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PHYTOPLANKTON DISTRIBUTION IN THREE THERMALLY DISTINCT REACTOR COOLING RESERVOIRS

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A paper for presentation at the First International Phycological Congress
St. John's, Newfoundland
August 8-14, 1982
and proposed for publication in Transactions of the American Microscopical Society

5 tables and 3 figures

This paper was prepared in connection with work done under Contract DE-AC09-76SR00001 with the United States Department of Energy. Appreciation is expressed to Dr. Laurence J. Tilly for providing several helpful suggestions during discussions of the study and for assistance with sampling. Thanks also are due to A. S. Dicks and W. H. Fellner for assistance with computer analyses, and to R. J. Soracco, W. R. Cody, and D. H. Buetow for critically reviewing the manuscript.

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PHYTOPLANKTON DISTRIBUTION IN THREE THERMALLY DISTINCT REACTOR COOLING RESERVOIRS[1]

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5 tables and 3 figures

Abstract. Phytoplankton community structure was studied in relation to physiochemical characteristics of three South Carolina reservoirs in close proximity and of similar age and bottom type. Thermal alteration, resulting from the input of cooling water from a nuclear reactor, was substantially different in each reservoir. This provided an opportunity to compare water temperature effects separated from season. Water temperature (when examined independently in statistical models) appeared to be less important than other environmental variables in determining phytoplankton community structure. Pond C, a reservoir receiving intensely heated effluent (>20°C ΔT), displayed low species diversity (Shannon-Weaver *H'* <2.0), except in winter. Unexpectedly, more than 50% of the total phytoplankton density in this reservoir was consistently comprised of green algae (principally *Chlamydomonas* sp.) despite water temperatures that averaged 47.3°C in summer. Par Pond, having a maximum ΔT of 5°C displayed no temperature-induced alteration of phytoplankton community structure.

A large and increasing number of aquatic ecosystems are receiving waste heat from electric power generating plants. Therefore, a better understanding of the biological characteristics of thermally altered aquatic ecosystems is an essential step toward a desirable trade-off between efficient, economical energy production and environmental perturbations resulting from thermal discharges. Planktonic algae provide the base for most lacustrine food chains. Thus, it is important to examine them in evaluating the effects of thermal pollution on lakes and reservoirs.

The present study was conducted at the Savannah River Plant (SRP) near Aiken, South Carolina. Intermittent operation of nuclear reactors at this 777 km^2 site provided a unique combination of cooling ponds to examine. Many previous aquatic ecological studies have been conducted within the environs of SRP (Bennett, 1971; Tilly, 1973; Fliermans, et al., 1977; Gibbons & Sharitz, 1981 and others); however, no information regarding phytoplankton community structure in SRP cooling reservoirs has been reported previously. The principal objective of this study was to characterize and compare phytoplankton abundance, composition, and diversity in three otherwise edaphically similar reactor cooling reservoirs that have been exposed to vastly different thermal regimes over the past 20 years.

Although comparatively few studies have been made on the effects of thermal discharges on algae in lakes (Patrick, 1974; Yost & Talmage, 1981), studies of phytoplankton composition in

thermally altered reservoirs in the southeastern United States have been conducted by Dryer & Benson (1957), Weiss et al., (1975), Wilde et al., (1977), and Campbell (1978). Generally, these studies demonstrated insignificant or highly localized effects from typical (<10°C ΔT) power plant thermal discharges on phytoplankton composition.

STUDY SITES

Three reactor cooling reservoirs in close proximity at SRP were studied (Fig. 1). Par Pond, the largest (1,012 ha) reservoir, was constructed in 1958 by damming three adjacent stream systems. More than 95% of the cooling water for P Reactor is pumped from the south arm of Par Pond. Water from the Savannah River is added to compensate for evaporation and maintain a constant volume in the pond. Par Pond has a mean depth of 6.2 m, a maximum depth of 18 m, and a shoreline length of 53 km.

Pond C is part of the same closed-loop cooling system as Par Pond and was constructed in 1958. These two reservoirs are separated by a dam; however, they are connected by a 3 m^2 culvert through which water is drawn from Pond C at a depth of 10 m and forced out over the surface of Par Pond. Pond C has an area of 67 ha, a mean depth of 4 m, a maximum depth of 10 m and a shoreline length of 7.5 km. Pond C receives thermal effluent from P Reactor via a series of canals and small ponds (Fig. 1).

Pond B was created in 1961 as a cooling pond for R Reactor and was used until 1964. Although Pond B received large volumes

of intensely heated water during reactor operation, water temperatures in the reservoir remained ambient for 14 years prior to this study. Rainfall has been the principal source of water input to the pond since reactor shutdown. Pond B has an area of 81 ha, a mean depth of 4.2 m, a maximum depth of 12 m, and a shoreline length of 6.4 km.

METHODS

Sample Collection and Preservation

Twenty-one sampling locations (Fig. 1) were marked by anchored buoys. Water samples were taken quarterly at each location during 1978. A non-metallic Kemmerer sampler was used to collect 1-liter samples at 1 m depth intervals from the surface to a maximum depth of 8 m (approximating the euphotic zone). Collections from the various depths were composited in a carboy with a spigot. Each composite sample was thoroughly stirred while 1-liter aliquots were withdrawn for chemical analyses and phytoplankton enumerations. Aliquots for phytoplankton analyses were preserved immediately in a 3% solution of M^3 preservative (Meyer, 1971).

Phytoplankton Identification and Enumeration

A Zeiss inverted microscope was used to identify and count the iodine-stained phytoplankton, following approximately 24 h of sedimentation (Lund et al., 1958). A minimum of 400 organisms (cells, filaments, or colonies, all of which contained intracellular material) were counted per sample using 1250X magnification. Principal taxonomic references included Prescott (1962), Whitford & Schumacher

(1973), Smith (1950), Huber-Pestalozzi (1968), Patrick & Reimer (1966; 1975), and Hustedt (1930). As is generally the case, small (<2 μm diameter) coccoid unicellular blue-green algal cells were ignored in this study because they could not be differentiated consistently from silt and detritus. Enumeration of small, coccoid, unicellular blue-green algal cells from natural phytoplankton assemblages requires specialized procedures such as autoradiography, electron microscopy, or fluorescence microscopy (Paerl & Mcckenzie 1977; Wilde & Fliermans, 1978). Relative abundance (determined by fluorescence microscopy), and productivity of coccoid unicellular blue-green algae in Par Pond and Pond C have been reported elsewhere (Tison & Wilde, 1981).

Physical and Chemical Measurements

Physical and chemical parameters were measured in conjunction with the collection of the water samples. Temperature, dissolved oxygen, pH, and specific conductance were monitored at 1 m depth intervals using a Hydrolab 8000 (Hydrolab Corp., Austin, Texas). Transparency was measured with a 25 cm Secchi disc. Unfiltered water samples and samples filtered in the field (using acid-washed 0.45 μm membrane filters) were returned to the laboratory for other water chemistry determinations. Orthophosphate and inorganic nitrogen (NO_3+NO_2) were measured using EPA methods (Kopp and McKee, 1979). Sulfate, silica, and alkalinity were measured by APHA standard methods (APHA, 1975).

Data Analyses

Data were analyzed primarily with the aid of an IBM computer and a group of computer programs collectively called the Statistical Analysis System (SAS) (Barr et al., 1976; Helwig, 1978). Statistical comparisons were performed using the general linear model (GLM) procedure which uses least squares to fit fixed-effects linear models to the data. Principal analyses included analysis of variance and analysis of covariance.

Species diversity values were calculated using the formula of Shannon & Weaver (1949). Logarithms to the base 2 were used; thus, H' values were expressed in bits per individual.

RESULTS

Physicochemical and phytoplankton data were quantitated and compared in terms of variation among: (1) the three SRP reactor cooling reservoirs; (2) the four seasonal sampling dates; and (3) the three major arms of Par Pond (only one of which received thermal effluent). In addition, data were examined descriptively and statistically to detect relationships between water temperature and phytoplankton abundance, composition, and diversity.

Physicochemical Characteristics

Physicochemical data are summarized in Tables I and II. The annual mean water temperature for Pond B, which did not receive thermal effluent was 20.5°C lower than for Pond C and 2.3°C lower than for Par Pond. The 14-year isolation of Pond B from the Savannah River and Par Pond also was reflected by lower

conductivity, lower pH and greater transparency. Considerable seasonal variation in the availability of major algal nutrients occurred in each reservoir. Orthophosphate concentrations were extremely low (<2.0 μg/liter) in all three reservoirs during summer. Measurements of the diatom nutrient SiO_2 in Pond B revealed less than 0.8 mg/liter on all sampling dates.

Water temperatures within Par Pond were, as expected, consistently highest in the middle arm which received thermal effluent. Lowest water temperatures were in the north arm, except in August when the south arm was coolest. Mean water temperatures in the north arm were significantly ($P < 0.05$) cooler than the other two arms in January and November. Otherwise, the differences in water temperatures between the three arms were not statistically significant. There were no consistent differences in the nutrient levels among the three arms of Par Pond.

Phytoplankton Abundance and Group Composition

The three reservoirs differed substantially from one another in terms of phytoplankton density and composition on all sampling dates (Fig. 2). Generally, phytoplankton community structure was similar in the three arms of Par Pond (Fig. 3). Major algal groups (divisions), listed in order of their overall contribution to total phytoplankton abundance were: Chlorophyta, Cyanophyta, Cryptophyta, and Bacillariophyta. Chlorophyta (green algae) also accounted for the largest number of taxa observed in each reservoir and for more than 50% of all taxa observed in the study.

Two-way analysis of variance tests were performed to compare density variations among sampling locations of each reservoir with seasonal variations for total phytoplankton and each of the major algal groups. Densities of total phytoplankton and the four major taxonomic groups differed significantly ($P < 0.0005$) among sampling dates. Density differences between locations within a reservoir on any particular sampling date were not significant ($P > 0.05$). Thus, the sampling sites in each reservoir were considered to be replicates for statistically comparing phytoplankton densities of the three reservoirs with one another and for comparing seasonal density variations within reservoirs.

Total phytoplankton densities were consistently higher in Par Pond than in Ponds B and C. Bacillariophyta and Cryptophyta populations were significantly ($P < 0.05$) greater in Par Pond than in Ponds B and C on all sampling dates. Densities of Cyanophyta were significantly greater in Par Pond than in Ponds B and C in summer and fall. Chlorophyta densities were also significantly greater in Par Pond than the other two ponds in the fall. During winter, Cyanophyta were significantly more abundant in Pond C than in the other two reservoirs. Pond B always contained the lowest amount of phytoplankton, except in spring when a pulse of Chlorophyta resulted in total phytoplankton quantities higher than those of Pond C.

Total phytoplankton quantities were greatest in summer in all three reservoirs, primarily because Cyanophyta densities were

significantly greater during summer than on the other sampling dates. Chlorophyta populations in Pond C also were significantly greater in summer than the other seasons. Bacillariophyta and Cryptophyta were both significantly less abundant during summer than in winter or spring.

Occasional significant ($P<0.05$) phytoplankton population differences among the three arms of Par Pond did not reveal any consistent pattern of heterogeneity; however, the north arm tended to have the lowest populations when differences occurred.

Species Composition

A total of 169 taxa representing 88 genera and eight divisons was recorded (Table III). Thirty-six of the taxa individually contributed at least 5% of total phytoplankton abundance in one or more samples and were designated as "major" species. Less than 50% (17 of 36) of the major species were observed in all three reservoirs. The green alga *Selenastrum minutum* (naeg.) Collins and a flagellated cryptomonad, *Rhodomonas minuta* skuja, were the only species that achieved "major" status in all three reservoirs.

A species of green algae, *Chlamydomonas* sp., was dominant in Pond C on all sampling dates. Relatively dense populations (averaging 2,597 cells/ml) of this taxon were observed in all samples from Pond C in August, even though water temperatures were well above 40°C.

Rhodomonas minuta was the most abundant taxon in the January and April collections from Par Pond and in the November collections

from Pond B. The filamentous blue-green species Lyngbya limnetica Lemm. and the colonial blue-green species Merismopedia tenuissima Lemm. were dominant in the August collections from Par Pond and Pond B, respectively. Selenastrum minutum was the dominant species in Pond B in January and April.

Statistical comparisons of populations of the major taxa in the three arms of Par Pond revealed no significant differences with one exception; the middle arm had greater quantities of Chlamydomonas sp. than did the north or south arms.

Species Diversity

A considerably larger number of species were observed in Par Pond than in Pond B or Pond C. This was true even when species collected from any one of the three arms of the pond were not considered; thus making the comparisons on the basis of an equal number of samples, six per date per reservoir.

Shannon-Weaver species diversity index (H') values for the three reservoirs are presented in Table IV. Mean H' values for Pond C were significantly higher in January and significantly lower on the other sampling dates, as compared to those of Par Pond and Pond B. There was significant seasonal variation in the H' values of all three reservoirs. January H' values for Par Pond and Pond B were significantly lower than those of the other sampling dates. The annual mean H' values for the three arms of Par Pond were similar; however, H' values were significantly higher in the middle

arm than in the north arm in January, and significantly higher in the north arm than the other two arms in April.

Phytoplankton/Water Temperature Relationships

Water temperature was not a major factor in explaining phytoplankton variability when viewed independently of season and reservoir. Pond C water temperatures in January were only slightly higher than those of Par Pond and Pond B in August (Table II). However, phytoplankton abundance and composition in Pond C in January were more similar to the January communities of Par Pond and Pond B than to the August communities which had more comparable temperatures (Fig. 2). Analyses of covariance showed that only an insignificant amount of phytoplankton variability observed between reservoirs and sampling dates could be uniquely explained by differences in water temperatures.

DISCUSSION

The cooling reservoirs differed substantially in phytoplankton community structure and physicochemical properties of the water. Differences in water temperatures on each sampling date were attributed to differing amounts of nuclear reactor cooling water received. Par Pond and Pond C, the two reservoirs linked to the Savannah River (for the addition of water to compensate for evaporation) exhibited higher algal nutrient levels (with the exception of ortho-phosphate) than Pond B, isolated from the Savannah River for 14 years, and primarily receiving nutrient input from rainfall

runoff. Nutrient levels in all three ponds were substantially lower than reported for the Savannah River (Matthews, 1982).

Densities of major phytoplankton groups (examined individually or collectively) and Shannon-Weaver diversity index values varied significantly among reservoirs and among sampling dates. Par Pond always had the largest standing crop and usually displayed the greatest diversity. Compared to Par Pond, the phytoplankton community of Pond B was probably influenced adversely by lack of river water input which provides nutrient enrichment and increased water circulation. Phytoplankton community structure in Pond C was probably influenced adversely by average water temperatures that consistently exceeded the temperature optima for most known algal species (Patrick, 1969). Substantial temperature stress on phytoplankton in Pond C in August was reflected by very low species diversity. However, the high water temperatures in Pond C in August (41.5-55.0°C) did not result in a dominance of blue-green algae as often happens at water temperatures above 35°C (Patrick, 1969; Brock, 1978). Although blue-green algae were more abundant in Pond C in August than on other sampling dates, Cyanophyta did not achieve numerical dominance because of a seasonal pulse of the green alga Chlamydomonas sp.

The relatively large number of Chlamydomonas cells observed in Pond C in August was especially interesting, since no previous report of Chlamydomonas growing at such high temperatures could be found in the literature. High temperature strains of green algae

(principally Chlorella spp. are known to grow at temperatures up to 43°C (Sorokin, 1971). Brock (1978) pointed out that a likely reason eucaryotic algae usually are absent from waters above 30-40°C is because they must compete with the more successfully adapted blue-green algae. Chlamydomonas sp. apparently has some competitive advantage over blue-green algae in Pond C. Relatively low concentrations of nutrients, particularly phosphorus (Welch et al., 1975), may have prevented blue-green algae from becoming dominant in this pond. A similar finding was reported in a southwestern reservoir in which blue-green algae did not become abundant despite water temperatures of 39.5°C in the area of a thermal effluent (Stuart & Stanford, 1978). Single algal species reportedly develop strains with very different temperature optima (Sorokin, 1967; Hutchinson, 1967). Therefore, the Chlamydomonas sp. strain in Pond C is probably a high-temperature-tolerant strain of a common indigenous Chlamydomonas species, rather than a unique previously unreported species.

Maximal phytoplankton densities in all three reservoirs occurred in August and corresponded with minimal levels of residual ortho-phosphate, which probably is the principal limiting nutrient in each of the reservoirs. The seasonal distribution of phytoplankton by major taxonomic groups and principal species was not altered conspicuously by temperature variations among reservoirs resulting from reactor operation. Maximal Cyanophyta densities occurred during August in all three reservoirs. During January,

maximal densities of Bacillariophyta occurred in Ponds C and B, and maximal densities of cryptophyta occurred in Pond C and Par Pond.

Analyses of covariance tests revealed that an insignificant amount of the photoplankton density and diversity differences that occurred among sampling dates and among reservoirs was uniquely attributable to water temperature. Thus, in these reservoirs, photoperiod-related changes appear to be more influential in the development of phytoplankton community structure than is water temperature.

The relatively small temperature increase ($<5°C\ \Delta T$) attributable to the flow of reactor cooling water effluent into one arm of Par Pond caused insignificant changes in phytoplankton community structure, considering comparisons with the two arms which did not receive thermal effluent. Phytoplankton community structure in Par Pond appeared to be influenced more strongly by the direct inflow of organisms (i.e., Chlamydomonas sp.) from Pond C than by temperature changes associated with the input of thermal effluent.

The general trophic nature of the three reservoirs (based on criteria described by Hutchinson, 1967) indicated oligotrophic-mesotrophic conditions with progressively increasing eutrophication from Pond B to Par Pond to Pond C. This sequence was corroborated by the computation of Carlson's (1977) Secchi disc trophic state indices for all samples and the application of mean values to the classification scheme proposed by Kratzer & Brezonik (1981).

Thirty of the 169 species observed in the study are considered indicators of eutrophication or organic pollution according to a recently published report (Taylor et al., 1981); of these, 23 were observed in Pond C, 21 in Par Pond, and 13 in Pond B. The mere presence of these indicator species does not, of course, mean that any of the reservoirs have or will have problems with eutrophication or organic pollution. However, these findings support the idea that some degree of eutrophication results from reactor operation at SRP, since the ponds currently linked to the Savannah River and receiving thermal effluent appear to be more eutrophic than the pond no longer involved in reactor operation.

Table V shows how the three SRP reservoirs compare with 13 other South Carolina reservoirs in which spring, summer, and fall physicochemical and phytoplankton characteristics were studied by the United States Environmental Protection Agency (Hern et al., 1977; Taylor et al., 1978). Mean water temperatures in Pond C were more than 17°C higher than the mean of the 13 other South Carolina reservoirs. Levels of orthophosphate and NO_2+NO_3 nitrogen were substantially lower and transparency was higher in the three SRP reservoirs. Pond C had higher pH levels than most of the other South Carolina reservoirs, whereas Pond B differed by being less alkaline.

Measurements of phytoplankton standing crop and diversity in Par Pond resembled the average measurements of these parameters in the other South Carolina reservoirs. In terms of relative

abundance, Par Pond tended to have more cryptomonads and fewer diatoms. Small centric diatoms [particularly Cyclotella spp. and Melosira distans (Ehr.) Kutz] were sparse in all three SRP reservoirs when compared to the 13 other South Carolina reservoirs.

The phytoplankton in Pond B displayed average diversity when compared to the other South Carolina reservoirs. Total standing crop was lower in Pond B, primarily because of a paucity of diatoms. The lack of substantial diatom quantities in Pond B may have been partially due to inadequate levels of silica (see Table II). Diatom species have differing silica requirements (Coetzer et al., 1977); however, limiting concentrations of SiO_2 are usually 0.1 mg/liter or less (Schelske & Stoermer, 1971). A more likely cause of the paucity of diatoms in Pond B is lack of water movement. Diatoms often have considerable difficulty staying afloat in small lakes and ponds due to the lack of turbulence (Duthie & Ostrofsky, 1974). Whitford (1958) found that diatoms were much less important in the phytoplankton of lakes and ponds of North Carolina than in the northern United States, Canada, or Colorado and the far western United States. A relative lack of diatoms also appears tc be characteristic of the South Carolina phytoplankton.

All species identified in the study have previously been reported from southeastern United States phytoplankton collections (Patrick, 1961; Whitford & Schumacher, 1973; Jensen, 1974; Wilde & Paulishen, 1974; Duke Power Company, 1977; Hern et al., 1977; Morris et al., 1978; Matthews, 1982), except Rhodomonas minuta,

Mastigocladus laminosus cohn, Merismopedia trolleri Bachmann, and Scenedesmus longispina var. asymetricus Hortob. The latter two taxa were observed in only a few samples and in low quantities, whereas the former two were major taxa (see Table III).

Rhodomonas minuta is a common phytoplankton organism that is typically abundant in dystrophic lakes (Eloranta, 1980). The apparent absence of this taxon from species lists for other South Carolina lakes is probably due to the substantial synonymy associated with this group (cryptomonads) of organisms, rather than its exclusive statewide occurrence in SRP reservoirs. Recently, Anton & Duthie (1980) have recently proposed that R. minuta be classified as Cryptomonas pusilla Bachmann.

Mastigocladus laminosus (Fischerella sp.), the other major species not reported for other South Carolina reservoirs, is a thermophile that develops thick mats in the warmer (up to 58°C) portions of the P Reactor effluent system (Tison et al., 1981). It occurs in Pond C and Par Pond as a member of the "tychoplankton" or "pseudoplankton" (Hutchinson, 1967).

Many of the major species collected from the SRP reservoirs also were found to be major contributors to the phytoplankton of several other South Carolina reservoirs (Hern et al., 1977). Species in this category included Ankistrodesmus falcatus (corda) Ralfs, Cryptomonas erosa Ehr., Lyngbya limnetica, and Merismopedia tenuissima.

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(FIGURE CAPTIONS)

FIG.1. Study site showing sampling locations.

FIG.2. Mean phytoplankton abundance (±SE) and group composition in Par Pond (P), Pond B (B), and Pond C (C) during four seasonal sampling periods of 1978.

FIG.3. Mean phytoplankton abundance (±SE) and group composition in the three major arms of Par Pond during four seasonal sampling periods of 1978.

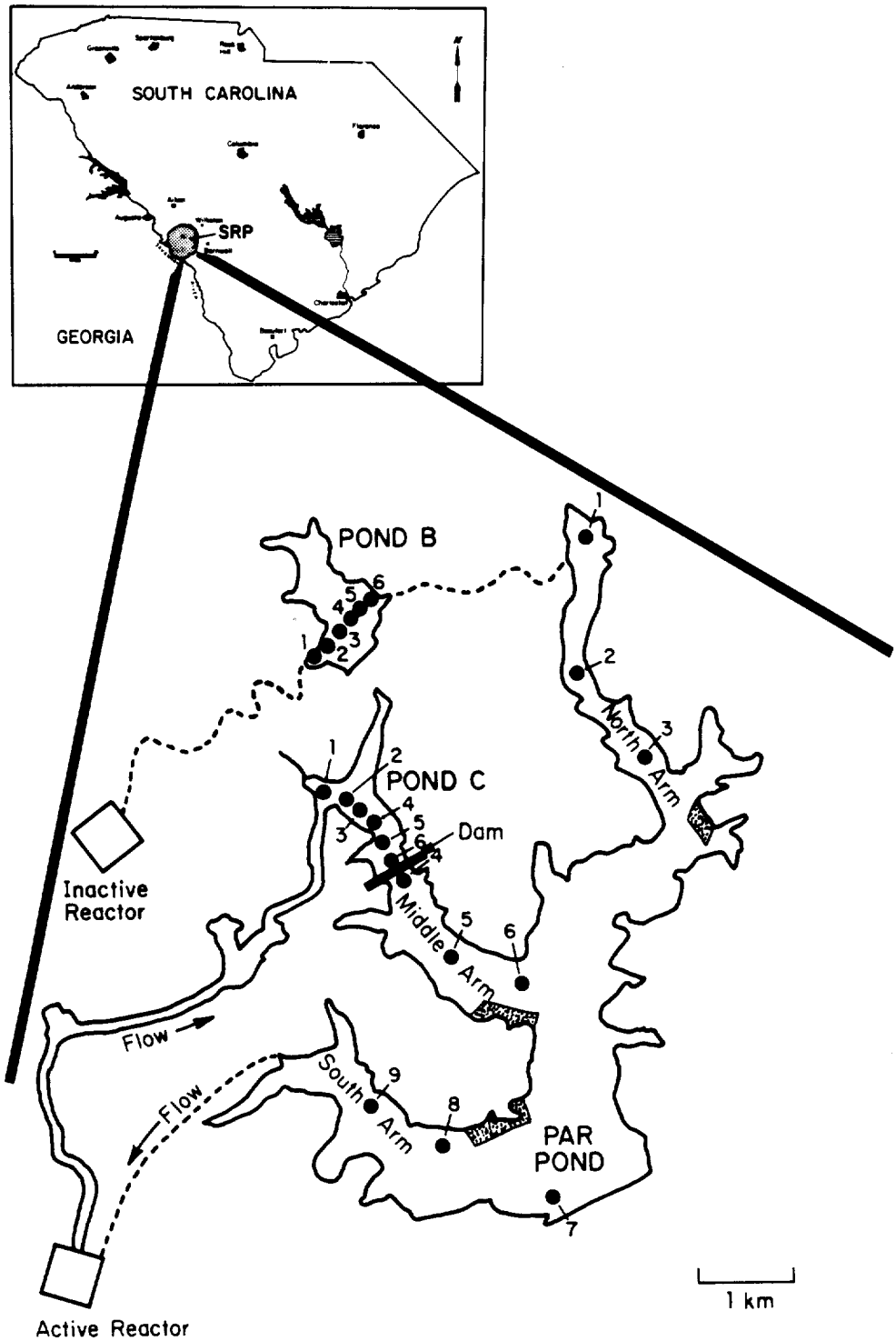

FIG.1. Study site showing sampling locations.

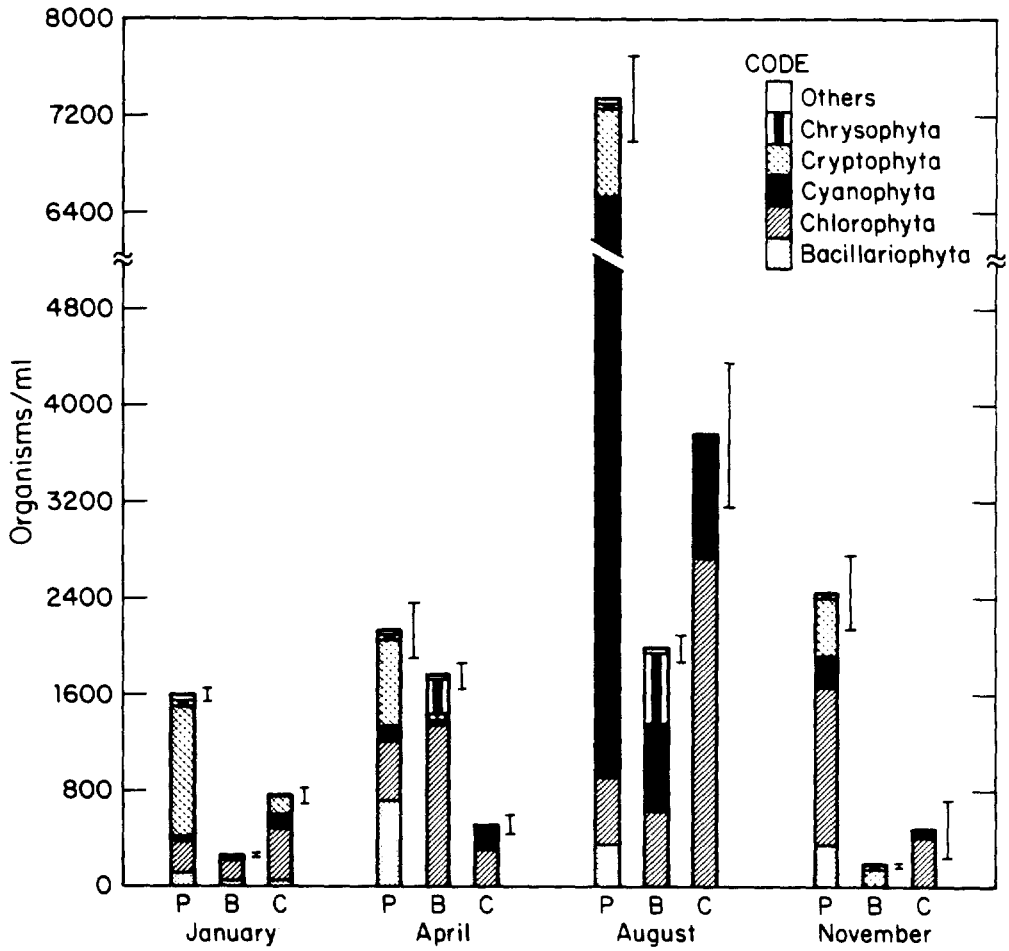

FIG.2. Mean phytoplankton abundance (±SE) and group composition in Par Pond (P), Pond B (B) and Pond C (C) on four seasonal sampling periods of 1978.

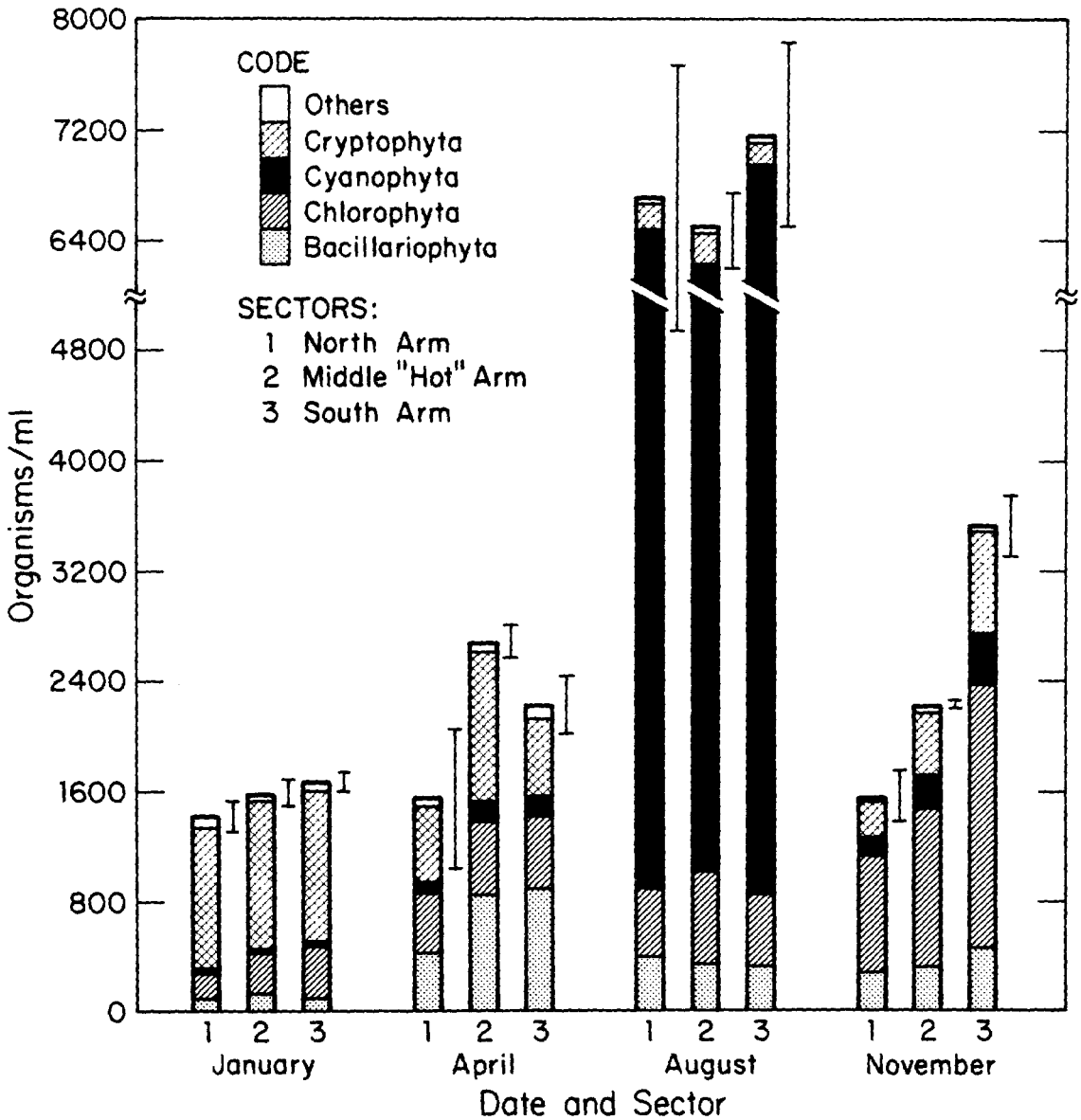

FIG.3. Mean phytoplankton abundance (±SE) and group composition in the three major arms of Par Pond on four seasonal sampling periods of 1978.

TABLE I

Water quality data for three reactor cooling reservoirs (annual means ± SE and ranges)

	Pond C		Par Pond		Pond B	
	Mean	Range	Mean	Range	Mean	Range
Temp. (°C)	37.2±2.4	28.5-55.0	19.0±3.8	6.8-35.0	16.7±4.4	6.0-29.5
DO mg/liter	5.8±0.4	3.8-9.0	7.0±1.0	0.7-10.8	8.0±1.3	0.8-12.2
pH	7.4±0.1	6.5-8.5	6.9±0.1	5.7-8.1	6.3±0.2	5.7-6.9
Spec. cond. (μmho/cm)	59.7±4.8	42-76	53.1±5.0	33-100	19.3±1.7	9-49
Ortho-PO_4(μg/liter)	5.1±2.6	1.2-10.4	1.7±0.6	<0.2-2.8	2.0±0.9	0.2-4.0
N-NO_2+NO_3(μg/liter)	85.0±24.9	43-132	32.0±12.0	6-76	13.0±4.0	5-29
SiO_2(mg/liter)	3.3±1.0	1.3-5.8	3.0±1.3	0.5-5.5	0.53±0.2	0.1-0.7
SO_4(mg/liter)	3.6±0.1	3.1-3.9	2.8±0.1	1.5-3.4	3.4±0.9	1.7-4.9
Total Alk.(mg/liter)	14.4±1.5	10.6-18.5	14.0±1.6	6.6-16.5	3.7±1.0	1.3-4.9
Transparency (m)	2.3±0.2	0.9-3.1	2.5±0.3	1.8-3.8	3.1±0.2	1.5-4.2

TABLE II

Seasonal variations of water temperature and major algal nutrient concentrations (means ± SE)

	Pond C	Par Pond	Pond B
Temp. (°C)			
January	32.2±0.4	10.4±0.2	6.0±0.0
April	36.3±0.4	18.7±0.2	17.5±0.3
August	47.3±0.2	28.9±0.4	27.7±0.5
November	36.5±0.5	17.9±0.1	15.4±0.0
Ortho-PO_4(μg/liter)			
January	ND	ND	ND
April	3.4±0.0	2.4±0.4	2.4±1.2
August	1.9±0.7	0.5±0.4	<0.2±0.0
November	10.2±0.2	2.1±0.4	3.4±0.7
NO_2+NO_3N(μg/liter)			
January	ND	ND	ND
April	44±1	19±8	9±3
August	80±6	20±10	20±6
November	130±3	56±16	9±4
SiO_2(mg/liter)			
January	1.4±0.1	ND	ND
April	1.9±0.0	0.8±0.2	0.1±0.0
August	4.1±0.0	3.0±0.2	0.2±0.1
November	5.8±0.0	5.3±0.1	0.7±0.0

ND, Not Determined.

TABLE III

Phytoplankton collected from Pond C, Par Pond, and Pond B

	Pond C	Par Pond	Pond B
Bacillariophyta			
Achanthes linearis (W. Smith) Grun.	X	X	
Achanthes minutissima Kutz.	X	X	X
Asterionella formosa Hassal.	X	X	
Atthea zachariasi J. Brun.		X	
Caloneis sp.	X		
Cyclotella stelligera Cleve and Grun.	X	X	
Cymbella minuta Hilsc ex. Rabh.	X	X	
Eunotia pectinalis (Kutz.) Rabh.	X	X	X
Fragilaria crotonesis Kitton	X	X	
Frustulia rhomboides (Ehr.) Det.		X	
Gomphonema gracile Ehr.			X
Gomphonema parvulum Kutz.	X		
Melosira ambigua (Grun.) O. Miller	X		X
Melosira granulata (Ehr.) Ralfs	X	X	
Melosira granulata v. angustissima Mull.	X	X	
Navicula cryptocephala Kutz.	X	X	X
Navicula hustedtii Krasske	X		
Navicula sp.		X	

X, observed in at least one sample from the reservoir.

(M), major taxon comprising >5% of the total phytoplankton in at least one sample.

TABLE III, Contd

	Pond C	Par Pond	Pond B
Bacillariophyta, Contd			
Nitzxchia acicularis W. Smith	X	X	
Nitzschia denticula Grun.		X	
Nitzschia dissipata (Kutz). Grun.	X	X	
Nitzschia holsatica Hust.		X	
Nitxschia palea (Kutz.) W. Smith	X(M)	X	X
Rhizosolenia eriensis H.L. Smith	X	X(M)	
Stauroneis sp.		X	
Stephanodiscus hantzschii Grun.			X
Stephanodiscus sp.		X	
Synedra delicatissima W. Smith		X	
Synedra rumpens Kutz.	X	X	X(M)
Synedra planktonica Hains and Sebring	X	X(M)	
Synedra ulna (Nitz.) Ehr.	X	X	
Synedra vaucheriae Kutz.		X	
Tabellaria fenestrata (Lynbg.) Kutz.	X	X(M)	
Chlorophyta			
Actinastrum hantzschii Lag.		X	
Ankistrodesmus convolutus Corda		X	
Ankistrodesmus falcatus (Corda) Ralfs	X	X(M)	X(M)
Ankistrodesmus falcatus v. mirabilis (Corda) Ralfs		X(M)	
Ankistrodesmus spiralis (Turner) Lemm.		X(M)	X
Arthrodesmus sp.		X	X

TABLE III, Contd

Chlorophyta, Contd	Pond C	Par Pond	Pond B
Botryococcus braunii Kuetzing			X
Carteria sp.	X	X	
Chlamydomonas sp.	X(M)	X(M)	X
Chlorogonium elongatum (Dang.) Franze	X(M)		X
Chlorogonium euchlorum Ehr.	X(M)		X
Closteridium lunula Nitzsch.	X		
Closteridium sp.			X
Closteriopsis longissima Lemm.		X	
Closterium sp.	X		
Coelastrum cambricum Archer	X	X	X
Coelastrum proboscideum Bohlin	X	X	
Cosmarium sp. 1		X	X
Cosmarium tenue Archer			X
Crucigenia quadrada Morren		X	X
Crucigenia tetrapedia (Kirch.) West and West		X	X
Dictyosphaerium pulchellum Wood		X	X(M)
Elakatothrix gelatinosa Wille		X	X
Elakatothrix viridis (Snow) Printz			X(M)
Eudorina elegans Ehr.		X	
Franceia droescheri (Lemm.) G.M. Smith	X	X	
Franceia ovalis (France) Lemm.		X	X
Gloeocystis ampla (Kutz.) Lag.		X	
Gloeocystis gigas (Kutz.) Lag.		X	

TABLE III, Contd

Chlorophyta, Contd	Pond C	Par Pond	Pond B
Gloeocystis planctonica (West and West) Lemm	X	X	X(M)
Glococystis vesiculosa Naeg.		X	
Gloeocystis sp.		X	
Golenkinia radiata (Chod.) Wille	X	X(M)	X
Gonatozygon aculeatum Hastings			X
Gontozygon brebissonii De Bary		X	
Gonium pectorale Mueller	X	X	
Kirchneriella contorta (Schmidle) Bohlin			X
Kirchneriella lunaris (Kirch.) Moebius			X
Kirchneriella subsolitaria G.S. West	X	X	
Lagerheimia quadriseta (Lemm.) G.M. Smith		X	
Lagerheimia sp.			X
Micractinium pusillum Fresenius	X(M)	X	X
Mougeotia sp.	X	X	
Nephrocytium sp.	X		
Oedogonium sp.	X		
Oocystis borgei Snow		X	X
Oocystis elliptica W. West		X	
Oocystis gloecystiformis Borge			X
Oocystis lacustris Chod.		X	X(M)
Oocystis parva West and West			X
Oocystis pusilla Hansgirg	X	X	

TABLE III, Contd

Chlorophyta, Contd	Pond C	Par Pond	Pond B
Pandorina charkowiensis Korshikov	X		
Pandorina morum (Muell) Bory	X		
Pediastrum boryanum (Turp.) Meneghini		X	
Pediastrum duplex Meyen	X		
Pleurotaenium sp.			X
Plurotaenium tridentulum (Wolle) West		X	
Protococcus viridis C.A. Agardh			X
Scenedesmus abundans (Kirch.) Chod.	X		
Scenedesmus bijuga (Turp.) Lag.	X		X
Scenedesmus brevispina (Smith) Chod.	X	X	X
Scenedesmus denticulatus Lag.	X	X	
Scenedesmus intermedius Chod.		X	
Scenedesmus longispina v. asymmetricus Hortob.	X		
Scenedesmus opoliensis P. Richter	X	X	
Scenedesmus quadricausa (Turp) Breb.	X	X	
Schroederia setigera (Schroed.) Lemm.	X	X	
Selenastrum capricornutum Printz.		X	X
Selenastrum gracile Reinsch		X	
Selenastrum minutum (Naeg.) Collins	X(M)	X(M)	X(M)
Staurastrum brasiliense W. and G.S. West			X
Staurastrum chaetoceros (Schroed.) G.M. Smith		X	X
Staurastrum paradoxum Meyen		X	X(M)

TABLE III, Contd

	Pond C	Par Pond	Pond B
Chlorophyta, Contd			
Staurastrum ravenellii Irenee-Marie		X	
Staurastrum sp. 1	X	X	
Staurastrum sp. 2			X
Tetraedron caudatum (Corda) Hansgirg	X	X	X
Tetraedron gracile (Reinsch) Hansgirg	X		
Tetraedron minimum (A. Braun) Hansgirg		X	X(M)
Tetraedron regulare Kutz.		X	
Tetraedron sp.		X	
Tetraedron trigonum (Naeg.) Hansgirg		X	
Tetrastrum staurogeniaeforme (Schroed.) Lemm		X	
Undetermined green flagellates		X(M)	
Westella botryoides (W. West) deWildemann		X	X
Xanthidium cristatum v. leiodermum W. and G.S. West			X
Xanthidium sp.		X	
Cyanophyta			
Anabaena sp.	X	X(M)	X
Anacystis sp.	X	X(M)	X
Arthrospira jenneri (Kutz) Stitz.			X
Arthrospira sp.	X		
Chroococcus limneticus Lemm.			X
Chroococcus sp.	X	X	X
Dactylococcopsis fascicularis Lemm.	X		

TABLE III, Contd

	Pond C	Par Pond	Pond B
Cyanophyta, Contd			
Lyngbya limnetica Lemm.	X(M)	X(M)	X
Mastigocladus laminosus Cohn.	X(M)	X	
Merismopedia sp.	X		
Merismopedia tenuissima Lemm.	X	X	X(M)
Merismopedia trolleri Bachmann			X
Oscillatoria geminata Menegh	X	X	X
Oscillatoria princeps Vaucher	X		
Oscillatoria sp.	X		X
Phormidium sp.	X(M)	X	X(M)
Schizothrix sp.		X	X
Spirulina major Kutz.		X	
Cryptophyta			
Chroomonas sp.	X		X
Cryptomonas erosa Ehr.	X	X(M)	X(M)
Cryptomonas marsonii Skuja		X	
Rhodomonas minuta Skuja	X(M)	X(M)	X(M)
Rhodomonas sp.	X	X(M)	X(M)
Chrysophyta			
Chromulina sp.	X(M)		
Dinobyron divergens Imhof.	X(M)	X	X(M)
Dinobyron sertularia Ehr.			X
Mallomonas alpina Pascher and Ruttner			X

TABLE III, Contd

	Pond C	Par Pond	Pond B
Chrysophyta, Contd			
Mallomonas caudata Conrad		X	X
Mallomonas pseudocoronata Prescott		X	
Mallomonas sp.		X	
Mallomonas tonsurata Teiling		X	X
Ochromonas sp.		X	X(M)
Ophiocytium capitatum Wolle			X
Ophiocytium capitatum v. longispinum (Moebius) Lemm.		X	X
Synura caroliniana Whitford			X(M)
Synura petersenii Korshikov		X	
Synura uvella Ehr.		X	X
Pyrrhophyta			
Glenodinum sp.		X	X(M)
Peridinium sp.	X	X	X
Euglenophyta			
Euglena minuta Prescott		X	X
Euglena sp. 1			X(M)
Euglena sp. 2	X	X	
Eutreptia viridis Perty	X		
Lepocinclis sp.			X
Phacus sp.	X		
Trachelomonas horrida Palmer		X	
Trachelomonas sp.	X		
Trachelomonas volvocina Ehr.	X		

TABLE III, Contd

	Pond C	Par Pond	Pond B
Rhodophyta			
Audouinella violacea (Kuetz.) Hamel	X		

TABLE IV

Shannon-Weaver diversity index (H') values (means ± SE) for phytoplankton samples collected from three reservoirs during four seasonal sampling periods

	Pond C	Par Pond	Pond B	P[a]
January	3.10 ± 0.08	2.12 ± 0.06	1.97 ± 0.12	0.0001
April	1.88 ± 0.20	3.79 ± 0.06	3.02 ± 0.07	0.0001
August	1.28 ± 0.08	2.41 ± 0.08	2.93 ± 0.07	0.0001
November	1.44 ± 0.33	3.70 ± 0.07	2.89 ± 0.05	0.0001
Annual Mean	1.93 ± 0.18	3.01 ± 0.13	2.70 ± 0.10	0.0001

[a]Probability of > F value as determined by ANOVA comparing values for the three reservoirs.

TABLE V

Physicochemical and phytoplankton characteristics (means and ranges of spring, summer, and fall values) of SRP cooling reservoirs and other South Carolina reservoirs

Parameter	Pond C	Par Pond	Pond B	13 Other SC Reservoirs[a]
Physicochemical				
Temp. (°C)	39.4 (35.3-44.7)	21.8 (15.5-30.5)	20.4 (15.0-29.2)	21.8 (8.8-30.6)
Ortho-PO_4(μg/liter)	5.2 (1.2-10.4)	1.7 (0.1-2.8)	2.0 (0.1-4.0)	14.0 (2.0-65.0)
NO_2 + NO_3(μg/liter)	85.7 (43-132)	32.6 (6-76)	13.7 (5-29)	188.0 (31-684)
Secchi (m)	2.3 (1.6-3.1)	2.2 (1.8-2.8)	3.3 (2.8-4.2)	1.2 (0.1-4.0)
pH	7.5 (7.2-8.1)	6.8 (6.2-7.5)	6.1 (5.8-6.4)	6.8 (5.4-7.7)
Alkalinity (mg/liter)	15.4 (12.2-18.5)	14.2 (6.6-16.5)	4.4 (2.5-6.5)	15.9 (10.0-25.2)
DO (mg/liter)	5.8 (4.7-7.5)	6.2 (4.4-8.3)	6.9 (4.6-8.1)	6.4 (3.3-10.3)
Phytoplankton				
Total Crop (orgs/ml)	1565 (103-5418)	3779 (556-8456)	1316 (165-2281)	4402 (60-22,032)
% Cyanophyta	30.0 (6.5-92.1)	33.0 (3.1-89.7)	14.9 (0.2-46.0)	23.9 (0-79.9)
% Chlorophyta	66.9 (7.7-93.2)	28.9 (3.3-60.5)	46.5(26.8-80.1)	27.4 (1.0-99.8)
% Bacillariophyta	1.0 (0-9.4)	17.6 (2.7-42.0)	0.2 (0-0.7)	39.0 (0.1-90.3)
% Cryptophyta	0.1 (0-0.2)	18.3 (1.2-46.5)	13.9 (0-42.5)	6.5 (0-55.1)
Total No. of spp/per sample	11 (6-21)	29 (20-44)	21 (16-25)	35 (11-70)
No. Cyanophyta spp.	4 (2-6)	4 (3-6)	3 (1-5)	5 (0-13)
No. Chlorophyta spp.	5 (2-9)	12 (7-16)	10 (5-15)	13 (1-29)
No. Bacillariophyta spp.	2 (1-6)	7 (3-13)	1 (1-2)	12 (4-26)
No. Cryptophyta spp.	1 (1-1)	3 (1-4)	2 (1-3)	1.0 (0-2)
Shannon's Div. Index(H')	1.5 (0.5-2.7)	3.3 (2.1-4.1)	2.9 (2.7-3.2)	3.0 (0.5-4.5)

[a]Data from reports of Taylor et al. (1978) and Hern et al. (1977).

(FOOTNOTE TO TITLE PAGE)

[1]This paper was prepared in connection with work done under Contract DE-AC09-76SR00001 with the United States Department of Energy. Appreciation is expressed to Dr. Laurence J. Tilly for providing several helpful suggestions during discussions of the study and for assistance with sampling. Thanks also are due to A. S. Dicks and W. H. Fellner for assistance with computer analyses, and to R. J. Soracco, W. R. Cody, and D. H. Buetow for critically reviewing the manuscript.