The Distribution of Nutrients in Swartvlei, a Southern Cape Coastal Lake

C HOWARD-WILLIAMS
[INSTITUTE FOR FRESHWATER STUDIES, RHODES UNIVERSITY, GRAHAMSTOWN

Abstract

Like most other Southern Cape coastal lakes, Swartvlei has a large aquatic macrophyte community. As part of a continuing study to understand the role of these macrophyte beds, data on nutrient stocks in Swartvlei have been compiled. This paper gives nitrogen and phosphorus values in the macrophytes, the sediments and the waters of Swartvlei, and discusses the distribution patterns of these elements in the lake.

Introduction

The Wilderness lakes form a chain of coastal lakes lying in close proximity of the sea in the Southern Cape, between Knysna and Wilderness. With the exception of Groenvlei (Fig. 1) they are all connected to the sea, either directly (Swartvlei) or indirectly. The salinity varies from 4‰ in Groenvlei to about 20‰ in Rondevlei. The lakes all lie on quaternary sands (Martin 1962) and most, including Swartvlei which is the biggest, are drowned parts of former estuarine systems (Hill 1974). The inflowing rivers arise from the Table Mountain sandstones of the Outeniqua Mountains and are acid (pH 5,0), very deeply stained with humic material (light transmission $^{4\ \mathrm{cm}}_{430\ \mathrm{nm}} = 12\%$), and have a very low level of soluble phosphate (ca. 5 μg l^{-1} PO_4-P). According to Toerien (1977) the algal growth potential of two rivers along this coast is extremely low (3 mg l^{-1}). With the exception of Rondevlei which is shallow and turbid, the lakes are oligotrophic and all of them are, as yet, unpolluted.

In common with other Southern Cape coastal lakes (Soetendalvlei, De Hoopvlei, Sandvlei etc.) the Wilderness lakes support a large aquatic macrophyte community. The submerged plant community in these lakes consists primarily of *Potamogeton pectinatus L.* and members of the Characeae, largely *Chara globularis* var. *kraussii* (A.Br. ex Kütz) R.D.W. and *Lamprothamnium papulosum* (Wallr.) J. Gr.. In Langvlei, the macrophytes cover the entire lake bottom, and they appear to do so in Groenvlei also, whilst in Swartvlei, 30% of the lake area is occupied by macrophytes and in Eilandvlei, slightly less than this.

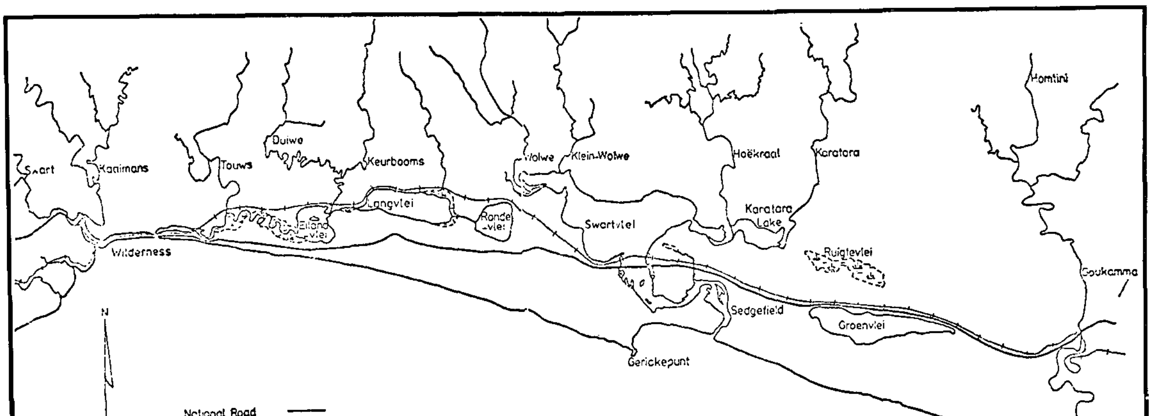

Figure 1
Map of the Wilderness lakes complex showing Swartvlei in the centre. Inflowing rivers from the Outeniqua Mountains are also shown.

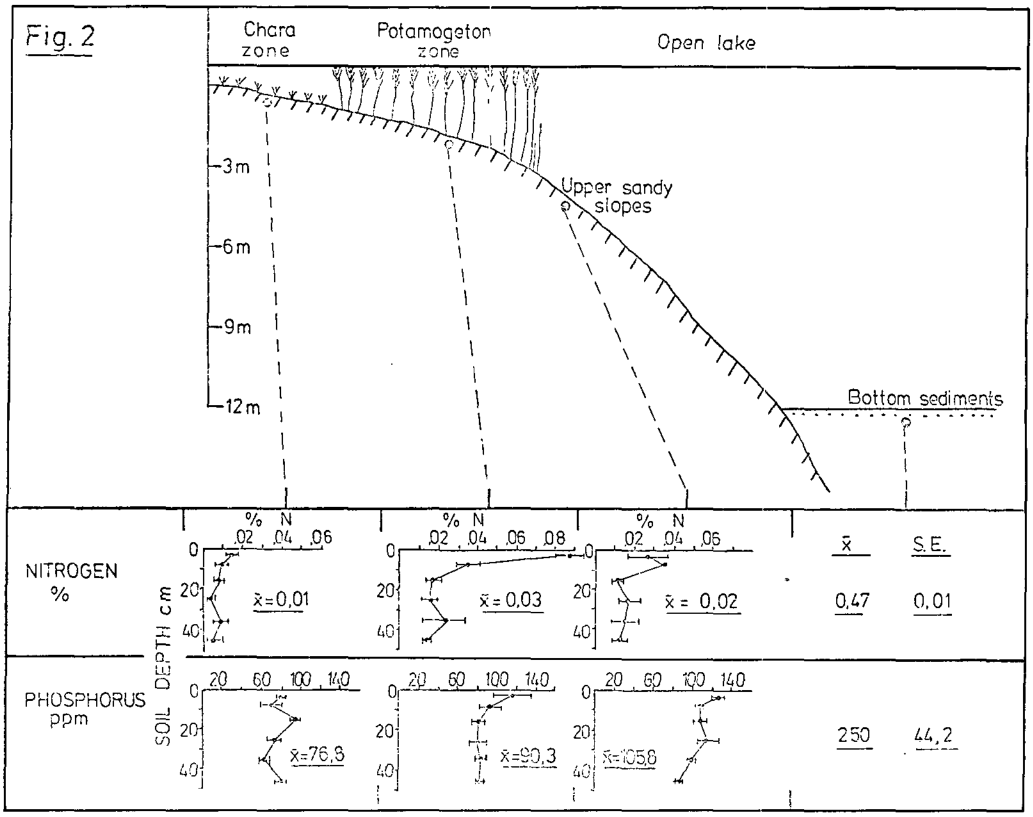

Figure 2

The distribution of Nitrogen and Phosphorus in the Swartvlei sediments. Fifty cm long core samples were collected from the Potamogeton *and* Chara *zones and the upper sandy slopes. The vertical distribution of N and P is shown in the graphs below. Points represent the means of three samples at each sampling depth, and the horizontal bars two standard errors. The mean for the whole core is also shown. Only the mean (n=5) for the open lake sediments is given, as coring was not possible here.*

The oligotrophic nature of these lakes and the low algal production rates measured in one of them (Robarts 1973) have invoked interest in the role of the extensive macrophyte beds in these lakes. This paper deals with the distribution of nitrogen and phosphorus in the macrophytes, sediments and waters of Swartvlei, and discusses the possible importance of the littoral zone in the nutrient dynamics of the lake.

Methods

Sediment samples were collected using a "mud snapper" – Kahlisko Instruments Ltd. – and sediment cores using a prawn pump operated under water with the aid of SCUBA. Water samples were collected with a Friedinger bottle, and macrophytes using a rotary sampler especially designed for this purpose (Howard-Williams & Longman 1976). Methods of soil and plant analysis are the same as those reported in Howard-Williams & Walker (1974) and Howard-Williams & Lenton (1975) respectively, except that for the determination of total P in the deep sediments, the samples were subjected to a wet ashing procedure and the resulting solutions determined by the ammonium molybdate/ascorbic acid method of Murphy & Riley (1958). Soluble PO_4-P was determined after extraction of the molybdenum blue colour from 200 cm^3 of water into 10 cm^3 of hexanol, by the method given in Golterman & Clymo (1969).

Total P and total soluble P in the water were determined before and after filtration through Whatman GF/C glass fibre paper respectively. Determinations were carried out by auto-analyser using the method in Strickland & Parsons (1960).

Statistical comparisons on nutrients in aquatic plants were made using the two sample 't' Test (Campbell 1967) assuming a normal distribution of P and N in the tissues. Howard-Williams and Junk (1977) showed from an analysis of 23 species of aquatic plants that P and N values in the tissues followed a normal distribution, and it is presumed that they did so in *Potamogeton* in Swartvlei as well.

Results

The sediments

The sediment types are shown diagrammatically in Fig. 2. The upper gentle slopes occupied by rooted aquatic plants have a surface layer consisting largely of organic material originating from decomposing macrophytes. On the slopes below the macrophyte zone, the sediments are largely sand, but the lake bottom consists of an infill of highly organic material. The sediments of Swartvlei can thus be divided into two distinct types, the sandy slopes and the flat bottom sediments of organic material. The latter sediment type can be classified according to the scheme of Ballinger & McKee (1971) as "actively decomposing sediments with a high oxygen demand and a high potential nitrogen release".

These bottom sediments have nitrogen levels of 0,5% whilst the sandy slopes have values of about 0,02%. The total phosphorus values of these organic soils are higher than those of the littoral. The values for the different sediments are given in Fig. 2. Because of the very soft nature of the bottom muds, a soil core could not be obtained there and therefore only surface values are given.

Fig. 2 also shows the vertical distribution of phosphorus and nitrogen in the littoral sediments. Very low N and P values were found throughout the 50 cm core in the very shallow and sparsely colonised *Chara* zone. In the *Potamogeton* zone the upper layers have high N values due to decomposing detritus, but at 10 cm these drop sharply. Total P in the upper 5 cm is also high.

In the littoral zone, the *Potamogeton* roots generally penetrate to a depth of 40 cm, although most are in the upper 10 cm. However, nutrients in the top 50 cm of the littoral soils should be considered as being available for uptake and must be included in the biogeochemical cycle.

The aquatic macrophytes

Analyses for P and N have been carried out on about 80 samples of plant material from Swartvlei collected in January 1975. In addition, coarse detritus from amongst the plants and from the sediment surface has also been analysed. The results are shown in Table 1.

TABLE 1

NITROGEN AND PHOSPHORUS VALUES IN VARIOUS COMPONENTS OF THE LITTORAL ZONE OF SWARTVLEI. SAMPLES WERE COLLECTED BETWEEN 23 AND 28 JAN. 1975.

Component	gm^{-2} dry mass + S.E.	% Nitrogen	% Phosphorus
Macrophytes (above ground)	906 ± 122	1,2	0,134
Macrophytes (below ground)	121 ± 9	1,25	0,116
Detritus (standing dead)	193 ± 26	1,35	0,09
Detritus (sediment surface)	115 ± 13	1,52	0,11
Filter feeders	190 ± 60	0,09	0,12

The nitrogen levels of the plants as a whole were above 1% (mean = 1,2%) although stems and rhizomes had values of below 1%. Although the mean value in the detritus (1,35%) appeared to be slightly higher than in the living plants, the difference was not significant at a probability level of 0,05. The mean level of phosphorus (0,13%) is fairly high for *Potamogeton* (Bernatowicz, 1969). The above ground coarse detritus has a significantly lower (0,09%) phosphorus value (at a probability level of 0,05) than the living plants. The concentrations of phosphorus and nitrogen in the Swartvlei macrophytes fall well within the range found in aquatic plants elsewhere (Boyd 1970, Howard-Williams & Junk, 1977).

The filter feeders, in this case *Musculus virgilae,* (Barnard) had N and P concentrations of 0,09% and 0,12% respectively, with the figures calculated on a total dry mass basis.

Lake waters

The phosphorus and nitrogen values of the waters of Swartvlei fluctuate considerably with both depth and time. The anaerobic bottom waters of Swartvlei have considerably more soluble phosphate than the surface waters (Howard-Williams, unpublished). In 1972 Robarts (1973) found PO_4-P values ranging from not detectable to 15 $\mu g\ l^{-1}$ at the surface and 21 $\mu g\ l^{-1}$ at 8 m. Robarts' data show that between the surface and 8 m the PO_4-P values are similar. The mean surface value between March and December 1972 was 10 $\mu g\ l^{-1}$ and at 8 m it was 11 $\mu g\ l^{-1}$. Unfortunately measurements were not made in the anaerobic zone. Measurements of various phosphorus fractions in the water column made during July, August and September 1976 are shown in Table 2. At this time the stratification in the lake had remained constant for 9 months and the zone from 9 to 11 m was anaerobic. It appears that a major proportion of the soluble phosphorus was in organic form in the epilimnion, but in the monimiolimnion the entire measurable stock of soluble phosphorus occurred as PO_4-P, and there were high concentrations in these bottom waters. Table 2 shows that particulate phosphorus (trapped in a GF/C filter) was negligible from 8 m downwards. Here, however, it is worth noting Rigler's (1973) argument that much of the phosphorus which passes through a 0,45 μ filter is in fact in particulate form, and, as Lean *et al.* (1975) demonstrated a close relationship between particulate phosphorus trapped on 0,45 μ millipore filters and Whatman GF/C filters, it is possible that a proportion of the particulate phosphorus passed through the filters used in the Swartvlei Study. This would only apply at 8 m, however, as all the total P at 11 m is accounted for by PO_4-P, so it must be assumed that here the other forms of phosphorus are negligible.

TABLE 2

FRACTIONS OF TOTAL PHOSPHORUS AT VARIOUS DEPTHS IN SWARTVLEI. ALL VALUES EXPRESSED AS μg P l^{-1}.

Depth	Zone	1. Soluble reactive phosphorus	2. Total soluble phosphorus	3. Particulate* phosphorus	4. Total phosphorus	P. soluble / P total
0	Epilimnion	1	17	4	21	0,81
2	Epilimnion	1	18	9	27	0,67
5	Epilimnion	1	16	3	19	0,84
8	Chemocline	7	24	N.D.	24	1,00
11	Monimolimnion	105	103	N.D.	103	1,00

*Obtained from 4-2
N.D. = not detectable
The difference between 1 and 2 at 11 m depth is within the limit of analytical error

Values for NH_3-N and NO_3-N obtained by Robarts (1973) were very variable with no distinct patterns except that NH_3 was higher in deoxygenated conditions. In 1972 the mean NO_3-N value was 26 $\mu g\ l^{-1}$ at the surface and 18 $\mu g\ l^{-1}$ at 8 m The mean NH_3-N values were 5 and 8 $\mu g\ l^{-1}$ at surface and 8 m respectively.

Discussion

It is convenient when viewing whole ecosystems to arrange the ecosystem components as standing stocks m^{-2}. Nutrient concentrations in Swartvlei have been recalculated on this basis and are given in Table 3 both on the basis of littoral and pelagic zones separately, and on a whole lake area basis.

By far the largest standing stocks of both nitrogen and phosphorus are in the sediments. The deep water organic sediments of Swartvlei have particularly high nitrogen concentrations. As the bottom waters of Swartvlei are anoxic and the sediments undisturbed, the available phosphorus stock which could influence the overlying water in these conditions probably extends to a depth of 10 cm (Wetzel 1975). However, the deep penetration of the roots of the aquatic macrophytes in the littoral zone sediments allows for the calculation of a much greater phosphorus stock here.

In terms of both nitrogen and phosphorus, aquatic macrophytes form the next largest reservoir. It should be noted, however, that when these samples were collected the peak annual biomass of macrophytes had not been reached, so these values are, in fact, underestimates of the potential macrophyte nutrient stocks. A more detailed analysis of seasonal changes in P and N in the plant community is under way at present (Howard-Williams unpublished). Detritus and filter feeding animals had the next largest stocks of nitrogen, with lake waters having the lowest values, although no data are available on particulate or organic nitrogen. In the littoral zone, detritus and filter feeders contained ten times more phosphorus than the waters on an aerial basis, but fairly large amounts of P m^{-2} were present in the deep waters of the open lake, mostly locked up in the anaerobic monimolimnion (Table 2).

As regards phosphorus in the lake waters, Table 2 shows that in the epilimnion there is a large difference between soluble reactive phosphorus (PO_4-P) and total soluble phosphorus. A number of authors (e.g. Lean 1973) have shown that inorganic phosphorus is rapidly converted in natural waters to colloidal phosphorus by micro-organisms. However, possibly of more importance in Swartvlei is the demonstration by Jackson & Schindler (1975) that ^{32}P orthophosphate in water is strongly bound by humic materials. More specifically their evidence indicates that the phosphorus is bound to humic chelate complexes of iron and aluminium. They suggest that humic matter may play a significant role in the phosphorus cycle. With the humic input from the rivers flowing into Swartvlei, much soluble phosphorus may be expected to be bound in this way here. This bound fraction could account for the difference between PO_4-P and total soluble P in Table 2.

The bottom waters of Swartvlei are anaerobic with H_2S present, for much of the year (Robarts 1973, Allanson, Howard-Williams & Longman, unpublished data) and in these conditions one would expect Fe^{3+}-phosphate complexes in the sediments to break down resulting in PO_4-P release into the water (Mortimer 1942), and an increase in the ratio of total to soluble P here. This is borne out in Table 2.

The high N and P stocks of the littoral (Table 3) are of particular importance here, when considering the role of the littoral in the lake system. Rigler (1973) in his analyses of several studies found that the turnover time of P in the epilimnion of lakes decreased as lakes became smaller, and the development of the littoral flora increased. Wetzel (1975) has recently reviewed the importance of the littoral zone in phosphorus cycling and emphasises the importance of the littoral in the phosphorus dynamics of many lakes. With respect to nitrogen, he also stresses that the metabolic activities of the littoral flora are not only a major source of organic nitrogen synthesis in many lakes, but "can influence significantly the flux of nitrogen from the sediments to the water."

TABLE 3

NUTRIENT STANDING STOCKS IN SWARTVLEI, EXPRESSED AS gm^{-2}. THE LITTORAL ZONE OCCUPIES 30% OF THE LAKES TOTAL AREA, AND FIGURES IN BRACKETS ARE THE STANDING STOCKS CALCULATED ON A WHOLE LAKE AREA BASIS.

Component	Nutrient stocks gm^{-2} Nitrogen		Phosphorus	
LITTORAL				
Water: soluble	0,05	(0,015)	0,03	(0,010)
particulate	?		0,02	(0,006)
Filter feeders	2	(0,6)	0,20	(0,006)
Detritus	4	(1,2)	0,30	(0,010)
Living macrophytes	13	(3,9)	1,3	(0,39)
Sediments: Top 10 cm	70	(21,0)	13	(3,9)
	152	(45,6)	53	(15,9)
11-50 cm	82	(24,6)	40	(12,0)
OPEN LAKE				
Water: soluble	0,34	(0,24)	0,37	(0,26)
particulate	?		0,04	(0,03)
Sediments: Top 10 cm	425	(289)	19	(13,3)

Recent studies by the author on production and decomposition within the littoral zone of Swartvlei show that rates of community metabolism here are very high and this, together with the large nutrient stocks bound up in the littoral suggests that the littoral zone of Swartvlei – and perhaps of many of the other Cape coastal lakes – has an important influence on the nutrient dynamics of the lake as a whole. This hypothesis is being looked at in more detail by the Swartvlei Project.

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