Dominant phytoplankters and environmental variables in Roodeplaat Dam, Pretoria, South Africa

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Abstract

The sequence of dominant phytoplankton populations in Roodeplaat Dam was investigated and related to certain environmental variables. Of the inflowing streams, the Pienaars River is the major contributor of dissolved substances resulting in the occurrence of nutrient and phytoplankton gradients in the impoundment. *Microcystis aeruginosa, M. incerta, Anabaena circinalis* (cyanobacteria), *Pediastrum duplex, Sphaerocystis schroeteri* (green algae) and *Melosira granulata* (diatom) were the dominant (reaching highest biomass concentrations) phytoplankton populations. Marked spatial differences in phytoplankton composition were recorded. Cyanobacteria were almost always dominant in the impoundment at the Pienaars River and Hartbees Spruit sampling positions, while green algae and diatoms were at times better represented at the dam wall and Edenvale Spruit sampling positions. Seasonal sequential patterns were most probably influenced by temperature, the onset and duration of stratification, underwater light availability, water inflow (i.e. water retention time) and possibly turnover. Inorganic P was the primary growth-rate limiting nutrient, but annual differences in phytoplankton composition, such as the appearance and dominance of *Anabaena circinalis* (a nitrogen fixer), may have occurred because inorganic N became increasingly important as a growth-rate limiting nutrient.

Introduction

Roodeplaat Dam has been studied extensively to describe limnological characteristics with regard to eutrophication. Toerien *et al.* (1975) ranked this impoundment as the third most eutrophic water body in a comparison of 98 South African impoundments, indicating that algal growth was limited primarily by nitrogen. Additional data of Toerien and Steyn (1975) and Steyn *et al.* (1976) indicated that both nitrogen and phosphorus could be the primary growth-rate limiting nutrient depending upon the time of the year, while Pieterse and Toerien (1978) found a statistically significant correlation between the average orthophosphate and chlorophyll *a* concentrations over a two-year study period. They also suggested that 26 $\mu g.\ell^{-1}$ PO_4-P represents a level above which algal nuisance conditions may develop in Roodeplaat Dam.

Pieterse and Bruwer (1980) and Walmsley and Toerien (1979) showed that one inflowing river, the Pienaars River, plays a major role in inorganic nutrient supply to the reservoir. This aspect, combined with the elongated, sinuous shape of the water body, results in chemical and biological gradients in the dam (Pieterse and Toerien, 1978; Walmsley *et al.,* 1978), that should result in spatial differences in the composition of phytoplankton assemblages.

With the exception of superficial observations made by Bruwer (1979), Howman and Kempster (1986), De Wet (1986) and Van Ginkel (1987), the phytoplankton of Roodeplaat Dam has not been investigated in detail. This investigation therefore adds to our knowledge of the phytoplankton of Roodeplaat Dam in particular and of South African impoundments in general. The concepts of succession as seasonal sequences (Hutchinson, 1967) and zonation (Round, 1981) are used to describe temporal changes and spatial differences in phytoplankton composition.

Study area and methods

Roodeplaat Dam (Fig. 1), situated in the Pretoria district, is an important recreational site and source of potable water.

The net capacity of Roodeplaat Dam is 41,9 x 10^6 m^3; it covers an area of 396 ha at full supply level, is 1 314 m above sea level, and has a mean depth of 10,6 m and a maximum depth of 43 m. The catchment (668 km^2) is situated in a summer rainfall region with an average annual rainfall of approximately 700 mm.

Three streams feed the Roodeplaat Dam (Fig. 1). The Pienaars River flows past the Baviaanspoort Sewage Works which treats effluent from the Mamelodi Township. The sewage works discharges between 220 and 470 x 10^3 m^3 of secondary treated effluent per month into the Pienaars River (Walmsley and Toerien, 1979) thus contributing up to 25 % of the total water inflow of the dam (Walmsley *et al.,* 1978). At the same time, this river is the major nutrient source of the dam, contributing up to 75 % and 87 % of the dissolved nitrogen and phosphorus annual loading respectively (Walmsley and Toerien, 1979). In general, the river inflow in strongly seasonal with flooding of the system occurring during the rainy summer months (Walmsley and Toerien, 1979).

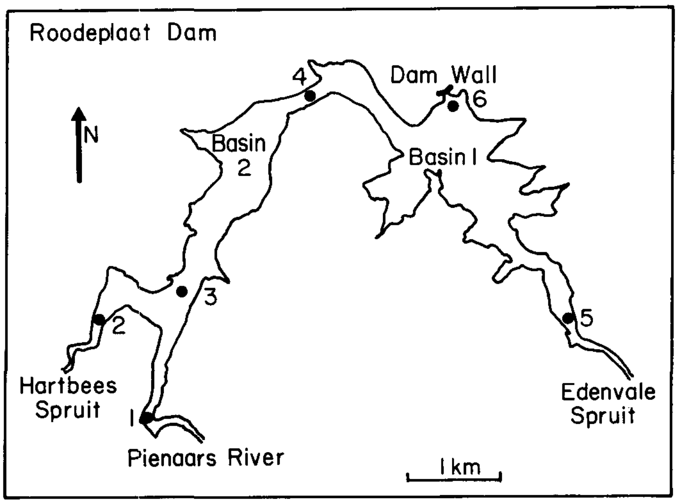

Figure 1
Map of Roodeplaat Dam showing sampling positions

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Six sampling positions were selected on the impoundment. (Fig. 1):

- after entrance of Pienaars River (6 m deep);
- after entrance of Hartbees Spruit (6 m deep);
- at confluence of Pienaars River and Hartbees Spruit valleys (19 m deep);
- channel linking Basins 1 and 2 (26 m deep);
- after entrance of Edenvale Spruit (6 m deep); and
- at the dam wall (43 m deep).

In addition, all three inflowing streams were sampled at monthly intervals for chemical analyses and algal growth potential and limiting nutrient assays were conducted employing batch culture tests with *Scenedesmus bijugatus* as test organism (Maloney, 1971). Standard methods were used for the investigation into environmental and phytoplankton variables of surface samples (Standard Methods, 1971; Lund *et al.,* 1958; Marker, 1972).

The following environmental variables were investigated: Temperature; oxygen; light penetration; Secchi disc transparency; concentrations of total suspended material (TSM); total N (unfiltered); inorganic N (NH_4-N, NO_3-N, NO_2-N); total P (unfiltered); and inorganic P (PO_4-P; filtered). Calculated retention times and loading rates for phosphorus and nitrogen were based on data provided by the Hydrological Research Institute, Department of Water Affairs, Pretoria. The following phytoplankton-related variables were investigated: Concentrations of chlorophyll *a* and individual algal species, algal growth potential and limiting nutrient assays.

Samples were on average taken bi-weekly or monthly during the period of investigation.

Data from surface water samples were averaged to give annual or monthly values for specific sampling positions or for the entire impoundment. Standard deviations generally varied between 20% and 90% of mean values. Frequency histograms, not presented here, indicated that a normal distribution around the mean was not displayed by the variables of this investigation. This fact should be recognised when considering summarised information. Linear regression analyses were applied and significance of correlation, as well as positive (direct) and negative (inverse) relationships, were employed to interpret results. The analysis was done on a data set with no missing values, i.e. all values of a specific date were excluded when one value of that date was missing. Correlation, however, does not necessarily indicate cause and effect and was employed here only as a general aid in considering certain trends in phytoplankton abundance and composition.

Results and discussion

Physical variables

The total annual inflow for the years 1976, 1977 and 1978 amounted to 120, 58 and 111 x 10^6 m^3, giving a water retention time of 4,2; 8,5; and 4,6 months respectively (Table 1). The average mean annual inflow for the period 1970 to 1978 was 59 x 10^6 m^3 (water retention time 8,4 months). Consequently, the inflow for 1976 and 1978 was about twice the long-term inflow, possibly indicating above-average wet summers. Despite the variation in inflow volume the water level, surface area and water volume of Roodeplaat Dam remained relatively constant during the study period (compare mean depth, Table 3).

Isopleth diagrams (not presented here but see Pieterse and Bruwer, 1980) indicate that the water column was stratified, both in temperature and in oxygen, between August and April. From November to March water below the 10 m level was anoxic, representing a volume of approximately 20 x 10^6 m^3, i.e. some 50% of the total volume of the impoundment. Secchi disc transparency values generally increased from sampling position 1 (mean = 0,7 m) to 6 (mean = 1,8 m), apparently because of a reduction in allochthonous suspended material (TSM; Table 2).

TABLE 1
TOTAL ANNUAL INFLOW AND WATER RETENTION TIMES FOR ROODEPLAAT DAM

	Total inflow x 10^6 $m^3.a^{-1}$	Water retention time Year	Months
1976	119 952	0,35	4,2
1977	58 422	0,71	8,5
1978	110 963	0,38	4,6

Chemical variables

Pienaars River water had by far the highest concentration of inorganic N and P compounds (Table 2). A general reduction in inorganic N and P concentration was observed from sampling position 1 to 6 (Table 2), while N/P ratios increased. Basin 2 (Fig. 1) showed higher concentrations of nutrients than Basin 1, and a general nutrient gradient is therefore illustrated. The average total N/P ratios (Table 2) for basins 1 and 2 were 32 and 18 respectively, indicating that inorganic P exerts a growth-limiting influence on the phytoplankton. N/P ratios smaller than 7 indicate N limitation (Grobler and Silberbauer, 1984; Saad and Antoine, 1978; Dokulil, 1984; Rossouw, 1986). Consequently, in Roodeplaat Dam inorganic phosphate would in general be more important as a growth-rate limiting nutrient than inorganic nitrogen. Grobler and Silberbauer (1984), taking predicted increases in sewage outflow entering the system into account, showed that the phytoplankton growth rate in Roodeplaat Dam might become N limited.

The surface-loading rates of PO_4-P for 1978 (Table 3) were higher than those of the 1973/74 (6,8 $g.m^{-2}.a^{-1}$) and 1974/75 (7,3 $g.m^{-2}.a^{-1}$) periods studied by Walmsley and Toerien (1979). Loading for 1977 was similar to that of 1973/74 and 1974/75. When the retention time and surface-loading rate of total P are applied to the OECD (1982) model, Roodeplaat Dam falls well within the eutrophic category.

Phytoplankton assemblages

Of the total number of some 250 phytoplankton species identified in Roodeplaat Dam, only 20 reached dominant proportions (i.e. highest biomass concentrations as measured by volume; Fig. 2), and of these (Table 4) only 10 to 11 became dominant during any one year. *Microcystis aeruginosa, M. incerta, Anabaena circinalis, Pediastrum duplex, Sphaerocystis schroeteri, Melosira granulata* and *Lepocinclis radiata* were the more important phytoplankton species of Roodeplaat Dam (Table 4) because of their frequency of dominance (Table 4).

A phytoplankton species was taken as dominant for the entire impoundment for a specific period of time (i.e. month or months) when it reached highest concentrations by volume at three or more of the sampling positions (Fig. 2). The sequence of individual dominant algal populations is illustrated in Fig. 3. *Lepocinclis radiata* (winter, early spring of 1976) and *Pediastrum duplex* (early summer

TABLE 2

MEAN (m), MINIMUM AND MAXIMUM SECCHI DISC TRANSPARENCY (SDT; m), TOTAL SUSPENDED MATTER (TSM; mg.ℓ^{-1}), CHLOROPHYLL *a* (Chl *a*; μg.ℓ^{-1}), PHYTOPLANKTON BIOMASS IN VOLUME UNITS (PB; x 10^6 $\mu m^3.m\ell^{-1}$) CONCENTRATIONS AND ALGAL GROWTH POTENTIAL (AGP; mg.ℓ^{-1}) AND INORGANIC N AND P CONCENTRATIONS (μg.ℓ^{-1}) AT THE DIFFERENT IMPOUNDMENT SAMPLING POSITIONS (SEE FIG. 2) FOR THE PERIOD 1976 TO 1978. N_i = NO_3 + NO_2 + NH_4-N. N/P RATIO = NO_3 + NO_2 + NH_4-N/PO_4-P. n = NUMBER OF DATA PAIRS.

		Impoundment sampling positions 1	2	3	4	5	6
SDT	m	0,7	0,7	1,3	1,4	1,2	1,8
	n	66	62	65	66	63	64
	range	0,2-1,5	0,1-2,0	0,1-4,4	0,1-4,1	0,1-3,5	0,1-5,2
TSM	m	17,3	13,6	9,8	7,2	9,3	4,9
	n	22	22	22	21	20	20
	range	6,8-47,5	2,9-33,4	1,2-24,6	1,1-15,4	2,1-21,9	0,8-10,8
Chl *a*	m	34,9	37,9	39,2	33,9	14,1	21,3
	n	63	64	66	65	61	63
	range	11-118	1-187	1-204	2-169	1-82	1-64
PB	m	353	470	761	264	277	486
	n	34	35	35	34	33	34
	range	0,1-1705	0,2-3112	0,2-3793	0,1-2212	0,6-1600	0,2-8492
AGP	m	53,0	31,0	30,1	30,5	31,6	33,2
	n	43	44	44	42	37	43
	range	1-143	1-93	1-93	3-87	1-92	1-78
PO_4-P	m	324	93	82	71	58	60
	n	57	57	60	59	54	57
	range	10-1240	5-210	0-300	2-200	2-200	2-280
NH_4-N	m	280	202	169	177	212	169
	n	57	57	60	59	55	57
	range	17-1750	10-930	6-1980	8-1060	11-1840	6-1000
NO_3+NO_2-N	m	1 192	621	469	416	388	387
	n	57	57	59	59	54	57
	range	106-3070	5-1980	10-1220	5-1440	8-1070	6-1130
N_i	m	1 472	823	638	593	600	556
	n	57	57	60	60	55	59
	range	128-3550	30-2280	10-2400	5-1640	19-2540	7-1360
N/P ratio	m	14	24	16	25	38	32
	n	57	57	59	59	54	57
	range	0,8-147	0,9-164	0,2-80	0,8-181	2-250	0,4-353

TABLE 3

HYDROLOGICAL CHARACTERISTICS AND NUTRIENT LOADING RATES OF ROODEPLAAT DAM

	1976	1977	1978
Mean depth (m)	10,6	10,6	10,6
Retention time (a)	0,35	0,71	0,38
Hydraulic load (m.a^{-1})	30,3	14,8	27,9
Surface-loading rates (g.m^{-2}.a^{-1}):			
PO_4-P	11,99	5,79	11,08
Total P	16,18	7,82	14,97
Inorganic nitrogen	145,35	70,25	134,45
Total nitrogen	169,50	81,92	156,78

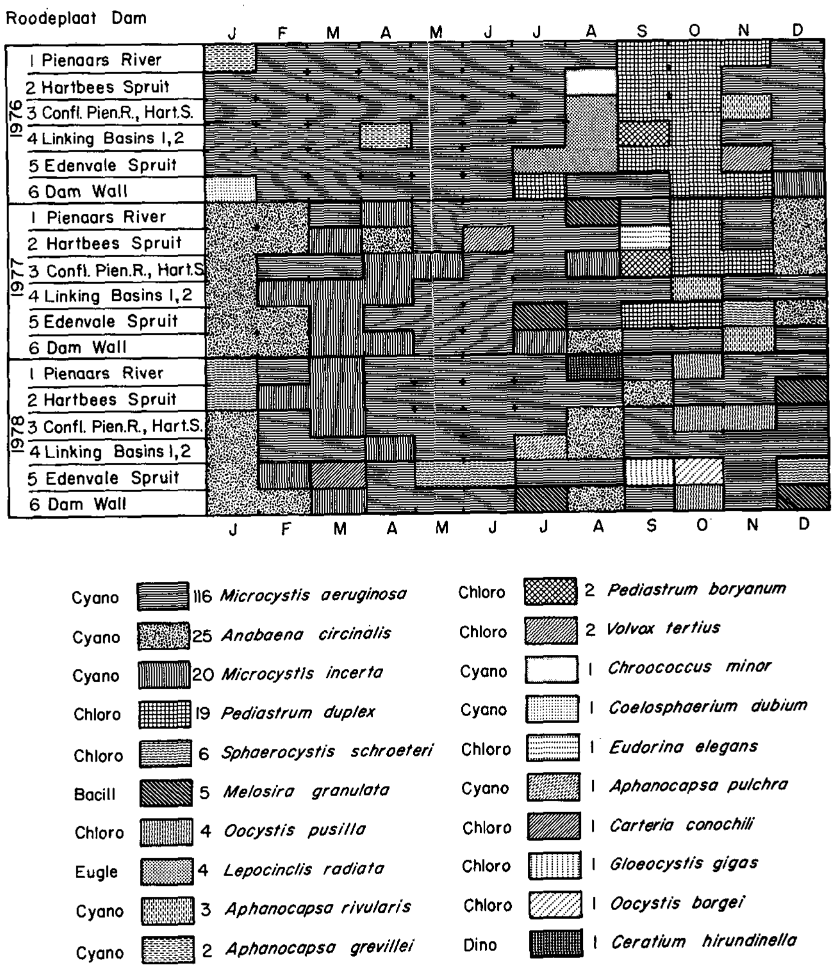

Figure 2

Dominant phytoplankton species for each month at the different sampling positions in Roodeplaat Dam. Numbers given in the legend represent counts of the number of times species reached dominant proportions.

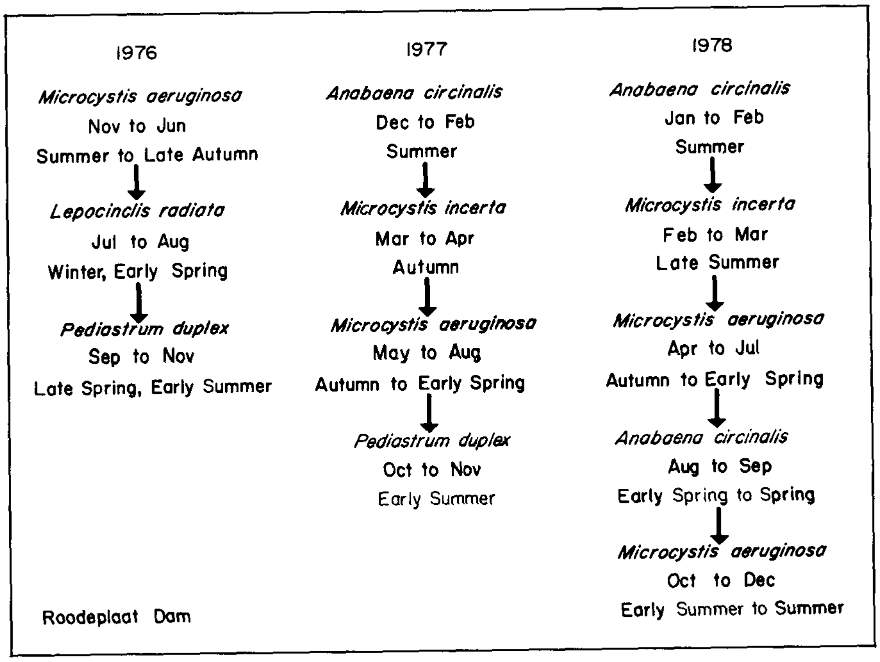

Figure 3

Seasonal sequence of individual dominant phytoplankton species in Roodeplaat Dam

TABLE 4
NUMBER OF TIMES THAT DIFFERENT PHYTOPLANKTON SPECIES WERE DOMINANT AT THE DIFFERENT SAMPLING POSITIONS IN ROODEPLAAT DAM (SEE FIG. 2)

	1976	1977	1978
Microcystis aeruginosa	47	30	39
Anabaena circinalis	0	16	9
Microcystis incerta	1	12	7
Pediastrum duplex	13	6	0
Sphaerocystis schroeteri	0	1	5
Melosira granulata	0	2	3
Oocystis pusilla	0	0	4
Lepocinclis radiata	4	0	0
Aphanocapsa rivularis	1	2	0
Aphanocapsa grevillei	2	0	0
Pediastrum boryanum	1	1	0
Volvox tertius	1	1	0
Chroococcus minor	1	0	0
Coelosphaerium dubium	1	0	0
Eudorina elegans	0	1	0
Aphanocapsa pulchra	0	0	1
Carteria conochili	0	0	1
Gloeocystis gigas	0	0	1
Oocystis borgei	0	0	1
Ceratium hirundinella	0	0	1
Number of dominant species	10	10	11

of 1976 and 1977) were replaced by *Microcystis incerta, M. aeruginosa* and *Anabaena circinalis* during 1977 and 1978. Cyanobacteria increased their dominance between 1976 and 1978, while the instances of dominance (number of times when highest concentrations were reached) by other species also increased. While representatives of major algal groups were more confined to relatively large temporal/spatial blocks (Fig. 2) during 1976, the distribution of dominant species was more patchy during 1977 and 1978 (Fig. 2), indicating a gradual diversifying trend in instances of dominance.

During June 1976, cyanobacteria dominance (*Microcystis aeruginosa)* was probably curtailed by low temperatures, allowing an euglenophyte (*Lepocinclis radiata)* to become dominant until the onset of stratification in August (Fig. 2). Hereafter green algae (*Pediastrum duplex)* increased and dominated for the first half of the summer. *P. duplex* was also dominant in October to November in 1977. The green algae were subsequently replaced by *Microcystis aeruginosa* during 1976, and by *Anabaena circinalis* during 1977 (Fig. 2). Young and Silberbauer (Howman and Kempster, 1986) found that cyanobacteria species were the dominant part of the phytoplankton in Roodeplaat Dam between January and May during 1981 to 1982. Green algae were, however, according to Young and Silberbauer's results, dominant between September and November (1981) and July to October (1982), possibly indicating that the importance of cyanobacteria was decreasing since the 1976 to 1978 period. These differences may, however, also be due to annual differences that are known to occur in lakes (Round, 1981). It is clear that green algae invariably dominated in the summer, autumn and early winter months.

Ashton (1985) described a situation in Rietvlei Dam which was essentially similar to that in Roodeplaat Dam during 1976 and 1977. The occurrence of diatoms correlated with increases in mixed layer depth (found also for Roodeplaat Dam but not described here), followed by increases in the concentration of green algae (August to October) which were particularly evident at the onset of vernal stratification in Rietvlei Dam. Large summer blooms of nitrogen fixing *Anabaena circinalis* followed the green algae, replaced in turn by *Microcystis aeruginosa.* The onset of overturn marked a temporary resurgence of green algae and diatoms in Rietvlei Dam. *Volvox* spp. also dominated in Rietvlei Dam during September and October of 1976. Zohary (NIWR, 1985) found green algae dominant in Hartbeespoort Dam during August to November between 1981 and 1983. Green algal growth occurred prior to stratification and lasted for 2 to 3 months thereafter. During the autumn and early summer months diatoms were a fairly important part of the phytoplankton from 1981 to 1982. For the rest of the time *Microcystis aeruginosa* was by far the most important phytoplankter.

Dominance of *Anabaena circinalis* in Roodeplaat Dam during 1977 and 1978 (Fig. 2) may indicate nitrogen-limiting conditions. This observation is supported by the fact that the algal bio-assay tests indicated an increase in growth limitation due to N during the same period (Table 5). *A. circinalis,* a nitrogen fixer, possibly has a distinct competitive advantage under nitrogen-limiting conditions, which allows it to replace *Microcystis aeruginosa* as the dominant phytoplankter. A subsequent increase in the supply of N to the system may have resulted in the resurgence of *M. aeruginosa* (on two occasions during 1987 in Roodeplaat Dam) and other non-fixers such as *M. incerta* and *Carteria conochili* (Fig. 2; compare with results in Walmsley and Ashton, 1977).

During the periods February to June (1976), October (1976) and January (1977) three species (*Microcystis aeruginosa, Pediastrum*

TABLE 5
NUMBER OF TIMES (EXPRESSED AS PERCENTAGES) WHEN DIFFERENT NUTRIENTS WERE GROWTH-LIMITING AT DIFFERENT SAMPLING POSITIONS (FIG 1; BATCH CULTURE TECHNIQUE, TEST ORGANISM *SCENEDESMUS BIJUGATUS;* N = INORGANIC N; P = INORGANIC P; HS = HARTBEES SPRUIT; PR = PIENAARS RIVER; ES = EDENDALE SPRUIT; m = MEAN FOR IMPOUNDMENT SAMPLING POSITIONS)

		Impoundment sampling positions							Inflowing streams		
Year	Nutrient	1	2	3	4	5	6	m	HS	PR	E
1976	N	25	33	25				14	-	-	-
	P		33	50	50	75	66	46			
1977	N	41	41	39	24	7	13	28			20
	P		29	22	41	53	67	35	80		60
1978	N	94	50	44	50	38	31	34	7	81	44
	P		44	44	44	56	56	41	87	19	50

duplex and *Anabaena circinalis* respectively) were dominant at all sampling positions, consequently showing no horizontal zonation (Fig. 2). Cyanobacteria representation was more extensive at sampling positions 1 to 3 (at the Pienaars River and Hartbees Spruit inflow positions which showed higher concentrations in inorganic N and P) than at sampling positions 4 to 6. Euglenophytes, cryptophytes and chrysophytes (diatoms) were better represented at the dam wall, while green algae, in addition to being well represented at the Pienaars River inflow position, were best represented at the less nutrient-rich sampling positions (sampling positions 5 and 6; i.e. dam wall and Edenvale Spruit inflow). The nutrient gradient observed earlier was therefore accompanied by spatial differences in the phytoplankton populations.

Phytoplankton biomass and related environmental variables

The average chlorophyll *a* concentration for all sampling positions was higher during 1977 than during the previous and following years (Table 6) most probably because of longer water retention times which allowed algal populations to grow for longer periods and to stabilise.

Higher chlorophyll concentrations were recorded during January to April than during the remainder of the year. The mean chlorophyll *a* concentration at each sampling position decreased from the Hartbees Spruit sampling position to the dam wall position (Table 2). The mean chlorophyll *a* concentration was lower at the Pienaars River position than at the Hartbees Spruit position, possibly because of higher turbidity (stronger inflow) on account of higher TSM concentrations (Table 2). The mean chlorophyll *a* values were positively correlated with TSM at $p<0,05$ levels, indicating that phytoplankton might be the main component of the suspended material. Phytoplankton biomass, expressed in volume units, showed on average highest mean concentrations at sampling positions 2 and 3 (Table 2).

The mean algal growth potential (AGP) was lower for 1977 than for the other two years of investigation (Table 6). Because these values generally follow the mean annual $NO_3+NO_2+NH_4$-N and PO_4-P concentrations (Table 6), one can assume that AGP represents a fairly good indication of available nutrients. This conclusion is supported by the mean AGP values for individual sampling positions and their respective inorganic N and P concentrations (Table 2). The AGP results confirm the existence of nutrient gradients as described earlier.

TABLE 6

MEAN (m), MINIMUM AND MAXIMUM CHLOROPHYLL *a* (Chl *a*), INORGANIC N AND P CONCENTRATIONS AS WELL AS MEAN ALGAL GROWTH POTENTIAL VALUES (AGP; TEST ORGANISMS *SCENEDESMUS BIJUGATUS*) FOR SURFACE WATERS AT THE DIFFERENT SAMPLING POSITIONS IN ROODEPLAAT DAM (MEAN, MINIMUM AND MAXIMUM ANNUAL VALUES FOR ALL SAMPLES AT ALL SAMPLING POSITIONS; n = NUMBER OF DATA PAIRS; N_i = NO_3 + NO_2 + NH_4-N

		Chl *a* $\mu g.\ell^{-1}$	PO_4-P $\mu g.\ell^{-1}$	N_i $\mu g.\ell^{-1}$	AGP $mg.\ell^{-1}$
1976	m	30	124	714	37
	n	118	118	118	19
	range	1-187	2-600	10-3000	2-130
1977	m	34	106	504	17
	n	102	84	88	91
	range	0,5-204	2-1000	5-3550	1-101
1978	m	28	113	999	49
	n	162	142	142	143
	range	1-169	2-1240	120-3540	12-143

Results from batch culture tests (Table 5) for the three years of investigation showed that, on average, phosphorus more frequently limited the growth of the test organism in Roodeplaat Dam water than did inorganic N. This observation supports earlier conclusions that phosphorus may be the primary limiting nutrient in Roodeplaat Dam. Table 5 also shows that the growth of the test organism in water from positions 1 and 2 was more likely to be limited by inorganic N rather than by inorganic P. This observation also supports earlier conclusions on the possible importance of inorganic N at the Pienaars River and Hartbees Spruit inflow positions. In Pienaars River water itself, inorganic N limited the growth of the test organism more frequently during 1978 than did PO_4-P (Table 5), while PO_4-P was apparently a more important growth-limiting nutrient in Edenvale Spruit water. The increased frequency of N limitation between 1976 and 1987 may indicate that the growth-limiting role of inorganic N was being extended spatially and temporally.

Table 7 illustrates that temperature in general correlated positively with chlorophyll *a*. Correlations were significant only at positions 2 (1976; $p<0,05$) and 5 (1977; $p<0,01$), suggesting that temperature may have stimulated phytoplankton biomass development only in general terms.

The correlation between chlorophyll *a* and Secchi depth was statistically significant for positions 2, 6 ($p<0,01$) and 5 ($p<0,05$) during 1976 and 4 ($p<0,05$) during 1978. In contrast with 1976 and 1978, correlations were positive, all at $p<0,05$, between chlorophyll *a* and Secchi at sampling positions 3 to 6 during 1977, suggesting possibly a much stronger and direct relationship between underwater light availability and phytoplankton biomass during 1977 in the largest part of the impoundment. This aspect must be investigated further because the correlations should be expected to be negative.

Chlorophyll *a* was positively correlated with PO_4-P during 1976 (statistically significant only at position 1; $p<0,05$), and at sampling positions 2 to 4 during 1978 (Table 7). Chlorophyll *a* was negatively correlated with inorganic N for the entire study period (except two positions during 1977). Chlorophyll *a* was generally negatively correlated with N/P ratios (Table 7) and only statistically significant at positions 1 and 5 (at $p<0,05$).

The generally weak and inverse correlations between chlorophyll *a* and inorganic N and N/P ratios (except positions 1 and 2 particularly, 1977), were expected due to indications that algal growth in Roodeplaat Dam was primarily PO_4-P limited during the entire study period. N limitation was indicated for positions 1 and 2 only (Pienaars River and Hartbees Spruit inflows).

The direct, although weak, correlations between chlorophyll *a* and PO_4-P for 1976 and 1978 were expected because of the indicated importance of phosphate phosphorus to phytoplankton growth. However, the inverse correlation for 1977 was not expected, but may indicate that other environmental factors also played an important role. One such factor may be underwater irradiance.

The direct correlation between Secchi disc depth (indication of underwater light availability) and chlorophyll *a* was moderately strong, confirming that improved light conditions could stimulate phytoplankton growth. Inflow during 1977 was low with a water retention time of 8,5 months as opposed to approximately 4,5 months for 1976 and 1978, which indicates that the environmental conditions during 1977 were more stable and allowed the phytoplankton assemblages to grow and develop in a stabilised

TABLE 7
CORRELATION COEFFICIENTS (r) BETWEEN CHLOROPHYLL *a* (DEPENDENT VARIABLE) AND CERTAIN ENVIRONMENTAL VARIABLES, MEASURED AT THE SURFACE, AT THE DIFFERENT IMPOUNDMENT SAMPLING POSITIONS (FIG. 1). NUMBER OF DATA PAIRS GIVEN IN BRACKETS. (*p< 0,05; **p<0,01; N = $NO_3 + NO_2 + NH_4$-N; N/P = $NO_3 + NO_2 + NH_4$-N/PO_4-P). THE ANALYSIS WAS DONE ON A DATA SET WITH NO MISSING VALUES, I.E. ALL VALUES OF A SPECIFIC DATE WERE EXCLUDED WHEN ONE VALUE OF THAT DATE WAS MISSING

Year	Variable	1	2	3	4	5	6
1976	Secchi	-0,007	-0,55**	-0,35	-0,30	-0,52*	-0,63**
		(18)	(20)	(20)	(19)	(19)	(19)
	T°C	0,30	0,50*	0,24	0,18	0,38	0,43
		(19)	(20)	(20)	(20)	(20)	(19)
	PO_4-P	0,51*	0,34	0,11	0,35	0,28	0,40
		(19)	(19)	(19)	(19)	(19)	(18)
	N	-0,19	-0,73**	-0,37	-0,38	-0,11	-0,37
		(18)	(18)	(18)	(19)	(18)	(16)
	N/P	-0,03	-0,30	-0,04	-0,38	-0,35	-0,29
		(18)	(18)	(18)	(19)	(19)	(19)
1977	Secchi	-0,61**	-0,38	0,58*	0,48*	0,59*	0,60*
		(17)	(15)	(15)	(18)	(16)	(14)
	T°C	0,24	-0,02	0,24	-0,46	0,79**	0,39
		(17)	(18)	(19)	(13)	(16)	(14)
	PO_4-P	-0,38	-0,35	-0,47	-0,53*	-0,33	-0,23
		(13)	(15)	(16)	(14)	(13)	(10)
	N	0,37	0,37	-0,45	-0,34	-0,57*	-0,58
		(12)	(15)	(16)	(14)	(13)	(10)
	N/P	0,55*	0,40	0,07	-0,18	-0,60*	0,04
		(13)	(15)	(16)	(14)	(13)	(10)
1978	Secchi	-0,10	-0,20	-0,09	-0,42*	-0,08	-0,21
		(27)	(25)	(24)	(22)	(25)	(26)
	T°C	0,06	0,20	-0,01	0,38	0,27	0,33
		(27)	(26)	(26)	(21)	(26)	(26)
	PO_4-P	-0,13	0,12	0,12	0,23	-0,16	-0,25
		(23)	(22)	(22)	(21)	(22)	(21)
	N	-0,34	-0,49*	-0,62**	-0,03	-0,02	-0,40
		(22)	(22)	(22)	(21)	(22)	(21)
	N/P	0,28	-0,08	-0,42*	-0,17	-0,27	-0,14
		(22)	(22)	(22)	(21)	(22)	(21)

fashion. Under these conditions phytoplankton growth was most probably stimulated by light availability, allowing the development of higher concentrations during 1977 despite indications of the water having had a lower growth potential for phytoplankton. Under supposedly more unstable conditions, i.e. during periods of high inflow and short water retention times (notably during 1976 and 1978), phytoplankton growth may have been limited by PO_4-P. The fact that sampling positions 1 and 2 showed contrasting correlations (compared to the other sampling positions) between Secchi and inorganic N on the one hand and chlorophyll *a* on the other hand, most probably supports a previous conclusion that inorganic N played a more important growth-limiting role at the Pienaars River and Hartbees Spruit inflow stations.

Conclusions

Because one inflowing stream, the Pienaars River, plays a major role in inorganic nutrient supply, a nutrient gradient occurred from the western to the eastern section which was accompanied by a gradient in phytoplankton biomass.

Microcystis aeruginosa, M. incerta, Anabaena circinalis, Pediastrum duplex, Sphaerocystis schroeteri, Melosira granulata and *Lepocinclis radiata* represented the dominant and most important phytoplankton species in Roodeplaat Dam.

The levels of inorganic N and P loading during the study period were such that the impoundment falls well within the eutrophic category. Surface-loading rates varied from year to year in conjunction with the inflow rate.

Between 1976 and 1978 cyanobacteria first replaced euglenophytes and then green algae to become dominant at most of the sampling positions.

Spatial differences in phytoplankton composition, as indicated by dominants, were manifested mostly in a patchy fashion rather than in a typical zonation pattern. Euglenophytes, cryptophytes, diatoms and green algae were best represented at the less nutrient-rich sampling positions. Increased nutrient availability was probably responsible for the increased importance of the cyanobacteria in the western part of the impoundment, notably at the Pienaars River inflow sampling position.

Inorganic P was considered to be the primary growth-limiting nutrient based on N/P ratios and bio-assay tests. Indications were found that inorganic nitrogen may have limited algal growth at the Pienaars River and Hartbees Spruit inflow stations. Bio-assay tests showed that inorganic N may have become increasingly important as a growth-limiting nutrient, possibly resulting in the appearance and dominance of *Anabaena circinalis* during 1977 and 1978.

Seasonal patterns in the sequence of dominant phytoplankters were most probably influenced by temperature, the onset and duration of stratification, underwater light availability, inflow (i.e. water retention time), brief periods of nitrogen limitation and possibly turnover in autumn. The influence of environmental variables on the annual differences of phytoplankton populations is less clear, possibly because a relatively short-term study like this is not suitable to investigate long-term phenomena. In the case of Roodeplaat Dam, increased importance of inorganic N limitation may have resulted in the appearance of, and frequent domination by, *Anabaena circinalis*.

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