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SEASONAL PLANKTON CHANGES AND PRIMARY PRODUCTIVITY IN BEECH RESERVOIR

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ABSTRACT

The Beech River drainage basin covers 302 square miles in west Tennessee and empties into Kentucky Lake at Tennessee River Mile (TRM) 136.0. Beech Reservoir, with a shoreline of 22 miles and a pool area of 347 hectares, is one of eight reservoirs located in this drainage basin.

In this study, phytoplankton productivity studies, phytoplankton standing crop and certain chemical analyses indicated that Beech is a more productive reservoir. Primary productivity values ranged from 85 mg C/m^2/day in February to 5,563 mg C/m^2/day in September. The 9-month primary productivity mean was 1,619 mg C/m^2/day. Chlorophyll *a* concentrations ranged from 14 mg/m^2 in August to 124 mg/m^2 in March. Phytoplankton cell counts averaged 6,961,555/1. The major ionic change was shown when total iron increased in the hypolimnion during April. Iron concentrations reached a maximum in August.

INTRODUCTION

The Beech River watershed is located in west Tennessee near Lexington about midway between Nashville and Memphis (Figure 1). The topography of the watershed is gently rolling to hilly, and is dissected by many small streams which combine to form the Beech River.

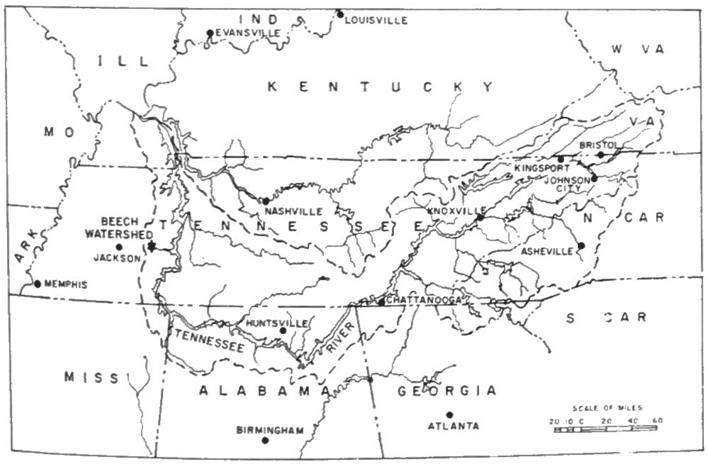

Figure 1. Beech watershed located halfway between Nashville & Memphis, indicated by star.

The river flows eastward across Henderson and Decatur counties to join the Tennessee River near Perryville, at an elevation of approximately 360 feet, at Tennessee River Mile (TRM) 136.0. The Beech River drainage basin, about 22 miles long and 14 miles wide and lying within a 600-foot high rim, covers 302 square miles (Figure 2).

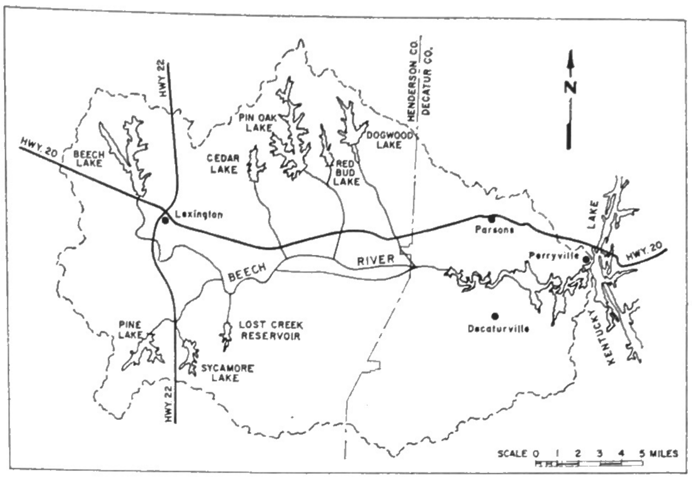

Figure 2. Beech River watershed.

Beech Reservoir (Figures 3 and 4) is the largest of eight reservoirs in the Beech River Tributary Area Development watershed project. The reservoir is situated on unconsolidated sediments of cretaceous age. Most of the basin is composed of these sediments which extend from the Mississippi River escarpment on the west to within 10 miles of the Beech-Tennessee River confluence on the east. These sediments consist of sands, clays, and marls which erode under the influence of surface waters and result in soils which are generally

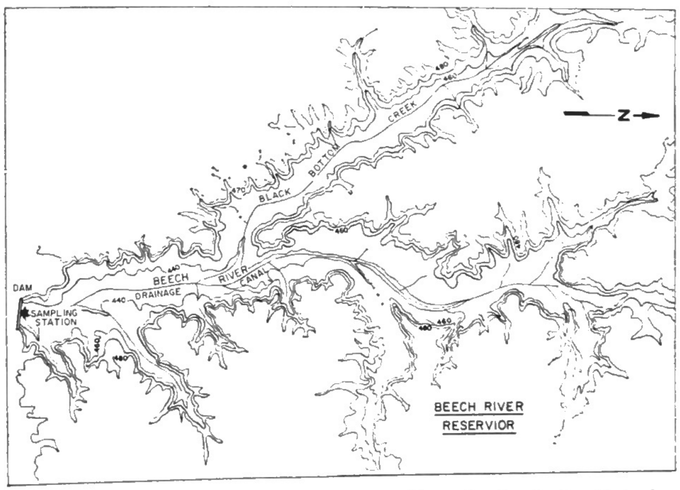

Figure 3. Location of biological sampling site in fork of drainage canal and stream directly above dam as indicated by star.

sandy. The final 10 miles to the confluence is characterized by consolidated rock of Devonian-Silurian age which, when fragmented, produces cherts, novaculites, limestone, and shales, and also results in sandy soils. The eastern part of the watershed has a higher percentage of clay and silt than the western portion. At the present time, approximately 40% of the basin is forested. The remainder is cropland, pasture, or idle land. The idle land is among the most severely eroded of any in Tennessee Valley—only the Ducktown area in east Tennessee has more erosion (TVA, 1951). Annual rainfall of 39 to 67 inches and extreme variations of temperature, −21° to 110° F, have contributed to severe erosion and soil leaching. Mean annual rainfall is 50 inches, and the mean annual temperature is 60° F.

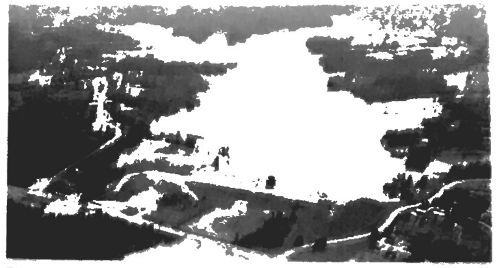

Figure 4. Aerial view of Beech Reservoir, sampling station indicated by star.

The development plan for Beech River provided that Beech Reservoir would be the only reservoir in the watershed especially constructed for flood control, recreation, and a municipal water supply (for Lexington, Tennessee). To enchance recreational values of Beech Reservoir, the Tennessee Game and Fish Commission and TVA removed all rough fish in 1964 and restocked it with black bass, bluegill, and channel catfish. The reservoir was opened for fishing, boating, water skiing, and swimming in 1965. The pertinent facts about all permanent pool reservoirs in the watershed are shown in Table 1.

TABLE 1. Normal Pool Reservoir Statistics (Agreement Between Beech River Watershed Development Authority and TVA)

September 18, 1967

Reservoir	Normal Pool Elevation	Pool Area (Acres)	Length of Shoreline (Miles)	Surrounding Benefited Land (Acres)
Beech	459.90	860	22	2,200
Cedar	438.85	150	8	800
Pin Oak	448.20	690	21	1,600
Redbud	439.15	230	7	800
Dogwood	443.66	490	11	1,500
Sycamore	449.96	220	9	950
Pine	464.63	210	4	775
Total		2,850	82	8,625

During the time of this survey, February through October 1968, the reservoir had an average depth near the dam of only 8 m (meters). Orientation and surrounding topography allow strong northerly and north-northwesterly winds (15-20 mph) to churn the reservoir during certain intervals of winter and spring. During mid and late summer, little mixing occurs except for brief windy periods. The immediate surroundings of the reservoir are forested hills and pastures; thus the water is usually not too turbid from surface runoff. The inflow particulate levels are normally low, but brief, severe rainy periods can cause a sharp increase in particulate flow.

A biological survey of seasonal plankton changes and productivity was conducted during 1968. Carbon fixation rate measured by C^{14} method was used to assess phytoplankton growth potential which was then related to fertility. The index obtained can be used to compare Beech Reservoir with other reservoirs of the TVA system. In addition to carbon fixation studies, chlorophyll and phytoplankton samples were collected for enumeration, and water samples were collected for chemical analyses.

METHODS

Measurements of primary productivity, chlorophyll, and phytoplankton were made at monthly intervals. All samples were collected at the sampling station above the dam.

Carbon^{14} *Technique*

It has been established that considerable variation occurs in day-to-day primary productivity rates in lakes (Rodhe et al. 1958; Goldman, 1960). However, the general productivity trend can be analyzed from monthly determinations with limited loss in precision, depending upon daily population oscillations within the month.

C^{14} standardization was determined by C. R. Goldman, Institute of Ecology, University of California, by combustion and gas-phase assays. Water samples for C^{14} assimilation measurements were collected with a non-metallic (Van Dorn) water sampler at the surface and at depths of 1 m, 3 m, and 5 m. The samples were transferred to clear 125-ml pyrex bottles, and 2.0 $_{\mu}$Ci of $Na_2C^{14}O_3$ was injected into each bottle with a syringe. Duplicate sampling bottles were supended at the collection depth by a line from a float. At selected depths, a dark bottle was used with the clear bottles to compensate for the amount of non-photosynthetic assimilation of C^{14}.

The C^{14} samples were usually incubated for 3 hours. After incubation, 1 ml of 10% Formalin was added to each bottle to stop the photosynthetic process and fix its products. The bottles were immediately placed in a lightproof box, and the samples filtered through HA($0.45_{\mu} \pm 0.02_{\mu}$) Millipore filters. The filters were held in desiccators in the dark until counted at the laboratory. Activity on the filters was measured with a thin-window, low-background, gas-flow proportional Beckman counter for which counting efficiency was 12.1%. Total inorganic carbon available for photosynthesis (mg C/1) was calculated by titrametrically determined total aklalinity values, pH readings, and temperatures from the conversion table of Bachmann (1962).

The C^{14} method adapted to this study was first used by Steemann—Nielson (1952) with procedures similar to those used by Parsons and Strickland (1963). The equations incorporated in those procedures were processed through TVA's IBM 360 computer. By comparing a ratio of total incident light with light available during the incubation period, productivity during the incubation period could be extrapolated to the total productivity per day. Light data were obtained from the U.S. Weather Bureau station, Nashville, Tennessee, which is the nearest station measuring incoming solar radiation.

Chlorophyll a Technique

Plant pigment content is used as a measure of phytoplankton standing crop and its potential to use incoming light energy in carbon fixation. Water samples for chlorophyll determinations were collected with a Van Dorn sampler from depths corresponding to C^{14} productivity samples. Phytoplankton cells were filtered from the water through a 1.2-micron Millipore filter. Subsequently the chlorophyll was extracted from the filters with 90% acetone for a period of at least 24 hours in the darkness of a refrigerator. Chlorophyll absorption was determined with a Bausch and Lomb Model 505 recording spectrophotometer. Chlorophyll *a* concentrations were calculated by the equation of Richards and Thompson (1952), as modified by Parsons and Strickland (1963). These chlorophyll equations have also been processed through TVA's IBM 360 computer.

Phytoplankton Analysis (Nannoplankton)

Phytoplankton samples were collected at the same depths as chlorophyll and C^{14} samples and preserved with Lugol's solution. Organisms were identified according to genera with an inverted microscope at a magnification of 312.5X.

Percentage of Light Penetration

Solar radiation at the water surface and throug the water column was measured with a submarine photometer. This photometer consisted of an underwater cell and a matching deck cell for alternate surface and underwater illumination monitoring.

Water Chemistry

Temperature profiles and all water chemistry sampling were conducted by the Water Quality Branch, Division of Environmental Research and Development, TVA.

RESULTS

Biological

Primary productivity values, average daily light energy (gm cal/cm²), and total monthly rainfall showed seasonal changes which are illustrated in Figure 5. The annual fluctuations in primary productivity are typical of phytoplankton populations in this type of reservoir. A spring peak in primary productivity was not noted. The rate of carbon fixation gradually increased from 85 mg C/m²/day in February to 5563 mg C/m²/day in September, with a sharp decline to 825 mg C/m²/day in October. Solar radiation increased from February through June, declined gradually through July, increased slightly through August, then declined sharply through October. Primary productivity estimates correlated well with the changing trends of solar radiation through mid-June; then the curves tended to converge in mid-July and rapidly diverged as primary productivity peaked in September, followed by the winter productivity decline. Rainfall did not hinder increase in productivity and may have enhanced it on occasion, especially from March through May and again in July.

The vertical distribution of carbon fixation, light penetration, dissolved oxygen, temperature, and total energy measured as langleys per day from February through October 1968 are shown in Figure 6. All values

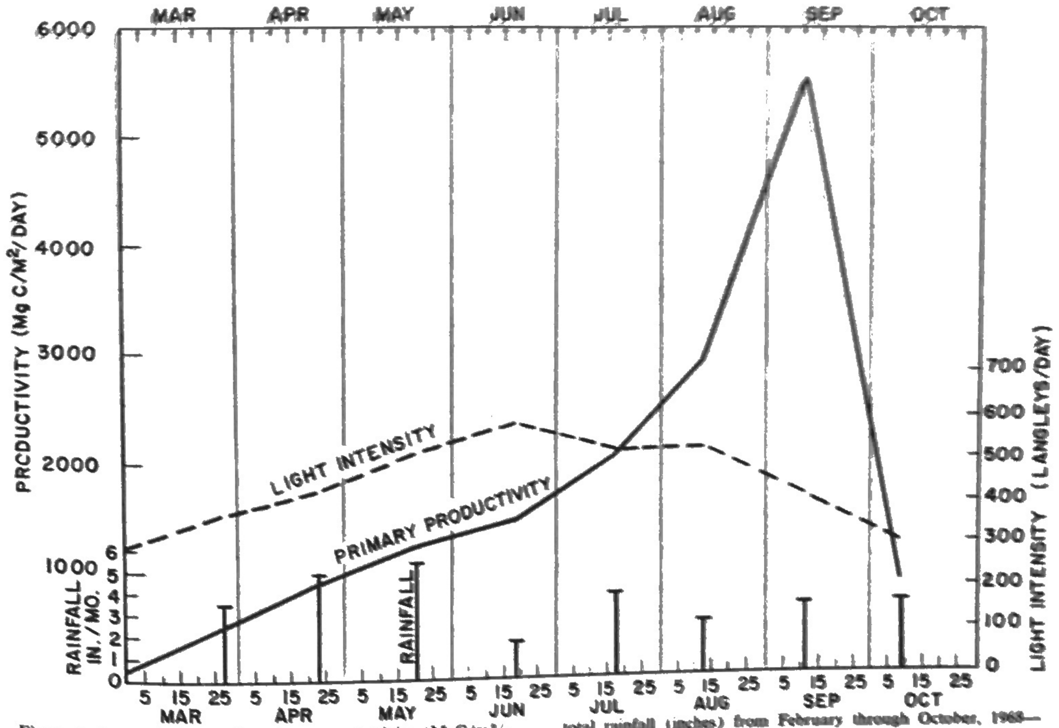

Figure 5. Seasonal changes in primary productivity (MgC/m²/-day), surface light intensity (langleys per day), and monthly total rainfall (inches) from February through October, 1968—Beech Reservoir.

in Figure 6 were determined during the day of investigation. Monthly mean values are not used in this figure. During February and March 1968, relatively low productivity measurements were found throughout the photic zone. A significant increase in surface productivity occurred in April and May (77 and 61 mg C/m³/hour at the surface). Surface productivity rapidly increased from June through October (107, 143, 242, 405, and 422 mg C/m³/hour). However, productivity at other depths was suppressed during September and October, especially October when no productivity occurred below 2 meters. The month of greatest productivity in lower depths (5 m) was August with 17 mg C/m³/hour.

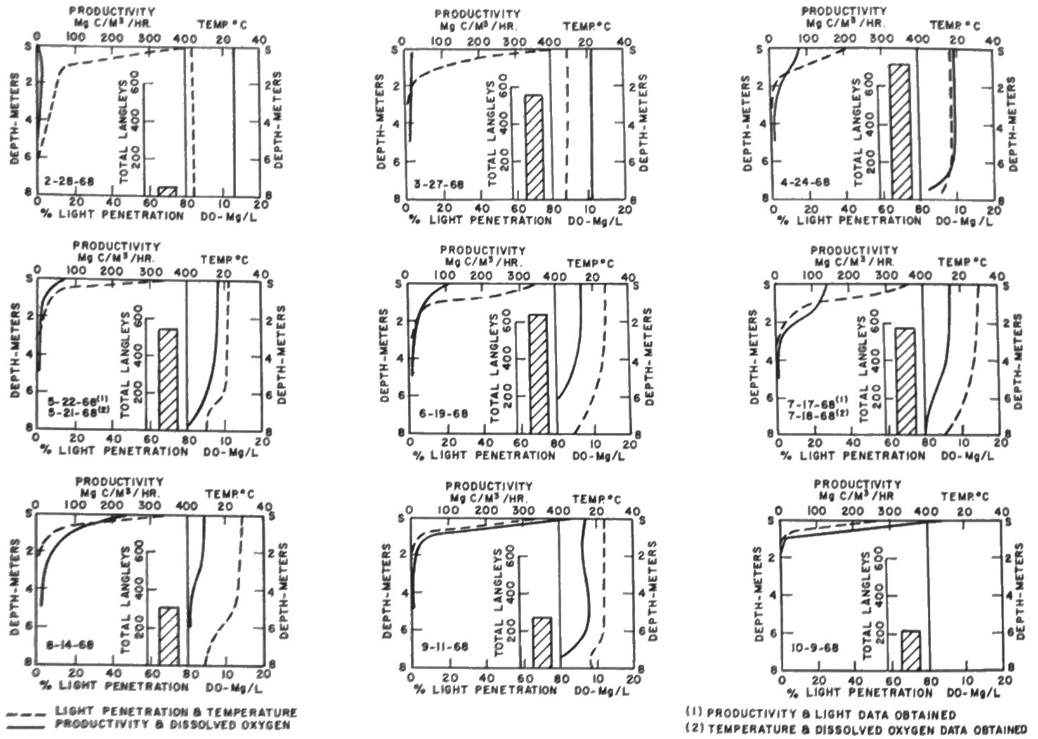

Figure 6. Seasonal comparison of the variation with depth of primary productivity, light penetration, temperature, dissolved oxygen, and total langleys of light available each day—Beech Reservoir.

Greatest light penetration occurred in February (1 percent at 6 m). Light penetration ranged from 3 m to 4 m from March through August. Rapid reduction of light occurred during September and October (0.0 percent at 1.8 m and 1.2 m). At these times rapid reduction of light was closely related to water turbidity caused by organic detritus and phytoplankton.

The total langleys per day of available light was extremely low on February 28 (49 langleys per day), while the greatest solar radiation was observed on April 24 (724 langleys per day). Solar radiation decreased from June to October from 646 langleys per day to 210 langleys per day.

Water temperature profiles did not indicate stratification during February and March; stratification was first found in April with the thermocline at approximately 6 m. Thermal stratification prevailed from April through September and ranged from 4 m to 6 m during April through August. As the water temperature slowly began to cool in September, thermal stratification was evident even below 6 m. Surface temperatures ranged from 3.9° C in February to a maximum of 28.4° C in July and August. The average September surface temperature was 23.9° C. Temperatures and dissolved oxygen values were not determined in October.

Dissolved oxygen values were over 10 mg/1 throughout the profile during February and March, and from April through July they ranged from 8.8 to 6.7 mg/1 in the epilimnion (except for a drop to 4.6 mg/1 and 5.6 mg/l at 4.57 m in June and July, respectively). Oxygen throughout the profile was severely depleted in August with a maximum of 4.7 mg/1 at 0.32 m below the water surface to 0.9 mg/1 at a depth of 3 m. Oxygen increased to about 7.5 mg/1 in the epilimnion in September.

Daily solar radiation varied with weather conditions and seasons as illustrated in Figure 7. It is highly unlikely that any area ever receives the same amount of available solar energy on successive days. Light rainfall was recorded during the February and August sampling periods; extremely clear and sunny days occurred during the March, April, and June sampling periods; and the remaining sampling days were partly cloudy.

The chlorophyll *a* estimates for assessing the abundance of planktonic algae are shown in Table 2. This parameter estimates "standing crop" (stock) rather than productivity (a rate of change in stocks). Pigment determinations express total cell photosynthetic potential of a standing stock.

TABLE II. Chlorophyll *a* concentrations at the biological sampling site on Beech Reservoir from February through October 1968 by depth and surface area

Depth Meters	*Reported in Mg of Chl a/m² by Depth*								
	2-28	3-27	4-24	5-20	6-19	7-17	8-14	9-11	10-9
Surface	13	28	13	11	7	2	3	10	11
1	14	25	11	15	5	2	3	9	12
3	10	26	14	19	6	3	3	10	13
5	16	20	16	20	8	19	2	9	14
Mg Chl *a*/m²*	64	124	67	86	31	29	14	48	64

*Each value represents chlorophyll *a* concentration in a volume of water that is 1 square meter in area and extends from the surface to a depth of 5 meters.

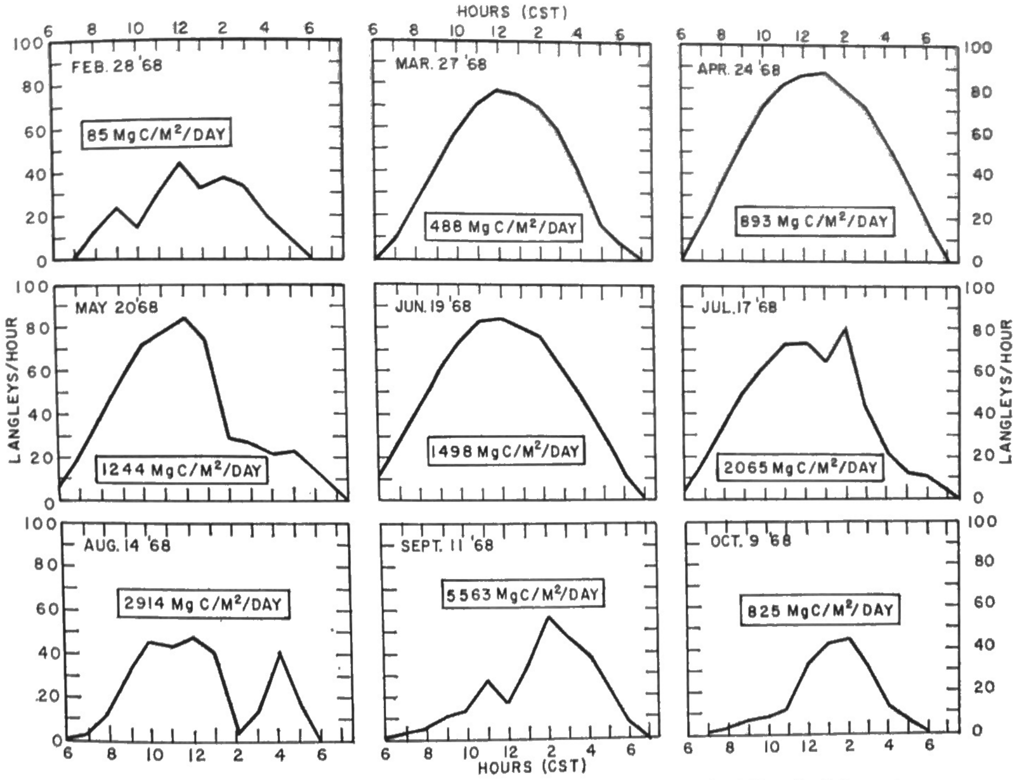

Figure 7. Seasonal and daily variation comparison of langleys/hr., and total productivity in MgC/m²/day—Beech Reservoir.

The values in Table 2 should not be considered as 100% photosynthetically active cell substances because values at 5 m (below the euphotic zone) sometimes were greater than those in photic zone. These larger values were obtained from dying and sinking phytoplankton—not an uncommon occurrence in small, shallow reservoirs where this is little flow.

Total pigment concentration was heaviest throughout the profile during March. The concentration, 20-28 mg chlorophyll a/m³, was about twice as great as in allother months. Total phytoplankton cell concentrations were similar in February, April, May, September, and October. During July, a notably larger concentration of singing cells was found at 5 m than in the upper 3 m. Decomposition of the cells was evident as low dissolved oxygen values were obtained during August (Figure 6) when almost anaerobic conditions existed throughout the water column. An extremely low chlorophyll *a* concentration was obtained in August between the surface and a depth of 5 m.

Figure 8 illustrates the "standing crop" of phytoplankton in terms of actual number of phytoplankton cells. Cell numbers are reported as the mean value for the epilimnetic waters during 1968. The spring maximum (approximately 12,656,000 cells/1) of total phytoplankton cells was reached in May. Similar concentrations of total phytoplankton (12,516,000 cells/1) were measured in September after relatively low summer concentrations.

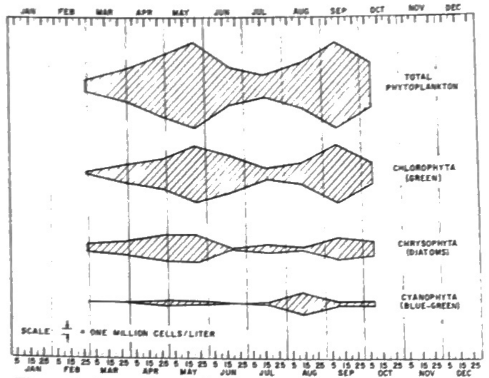

Figure 8. Seasonal variation in standing crops of total phytoplankton and the major divisions of algae in the epilimnion in Beech Reservoir during 1968.

Total phytoplankton values represent a steady increase from February through May, a decline through July, a slight increase through August, and a fall maximum in September with a decline in October. Chlorophyta (green algae) and Chrysophyta (diatom) numbers followed a pattern similar to total phytoplankton. February was the only month in which more diatoms than green algae were observed. During March and October about equal concentrations occurred with slightly fewer diatoms than green algae. Extremely high Cyanophyta (blue-green algae) numbers (3,080,000 cells/1) were noted in August while the reservoir was nearly anaerobic. The dominant blue-green was *Raphidiopsis*. *Nitzschia* was the dominant diatom in the spring and *Synedra* in the fall. *Ankistrodesmus* and a biflagellate were the most common green algae with the genus *Ankistrodesmus* occurring mostly in the spring and biflagellates in the late summer and fall. *Scenedesmus* was also prominent throughout the year especially in the spring. *Chlorella* represented over 2 million cells/1 in April, May and October.

Water Chemistry

Table 3 contains the mean values for nitrogen and phosphorus in the upper 4.57 m and for the remainder of the water column of Beech Reservoir. Total nitrogen (organic, ammonia, nitrite, and nitrate) values in the upper 4.57 m ranged from 0.61 mg/1 in May to 0.99 mg/1 in October. The mean total nitrogen content from February to October 1968 was 0.78 mg/1. The highest total nitrogen value recorded in the epilimnion during this survey period was 1.21 mg/1 at 0.30 m below the water surface on June 19. Samples on this date and at this depth also had the highest nitrate value (0.28 mg/1). During the entire period over 87% of the total nitogen in the epilimnion was a combination of organic nitrogen and ammonia,

TABLE III. Beech Reservoir—Nitrogen and Phosphorus Concentrations Using Depths Sampled To Obtain Mean Values—1968

	Depths Sampled in Meters	Organic Nitrogen N mg/1	Ammonia NH_3-N mg/1	Nitrite NO_2-N mg/1	Nitrate NO_3-N mg/1	Total Nitrogen mg/1	SPO_4 mg/1	TPO_4 mg/1
		Mean Values						
February 28, 1968								
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	0.60	0.12	<0.01*	0.06	0.78	0.02	0.02
Below 4.57 Meters - bottom	6.10, 7.62, 9.14	0.58	0.06	<0.01*	0.05	0.69	0.02	0.04
March 27, 1968								
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	0.72	0.20	0.01	0.02	0.95	0.10	0.22
Below 4.57 Meters - bottom	6.10, 7.62, 8.53	0.63	0.03	0.01	0.02	0.69	0.03	0.09
April 24, 1968								
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	0.67	0.02	<0.01*	0.03	0.72	0.06	0.11
Below 4.57 Meters - bottom	6.10, 7.62	0.81	0.32	<0.01*	<0.01*	1.13	0.07	0.28
May 21, 1968								
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	0.56	0.05	<0.01*	<0.01*	0.61	0.05	0.11
Below 4.57 Meters - bottom	6.10, 7.62, 8.84	0.69	0.53	0.02	<0.01*	1.24	0.07	0.15
June 19, 1968								
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	0.52	0.19	0.01	0.09	0.81	0.05	0.10
Below 4.57 Meters - bottom	6.10, 7.62	0.53	0.12	0.02	<0.01*	0.67	0.04	0.12
July 18, 1968								
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	0.78	0.09	<0.01*	0.01	0.88	0.02	0.07
Below 4.57 Meters - bottom	6.10, 7.62	0.64	0.25	<0.01*	0.03	0.92	<0.01*	0.07
August 14, 1968								
Upper 4.57 Meters	0.30, 3.05, 4.57	0.59	0.03	<0.01*	0.02	0.64	0.02	0.11
Below 4.57 Meters - bottom	6.10, 7.92	1.15	2.95	0.02	0.01	4.13	0.02	0.29
September 11, 1968								
Upper 4.57 Meters	0.30, 3.05, 4.57	0.65	0.04	<0.01*	<0.01*	0.70	0.04	0.08
Below 4.57 Meters - bottom	6.10, 7.32	0.88	1.79	0.01	<0.01*	2.68	0.03	0.11
October 9, 1968								
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	0.80	0.17	0.01	0.01	0.99	0.06	0.11
Below 4.57 Meters - bottom	6.10	1.30	0.16	<0.01*	<0.01*	1.17	0.03	0.13
Upper 4.57 Meters (February-October)		0.65	0.10	<0.01*	0.03	0.78	0.05	0.10
Upper 4.57 Meters - bottom (February-October)		0.80	0.69	<0.01*	0.01	1.48	0.04	0.14

*<0.01 is considered as 0.00 mg/1.

Total nitrogen below 4.57 m ranged from 0.67 mg/1 in June to 4.13 mg/1 in August, and the average total nitrogen was 7.48 mg/1 from February through October. Ammonia concentrations were extremely high in the lower water mass in August and September (2.95 mg/1 and 1.79 mg/1, respectively). Organic nitrogen values were also high during these two months (1.15 mg/1 and 0.88 mg/1. On August 14, at depth of 7.92 m 5.20 mg/1 ammonia was recorded which was the highest value of the sampling period. A value of 3.50 mg/1 at 7.32 m was also recorded in September.

The highest average total phosphate value in the upper 4.57 m was 0.22 mg/1 in March and the lowest concentration was 0.02 mg/1 in February. The average phosphate concentration during the sampling period was 0.10 mg/1. The highest soluble phosphate value (0.10 mg/1) also occurred in March. Phosphate below a depth of 4.57 m had a 9-month mean slightly higher than in the upper 4.57 m of water (0.14 mg/1). A mean of 0.29 mg/1 of total phosphate in the area below 4.57 m was recorded in August for the highest concentration during this study. High total phosphate concentrations were also recorded during April (0.28 mg/1).

Monthly values of chemical analyses other than nitrogen and phosphorus are shown in Table 4. Beech Reservoir water is soft, as shown by the low values for total alkalinity and hardness. Total alkalinity ranged from 12 mg/1 in the upper 4.57 m in February to 20 mg/1 in June. Below 4.57 m, the range was from 12 mg/1 in February to 66 mg/1 in August. Nine-month averages were 15.4 mg/1 in the upper meters and 27.4 mg/1 in the lower meters. The highest total hardness (21 mg/l) and highest calcium concentrations (4.9 mg/1 Ca++) in the upper 4.57 m were recorded on July 18. Total hardness and Ca++ values below 4.57 were high for the reservoir during August (36.0 mg/1 $CaCO_3$ and 11.0 mg/1 Ca++). Mg++ ions were scarce.

Sodium and potassium were present in relatively low concentrations. The chloride anion averaged 3.1 mg/1 in the upper 4.57 m and 3.4 mg/1 below 4.57 m. Sulfate and silica averaged 3.0 mg/1 SO_4^{--} and 1.4 mg/1 SiO_2 in the top 4.57 m of water and 2.4 mg/1 SO_4^{--} and 1.8 mg/1 SiO_2 below 4.57 m. The average pH was 7.0 for the upper 4.57 m and 6.8 below 4.57 m. The lowest pH (6.2) recorded was at 7.62 m in July and at 7.32 m in September. Lower pH values were found during periods of strong stratification and anaerobic conditions. The highest pH (7.6) was recorded at the surface on March 27.

On April 24, total iron increased rapidly to 2,000 ug/1 at 8.84 m near the bottom with a mean of 1,165 ug/1 below 4.57 m. Total iron in the hypolimnion increased from 283 ug/1 in March to 1,165 ug/1 in April and continued throughout the studies. The higher concentrations gradually rose toward the upper limit of the hypolimnion (approximately 4.57 m from the surface). On August 14, the maximum total iron concentration (15,000 ug/1) was measured at a depth of 7.92 m; on

TABLE IV. Beech Reservoir—Chemical Concentrations Other Than Nitrogen and Phosphorus Using Depths Sampled To Obtain Mean Values—1968

	Depths Sampled in Meters	Specific Conductance Micromho/Cm at 25° C	Total Alkalinity $CaCO_3$ mg/1	Total Hardness $CaCO_3$ mg/1	Ca^{++} Diss mg/1	Mg^{++} Diss mg/1	Na^{+} mg/1	K^{+} mg/1	Total Fe ug/1	Total Mn ug/1	Cl^{-} mg/1	SO_4^{--} mg/1	SiO_2 mg/1	pH
		Mean Values												
February 28, 1968														
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	57	12	10	1.3	1.8	1.6	1.2	180	93	2.0	7.3	2.8	6.8
. Below 4.57 Meters - bottom	6.10, 7.62, 9.14	50	12	9	1.0	1.5	1.6	1.7	323	80	2.0	4.3	2.4	6.8
March 27, 1968														
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	45	15	9	1.0	1.5	2.1	1.4	260	58	2.8	3.0	0.7	7.4
Below 4.57 Meters - bottom	6.10, 7.62, 8.53	44	15	9	1.0	1.5	1.9	1.4	283	73	2.0	3.0	0.5	7.2
April 24, 1968														
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	50	13	10	1.3	1.5	0.2	2.6	310	80	3.5	4.0	0.9	7.3
Below 4.57 Meters - bottom	6.10, 7.62, 8.84	61	21	11	1.8	1.8	0.6	2.6	1165	2040	4.0	2.5	1.1	7.3
May 21, 1968														
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	45	17	11	1.9	1.5	5.3	2.6	128	105	3.7	1.0	1.5	7.2
Below 4.57 Meters - bottom	6.10, 7.62, 8.84	64	30	13	2.2	1.8	4.4	2.0	2550	4200	3.3	1.0	2.5	7.0
June 19, 1968														
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	45	20	11	2.0	1.5	0.9	3.0	190	123	3.7	2.0	0.1	7.3
Below 4.57 Meters - bottom	6.10, 7.62,	60	24	15	3.0	1.8	1.3	3.3	1800	1600	4.0	3.0	<0.1	6.9
July 18, 1968														
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	47	15	21	4.9	1.7	1.9	2.0	247	88	4.0	2.0	2.1	6.6
Below 4.57 Meters - bottom	6.10, 7.62	54	18	14	2.8	1.5	1.9	2.1	2520	1850	4.0	2.0	2.0	6.4
August 14, 1968														
Upper 4.57 Meters	0.30, 3.05, 4.57	54	15	17	4.5	1.5	3.4	1.6	247	280	3.3	2.0	1.1	6.5
Below 4.57 Meters - bottom	6.10, 7.92	119	66	36	11.0	2.0	1.7	1.8	8350	6000	4.5	1.0	3.4	6.5
September 11, 1968														
Upper 4.57 Meters	0.30, 3.05, 4.57	49	16	10	1.8	1.5	1.8	4.7	333	297	3.0	2.0	1.5	6.9
Below 4.57 Meters - bottom	6.10, 7.32	80	33	15	3.3	1.8	1.6	5.2	6570	4740	4.0	1.0	2.7	6.5
October 9, 1968														
Upper 4.57 Meters	0.30, 1.52, 3.05, 4.57	52		13	2.0	2.0	1.8	2.4	683	470	2.0	4.0	1.8	
Below 4.57 Meters - bottom	6.10	57		14	3.0	2.0	1.8	2.5	2400	780	3.0	4.0	2.1	
Upper 4.57 Meters (February-October)		49	15.4	12.4	2.3	1.6	2.1	2.4	284	177	3.1	3.0	1.4	7.0
Below 4.57 Meters - bottom (February-October)		65	27.4	15.1	3.2	1.7	1.9	2.5	2885	2373	3.4	2.4	1.8	6.8

the same date, at 6.10, 1,700 ug/1 was recorded. A decrease in iron (12,200 ug/1) was observed at the reservoir bottom in September and the decrease continued through October (2,400 ug/1). Manganese concentrations followed a similar pattern.

DISCUSSIONS

Monthly fluctuations of total primary productivity per square meter in the photic zone were pronounced. There was an increase each month from February through September (Figure 5). The rate of increase was rapid as is expected for a small, shallow reservoir. A large portion of the nutrients was tied up in dissolved and particulate fractions as shown in Table 4 where organic nitrogen and ammonia were more excessive than nitrates. Apparently nutrients were never the limiting factor for phytoplankton productivity in Beech. High phosphate and nitrogen values occurred from February through October. There is no simple relationship between the amounts of nutrients and phytoplankton growth or maturing processes because many other minor elements and environmental factors are involved.

Penetration of incident light was limited by turbid waters from April through August (Figure 6). This turbidity was not due to surface runoff but to a heavy phytoplankton population. In February and March, the light penetration was limited by seasonally reduced sunlight. The severe limitation of light penetration in September and October was caused by low seasonal light energy supplied (Figure 7) and also the heavy phytoplankton population. Light penetration had to be a limiting factor since availability of light was low and nutrients were present in high concentrations.

The depletion of hypolimnetic oxygen was evident from April through September. Figure 8 shows the times and amounts of heaviest incidences of phytoplankton. Particulate carbon produced by the phytoplankton settles to the hypolimnion. Phytoplankton decomposition adds to the oxygen depletion occurring below the thermocline. This is the same pattern of oxygen depletion that occurs when a heavy phytoplankton crop settles in deep, stratified storage reservoirs such as Douglas and Cherokee. Oxygen depletion occurs earlier each year in these reservoirs than in reservoirs such as Nottely and Norris which have smaller populations of phytoplankton. Oxygen in Beech actually was depleted earlier than in Cherokee because of a shallower and smaller hypolimnion in relation to the total area supplying algae.

The standing crop of phytoplankton was examined in two ways—by (1) chlorophyll *a* content and (2) total cell numbers. Both methods are needed. If only chlorophyll were used as a basis for determination of standing stock, too much stress might be placed on the large phytoplankton algae in relation to their importance as producers; similarly, the use of total cell number alone could cause an overestimate when small-celled species occurred in large concentrations. The correlation of these two assessments was similar from February through October. Lowest chlorophyll a concentrations were found during June, July, and August, as were the lowest total numbers of cells. February and March also had low concentrations of cells. Cell counts in March were higher than those of July but less than those of June or August. The larger chlorophyll values for February, March, April, May, September, and October were contributed by diatoms rather than green algae. Diatom cells were, in general, much larger than the green algal cells (linear measurement: green algae, *Ankistrodesmus*, 2-4 microns; diatoms, *Nitzschia*, 6-8 microns; *Synedra*, 8-10 microns). From June through August diatom cell counts were comparatively low. The large chlorophyll *a values at* 5 m, as shown in Table 2, were attributed to sinking phytoplankton that had not had time to decompose, thus the photosynthetic potential could not be realized.

In open water systems, such as rivers and main stream Tennessee River reservoirs, diatoms are more commonly the dominant algae throughout the year. There is a tendency in closed systems in the Tennessee Valley for Chlorophyta (green algae) to be the dominant algae after an early spring peak of diatoms. When greens are not the dominant summer algae, they are still numerous. Environmental and water chemistry factors are also important in considering the types of algae present.

Cyanophyta (blue-green) seems to follow the same productivity pattern as green algae in the Tennessee Valley in the open, closed, and semi-closed systems. Blue-greens are seldom the dominant group unless the water is extremely rich. The highest blue-green count, 3,080,000 cells/1 obtained during August, was unusually high for a "clean-water" reservoir. Although the Cyanophyta behave ecologically much like other algae, cytologically they are closer to the bacteria (Jackson, 1967). Heavy blue-green algal populations are not suitable food for zooplankton and fish, and they may produce external metabolites that adversely affect the upper levels of food chains. It is believed that blue-greens do not have as much photosynthetic ability as diatoms or green algae. Low oxygen values throughout the water column in August helped create favorable media conditions for blue-green algal growth and unfavorable conditions for diatom and green algal growth. Oxygen values increased at the surface from 4.7 mg/1 in August to 7.0 mg/1 in September and the blue-green bloom diminshed rapidly due to mixing.

Other groups of algae were sparse in Beech Reservoir. Pyrrophyta, golden tan algae, were present in February; and Euglenophyta, represented by primitive colorless, flagellated algae, were present in samples during February, March, August, and October. Both groups were present only in trace amounts and are not shown in Figure 8.

The total iron increase arising from the sediments by redox changes in the hypolimnion can be correlated with a number of factors. Ferric and ferrous iron are ionic and the reaction goes both ways quite readily; therefore, ferric and ferrous forms were not tabulated as such in Table 4. As oxygen in the hypolimnion became depleted in April, the ferric form was reduced to ferrous iron which dissolved. The concentrations present are dependent on the original chemical nature of the

water and reactions in the hypolimnion. The reactions are related to a number of chemical factors, such as lower pH, higher silica values, higher conductivity, higher alkalinity, higher manganese values, and lower dissolved oxygen values. The oxygen reduction alone was not the result of higher total iron values but contributed to the iron increase. Oxygen in the hypolimnion became depleted largely through organic decomposition. This decomposition formed other organic compounds that contributed to the reduction of the ferric iron. The total iron content in the upper water was relatively low except during September and October when a significant increase was observed in the upper 4.57 m. In April, high iron concentrations became noticeable throughout the lower 4.57 m. High concentrations were also observed throughout the lake in October. The first high concentration in April (2,000 μg/1) was only observed at a depth of 7.62 m. Thereafter, noticeably higher values were observed farther from the bottom but still in the anaerobic zone. The maximum concentration for the 1968 survey was 15,000 μg/1 at 7.92 m on August 14. High concentrations have been previously reported for Beech. On August 16, 1966, at the same sampling site, 27,000 μg/1 Fe was measured at a depth of 8.84 m.

Increases in iron of this magnitude in the hypolimnion are not uncommon in other parts of the world. In certain small, shallow reservoirs the chemical nature of the water in the hypolimnion allows the iron concentration to become high as a function of oxygen content and redox potential. Usually in small, shallow lakes with a markedly clinograde oxygen curve, an inverse relationship between iron and oxygen is well developed (Hutchinson, 1957). Some acid bog surface water has been known to have up to 50,000 μg/1 total iron (Uspenski, 1927). Hutchinson et al. (1932) have reported 18,600 μg/1 of total iron in surface waters. Thus the reported surface values for iron in Beech Reservoir are not unusually high. Evidently the iron present in Beech Reservoir was originally derived from surrounding sediments. Samples from Beech River Mile 37.5 and Black Bottom Creek Mile 0.5, where stratification did not occur, had no high iron values.

According to Reid (1961), one of the forms of iron which appears to be most readily available to phytoplankton is ferric hydroxide [$Fe(OH_3)$]. Ferric hydroxide becomes available to phytoplankton in Beech when the iron is transferred to the epilimnion from the hypolimnion during the fall overturn.

SUMMARY

A biological study of primary productivity and the factors which influence it was conducted on Beech Reservoir from February through October 1968. This small, more productive lake has a shoreline of 22 miles, a pool area of 347 hectares, and a mean depth of 8 m at the sampling site. The reservoir has limited light penetration due largely to phytoplankton turbidity. Thermal stratification occurs at 4 to 7 m from April through September. Primary productivity is mainly limited to the phytoplankton.

C_{14} was used to measure primary productivity. Chlorophyll *a* and phytoplankton enumerations were used to assess phytoplankton standing crop at monthly intervals in the center depression of the reservoir, 30 yards above the dam. Measurements of available light, light penetration, water temperature, dissolved oxygen, pH, alkalinity, and certain ionic components were made in conjunction with the productivity studies.

Primary productivity values plotted as mg C/m^2/day indicate a seasonal fluctuation. Beginning in early spring, productivity increased successively month by month to an autumn maximum before a rapid decline to low values in winter months. Seasonal fluctuation of primary productivity correlated better with light and temperature fluctuations than with nutrients (nitrogen and phosphorus).

The mean monthly primary productivity ranged from 85 mg C/m^2/ day in February to 5,563 mg C/m^2/day in September with a 9-month means of 1,619 mg C/m^2/day. Chlorophyll *a* concentrations ranged from 14 mg/m^2 in August to 124 mg/m^2 in March; whereas cell counts averaged 6,961,555/1 and ranged from 1,843,000/1 in February to 12,656,000/1 in May.

The major ionic change was in total iron which increased rapidly in the hypolimnion in April, slowly rising through the water column until August when extremely high concentrations were observed throughout the lower water profile. In August, altered water quality, resulting primarily from this phenomenon, may have contributed to a blue-green algal bloom that was terminated by the change in water chemistry as the water was mixed in September.

LITERATURE CITED

Bachmann, R. W. 1962. Evaluation of a modified C^{14} technique for shipboard estimation of photosynthesis in large lakes. Great Lakes Res. Pub. No. 8:61.

Goldman, C. R. 1960. Primary productivity and limiting factors in three lakes of the Alaska Peninsula. Ecol. Monogr. 30:207-230.

Hutchinson, G. E. 1957. *A Treatise on Limnology*. John Wiley and Sons, Inc. 1015 pp.

Hutchinson, G. E., G. E. Pickford, and J. F. M. Schuurman. 1932. A contribution to the hydrobiology of pans and other inland waters of South Africa. Arch. Hydrobiol. 24:1-136.

Jackson, D. F. 1967. *Algae, Man, and the Environment*. Syracuse University Press, 554 pp.

Parsons, T. R. and J. D. H. Strickland. 1963. Discussion of spectrophotometer determination of marine-plant pigments, with revised equations for ascertaining chlorophylls and carotenoids. J. Mar. Res. 21:158-163.

Reid, G. K. 1961. *Ecology of Inland Waters and Estuaries*. Reinhold Publ. Co., 375 pp.

Richards, F. A. and T. G. Thompson. 1952. The estimation and characterization of plankton populations by pigment analysis. II. A spectrophotometric method for the estimation of plankton pigments. J. Mar. Res. 11:156-172.

Rodhe, W., R. A. Vollenweider, and A. Nauwerck. 1958. The primary production and standing crop of phytoplankton. In: A. A. Buzzati-Traverse (ed.), *Perspectives in Marine Biology*. Berkeley and Los Angeles, Univ. of Calif. Press, p. 299-322.

Steemann-Nielsen, E. 1952. Measurement of the production of organic matter in the sea by means of carbon-14. Nature 167:684-685.

Tennessee Valley Authority. 1951. Reconnaissance survey Beech River Watershed. TVA internal report-18.

Uspenski, E. E. 1927. *Eisen als Fakton fur die Verbreitung Neidler Wasserpflanzen*. Pflanzenfasschung. Jena Fischer. VI, 104 pp.