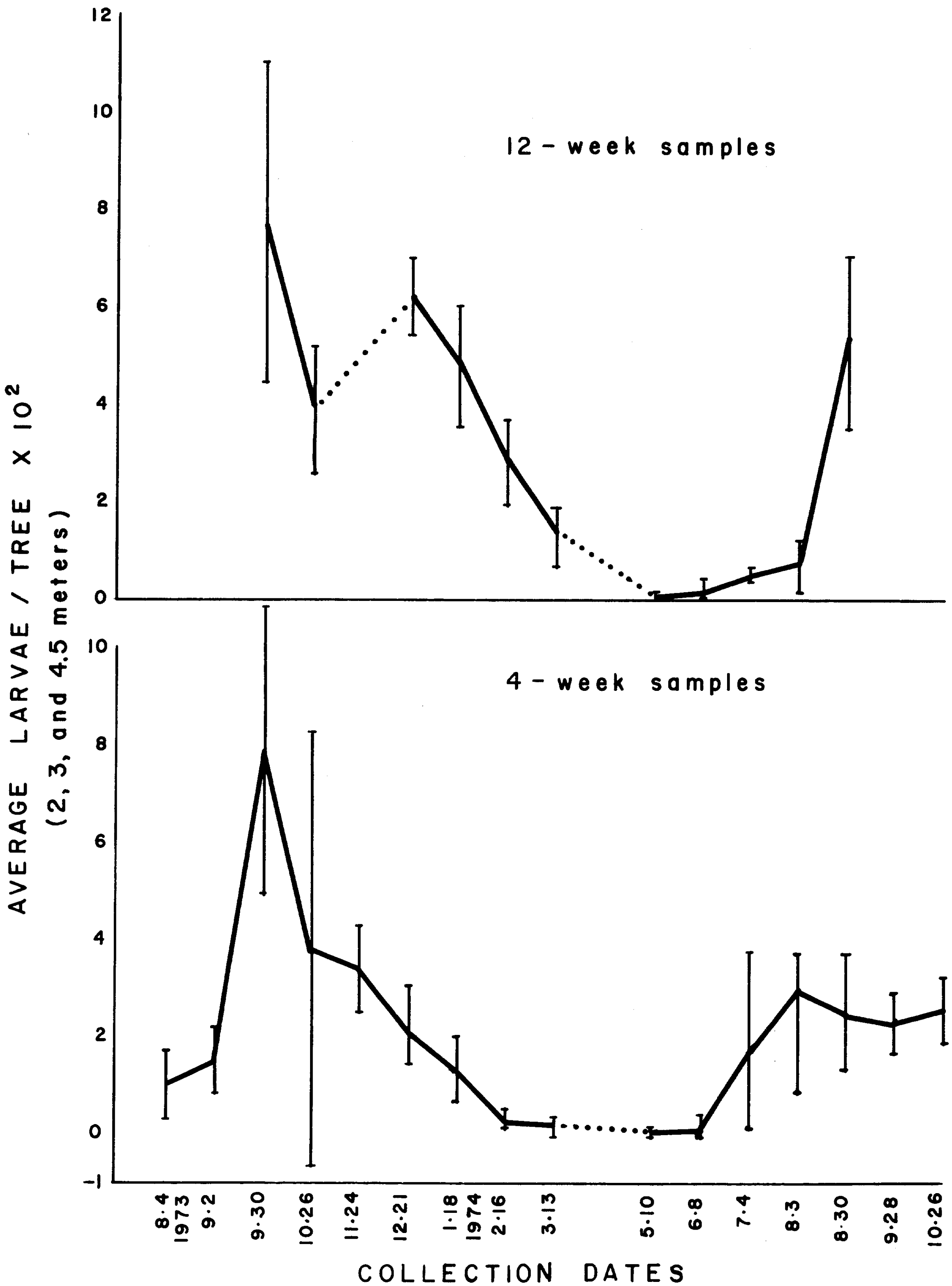


Figure 1: Variation of chrionomid larval density with time for 4-week samples (three depths) and 12-week samples (three depths). Vertical lines indicate 95-percent confidence limits.

Macroinvertebrates, in toto, were found least frequently from December through February.

Trees submerged for 12 weeks averaged greater macroinvertebrate densities than did the 4-week trees at the three depths compared (2, 3, and 4.5 m). Hydracarina (water mites) occurred more often on the 4-week trees. The occurrence of *Physa* increased greatly with duration of submergence (Table 2).

Diatoms

Sixty-nine diatom taxa were found in the 4-week samples. Numbers of diatoms peaked in the spring, declined through the summer, and reached a secondary peak in the autumn. Numbers varied throughout the winter. At any collection date, six species made up 65 to 94 percent of the individuals present. Three of these species exhibited a shifting pattern of abundance with depth: *Cymbella microcephala* (r = -1.00) and *Fragilaria vaucheriae* (r = -0.83) decreased with depth from 2 to 8 m; *Navicula radiosa* var. *tenella* increased with depth (r = 0.95). The other three dominant species, *Anomoeoneis vitrea*, *Synedra radians*, and *Achnanthes minutissima*, did not show consistent changes over the depths studied.

Greatest diatom density occurred at 3 m; density was least at 2 and 8 m. The most taxa occurred at 4.5 m; the least were found at 2 m. A complete list of species is given in the Appendix.

Species diversity indices varied over time, peaking in the winter months and again in July. Diversity was lowest in September and October.

Table 2: Species and density of macroinvertebrates.

Taxa	4-week (N=124)[a]	12-week (N=83)
Coelenterata (jellyfish)		
Hydra	433	499
Platyhelminthes		
Prorhynchus	2	
Arthropoda		
Hydracarina (water mites)	392	134
Ephemeroptera (mayflies)		
Cinygmula	1	
Paraleptophlebia		1
Odonata (damselflies)		
Coenagrionidae	31	69
Enallagma	45	34
Coenagrion	4	3
Ischnura	20	25
Hesperagrion	6	2
Hemiptera	1	
Diptera		
Tubifera		4
Chryzoma	1	
Tendipedidae (midges)[b]	21,333	25,488
Mollusca		
Pulmonata		
Physa	97	356[c]
Gyraulus		1

[a] N = number.

[b] Includes 13 taxa of chironomid larvae discussed in detail elsewhere.

[c] Total for N=83 samples at 2.3- and 4.5-meter depths. Total *Physa* in 179 12-week samples at all depths = 998.

DISCUSSION

Chironomid Larvae

Studies of benthic zones in several newly inundated reservoirs have revealed an immediate dominance of benthic and periphytic macroinvertebrate communities by chironomid larvae (Fillion 1967; Claflin 1968; McLachlan and McLachlan 1971). This pattern is evident in Lake Powell where the midge larvae comprise 95 percent of the macroinvertebrates sampled during the 17-month study. The initial high density of chironomids in other reservoirs has not been maintained in Lake Powell because of the changing nature of the substrate (Fillion 1967). Such changes can be expected to affect chironomid density in the littoral zone of Lake Powell as frequent water level fluctuations wash loosely structured desert soil into the lake. Productivity in the lake eventually will contribute to change as great amounts of organic matter accumulate on the bottom and lead to decreased dissolved oxygen levels in the benthic zone. Chironomid dominance is suspect to reduction under these conditions because of the inability of the organisms to adapt to severely decreased dissolved oxygen levels. Such oxygen pressures result in replacement of chironomids by other organisms, e.g., oligochaetes, which either utilize less oxygen or are physiologically adapted to obtain greater amounts of oxygen at lower oxygen pressures (Wetzel 1975).

The variation of chironomid larval density over depth and season in the study area is significant ($P < .05$). Both total and relative density decreased steadily with depth. This relationship may be a function of food supply and temperature, as both parameters follow the same depth-related pattern. A temperature dependence is indicated by the parallel variation of chironomid density and temperature over time in Lake Powell (Figure 2). Water in the study area was coldest (9.5°C) in February and March. The warming trend began in late March and continued to a peak (28°C) in early August. The water cooled slowly through September, then all depths chilled quickly during fall overturn in October. Average temperatures continued to decrease through the winter to the minimum in February.

The third factor likely to exert a strong influence on chironomid density is predation. Studies in Lake Powell by the Utah Division of Wildlife Resources (1971) showed that the larvae make up a variable portion of the food supply of many fish species. A study of food habits in largemouth bass (*Micropterus salmoides*) in Lake Powell indicates that chironomid larvae comprise up to 100 percent of the diet of fingerlings 20 to 99 mm in length. Fingerlings typically attain this size in the lake from June through October (Miller and Kramer 1971). This includes the time of greatest availability of chironomid larvae in the study area. Hayne and Ball (1956) evaluated the effect of fish predation on the productivity of benthic macroinvertebrates in the littoral zone. Benthic productivity increased as benthic biomass decreased, resulting in a lower standing biomass and a higher turnover rate. Predation resulted in higher total productivity of the organisms (Hayne and Ball 1956).

Snails

With the exception of one individual of the genus *Gyraulus*, all snails found in all samples were of the genus *Physa*. The snails exhibited a preference for the trees that were submerged for 12 weeks. The average number of individuals per 4-week tree at all depths was 0.78 versus 5.58 for

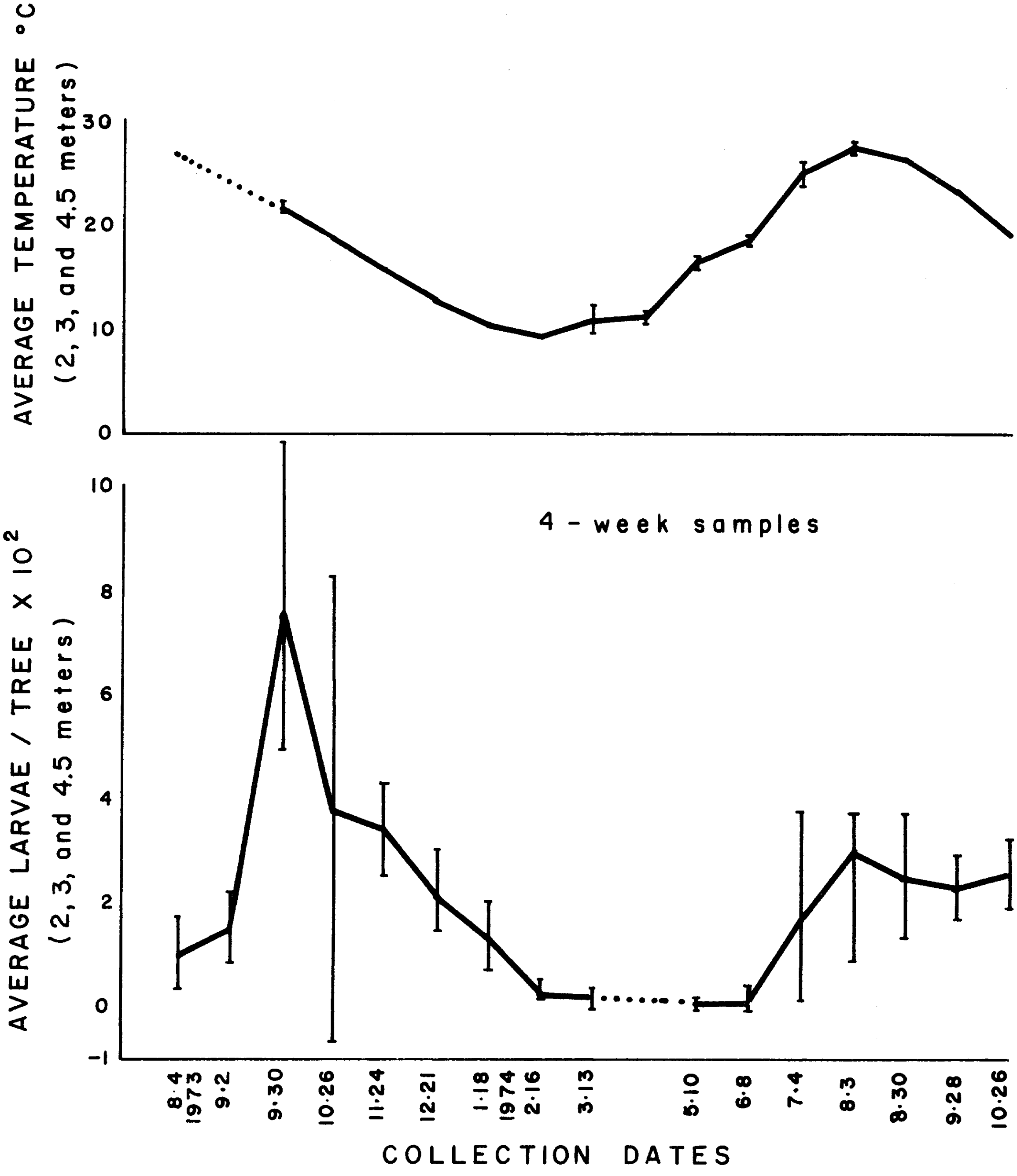


Figure 2: Relation of chironomid larval density of 4-week samples (three depths) to temperature over time. Vertical lines indicate 95-percent confidence limits.

each 12-week sample. The number of individuals present on the 12-week trees ranged from 0 to 86. For the 12-week trees at the shallower depths (2, 3, and 4.5 m) the average number of individuals was highest at 2 m (Table 3). Below 4.5 m, the average number of snails per tree increased with depth. Physa occurred in greatest numbers in July and August. Snails on the 4-week trees followed the same pattern but occurred much less frequently.

The presence of Physa has implications for the potential incidence of schistosome dermatitis, or "swimmer's itch," in the lake. Species of this genus may function as hosts for one dermatitis-producing schistosome species, Cercaria physellae. Whether this organism would affect the recreational value of Lake Powell would depend on the life cycle of the Physa in the lake. Most species of Physa studied breed in the early summer. Studies done in Wisconsin on host life cycles reveal that juveniles are seldom, if ever, infected. Only adults carry and release cercariae to the water (Cort et al. 1940). If the Physa in the lake breed early in the summer and die off quickly, cercariae will no longer be present in the water when it warms enough to attract swimmers. However, there is great variety in the life cycles of Physa species (Brackett 1940), and if conditions favor a later, or longer, breeding season schistosome dermatitis could become a problem in Lake Powell. Inundated vegetation provides a habitat for the snails with constant food supply and protection. As the groves of salt cedar (Tamarix pentandrus) continue to expand along sandy shores of the lake (Potter and Pattison 1976), and as they are alternately flooded and uncovered, much more of this favorable habitat would be available to the snails.

Table 3: Variation in density of *Physa* over depth in the 12-week samples.

Depth (meters)	Average Physa/Tree	S.E.±[a]	N[b]
2	7.76	4.47	21
3	3.86	1.55	28
4.5	2.58	.98	33
6	5.21	1.73	31
8	5.76	1.39	34
10	9.10	2.27	29

[a] S.E. = standard error.

[b] N = number.

Diatoms

Many studies of diatom community composition and density have been conducted in an attempt to establish some easily measurable biological criteria for water quality standards (Butcher 1947; Douglas 1958; Williams 1964). Studies correlating physical and chemical aquatic parameters with one species or with total density have defined the tolerance limits of some organisms, but researchers generally have concluded that community structure and stability are more valid indicators of aquatic conditions than is the presence, absence, or abundance of a particular species (Patrick, Hohn, and Wallace 1954; Patrick and Strawbridge 1963).

One widely employed measure of community structure and stability is H', the Shannon-Weaver diversity index. H' comes from information theory and is a measure of the uncertainty of predicting the classification of an individual drawn at random from a population of several species. If the population is divided equally among many species, it is more difficult to predict the identification of the next randomly encountered individual; therefore, the uncertainty, or diversity, is high. The diversity is lessened in a population dominated by many individuals of one or two species. H' is a function of the distribution of individuals among the species present. The potential range of the index is limited by the number of species present, 0-ln s (zero to the natural log of the number of species). If a community diversity index varies within normal limits, the structure of that community, as the relative numbers of individuals of dominant species or of rare species, remains stable.

The index has been modified by Pielou (1966) to measure diversity in an aliquot of sample from a population where the entire sample is too large to be counted. The use of estimated H' (EH') assumes that the aliquot is randomly drawn from the sample and that the total number of species represented in the sample is known, even if not all are represented in the aliquot.

Two major criticisms have been leveled at the use of the Shannon-Weaver diversity index: (1) because the number of individuals is used as part of the equation, the index overemphasizes the importance of the abundant organisms at lower trophic levels in contrast to the fewer and larger organisms of upper trophic levels; (2) the diversity index of a sample rises as the number of individuals counted increases (Dickman 1968). The index was used in this study to estimate the diversity of only the diatom community over depth and time, and does not attempt to relate these indices to other trophic levels. The index was calculated for each sample based on species distribution among 350 individuals, regardless of the density in the sample. The index also was used to describe the establishment of the diatom community associated with inundated vegetation, and may be used as a reference point for future evaluations of similar habitats.

Diversity indices did not vary significantly with depth. The average diversity index was higher at 8 m ($\bar{x}$ = 2.00) than at other depths ($\bar{x}$ = 1.68-1.74), but the difference was not great enough to be statistically significant. Diversity indices varied significantly over the 17-month time period ($P < .05$), representing seasonal changes. In general, diversity was greatest at times of lower density, indicating higher density was a result of an increased number of individuals in a few species (Figure 3).

Figure 3: Relationship of total diatom density to monthly diversity indices. Diversity index computed for total species composition for all depths each month.

Diatom density varied significantly over depth ($P < .05$) and showed highly significant variation with time ($P < .01$). The greatest number of diatoms occurred at 3 m, followed by 2 m, then decreased with depth. Round (1961) found the same pattern for benthic algae and reported that high light intensity may inhibit diatom density at the shallower depths. Wave action also may have an effect. The number of diatoms occurring at each depth changed over time as follows. At 2 m, density was greatest in October 1974 (5209 individuals); density was high in May also (4925). Diatoms at 3 m reached greatest density in May (7647). Density at 4.5 m was high in May (4374), but did not peak until June (5045). Density at 6 m also peaked in June (2057). For the 8-m samples, diatom density was greatest in August (2196). Temperature measurements taken at each collection date indicate little difference in average temperature over depth ($\bar{x}$ = 17.4 to 18.6°C). The study area remained above the level of the thermocline; therefore, decreasing diatom density with depth is more likely a function of available light or wave and current activity than of temperature. The lag in occurrence of greatest density at the lower depths may be a function of light and temperature. The variation of total diatom density over time, as described previously (Figure 3), corresponds to density patterns of benthic and planktonic diatoms described in other studies (Round 1964; Patrick 1964).

The availability of substrate in the littoral zone encourages a course of development of these organisms which has been noted in typical aquatic systems. Round (1964) cites several factors which influence the density and distribution of benthic flora. Unlike current dependent plankton, benthic diatoms have available a variety of habitats as a result of lake morphometry. Lake Powell, with its complex pattern of scouring currents, varying sediment loads, and intermittent water level fluctuations, presents a wide spectrum of physical habitats to be occupied by benthic flora. Species composition could be expected to change from site to site and over time as a result of the interplay of physical and chemical factors, as well as biological interactions among diatom species and between trophic levels. Even though the same range of number of species and percentage of dominance is generally present in a stable diatom community, there is a continual shifting of the dominant species over time (Patrick 1964). Patrick attributes this to the availability in any area of a large pool of diatom species. Any change in conditions could favor development of a new dominant. Round (1964) and Patrick (1964) used the relative percent dominance and the number of species present as a basis for determining the ecological status of the aquatic environment. As the present study included only one sampling site, it is not possible to use these results to evaluate water quality in the lake. The results do underline the role of inundated vegetation in the lake. The vegetation is available as habitat and is utilized by a community which establishes patterns of density and diversity over time and depth similar to the patterns and variations the organisms follow in a more usual aquatic situation. Occupation of the site is not a temporary phenomenon. The organisms capable of occupying this expanding habitat imply a potential contribution to the development of fish food and nutrient supply in the lake.

Throughout the study, six diatom species comprised 65 to 94 percent of the individuals present at each date. However, each species attained its greatest density at a different time of the year (Figures 4 and 5). The number of species represented at any one date ranged from 21 to 39. If a greater variety of benthic habitats had been included in the study, one should have found greater variations in

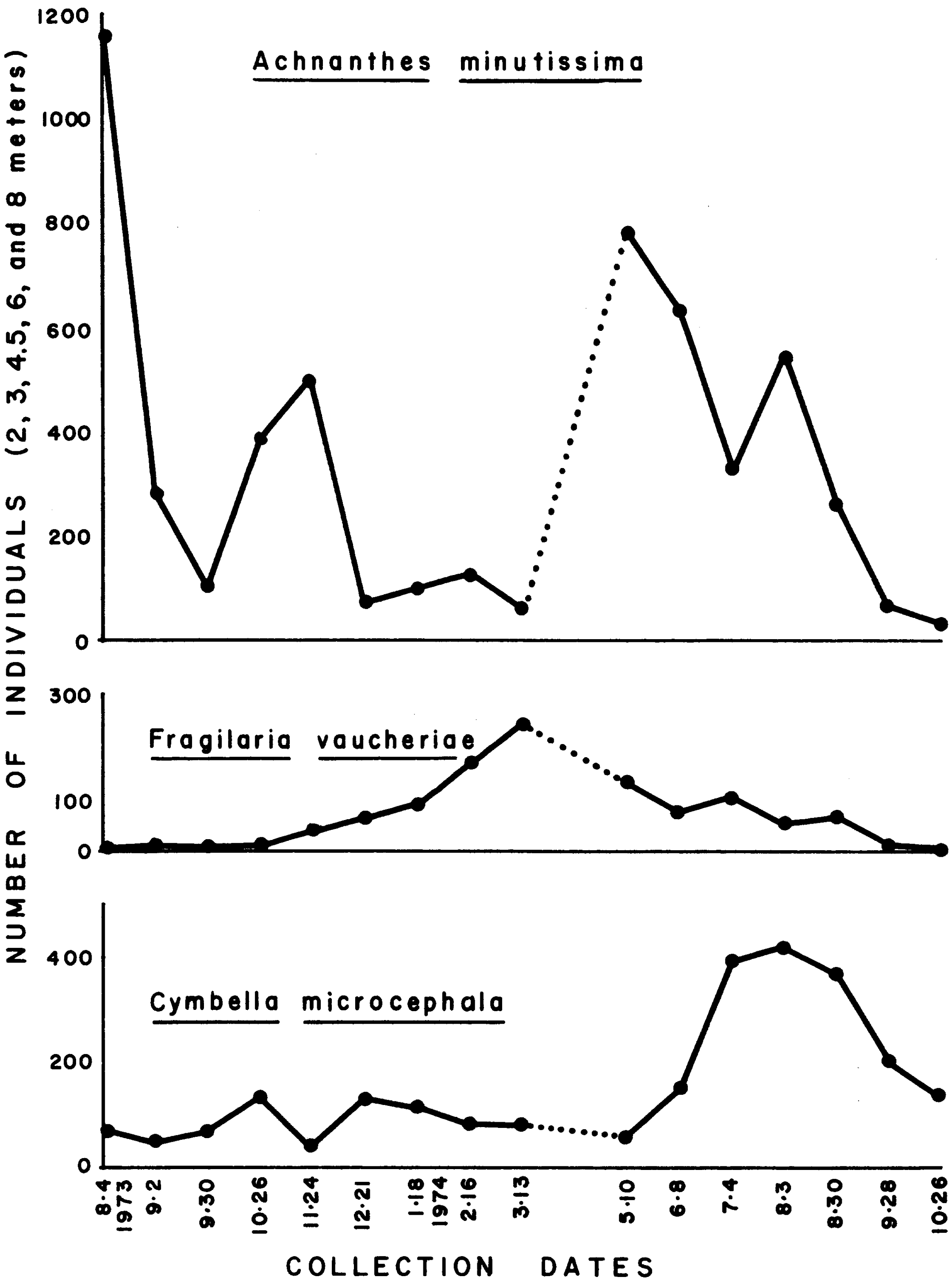


Figure 4: Variations over time of density of three dominant diatom species: Cymbella microcephala, Fragilaria vaucheriae, and Achnanthes minutissima.

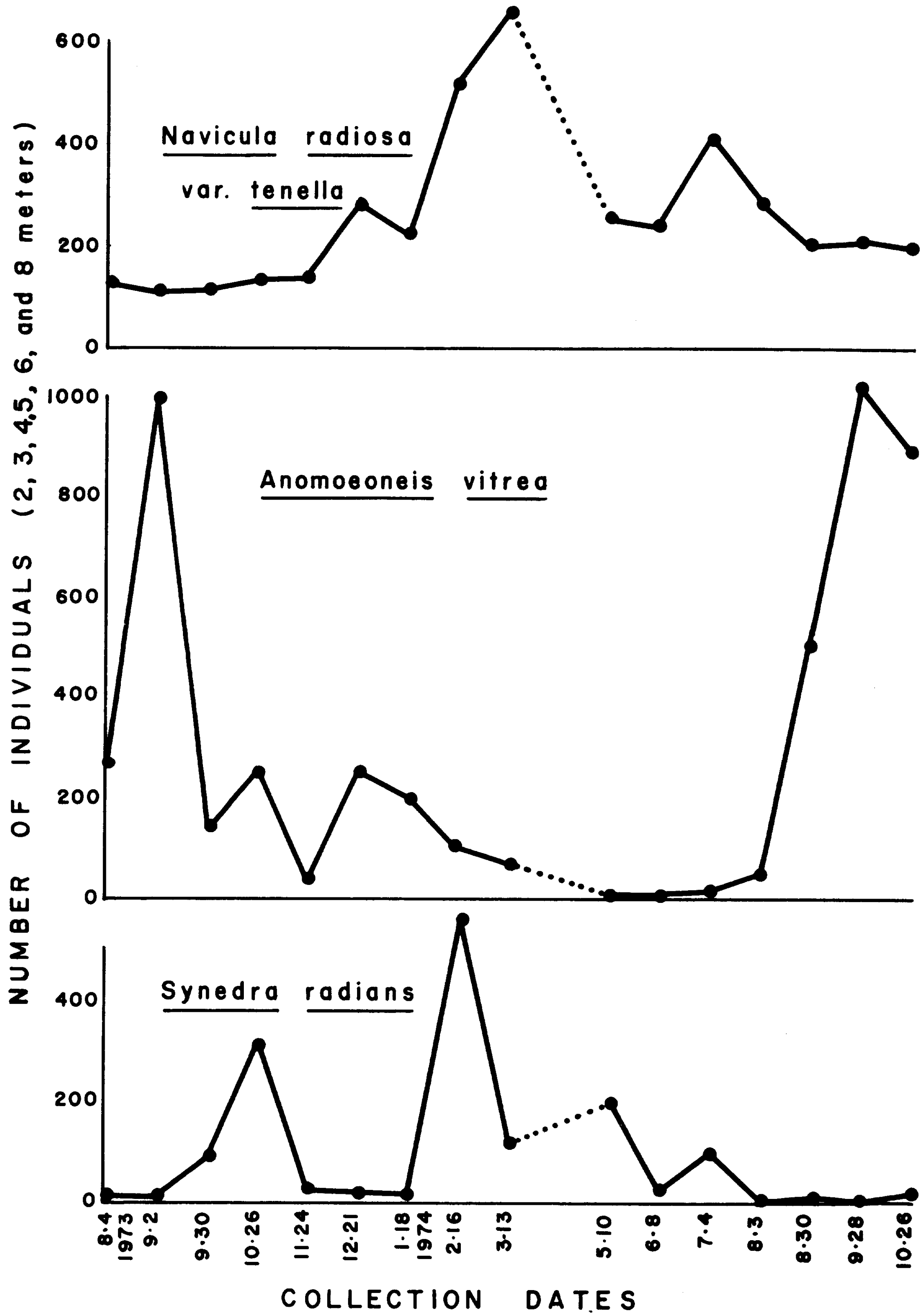


Figure 5: Variation over time of density of three dominant diatom species: Synedra radians, Anomoeoneis vitrea, and Navicula radiosa var. tenella.

total and relative densities, greater variations in total number of species, greater variations in species composition among habitats, and lower relative densities of the several dominant species.

SUMMARY

One of the primary reasons why the periphytic community has not been studied often is the difficulty involved in collecting, processing, and quantifying the material. The shrub-shaped artificial substrates used in the present study closely simulated the inundated terrestrial vegetation in Lake Powell, and, in conjunction with the use of SCUBA, allowed the sampling *in situ* of all organisms physically associated with the substrate. Some procedural problems remain, the greatest of which is the separation of fine silt from organisms that is necessary to obtain accurate organismal weight measurements. The investigator who is free to move and work under water may find it possible to modify known techniques and to apply them to evaluate communities within the relatively unexplored habitats of the lake.

The relative diversities and densities of the periphytic organisms discussed indicate that the course of development of the Lake Powell aquatic community mirrors that of other man-made lakes. However, Lake Powell is unique in several respects. The fluctuating water level and resulting redistribution of unstable desert soil, and the sediment load brought to the lake by the powerful rivers which feed it, produce a changing bottom substrate. The distinct morphometry, geology, and vegetation of the Glen Canyon region provoke numerous variations on the "typical" pattern of lake development.

The lack of aquatic macrophyton would seem to lessen the habitats available for other organisms. However, Lake Powell contains unique local areas of enrichment unknown in "typical" freshwater systems. For example, when the rodent nests that are distributed up the canyon walls are flooded, they provide thousands of years of accumulation of nutrients to be absorbed and recycled by organisms in the water (Potter and Pattison 1976). The diversity and density of species in the littoral zone of the lake show that organisms associating with inundated vegetation occupy an important niche in the food chain in the Lake Powell ecosystem.

Diatom density is usually greatest when diversity is lowest, suggesting that density is a result of short-term dominance by successive species. Chironomid larvae make up 95 percent of the macroinvertebrates found and are available to maturing fish in the lake. In addition, organisms such as Physa are present in this area and they are capable of harboring schistosome cercariae, which poses a potential threat to the recreational value of the lake.

LITERATURE CITED

Brackett, S. 1940. Studies on schistosome dermatitis VIII. Notes on the biology of the snail hosts of schistosome cercariae in the Wisconsin area and epidemiological evidence for the life cycles of some avian schistosomes. Am. J. Hyg. 31(D):85-104.

Bradbury, J.P. and T.C. Winter. 1976. Areal distribution and stratigraphy of diatoms in the sediments of Lake Sallie, Minnesota. Ecology 57:1005-1014.

Butcher, R.W. 1947. Studies in the ecology of rivers VII. The algae of organically enriched waters. J. of Ecology 35:186-191.

Claflin, T.O. 1968. Reservoir aufwuchs on inundated trees. Trans. Amer. Microsc. Soc. 87:97-104.

Cort, W.W., D.B. McMullen, L. Olivier, and S. Brackett. 1940. Studies on schistosome dermatitis VII. Seasonal incidence of Cercaria stagnicolae Talbot, 1936, in relation to the life cycle of its snail host, Stagnicola emarginata angulata (Stowerby). Am. J. Hyg. 31(D):33-69.

Dickman, M. 1968. Some indices of diversity. Ecology 49:1191-1193.

Douglas, B. 1958. The ecology of the attached diatoms and other algae in a small stony stream. J. of Ecology 46:295-322.

Fillion, D.B. 1967. The abundance and distribution of benthic fauna of three mountain reservoirs on the Kananaskis River in Alberta. J. of Applied Ecology 4:1-11.

Gaufin, A.R. and C.M. Tarzwell. 1956. Aquatic macroinvertebrate communities as indicators of organic pollution in Lytle Creek. Sewage and Industrial Wastes 28:(7)906-924.

Goodnight, C.J. 1973. The use of aquatic macroinvertebrates as indicators of stream pollution. Trans. Amer. Microsc. Soc. 92:1-13.

Hansmann, E.W. 1973. Diatoms of the streams of eastern Connecticut. Conn. Geol. and Nat. Hist. Surv. Bull. 106, 119 p.

Hayne, D.W. and R.C. Ball. 1956. Benthic productivity as influenced by fish predation. Limnol. and Oceanogr. 1:162-175.

Hutchinson, G.E. 1973. Eutrophication. Amer. Scientist 61:269-279.

Mason, W.T. 1973. An introduction to the identification of chironomid larvae. Anat. Qual. Control Lab., Nat. Environ. Res. Cen., U.S. Environ. Protection Agency. Cinn., Ohio. 90 p.

McLachlan, A.J. and S.M. McLachlan. 1971. Benthic fauna and sediments in Lake Kariba. Ecology 52:800-809.

Miller, K.D. and R.H. Kramer. 1971. Spawning and early life history of largemouth bass (Micropterous salmonides) in Lake Powell. In: Reservoir Fisheries and Limnology, Spec. Publ. No. 8, Amer. Fisheries Soc. Washington, D.C. pp. 73-83.

Nursall, J.R. 1952. The early development of a bottom fauna in a new power reservoir in the Rocky Mountains of Alberta. Can. J. Zool. 30:387-409.

Patrick, R. 1964. A discussion of natural and abnormal diatom communities. In: Algae and Man. ed. D.F. Jackson. Plenum Press, New York. 434 p.

Patrick, R., M.Y. Hohn, and J.H. Wallace. 1954. A new method for determining the pattern of the diatom flora. Not. Nat. Acad. Sci. No. 259:1-12.

_____ and C.W. Reimer. 1966. The diatoms of the United States, Vol. I. Philadelphia Acad. Nat. Sci. 688 p.

_____and D. Strawbridge. 1963. Variation in the structure of natural diatom communities. The American Naturalist 97:51-57.

Pennack, R.W. 1953. Fresh-water invertebrates of the United States, The Ronald Press Co., New York. 769 p.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theoret. Biol. 13:131-144.

Potter, Loren D. and Natalie B. Pattison. 1976. Shoreline Ecology of Lake Powell. Lake Powell Research Project Bulletin No. 29. Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, Calif. 235 p.

Round, F.E. 1961. Studies on bottom-living algae in some lakes of the English Lake District VI. The effect of depth on the epipelic algal community. J. of Ecology 49:245-251.

______. 1964. The ecology of benthic algae. In: Algae and Man. ed. D.F. Jackson. Plenum Press, New York. 434 p.

Usinger, R.L. 1971. (ed.) Aquatic insects of California with keys to North American genera and California species. Univ. of Calif. Press, Berkeley, Los Angeles, London. 508 p.

Utah Division of Wildlife Resources, Department of Natural Resources. 1971. Glen Canyon Reservoir post-impoundment investigations. Final progress report presented as a contribution of the section 8 program, Glen Canyon Unit, Colorado River Storage Project. 124 p.

Weber, C.I. 1971. A guide to the common diatoms at water pollution surveillance system stations. Anal. Qual. Control Lab. Nat. Envir. Res. Cen. U.S. Environ. Protection Agency, Cinn., Ohio. 101 p.

Wetzel, R.G. 1975. Limnology. W.B. Saunders, Philadelphia, Pennsylvania. 743 p.

Williams, L.G. 1964. Possible relationships between plankton-diatom species numbers and water quality estimates. Ecology 45:809-823.

ACKNOWLEDGMENTS

Appreciation is expressed to Natalie Pattison for her help in the field and to Dr. Gene Hansmann for his assistance in learning diatom identification. Research for this study was supported by grants NSF GI-34831 and NSF-AEN 72-03462 A03 to the Shoreline Ecology Subproject of the Lake Powell Research Project at The University of New Mexico, under the Research Applied to National Needs Program of the National Science Foundation.

APPENDIX

List of Diatom Taxa Ranked by Species Composition
Based on 350 Individuals Identified
Per Each of 77 Samples

Achnanthes (5558)	
A. minutissima	5492
A. flexella	29
A. detha	1
A. (girdle view)	36
Anomoeoneis vitrea	4797
Cymbella (4026)	
C. microcephala	2506
C. tumidula	704
C. laevis	454
C. "A"	195
C. ventracosa	41
C. affinis	1
C. (girdle view)	125
Navicula (3410)	
N. radiosa var. tenella	2289
N. laevissima	343
N. cryptocephala	218
N. "A"	146
N. pygmea	99
N. rhynchoncephala	67
N. exigua var. capitata	46
N. angilica	43
N. exigua	42
N. pupula	34
N. decussis	17
N. mutica	17
N. radiosa	8
N. cuspidata var. ambigua	5
N. hungarica var. capitata	4
N. viridula var. rostellata	2
N. acomada	2
N. elginensis var. neglecta	2
N. halophila	1
N. (girdle view)	25
Synedra (1665)	
S. radians	1475
S. filiformis	176
S. rumpens var. meneghiniana	8
S. ulna	3
S. (girdle view)	3
Fragilaria (1530)	
F. vaucheriae	1062
F. crotenensis	384
F. virescens	57
F. construens	12

F. brevistriata	2
F. (girdle view)	13
Nitzschia (836)	
N. denticula	369
N. palea	310
N. dissipata	66
N. amphibia	49
N. filiformis	17
N. sinnuata var. tabillaria	17
N. parvula	4
N. acicularis	2
N. pilum	1
N. hungarica	1
Cyclotella (811)	
C. cryptica	767
C. oscellata	23
C. stelligera	8
C. bodanica	6
C. meneghiniana	6
C. Kutzingiana	1
Caloneis (36)	
C. ventracosa var. trunculata	35
C. hyalina	1
Gomphonema (28)	
G. olivacieum	20
G. angustatum	5
G. parvelum	3
Stephanodiscus Hantzschii	20
Amphora (16)	
A. ovalis	14
A. "A"	2
Asterionella formosa	15
Diploneis (9)	
D. elliptica	4
D. occulata	4
D. interrupta	1
Nedium (2)	
N. dubium	1
N. dubium f. constrictum	1
Amphipleura pellucida	1

GLOSSARY

algae	chiefly aquatic, non-vascular plants with chlorophyll
aliquot	a selected portion of a solution
benthic	referring to those plants and animals living on the bottom of a lake
biomass	the total weight of matter incorporated into (living and dead) organisms
carrying capacity	the population density normal to an environment on a long-term basis
cercariae	one of the larval forms of flukes (Trematoda), produced asexually by larvae while these are parasitic in snails; cercariae are infective to a new host which

	they may enter by penetrating skin, becoming sexually mature in this, the definitive, host
chironomid larvae	larval form of the Tendipidae, or midges; the larvae are aquatic
diatoms	unicellular or colonial algae having a siliceous cell wall or frustule
eutrophication	the process of enrichment, as of dissolved nutrients in a lake
fingerling	a young fish from 2 weeks after complete absorption of the yolk sac up to 1 year of age
flocculated	combined or aggregated into a mass from fine suspended parts
gastropods	a mollusk of the Class Gastropoda; a snail or slug
genera	the first term of the binomial system of nomenclature

H'	a species diversity index which measures the uncertainty of predicting the classification of an individual drawn at random from a population of several species
Hyrax	commercial name of a medium used for mounting diatoms on slides
indicator species	a species whose presence or absence may define a particular community or environment
Kruskal-Wallis test	a statistical test of significance for non-parametric data
lake morphometry	measurement of the external form of a lake and its basin
level of significance	a percentage value selected by the investigator of acceptable error of data due to random chance caused by physical or biological variations

littoral zone	the marginal part of a body of fresh water extending downward to the limit of rooted vegetation
macroinvertebrate	any invertebrate large enough to be distinguished as an organism by the eye
macrophyton	large (macroscopic) forms of aquatic vegetation
metaphyton	single-celled or colonial algae living in aggregated masses of sand, silt, and organic debris, in shallow water on the lake bottom
odonata nymphs	larval stage of family Odonata which includes both dragonflies and damselflies
oligiochaetes	an annelid worm; some are aquatic
overturn	refers to the vertical mixing of strata in lakes, usually occurring in spring and fall

$P < .05$ level	the probability is less than 5 percent that the difference occurred by chance
parametric	refers to data which are normally distributed
periphyton	community of organisms usually small but densely set, closely attached to stems and leaves of rooted aquatic plants or other surfaces projecting above the bottom
plankton	passively floating or weakly swimming organisms in a body of water, consisting chiefly of minute plants and animals, but including large forms which have limited powers of locomotion
plankton net	a fine-meshed cloth net for filtering of suspended organisms in water

replicate	duplicate; an experiment or procedure that repeats another done at the same time
river-mile	distance upstream, or in this case up the reservoir from the dam
schistosome dermatitis	a skin irritation caused by the invasion of cercariae of the genus <u>Cercaria</u>
sclerotized sheath	outer layer of skin which has been hardened by substances other than chitin, as the cuticle of an insect
Spearman's rank correlation procedure	a comparison of non-parametric data to determine correlation
species area curve	graph of the number of species seen versus the number of individuals counted or the area observed; used to determine the individuals or area to be counted

	to describe validly the species-area or species-abundance relationships in the sample
substrate	the base on which an organism lives
terrestrial	pertaining to the earth
thermocline	a horizontal stratum in a body of water where the vertical temperature change is 1°C, or more, per meter
trophic	refers to feeding, and frequently to levels in a food chain

THE AUTHORS

Loren D. Potter is Professor of Plant Ecology in the Biology Department, University of New Mexico. From 1958 to 1972 he was chairman of that department. He is one of the founders of the Lake Powell Research Project. His plant ecology research has included studies in the arctic, ponderosa pine, rangelands, and ecology-archeology. His current research is with the National Park Service at Chaco Canyon and Bandelier, and he is directing research for the U.S. Forest Service and ERDA on land stabilization and revegetation. He is presently Principal Investigator of the Shoreline Ecology Subproject and Co-Principal Investigator of the Heavy Metals Subproject of the Lake Powell Research Project.

Ellen T. Louderbough, B.S. in 1968 from Skidmore College, was a graduate research assistant during the period of the submergence study, and received her M.S. degree from the Biology Department, University of New Mexico, in July 1976. She is currently a Ph.D. candidate in that department.

LAKE POWELL RESEARCH PROJECT BULLETINS

No. 1 Mercury in the Lake Powell Ecosystem, by D. R. Standiford, L. D. Potter, and D. E. Kidd. ($1.50)

No. 2 Demographic Change among the Hopi and Navajo Indians, by S. J. Kunitz. ($1.50)

No. 3 Air Quality in the Lake Powell Region, by E. G. Walther, M. D. Williams, R. Cudney, and W. Malm. (out of print)

No. 4 Legal-Political History of Water Resource Development in the Upper Colorado River Basin, by D. Mann, G. Weatherford, and P. Nichols. ($2.00)

No. 5 Major Element Geochemistry of Lake Powell, by R. C. Reynolds, Jr., and N. M. Johnson. ($1.50)

No. 6 Survey of Navajo Community Studies, 1936-1974, by E. B. Henderson and J. E. Levy. ($3.00)

No. 7 The Impact of Power Development on the Navajo Nation, by L. A. Robbins. ($2.00)

No. 8 Theoretical Analysis of Air Quality: Impacts on the Lake Powell Region, by M. D. Williams and E. G. Walther. ($1.50)

No. 9 Scientific Information in the Decision to Dam Glen Canyon, by P. C. Perkins. ($1.50)

No. 10 A Case Analysis of Policy Implementation: The National Environmental Policy Act of 1969, by Hanna J. Cortner. ($1.50)

No. 11 The Macroeconomic Impact of Energy Development in the Lake Powell Area, by W. Schulze, S. Ben-David, D. Brookshire, and R. Whitworth. ($1.50)

No. 12 Management of Scientific Collaboration in the Lake Powell Research Project, by O. L. Anderson. ($1.50)

No. 13 Utah Coal for Southern California Power: The General Issues, by O. L. Anderson. ($2.50)

No. 14 An Overview of the Effect of Lake Powell on Colorado Jacoby, Jr. ($1.50)

No. 15 Navajo Participation in Labor Unions, by L. A. Robbins. ($2.00)

No. 16 Bacterial Contamination of Lake Powell Waters: An Assessment of the Problem, by D. E. Kidd. ($2.00)

No. 17 Survey Estimates of Visitation and Expenditures for the Lake Powell Area, by J. Baxter, S. Ben-David, F. L. Brown, and J. Knight. (in press)

No. 18 Long-Term Surface-Water Supply and Streamflow Trends in the Upper Colorado River Basin Based on Tree-Ring Analysis, by C. W. Stockton and G. C. Jacoby, Jr. ($2.50)

No. 19 The Prospects for Navajo Taxation of Non-Indians by C. E. Goldberg. ($2.00)

No. 20 The Relationship of Economic Variations to Mortality and Fertility Patterns on the Navajo Reservation, by S. J. Kunitz. ($2.50)

No. 21 A Survey of Fertility Histories and Contraceptive Use Among a Group of Navajo Women, by S. J. Kunitz. ($2.50)

No. 22 The Effects of Power Production and Strip Mining on Local Navajo Populations, by D. G. Callaway, J. E. Levy, and E. B. Henderson. ($3.00)

No. 23 Utah Coal for Southern California Power: Historical Background, by P. C. Grew. (in press)

No. 24 Water Policy and Decision-Making in the Colorado River Basin, by D. E. Mann. ($2.00)

No. 25 Rural Industrialization: The Four Corners Region, by R. L. Little. (in press)

No. 26 Predicting the Transport of Air Pollutants from the Navajo and Kaiparowits Generating Stations into Lake Powell, by E. G. Walther. ($2.00)

No. 27 The Navajo Environmental Protection Commission and the Environmental Impact Statement, by H. J. Cortner. ($2.50)

No. 28 Boomtown Impacts of Energy Development in the Lake Powell Region, by B. Ives and W. D. Schulze. (in press)

No. 29 Shoreline Ecology of Lake Powell, by L. D. Potter and N. B. Pattison. ($4.50)

No. 30 Kaiparowits Handbook: Coal Resources, by D. Carey, J. Wegner, O. Anderson, G. Weatherford, and P. Grew. (in press)

No. 31 Kaiparowits Handbook: Air Resources, by M. Williams, S. Fry, G. Weatherford, and J. Wegner. (in press)

No. 32 Kaiparowits Handbook: Human Resources, by K. Weber. (in press)

No. 33 The Impact of Energy Development on Recreation Use and Value in the Glen Canyon National Recreation Area, by D. Brookshire, W. D. Schulze, and B. Ives. (in press)

No. 34 The Concentrations of Ten Heavy Metals in Some Selected Lake Powell Game Fishes, by R. E. Bussey, D. E. Kidd, and L. D. Potter. ($2.50)

No. 35 Inhibition of Calcite Precipitation by Polyphenols, by R. C. Reynolds, Jr. (in press)

No. 36 Impact Assessment and Environmental Planning in the Upper Colorado River Basin, by L. B. Leopold, R. H. Twiss, and N. Wakeman. (in press)

No. 37 Macroinvertebrates and Diatoms on Submerged Bottom Substrates, Lake Powell, by L. D. Potter and E. T. Louderbough. ($2.50)

No. 38 Kaiparowits Transportation Costs, by M. Rogozen. (in press)

No. 39 Colorado River Basin Coal for Electric Power Generation in California: Legal Constraints, by R. Purtich, M. Price, et al. (in press)

No. 40 Western Coal for Southern California Power Consumption: Air Quality Considerations, by A. Kashani et al. (in press)

No. 41 Western Coal for Southern California Power Consumption: Social and Environmental Impact, by D. Mann et al. (in press)

No. 42 The Effect of Lake Powell on Dissolved Silica Cycling in the Colorado River, by L. M. Mayer. (in press)

No. 43 Environmental Impact Assessment and Review in Energy Decision Making: State Participation in the Lake Powell Region, by H. J. Cortner. (in press)

No. 44 Shoreline Surface Materials and Geological Strata, Lake Powell, by L. D. Potter and N. B. Pattison. (in press)

No. 45 Prehistoric and Historic Steps and Trails of Glen Canyon-Lake Powell, by N. B. Pattison and L. D. Potter. (in press)

No. 46 Modeling of Visibility Reductions and Extreme Pollutant Concentrations Associated with Southwestern Coal-Fired Powerplants, by M. D. Williams. (in press)

No. 47 Changing Navajo Voting Patterns, J. E. Levy. (in press)

No. 48 Evaporation, Bank Storage, and Water Budget at Lake Powell, by G. C. Jacoby, Jr., S. Patch. R. Nelson, and O. L. Anderson. (in press)

No. 49 Coal Sources for Southern California Power, by D. L. Carey. (in press)

No. 50 The Role of Transportation of Energy in the Development of the Southwest, by O. L. Anderson and M. Rogozen. (in press)

No. 51 The Impact of Industrialization on Navajo Household Organization, by D. Callaway. (in press)

No. 52 The Excellent But Deteriorating Air Quality in the Lake Powell Region, by E. G. Walther, W. C. Malm, and R. Cudney. (in press)

No. 53 Toward a Framework for Evaluating the Impact of Procedural Change upon Policy: The Case of the Kaiparowits Environmental Impact Statement, by H. Ingram and J. S. Ullery. (in press)

No. 54 Navajo Energy Politics, by L. A. Robbins. (in press)

No. 55 The Distribution of Industrial Jobs in Local Navajo Populations, by L. A. Robbins, E. B. Henderson, and D. Callaway. (in press)

No. 56 Employment Benefits from Rural Industrialization, by R. L. Little and S. Lovejoy. (in press)

No. 57 Some Social Consequences of Boomtowns, by R. L. Little. (in press)

No. 58 Colorado River Basin Coal for Electrical Power Generation in Southern California, by O. L. Anderson, D. L. Carey, R. Purtich, and M. Rogozen. ($2.50)

No. 59 Application of the Nutrient Loading Concept and Effects of Nutrient Perturbations on Phytoplankton Productivity, by S. Gloss and D. E. Kidd. (in press)

No. 60 Trophic Status Investigations at Lake Powell Reservoir, by D. E. Kidd. E. Hansmann, and S. Gloss. (in press)

No. 61 Advective Circulation in Lake Powell, Utah-Arizona, by D. Merritt and N. Johnson. (in press)