The Phosphorus Cycle in Germiston Lake. 1. Investigational Objectives and Aspects of the Limnology of the Lake

J.F. VERMAAK, J.H. SWANEPOEL and H.J. SCHOONBEE
Research Group for Freshwater Biology, Rand Afrikaans University, P.O. Box 524, Johannesburg, 2000, South Africa

Abstract

The biologically unfavourable physico-chemical conditions which prevailed in Germiston Lake prior to 1969 resulting from mine and industrial pollution, have been reduced by control measures which prevented effluent from mines and industries and seepage waters from mine and ash dumps entering the lake. In addition, vast quantities of NaOH and agricultural lime were distributed through the lake during 1969 – 1970 resulting in an increase of the pH of the lake water from 4,5 to 7. These measures initiated the biological recovery of the lake which resulted amongst others in the large scale development of *Potamogeton pectinatus L.* This hydrophyte made its appearance during 1972 and within a few years invaded the littoral zone of the lake, virtually replacing *Scirpus lacustrus L.* and *Lagarosiphon major* (Ridley) Moss ex Wager. *Potamogeton* biomass for each of the four seasons of 1978 was estimated and its possible effect on seasonal phytoplankton chlorophyll-a and soluble reactive phosphorus values is discussed. Physico-chemical conditions of the lake water obtained during 1978 are discussed and compared with those of 1969 – 1970.

Introduction

The rapid and continuous population growth on the Witwatersrand, coupled with the industrial growth of this region, has resulted in increasing loads of sewage and industrial effluents reaching tributaries of the Vaal River, especially those upstream from the Vaal River Barrage. This has not only led to a progressive increase in the mineral load of these waters, but contributed to the severe eutrophication of some of these rivers. The invasion of rivers and impoundments by hydrophytes is only one of the consequences of eutrophication. The effective management of such water bodies, especially for recreational purposes, is seriously hampered by excessive growths of water weeds (Brandt, 1975). In various overseas countries and elsewhere in Africa, considerable amounts of money are spent annually to curb aquatic macrophyte growth in lakes and impoundments (Wild, 1961; Sculthorpe, 1967).

Phosphorus is regarded as the most important limiting nutrient with respect to primary productivity (Schindler, 1974). The fate of this nutrient in a biological system can be traced with great precision by making use of its two radio-isotopes ^{32}P and ^{33}P (Hutchinson and Bowen, 1947).

It is convenient to divide the freshwater lake phosphorus cycle into limnetic and sediment-water interface components, with the latter including a chemical and a biological subdivision. The limnetic component, in particular the limnion-sestonic interaction, has been satisfactorily elucidated (Rigler, 1973; Lean, 1973 a – c), whilst aspects of the sediment-water interface components, e.g. chemical interactions and the role of bacteria and invertebrates have been investigated to some extent (Mortimer, 1971; Serruya *et al.* 1974; Davis *et al.*, 1975). Concerning the role of aquatic macrophytes in the cycling of phosphorus considerable progress was made by McRoy and Barsdate (1970) and McRoy *et al.* (1972). These authors found that *Zostera marina,* in an estuarine habitat, absorbs ^{32}P from the sediment and then actively transports this isotope to the littoral water. A bi-directional movement of phosphorus between the water and sediment via the plant, was also recorded for the salt marsh cord grass, *Spartina alterniflora* (Reimold, 1972). With respect to the role of submerged macrophytes in the phosphorus cycle in a freshwater environment, Twilley *et al.* (1977) found that translocated ^{32}P in *Nuphar luteum* was secreted by the roots and submerged leaves during summer, but not during winter.

In many eutrophic man-made lakes in South Africa, particularly those of the Transvaal Highveld, e.g. Donaldson Dam near Westonaria, the biomass produced by submerged macrophytes was found to be substantial, exceeding 0,0087 kg dry mass per m^2 in the littoral regions of such impoundments (Brandt, 1975). Nevertheless, the importance of these hydrophytes in the phosphorus cycle, especially with respect to absorption, accumulation, and release of phosphorus compounds, has this far, with the exception of authors such as Howard-Williams and Allanson (1978a,b), been largely neglected by limnologists in South Africa.

In an investigation of the presence and distribution of noxious weeds in Transvaal impoundments *P. pectinatus* was singled out as the most hazardous aquatic weed in the Witwatersrand area (Brandt, 1975). A simulated vlei system was then employed to study *P. pectinatus* and eight other common hydrophytes with respect to their ability to absorb and accumulate ^{32}P (Vermaak *et al.*, 1976). This study proved that *P. pectinatus* not only absorbs ^{32}P, but that it also releases some of the ^{32}P to the surrounding water.

In view of the fact that more information on the role of submerged macrophytes in the phosphorus cycle in freshwater lakes was needed, *P. pectinatus* was again selected and Germiston Lake chosen as the locality for the present investigation.

This lake was chosen because *Potamogeton pectinatus* made its appearance in the lake within the past six years and at the time of study prolific growth resulted in biomass amounts that cause concern. The lake also contains an exceptionally nutrient-enriched sediment, potentially a source of inorganic nutrients for rooted macrophytes (Vermaak, 1972). In addition, some background information on the macro-invertebrate fauna, water chemistry and bacteriology of the lake was already available, following a limnological investigation by Vermaak (1972) which revealed extremely low soluble reactive phosphorus concentrations and chlorophyll-a values of the lake water during the period 1969 to 1971.

The aims of the present study on the fate of ^{32}P in a freshwater lake invaded by the submerged macrophyte *P. pectinatus* were to obtain answers on the following questions:

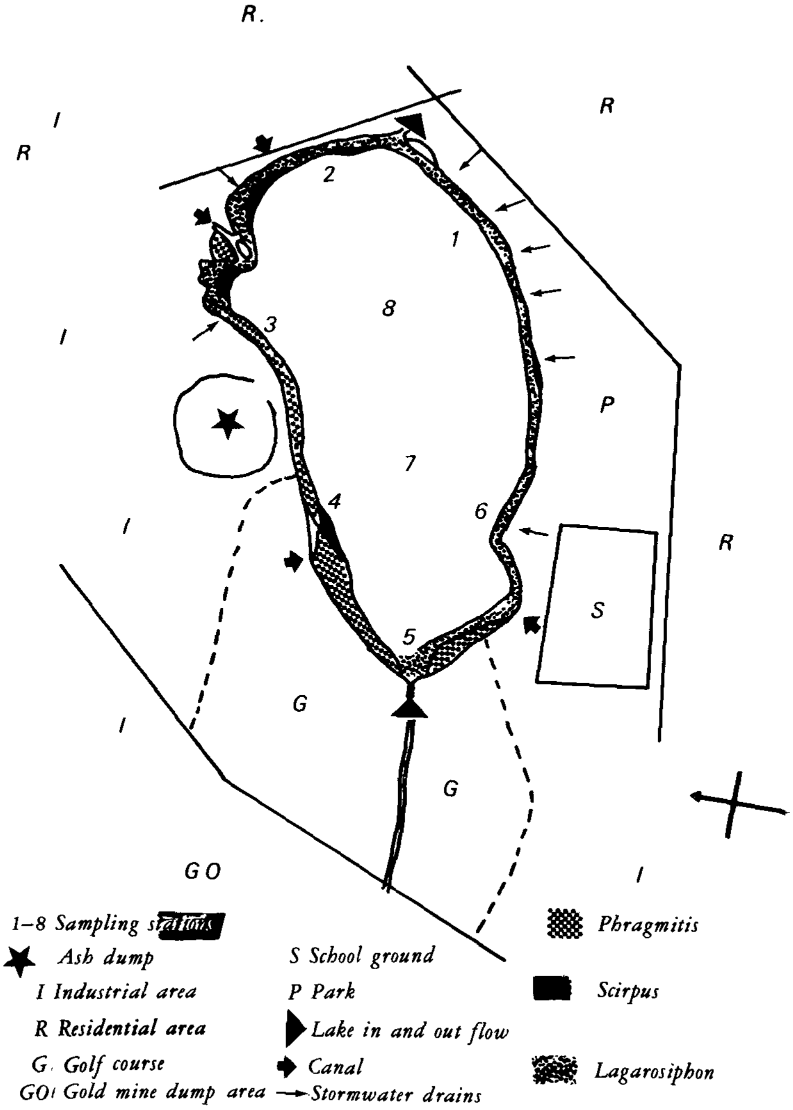

Figure 1
Germiston Lake sampling stations (1969—1970 and 1978) and distribution of macrophytes (1970)

(i) Is ^{32}P absorbed by all organs of *P. pectinatus* or only by specific ones and, if so, to what extent is the ^{32}P absorbed by the roots and foliage of this hydrophyte again released by these organs, following translocation of the ^{32}P?

(ii) Does *in situ* root absorption of ^{32}P take place?

(iii) Is there a seasonal pattern with respect to the absorption and release of ^{32}P by *P. pectinatus* in Germiston Lake?

(iv) Is there a correlation between the absorption and release of ^{32}P by this hydrophyte and the metabolic rate and phosphorus contents of its tissues?

The present paper is the first in a series of four on the problems outlined above and contains information on aspects of the limnology of the lake and the history of its recovery from severe mine pollution.

Description of Germiston Lake

Germiston Lake (originally a natural pan) is situated in the upper reaches of the Elsburgspruit System. Its catchment area is relatively small (1 174 ha) and its water level is largely maintained by surface runoff through a series of stormwater drains discharging into the lake (Fig. 1). It has a surface area of approximately 57,4 ha and a maximum water capacity of 2 839 x 10^6 m^3 (Department of the City Engineer, Germiston Municipality). The littoral zone is relatively wide and gradually slopes down towards the centre of the lake where it reaches a depth of approximately 8,2 m. The substrate in the littoral zone is mainly sandy in the more shallow areas but becomes progressively more silty towards the deeper littoral and central regions of the lake.

The lake lies within a densely populated and highly industrialized region and is therefore subject to pollution via the stormwater drains, small canals and the continuous addition of highly mineralized seepage water emanating from gold mine, ash and slime dumps in the vicinity of its western and southern banks (Fig. 1). In addition effluents from heavy metal industries also enter the lake.

The history of the abuse of the lake by pollution through mining and other industries is a relatively long one starting in the early days of gold mining on the Witwatersrand. Originally the lake was used as a depository for water pumped out of the old Simmer and Jack mine. Also, mineral rich sludge and slime from the latter as well as from other mines, industries and urban areas accumulated in the lake over many decades. Gold mine effluents which are rich in iron pyrite produces sulphuric acid when oxidised, contributing towards a substantial lowering of the pH (3,5 – 4,5) of the lake water (Vermaak, 1972).

In order to rehabilitate the lake and to increase its recreational value, its water was alkalinized and the pH then buffered through the addition of 1 064 700 ℓ NaOH followed by the distribution in the lake of 59 t agricultural lime. This treatment which took place during 1969–1970 together with other measures taken which prevented further direct pollution by the surrounding mines and industries, initiated recovery of the lake from mineral pollution (Vermaak, 1972).

Methods

Water samples were collected seasonally for a period of 3 weeks at the 8 localities indicated in Fig. 1 and the temperature, pH and conductivity of the samples recorded. Chemical analysis of the water samples were carried out following the methods of APHA (1971).

During the corresponding periods chlorophyll-a values, an indication of phytoplankton biomass, were also determined on 2 ℓ water samples at a depth of 1 m (usually immediately above the substrate) from the same 8 localities in which samples were taken for physico-chemical analysis. The methanol extraction procedure (Marker, 1972) was used to obtain chlorophyll-a values of samples. Light intensity measurements were also taken at this depth using a Dr Lange lux meter.

In order to determine *Potamogeton* biomass, samples were collected seasonally at 17 stations (Fig. 2) using a Forsberg sampler (Forsberg, 1959) modified by Brandt (1975). These stations were selected at approximately 200 m intervals in the littoral zone and 3 samples collected randomly at each station at 5, 25 and 50 m respectively from the shore, a total of 51 samples per season. Debris and periphyton were then removed (Gough and Woelkerling, 1976) and the dry mass of each sample determined following drying in an oven at 80°C for 24 h. The dried samples were then mixed and ground in a Wiley mill. The fine powder was thoroughly mixed and again dried for 24 h at 80°C. Three 1 g random sub-samples were then scooped out and the phosphorus content of each sample determined (Jackson, 1958).

The dry mass values obtained for the samples were converted to biomass values by using a dry mass to biomass ratio factor. This was obtained by determining the ratio of the biomass of 12 clean random samples and their respective dry masses.

All mass values of *P. pectinatus* collected with the modified Forsberg sampler (bite area 420 cm^2) were converted for the purpose of discussion to m^2 lake bottom surface area. In order to estimate the total *Potamogeton* biomass in Germiston Lake an aerial photograph of the lake was used and the ratio littoral:pelagial (1:4,2) determined. Using this ratio and the surface area of the lake (57,4 ha) the littoral containing *Potamogeton* was calculated (13,7 ha). This area occupied by *Potamogeton* remained fairly constant during the four seasonal surveys as plants varied only in height and density.

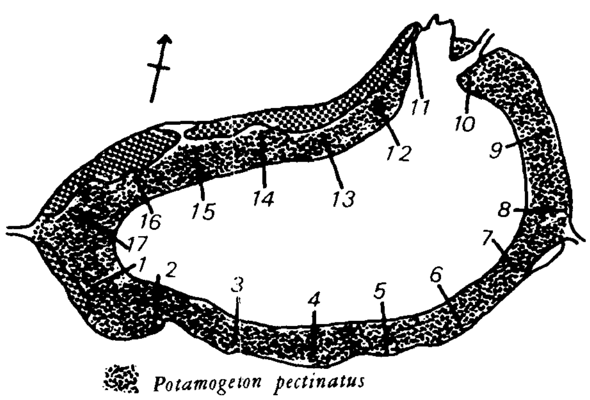

Figure 2
Potamogeton pectinatus *distribution and sampling stations (1–17) in Germiston Lake (1978)*

Results and Discussion

Water chemistry

During a previous investigation into pollution of Germiston Lake (Vermaak, 1972) various sources of mineral and organic pollution were identified and reduced as a result of steps taken by the Germiston City Engineer's Department. Seepage waters from mine and ash dumps were diverted to bypass the lake. As mentioned before, more than 10^6 ℓ of liquid caustic soda as well as 59 t of agricultural lime were distributed in the lake during 1969–1970. As a result of the strict control measures, mineral loads in the lake were reduced by almost 40% in one year (cf. conductivity value for 1969, Table 1). Even though the mineral loads in the lake are at present still relatively high there was a further decline in mineral content of the lake water between 1969 and 1978, when values obtained were already less than 50% of those measured in 1969 (Table 1). There was also a dramatic change in the water pH, from 4,5 prior to 1969 to values exceeding 8 during 1978 (Table 1). Where dissolved oxygen concentration of the lake water varied between 6,5 and 7,6 mg ℓ$^{-1}$ in 1969, the excessive growths of water weeds which developed during the recovery of the lake from pollution appeared to contribute much toward the fluctuation and generally higher oxygen values measured during the 1978 investigation. BOD values in the lake water, however, did not materially differ much between the two study periods with values seldom exceeding 4 mg ℓ$^{-1}$. Changes in alkalinity and hardness of the lake water between the two periods may largely be attributed to the addition of agricultural lime while the reduction in values of parameters such as chloride, sulphate and nitrate coincided with the elimination of pollution by mine seepage waters and industrial effluents.

Metal processing industries in the vicinity of the lake were found to contribute towards low concentrations in the water of a variety of heavy metals (Vermaak, 1972). Two metals which occurred in relatively higher concentrations in 1969 were Zn (740–240 ug ℓ$^{-1}$) and Ni (470–210 ug ℓ$^{-1}$). As a result of steps

TABLE 1
SOME PHYSICO-CHEMICAL PARAMETERS OF THE WATER IN GERMISTON LAKE BASED ON MEAN VALUES OBTAINED AT 8 SAMPLING LOCALITIES DURING THE VARIOUS SEASONS OF 1969—1970* AND 1978. ALL VALUES, EXCEPT pH AND CONDUCTIVITY, IN mg ℓ^{-1}

Parameter	Spring		Summer		Autumn		Winter	
	1969	1978	1969	1978	1970	1978	1970	1978
pH	4,5	8,24	6,9	9,17	6,6	8,43	6,6	7,8
Conductivity (μS cm^{-1})	2 580	1 061	1 893	976	1 920	969	1 644	922
DO	7,0	12,4	7,6	6,1	6,5	8,0	6,6	12,8
BOD	1,2	4,4	2,0	1,1	2,4	2,3	1,1	2,3
Total alkalinity	11	75,3	23	65	15	71	31	82
Mg-hardness ($CaCO_3$)	505	179	383	190	385	144	310	146
Ca-hardness ($CaCO_3$)	785	281	710	247	640	259	580	270
Total hardness ($CaCO_3$)	1 290	460	1 093	437	1 025	403	890	416
Cl^-	124	98	109	82	100	80	153	87
$SO_4^=$	1 094	320	1 034	280	897	280	886	309
SRP	–	0,05	0,07	0k20	–	0,06	–	0,05
NO_3-N	2,5	1,69	3,6	1,47	–	1,75	2,2	1,45

*Data from Vermaak (1972)

TABLE 2
CALCULATED *P. PECTINATUS* WET AND DRY BIOMASS VALUES AND ITS PHOSPHORUS CONTENT IN GERMISTON LAKE DURING 1978. DRY MASS AND SEASONAL RELATIONSHIP IS GIVEN BRACKETS

Season	Wet mass kg	Dry mass kg	mg P g^{-1} dry mass	Total P content (kg)
Spring	72 623	3 279(1)	3,95(1)	12,9
Summer	1 328 962	23 880(8)	5,91(1,4)	140,9
Autumn	203 664	11 516(4)	8,6 (2)	98,7
Winter	94 945	5 955(2)	4,1 (1)	26,4

TABLE 3
AVERAGE CHLOROPHYLL-a, SRP* AND LIGHT INTENSITY VALUES FOR THE FOUR SEASONS IN 1978

Season	Chlorophyll-a (μg ℓ^{-1})	SRP (μg ℓ^{-1})	Light intensity (lux)
Spring	11,977	52	28 666
Summer	3,382	196	40 333
Autumn	3,298	59	23 750
Winter	1,958	51	17 313

*SRP: *soluble reactive phosphorus*

taken by the City Engineer's Department of the Germiston Municipality a gradual reduction in these concentrations was effected.

The Macrophytes of the Lake

During a previous study (Vermaak, 1972) only three species of aquatic macrophytes were noted viz. *Phragmites communis, Scirpus lacustrus* and *Lagarosiphon major* (Fig. 1). After the aforementioned treatment of the lake, it was expected that a greater variety of aquatic organisms, including plankton, would appear and proliferate. It was further expected that the nutrient-enriched sediments would favour the expansion of the small *Scirpus* and *Lagarosiphon* communities. During 1972 a very small stand of *Potamogeton pectinatus* was noticed in the lake. Since then its distribution around the perimeter of the lake was exceptionally rapid and it virtually replaced *Scirpus* and *Lagarosiphon* so that *P. pectinatus* presently inhabits almost the total littoral zone (Fig. 2).

The estimated biomass and phosphorus content of *P. pectinatus* in Germiston lake collected during each of the four seasons of 1978 is given in Table 2. From this table it is clear that the *P. pectinatus* biomass reached a peak during summer, followed by those peaks of autumn, winter and spring. The biomass ratio for spring, winter, autumn and summer in this order is 1:2:4:8. In contrast, the seasonal relationship with regard to the phosphorus content of the plant tissue for the same periods is 1:1:2:1,4. These results clearly demonstrate how extensively *Potamogeton* infested Germiston Lake. The phosphorus values obtained show a relative increase in phosphorus content of the plant tissues from spring to autumn with a sharp drop towards

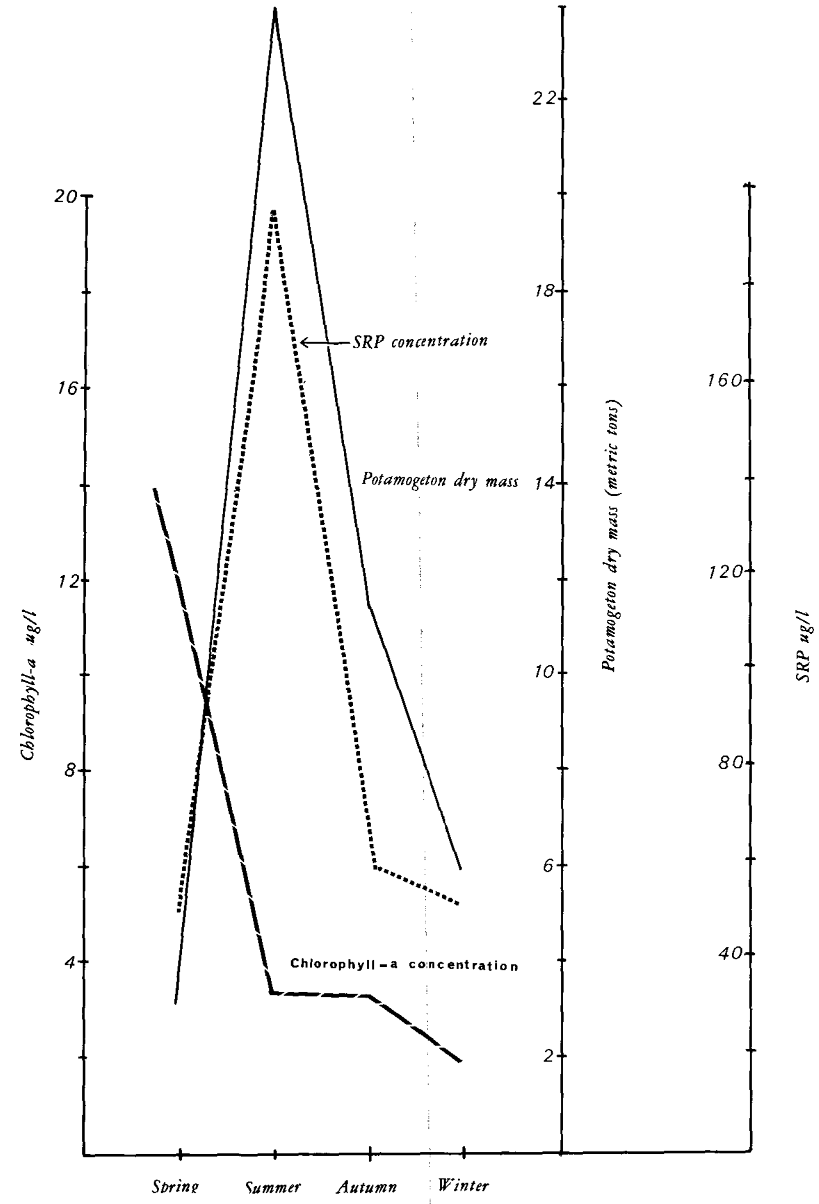

Figure 3
***Potamogeton** dry biomass, SRP and chlorophyll-a concentrations of the water in Germiston Lake (1978)*

winter. It is also obvious from these data that *P. pectinatus* may play a controlling role in the lake ecosystem with respect to the phosphorus cycle.

Phytoplankton

Average chlorophyll-a, soluble reactive phosphorus (SRP) and light intensity values for the 8 localities at the time of sampling during 1978 are given in Table 3. In an effort to find an explanation for the markedly higher spring chlorophyll-a concentration, the chlorophyll-a values were compared with the respective seasonal SRP and light intensity values. From Table 3 it is clear that SRP and light intensity values do not have any bearing on the chlorophyll-a concentrations. However, when the *Potamogeton* biomass values are compared with those of chlorophyll-a it is obvious that the increase in *P. pectinatus* biomass from spring to summer is accompanied by a sharp decline in the phytoplankton chlorophyll-a concentration (Fig. 3). Since there exists a direct relationship between the *P. pectinatus* biomass and the SRP concentration of the water, and as such a relationship is not evident with regard to SRP and chlorophyll-a concentrations (Fig. 3), it appears as if the presence and abundance of *Potamogeton* and associated periphyton complex affect phytoplankton productivity. Although the possible release of inhibiting substances by *P. pectinatus* was not investigated the possibility that such substances may be released by this species which may suppress phytoplankton development cannot be excluded. Investigators such as Hogetsu *et al.* (1960), Goulder

(1969) and Dokulil (1973) are of the opinion that aquatic macrophytes are capable of secreting substances that inhibit phytoplankton development. According to Boyd (1971) competition for nutrients between macrophytes and phytoplankton may be an important factor in phytoplankton development, especially early in the growing season.

Since the physico-chemical conditions in Germiston Lake favour the proliferation of *Potamogeton pectinatus* and this hydrophyte shows a distinct seasonal variation with respect to its biomass and phosphorus concentration, this species was further investigated to determine its role in the phosphorus cycle and its ecological impact on the lake. The result of this investigation will be presented in subsequent papers.

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