A preliminary bioassay was conducted in August 1966 to determine the concentration of nitrogen and phosphorus necessary for phytoplankton growth in Norris Reservoir. This study showed that at the 95% confidence level additions of 50 µg/l of nitrogen and 100 µg/l of phosphorus increased phytoplankton productivity in bottles incubated in the reservoir (Fig. 1). Higher levels of nitrogen increased productivity and caused a further significant increase. It was of interest to determine if the nutrient concentrations observed in the reservoir were optimum in the natural environment. Factors such as nutrient loss from the epilimnion, movement and exchange of water, and variability in the seasonal growth cycles of phytoplankton were not operative in the bottle bioassay and would probably modify the effect of the nutrients added to the open coves.

This study summarizes the effect of fertilization on nutrient concentration and productivity in cove environments of Norris Reservoir. The study demonstrates the overriding influence of thermal stratification on nutrient distribution, particularly phosphorus, and the resulting response of the phytoplankton to nutrient addition.

METHODOLOGY AND MATERIALS

ENVIRONMENTAL MONITORING

Design of the experiments, fertilizer application, and application methods are presented in Part 1 of this study (Wood and Sheldon, 1971). Phytoplankton cell counts, primary productivity, chlorophyll-a concentration, nutrient concentration, pH, total alkalinity, water transparency, and temperature were monitored on a continuous basis throughout the study. Each monitoring period was scheduled one week after the fertilization application. Samples were collected on Tuesdays and the schedule was interrupted for two days before termination. Phytoplankton cell counts and water samples were collected at eight depths, and these samples were collected with a Modified epifluorescence microscope and preserved with glutaraldehyde. Organisms identified were grouped into genera and subgenera when possible.

Carbon-N ratio was determined. The C:N ratio was used for measuring primary productivity of the epilimnion. Water samples for C:N productivity determinations were collected in a PVC Van Dorn sampler from surface water samples depending upon the depth of the phytoplankton zone. This method was first used by Stumm and Morgan (1955), and was similar to the method used by Bouldin (1969). From each sample approximately 200 ml of water was added to each of the four 100 ml N2BOO bottles. Each bottle was attached to a line and incubated at the collection depth for about three hours. After incubation, 1 ml of 10% ferricyanide was added to the bottle and they were placed in a light proof box for transport to the laboratory.

Each sample was filtered, within two hours, through a 0.45 µm Millipore filter in the laboratory. The 0.45 µm Millipore filters were used to trap the phytoplankton. A frame was placed in a slide for the filter and a photomicrograph of the phytoplankton for each dilution was taken in a dissecting microscope. Later they were counted in a thin-section, low-power microscope. The number of standard units and sample efficiency was determined by Dr. C. R. Musick and Dr. D. R. Cole of the University of California, Davis, with his total carbonate production. Productivity during the incubation period was calculated from the ratio of initial to final light intensity during the incubation.

Chlorophyll-a "a" test was performed using a photometric spectrophotometer. Water samples were filtered for chlorophyll determinations from depths corresponding to those sampled for C:N productivity. Phytoplankton cells were filtered from the water cove a 1.2 µ pore size Millipore filter. Chlorophyll-a was extracted with 95% acetone for a period of at least 24 hours. Absorption was determined on a model BBO spectrophotometer and chlorophyll-a was calculated according to several different procedures (Fig. 2). For results presented in this study, chlorophyll-a was calculated according to the equation by Richards and Thompson (1951) as modified by Parsons and Maitland (1964) for use with samples collected from Norris Reservoir. Water chemistry. During the regular weekly nutrient and chlorophyll-a measurements, samples were collected for total phosphorus (P-PO4-P) and total nitrogen (N-NH4-N and N-NO3-N) and chemical oxygen demand at various depths. The chemical oxygen demand was measured with the Van Dorn sampler, trans. These phosphate data were collected in the lab. N-NO3-N and N-NH4-N were determined by the Nessler's reagent method for determination of nitrogen. Total organic carbon can be calculated for total phosphorus and total nitrogen by using a spectrophotometer and nitric oxide gas. Total carbon and nitrogen were determined by the method of chlorophyll determination and the carbon dioxide content was determined by the method of carbon dioxide determination. 

Fig. 1 Simulazione di plantonico in BOD bottle di nitro- geno e fospataura durante un 96-hour test period in Norris Reservoir.

Fig. 2 Nitrogen and phosphorus concentration in the epilimnion of the three coves studied in Cove Creek.
Cove 1 and on August 14, when a comparatively low
10.04 mg N/L was observed in Cove 2. On two
10.04 mg N/L was observed in Cove 1 or Cove 2.
and organic phosphorus. Cove 2 is the shallowest
in Big Creek. Cove 1, the heaviest fertilized
in Big Creek, had the smallest amount of extractable and
organic phosphorus in the sediment.

| TABLE I | Nitrogen and phosphorus in sediment samples from all studies on October 24, 1967 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Cove 1, Cove Creek | 0.68 | 185 | 68 |
| Cove 2, Cove Creek | 0.68 | 310 | 107 |
| Control, Cove Creek | 0.67 | 230 | 0 |
| Cove 1, Big Creek | 0.69 | 130 | 20 |
| Cove 2, Big Creek | 0.66 | 215 | 64 |
| Control, Big Creek | 0.67 | 283 | 34 |

**Physiological and Environmental Conditions**

Fig. 5 provides a summary of data on physical variables that probably affect productivity. These include rainfall, evaporation, transparency (Secchi disk), mean temperature, and temperature distribution with depth.

![Figure 5](image.png)

As shown in Fig. 5A, rainfall in 1967 was much greater than rainfall during the period 1963 through 1966. As a result of the increased rainfall, the elevation ranged from 5 to 20 feet higher in 1967 during the period June through October than during this period in 1963-1966. Throughout July and August the elevation was approximately 15 feet higher in 1963-1966 (Fig. 5B).

Fig. 5C shows the insolation for sampling days during the study. Cloudy, partly cloudy, and sunny days caused considerable daily variation in the amount of light energy available. From April 13 to October 25 the insolation ranged from 142 to 667 langley/day. The lowest insolation values were in October and the highest in June and July.

The penetration of light into Norris Reservoir was measured by a Secchi disk (Fig. 6). A Secchi disk follows a similar pattern in coves. The average Secchi disk reading from April through October was 3.70 meters in all coves except Cove 1 in Big Creek, which was 3.60 meters. The Secchi disk was always visible at two meters and, as shown in Fig. 5D, it was visible at five meters during the middle of July.

The average of water temperature readings at surface, middle, and bottom depths followed a smooth seasonal curve throughout the study period. There was no significant difference in temperature in Big Creeks, so a single average represents these values in Fig. 5E.

The average of water temperature readings at surface, middle, and bottom depths followed a smooth seasonal curve throughout the study period. There was no significant difference in temperature in Big Creeks, so a single average represents these values in Fig. 5E.
Nitrizia accounted for over 65% of the total cell concentration of 4600 cells/ml during the second work week of April through October. Highest concentrations of green algae occurred during September and October months, while in October the most common species of Chlorotece, Scenedesmus, and diatom species were absent, some being present. Oocysticia and sp. were present at very low levels, with Oocysticia having the highest counts of 82 cells/ml in October. The April through October cycle of phytoplankton in Norris Reservoir included 28 genera of dinoflagellates, green algae, and blue-green algae.

**Primary Productivity**

Primary productivity showed a similar but marked seasonal variation in all three coves in Cove Creek (Fig. 5A). Productivity declined during June and remained low until September. During this period (June-August) the mean productivity was 275 mg C/M²/day (mean of the three coves) in Cove Creek. Highest productivity values occurred in September. An outburst of productivity occurred on September 12 with a mean of 3525 mg C/M²/day. Mean productivity in the Cove Creek coves declined to 260 mg C/M²/day in October.

Results of productivity in Big Creek are shown in Fig. 6B. Here again the seasonal variation was greater than the variation among coves. Productivity per square meter of reservoir surface was least during June, July, and August (mean of 290 mg C/M²/day) in Big Creek. Productivity was not measured in Cove Creek on July 31. Comparatively high productivity values were recorded in April (mean of 881 mg C/M²/day) and November (mean of 2102 mg C/M²/day on September 11 and 1343 mg C/M²/day on September 25). Mean productivity in Big Creek during the last two sampling periods in October had declined to 386 mg C/M²/day.

Control Cove for about 10 consecutive weeks during June, July, and August.

Cove Creek productivity showed 78% greater productivity than the Control Cove before addition of fertilizer. The pattern of productivity in Cove 2, Cove Creek, was similar to that in Cove 1 except that there were fewer instances when productivity was less than that in the Control Cove. The differences during June through August are not as evident.

The preference increase in productivity of Cove 1 over the Control Cove in Big Creek was 29% on April 28 (Fig. 7B). The pattern of productivity in this cove was very similar to that of the Cove Creek coves, except productivity was less in Cove 1 than in Control Cove on two occasions and not correspond to the period of strongest stratification.

These changes were May 22 and October 9. In Cove 2, Big Creek, 28% more productivity than the Control Cove before fertilization added. The percentage increase in productivity of Cove 2 compared to Control Cove exceeded 28% on six occasions after fertilization was added to Cove 2. Productivity in Cove 2 was less than that in Control Cove for two occasions. These three occasions were not restricted to midsummer, but rather they occurred during July, August, and October. In most cases when productivity in the test coves exceeded the preferential increment percentage increase between test and control cove, it occurred before or after the summer stratification.

Cove 2, Big Creek, was an exception. This cove is shallower, narrower, and longer. The bottom area that is shallower than the thermocline is about twice that of the other coves. Therefore, nutrient stratification between the bottom and surface water during the period of summer stratification probably was greatest in this cove.

Although there was some evidence that productivity increased slightly on several occasions as a result of fertilization, as indicated in Fig. 7, the differences in mean productivity between control and test coves for the whole study period are not significant, as shown by a mean of variance in Table 4. The F-values, in comparing productivity among all coves (Cove Creek and Big Creek, Table 2A), or among coves in each creek separately (Cove Creek, Table 2B, and Big Creek, Table 2C), are not significant at the 95% confidence level.

A comparison of productivity with time shows that the differences in values among the various sampling dates from April through October are highly significant (99% level) in both creeks.

Chlorophyll "a". Chlorophyll content does not follow a similar pattern with C1 and C2, both coves in the Cove Creek Reservoir. This is a clear example of a productivity measurement showing a more sensitive response to physical and chemical changes than to a standing crop measurement.

Chlorophyll content (total amount of photosynthetic units) increased gradually throughout the study period after reached a low in May (Fig. 8). Chlorophyll "a" content ranged from a low of 1.5 mg/m² in May to a high of 45.0 mg/m² in Cove 1 on October 24. In Big Creek the maximum amount of chlorophyll "a" (52 mg/m²) was found in Cove 2 on October 24 while the minimum (8.0 mg/m²) was found in Cove 1 on May 21.

**Discussion**

This study shows that the primary productivity of Norris Reservoir is governed by the interactions of several physical factors that control the distribution of nutrients seasonally. These factors control directly or indirectly from solar radiation. Increased radiation warms the water and leads to formation of a thermocline which serves as an effective barrier to mixing. Surface water temperature is increased further which strengthens the density gradient leading to more available light for phytoplankton growth. The thermocline restricts vertical movement of nutrients to the lighted zones and thereby eventually limits productivity. These factors must be considered in order to determine
Norris Reservoir Fertilizer Study

Although these previous farmpond and lake fertilization results are from different environments and may still provide useful information with some modifications, they do not reflect the results of reservoir fertilization studies. Since most involving the use of phosphorus fertilizers in reservoirs and lakes similarly found a rapid initial response of phosphorus deficiency in Norris Reservoir and Lake Superior and a subsequent disappearance of phosphorus from Norris Reservoir and Lake Superior. However, this may be a much less seemingly disappear even faster in reservoirs than in lakes, though this may be due to differences in depth, productivity, and water detention time.

The problem associated with fertilizing the coves in Norris Reservoir is keeping the added nutrients in the epilimnion. The added nutrients were completely gone from the epilimnion six months after fertilization and the nutrients with phytomass production in the photic zone of Norris Reservoir was probably not adequate in the late summer to sustain the rapid increase in productivity. The rapid disappearance of large amounts of added phosphorus in aquatic environments is not uncommon. However, some of the immediate fertilization programs in Florida in Israel are not being continued. These ponds received approximately 0.5 kg of phosphorus per hectare at each year. This amount of water soluble phosphorus should theoretically raise the phosphorus concentrations in the cove from 35 to 100 mg/L after 0.5 mg/L. Shortly after fertilization (24-48 hours), only 1 to 2 per cent of this fertilizer remained. Most of this phosphorus was found to be precipitated as FePO₄ or Ca₃(PO₄)₂. Nix (1951) and Zeller (1952), as reported a similar decrease in phosphorus during fertilization. July, and August, but not as abruptly as these reports indicated. The outburst in productivity that occurred in all ponds during September, N-D, O-N, and Ca-N content reached about a 2-6 meter lowering of the thermocline. The A-N content also increased to approximately 0.04 to 0.05 mg P/L in the epilimnion during late August and September. Following this productivity burst in September, N-D, O-N, and Ca-N content reached a summer low of about 0.01 mg N/L in most ponds. This was a considerable reduction in N-D, O-N from maximum concentrations of 0.35 mg/L, which occurred in the spring. Thermal stratification from June through August reduced productivity in spite of the addition of nutrients. Goldberg and Hooper (1964) observed in the stratified waters of Castle Lake, California, that the thermocline is an effective barrier to mixing and transport of nutrients lost in the thermocline. The total seasonal productivity in Big Creek is greater than that in a large number of lakes. Results in a number of lakes that in Big Creek and as the thermocline of Cove Creek (especially Cove 1) forms in Big Creek, productivity in the epilimnion is more abundant than the change in Big Creek. The sudden outburst in productivity indicates that the trapped nutrients are attributable to a decrease in the deeper hypolimnion (e.g., Cove 1, Cove Creek), are unused after an overcool. The productivity increase in Big Creek is greater than Big Creek and the greater total productivity in Big Creek, compared to Cove 1, Cove Creek, are probably due to their shallower and more gradual increase in productivity. The thermocline of Cove Creek, Big Creek, did not fully develop until two weeks after the development of thermocline in the epilimnion in Big Creek. The relationship between physical characteristics, nutrient distribution, and productivity was apparent in this study. In Cove 1 the bottom contact in the epilimnion is more than twice that of the other coves, except for Cove 2.

Cove 2, Big Creek, the contact of this greater bottoming is not clear. The hypolimnion may be reduced, the high concentrations of phosphorus observed in the epilimnion in the stratified period. Only one other pond, Cove 1, showed a high phosphorus value in the surface waters. In addition to this, the difference in hypolimnetic phosphorus content exceeds the preferential loss in the epilimnion in only Cove 2, Big Creek, during the stratified period. The occurrence of high bottoming is not continual in contact with the mixing zone, and recycling of nutrients is not prevented, productivity in the epilimnion in the bottom is almost as high in Cape Lake as it is in the deep lake. Hader (1947) has shown that a constant sequester of sewage to a lake, which probably keeps nutrients in continuous contact with phytoplankton in the epilimnion, promotes net productivity in deep lakes, such as Norris, continual addition of nutrients would be most effective in increasing phytoplankton productivity rather than adding it in shig. This procedure, which incidentally would need far less fertilizer, would result in greater availability of nutrients in the lake, and also in a greater probability of obtaining a greater increase in phytoplankton growth as indicated by the stage in the phytoplankton growth cycle.

The methods of applying fertilizer were used in this study need to be changed for future studies in similar environments. This method allowed less than 10% of the fertilizer to be applied in the epilimnion. This undoubtedly affected the expected results of the study and accounts for the insignificant increase in productivity.

LITERATURE CITED


