Limnological characteristics, water quality and conservation measures of a high altitude bog and rivers in the Maluti Mountains, Lesotho*

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Abstract

Bogs occur in cirque-shaped riverheads above 2 500 m above sea level in the Maluti and Drakensberg Mountains. Numerous streams drain these bogs and pools occur on some of them. These are temporary shallow waters which fill in the wet summer months. A benthic community of macrophytes with epiphytic algae usually covers the bottom of the waters. The ionic content which was low, is influenced by the high rainfall, erosion of the basalts and seepage from the soil and peat deposits. The waters were moderately acidic, with an ionic dominance order of Ca > Mg > Na > K : HCO_3 > SO_4 > Cl and low concentrations of N and P. The precipitation was acidic with a low ionic content, which was dominated by edaphic and anthropogenic sources. According to the primary productivity and nutrient contents, the streams were oligotrophic and the pools mesotrophic. Productivity of the benthic communities was much higher than that of the pelagic zone. The quality of the waters is good, being low in dissolved salts, nutrients and clear. Overgrazing and the presence of burrowing ice-rats has led to erosion and conservation measures are needed to protect these important filters and regulators of water in this important catchment area of southern Africa.

Introduction

South Africa is a dry country and the 400 mm isohyet roughly bisects the country into an arid western half and a less arid eastern section. Conversely, Lesotho which is mountainous and surrounded by South Africa, abounds with freshwater resources and the headwaters of many rivers and streams arise within this country, such as the Tugela, Caledon and Orange Rivers. The highest precipitation is measured on the NW face of the Maluti Mountains and the NE-SE escarpment of the Drakensberg (Figure 1). More than 43% of the total mean annual rainfall of southern Africa is recorded in Lesotho. Numerous schemes have already been designed for the exploitation of Lesotho's freshwater resources (e.g. Carter 1965, Commission of Enquiry into Water Matters, 1970; Hansard, 1979; The Cape Times, 1986). In recent times a joint announcement was made between the governments of Lesotho and South Africa, wherein the realisation of the Lesotho Highlands Water Project was confirmed (Kingdom of Lesotho, 1986). The full development of this project will extend over a 30-year period and will be completed in three phases, with the main purpose of generating electricity and selling water to South Africa (Kindom of Lesotho, 1986).

Bogs or as they are locally called "mokhaobo" are usually found in triangular-shaped riverheads approximately 2 500 m above sea level. Their importance in the ecology and hydrology of the Austro-Afroalpine environment (Coetzee, 1967), has been stressed by i.e. Van Zinderen Bakker (1955), Jacot-Guillarmod (1962), Pearce (1973), and Van Zinderen Bakker and Werger (1974). The bogs are of post-glacial (Holocene) age (Van Zinderen Bakker and Werger, 1974) and consist almost entirely of peaty-loam deposits. The bogs act as sponges in accumulating rain water and water percolating from the surrounding slopes. They function as filters, release a regular flow of clear water to the streams, and are important pastures, especially in summer times, for the livestock of the Basotho people.

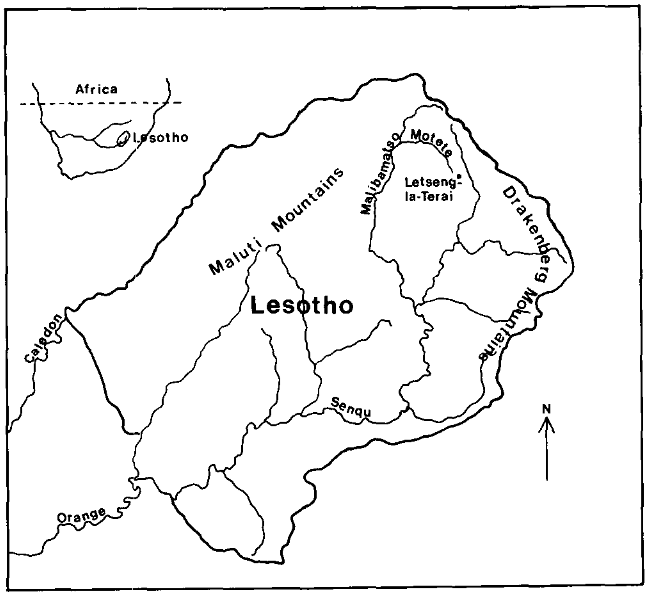

Figure 1
Locality map of the study area and major rivers of Lesotho, where the study area is just north of the Letseng-la-Terae diamond mine.

As a consequence of overgrazing, severe signs of erosion can be seen, which necessitates the implementation of conservation measures. Many of the once clear streams and rivers become muddy torrents in summer, which may have an adverse affect on the plannea Lesotho Highland Water Project (Kingdom of Lesotho, 1986). Studies of the physico-chemical and biological characteristics of pools, streams and ground water of one of the many bogs, as well as of the Motete and Malibamatso Rivers, were undertaken between February 1975 and March 1976, to determine the importance of the bogs in the water supply and quality of the highlands area.

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*This paper is dedicated to Prof. Dr. E.M. van Zinderen Bakker on occasion of his 80th birthday.
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Materials and methods

The study area was visited at monthly intervals, for 2 to 3 days, from February 1975 to March 1976.

Daily radiation was measured with a Li-Cor Model 185 Light Meter attached to a LI – 190 SEB Quantum Sensor and recorder. Water temperature and dissolved oxygen were measured with an YSI Model 57 combined meter. A Beckman Electromate pH-meter was used for pH measurements in the field. Alkalinity was determined titrimetrically with 0,01 M HCl. Conductivity was measured with a Philips PR 9501 meter.

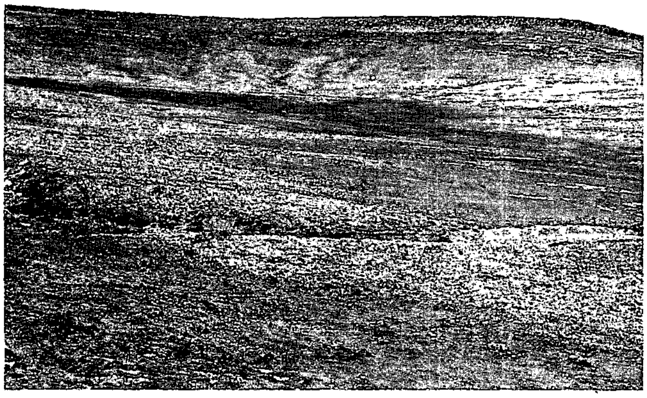

Figure 2
A photograph of the study area, showing the triangular-shaped bog (darker area) in the cirque-shaped riverhead.

Phytoplankton primary productivity was measured in light and dark bottles incubated over a depth profile *in situ* using $H^{14}CO_3$-uptake as described by Grobbelaar (1974). Productivity of the benthic algae and macrophytes were measured from oxygen differences in clear and darkened plexiglass boxes which were placed over the communities for a specific time (Grobbelaar, 1974). The results were calculated as mgC $m^{-2}.d^{-1}$, using the radiation results to integrate the 4 h incubation rates to daily rates.

Water samples for chemical analyses were collected from the edges of the ponds and streams in 1 ℓ polyethylene bottles. Although several preservatives were tested, e.g. $CHCl_3$, $HgCl_2$ and H_2SO_4, they were found to be unnecessary because of the short time lapse (usually less than 48 h) from collecting to analysing the samples. The samples were stored in the interim period at 4°C. Whenever possible, precipitation samples were collected at the bog, by placing a funnel into a 1 ℓ polyethylene bottle and leaving it in the rain. Water samples from the Motete and Malibamatso Rivers were collected from sites, where the road from Butha-Buthe to Sani Pass crosses them.

Na, K, Ca, Mg and Fe were determined by atomic absorption spectroscopy, using a Varian Techtron Model 1000 instrument. Lanthanum chloride buffer was added before Ca and Mg were determined to overcome ionisation and chemical interferences (Stainton *et al.*, 1974). Chloride was determined by $AgNO_3$ conductometric titration (Golterman, 1969). Sulphate was measured turbidimetrically after precipitation with $BaCl_2$ (Golterman, 1969). Ammonia and nitrate (reduced by Devarda's alloy) were determined colorimetrically after stream distillation and reaction with Nessler's reagent (Golterman, 1969). Total dissolved phosphate was measured colorimetrically after its reaction with a molybdate-antimony solution in strongly acidic conditions (Golterman, 1969). Soluble reactive silicon was measured after reacting with molybdate in acid solution (Stainton *et al.*, 1974). Water colour was measured with a BDH Nessleriser MK3 using the standard NSA and NSB colour discs.

Soil samples from the surface and just above the bed rock were collected from the north, east, and west-facing slopes, as well as from the top and bottom ends of the bog in order to determine leachable ions from the soil and peat deposits. The samples were dried at 105°C, ground with a pestle and mortar and sieved through a 2 mm mesh size sieve. A 100 g subsample was suspended in 500 ml distilled water, stirred for 30 min with a magnetic stirrer and allowed to stand for a further 48 h. The clear liquid phase was filtered through Whatman FA/C glass fibre filters, before analyses of the major ions.

Setting and climate

The mountain mass of Lesotho is formed of basalt, approximately 1 400 m thick and belongs to the Stormberg Series. This overlies a layer of Cave Sandstone, the interface varying in altitude between 1 800 and 2 100 m above sea level (Nixon, 1973; Stockley, 1974). Moist air, derived primarily from the tropical regions of the Indian Ocean, approaches these mountains from a NW direction (Schulze, 1979). Topographical features are responsible for precipitation in excess of 1 000 mm a^{-1} along the base of the Drakensberg, which decreases in an eastward direction, despite the high altitude. Because of this, most of the interior of Lesotho is dry (Shand, 1963).

Mean values for air temperature and rainfall over the period 1965 to 1970 at Letseng-La-Terae, as well as the rainfall measured during the study period are given in Table 1. It can be seen that this area is situated in a summer rainfall area (November to March), with an average annual total of 664 mm. Air temperatures ranged from 16,8°C in January to – 6,7°C in June, with an annual average of 5,9°C. Although the average minimum air temperature in the summer months is above freezing, temperatures of as low as – 1,5°C have been measured during the study period. It was unusually wet during the study period, with an annual rainfall of 1 070 mm.

Study area

A bog next to the road from Butha-Buthe to Sani Pass and approximately 10 km NE from the Letseng-La-Terae diamond mine was studied (Figures 1, 2 and 3). This bog, situated below a ridge known as "Khalong la dithingoa" is situated in the headwater region of the Motete River, at an altitude of 3 250 m above sea level. Here the river flows in a SW direction where it merges with the Malibamatso River, the latter being a tributary of the Orange River (known as the Senqu River in Lesotho), the largest river in South Africa.

The bog is triangular in outline, with the base at the top of a cirque-shaped valley. It measures about 1 100 m in length, 400 m at the base, drops 35,5 m in altitude from top to bottom and is oriented in a south-to-northerly direction (Figures 2 and 3).

Several shallow surface streams drain the bog during the wet summer months. They are usually less than 0,5 m deep, except where pools are cut into the peaty-loam deposits; depths of up to 1,0 m have been measured. Water levels fluctuate considerably in these streams and an ice layer of 0,25 m thick and more may develop in the winter months. Submerged macrophytes are dominated by *Crassula natans*, *Limosella capensis*, *L. longiflora*, *Lagarosiphon muscoides* and *Ranunculus meyeri*. The benthic algae are dominated by members of the Zygnemataceae.

Ponds or pools are scattered over the bog, though concentrated in the central area; they are less than 1 m deep and steep-sided, with no profundal zone. Several submerged macrophytes colonise the bottoms, often in patches with *Ranunculus meyeri* and *Limosella capensis* dominant along the shore and shallow regions, and *Limosella longiflora*, *Lagarosiphon muscoides* and *Crassula natans* occupying the central areas. The pools dry completely in winter, during which time they are mere depressions. The bog takes some time to saturate with water after the first rains, whereafter the pools rapidly fill and *Ranunculus meyeri* is the first macrophyte to appear. This is followed by *Limosella capensis* and thick masses of benthic filamentous algae (Zygnemataceae). By November the macrophyte and algal communities have become established in the pools.

Six sampling points (Figure 3) were chosen for regular sampling purposes and rates of primary production were measured at points 2, 3, 4 and 5. The sampling points were:

1 = A fountain at the top of the bog which flowed for most of the study period.

2 = Stream 1, a stream about 300 m from the top of the bog, where a gully approximately 0,5 m deep was cut into the peat.

3 = Pool 1, a small oval pond close to stream 1 with a surface area of approximately 15 m² and a maximum depth of 0,5 m. *Ranunculus meyeri* and *Limosella capensis* were the dominant macrophytes.

4 = Pool 2, a larger pool situated approximately halfway down the bog. It had a curved oval outline, a surface area of approximately 40 m² and a bottom sloping to a maximum depth of 0,7 m at the lower end. Dense stands of *Lagarosiphon muscoides*, *Limosella capensis*, *L. longiflora* and *Ranunculus meyeri* covered the bottom, except at the deepest end.

5 = Stream 2, a steep-sided cutting caused by the main stream, approximately two thirds down from the top of the bog, with a maximum depth of 0,9 m and *Lagarosiphon muscoides* and *Crassula natans* dominating the submerged macrophytes.

6 = Outflow, the stream draining the bog.

TABLE 1
TEMPERATURE AND PRECIPITATION AS MEASURED AT LETSENG-LA-TERAE (DATA PROVIDED BY LETSENG DIAMOND MINE)

Month	Air Temperature in °C			Average precipitation for period 1965 to 1977 in mm	Precipitation for study period in mm	
	Max	Min	Mean		1975	1976
F	15,5	4,7	10,1	84,7	123,0	127,5
M	14,1	3,2	8,7	96,2	101,0	171,8
A	10,6	−0,4	5,1	36,0	36,0	
M	7,9	−3,1	2,4	20,4	5,0	
J	4,9	−6,7	−0,8	7,7	6,0	
J	6,2	−6,0	0,1	6,2	15,7	
A	9,1	−3,3	3,6	15,5	7,0	
S	12,7	−1,0	6,1	17,2	140,0	
O	12,5	1,0	6,8	60,6	64,1	
N	13,7	2,7	8,2	87,4	166,7	
D	14,8	4,0	9,6	126,3	112,0	
J	16,8	5,4	11,0	105,5	256,9	
Yearly average	11,6	−0,8	5,9	Total 663,7		

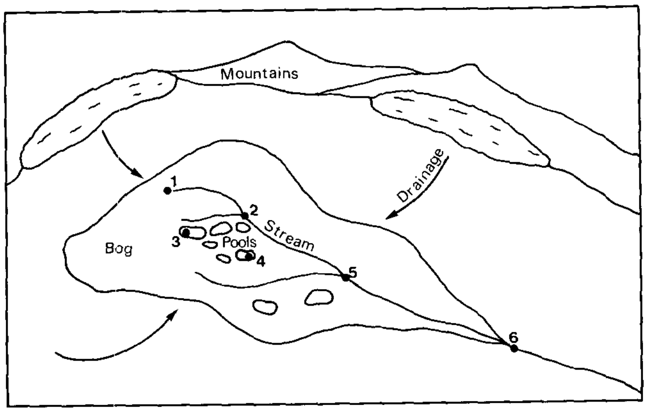

Figure 3
A diagrammatic sketch of the bog, showing the six sampling points.

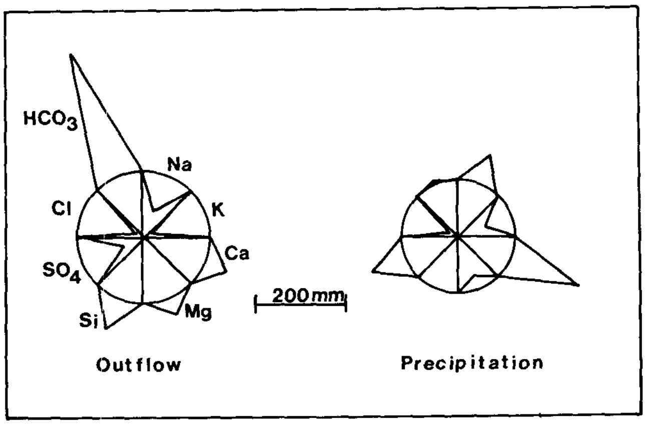

Figure 4
Ionic diagrams of the water leaving the bog and the precipitation, constructed according to Brock and Yake (1969). Scale for the outflow is 1 meq ℓ⁻¹ = 500 m² and for the precipitation, 1 meq ℓ⁻¹ = 5 000 mm².

Chemical composition of the surface waters, leachable ions from the soils and precipitation

A summary of the chemical composition of water samples collected from the various sampling points on the bog as well as of the Motete and Malibamatso Rivers over the study period is given in Table 2. As the composition of the surface waters was very similar only an ionic diagram of the composition of the water from the stream leaving the bog (Outflow) as well as of the precipitation are shown in Figure 4. The results show that the surface waters are moderately acidic, except for the Motete River which was on an average neutral (average pH's calculated from the hydrogen ion concentrations). The ionic content of the waters was low where conductivity ranged from 2,2 and 13,0 mS m^{-1}. Higher ionic contents were measured during the dry winter months (April to September), being not as pronounced in the Motete and Malibamatso Rivers as in the waters from the bog (Figure 5). The Malibamatso River generally had a lower ionic content than the smaller Motete River.

The ionic composition of the water was dominated by bicar-

TABLE 2
RESULTS OF CHEMICAL ANALYSES OF WATER SAMPLES COLLECTED MONTHLY FROM THE DIFFERENT SAMPLING POINTS IN THE BOG AS WELL AS OF THE MOTETE AND MALIBAMATSO RIVERS

($\bar{x}$ = mean, x_{min} = minimum value, x_{max} = maximum value, S_x = standard deviation, n = number and bd = below detection limit of the method used)

Sample	pH	Cond. (mS m^{-1})	Alk. (meq ℓ^{-1})	Na (mg ℓ^{-1})	K	Ca	Mg	Si	Fe	Cl	SO_4	PO_{4diss} (μg ℓ^{-1})	NH_3-N	NO_3-N	Colour Pt-units
1. Inflow fountain (n = 12)															
$\bar{x}$	6,45	5,21	0,394	1,61	0,37	4,67	2,26	5,88	1,0	1,6	3,61	1,6	0	50	55
x_{min}	5,4	3,05	0,227	0,9	bd	1,2	1,5	0,1	bd	0,14	0,9	bd	bd	bd	5
x_{max}	7,45	7,70	0,585	0,4	2,0	8,0	3,6	10,1	9,3	4,38	5,5	9,8	10	200	250
S_x	0,61	1,23	0,138	0,46	0,53	2,43	0,6	3,26	2,65	1,37	1,5	3,3	0	80	65
2. Stream 1 (n = 18)															
$\bar{x}$	6,99	4,62	0,384	1,48	0,13	4,8	2,16	6,2	0,08	0,06	3,82	0,0	0	30	55
x_{min}	6,1	2,96	0,139	0,65	bd	1,08	1,4	1,2	bd	bd	1,2	bd	bd	bd	30
x_{max}	7,6	6,70	0,85	2,5	0,4	9,6	2,6	9,81	0,32	3,03	6,7	bd	10	32	85
S_x	0,36	1,12	0,182	0,6	0,1	2,38	0,33	2,95	0,12	1,08	2,0	0,0	0	80	15
3. Pool 1 (n = 18)															
$\bar{x}$	6,28	3,97	0,215	0,84	0,11	3,98	1,73	5,8	1,19	0,28	8,1	0,7	10	50	134
x_{min}	5,85	2,90	0,62	0,5	bd	0,9	1,3	1,3	0,19	bd	bd	bd	bd	bd	70
x_{max}	6,75	6,30	0,758	1,5	0,3	6,6	2,2	11,4	2,1	1,03	15,4	6,8	140	200	175
S_x	0,26	7,64	0,184	0,31	0,08	2,16	0,29	3,68	0,64	0,36	4,51	2,0	40	70	34
4. Pool 2 (n = 12)															
$\bar{x}$	6,24	4,18	0,271	1,59	0,56	4,25	1,85	5,33	1,14	1,25	7,14	0,3	30	60	175
x_{min}	4,8	2,20	0,087	0,25	bd	0,7	1,3	0,3	bd	bd	1,7	bd	bd	bd	70
x_{max}	6,93	11,80	0,624	7,0	4,0	10,4	3,3	10,6	3,4	7,88	15,4	3,3	300	340	350
S_x	0,44	2,55	0,164	1,88	1,04	2,62	0,5	3,53	0,87	2,26	4,06	1,0	80	90	75
5. Stream 2 (n = 24)															
$\bar{x}$	6,45	6,94	0,708	1,62	0,4	5,26	2,99	6,78	2,18	1,03	3,39	0,3	10	30	84
x_{min}	5,85	3,18	0,09	0,2	bd	1,5	0,4	bd	bd	bd	bd	bd	bd	bd	30
x_{max}	6,93	13,00	1,72	3,7	2,3	15,2	6,4	14,9	8,1	4,1	8,6	6,8	130	160	300
S_x	0,34	3,26	0,497	0,77	0,54	3,53	1,48	3,6	2,44	1,07	2,67	1,3	30	50	78
6. Outflow (n = 14)															
$\bar{x}$	6,97	5,60	0,482	1,56	0,27	4,39	2,46	6,74	0,5	0,61	2,44	0,3	0	30	47
x_{min}	6,5	3,38	0,181	0,9	0,05	1,07	1,6	1,3	bd	bd	bd	bd	bd	bd	30
x_{max}	7,8	10,00	1,12	3,5	0,9	10,6	4,6	9,4	2,9	2,2	4,99	1,6	10	100	85
S_x	0,35	1,98	0,314	0,68	0,22	2,65	0,87	2,24	0,79	0,67	1,52	0,3	0	40	16
7. Motete River (n = 11)															
$\bar{x}$	7,08	4,75	0,423	1,22	0,28	4,26	1,88	5,62	0,04	0,51	0,82	0,3	20	10	16
x_{min}	5,9	2,40	0,151	0,8	0,1	1,8	0,9	1,3	bd	bd	bd	bd	bd	bd	5
x_{max}	7,82	5,80	0,556	2,1	0,6	6,8	2,4	10,6	0,3	1,41	3,35	2,9	200	80	30
S_x	0,65	9,50	0,112	0,34	0,12	1,74	0,43	2,97	0,09	0,47	1,29	1,0	60	20	10
8. Malibamatso River (n = 13)															
$\bar{x}$	6,98	4,07	0,327	1,25	0,4	3,22	1,15	5,68	0,02	0,28	0,46	0,7	0	10	8
x_{min}	6,1	2,82	0,153	0,8	0,15	0,9	0,7	1,4	bd	bd	bd	bd	bd	bd	0
x_{max}	7,5	9,40	0,53	2,4	2,1	5,8	1,8	9,58	0,32	0,91	2,6	6,2	30	50	30
S_x	0,39	1,69	0,107	0,44	0,52	1,78	0,3	2,32	0,09	0,27	0,91	0,2	10	10	8

bonate, reactive silica, calcium and magnesium, where the following ionic dominance order mostly prevailed: Ca > Si > Mg > Na > K: HCO_3 > SO_4 > Cl (Figure 4). The same ionic dominance order prevailed in the waters from the Motete and Malibamatso Rivers. Relatively high concentrations of Fe were sometimes measured in the flowing waters, with a maximum of 9,1 mg ℓ^{-1} recorded in the fountain at the top of the bog.

Although low, the highest concentrations of the biogenically important nutrients, N and P, were measured in the pools and fountain with maxima of 10 μg PO_4-P ℓ^{-1} and 340 μg NO_3-N ℓ^{-1}. Low concentrations of these nutrients were measured in the waters from the Malibamatso and Motete Rivers, the maxima being 6 μg PO_4-P ℓ^{-1} and 80 μg NO_3-N ℓ^{-1} (Table 2). The waters were stained with humic substances leached from the peaty soils, where the highest average Pt-colour units were measured in the pools. A high Pt-colour of 300 units was measured in Stream 2 on one sampling occasion only.

Results of the precipitation samples (Table 3) indicated that the water was acidic with a mean pH of 5,2 and a minimum of 3,4. The ionic content was very low and had a dominance order of Ca > Na > Mg > K: SO_4 > Cl (Figure 4). No PO_4-P could be measured in the precipitation samples.

Large quantities of ions were leached from the soils and peat deposits (Table 4). The leachate was acidic and an ionic dominance order of Ca > Mg > Na > K: SO_4 > Cl prevailed. Relatively high amounts of ammonia were measured with a maximum of 5,24 mg ℓ^{-1} in the peat from the top end of the bog.

Productivity of the phytoplankton and benthic communities of algae and macrophytes

Phytoplankton productivity in the streams was low, ranging from 0,1 to 43 mgC $m^{-2}.d^{-1}$ (Figure 6). A seasonal trend was discernable with higher rates in the summer (November to February) as compared to the winter.

TABLE 3
CHEMICAL ANALYSES (n = 5) OF THE RAINFALL SAMPLES COLLECTED AT THE STUDY AREA, LESOTHO

(Conductivity in mS m^{-1}, the ions in mg ℓ^{-1} and bd = below detection limit of the method)

Parameter	Mean	Minimum	Maximum
pH	5,2	3,4	7,0
Conductivity	1,1	0,3	2,05
Na	0,43	0,0	1,6
K	0,25	0,0	1,0
Ca	0,54	0,1	1,6
Mg	0,11	bd	0,3
Cl	0,05	bd	0,14
SO_4	0,93	bd	2,59
PO_4-P	bd	bd	bd

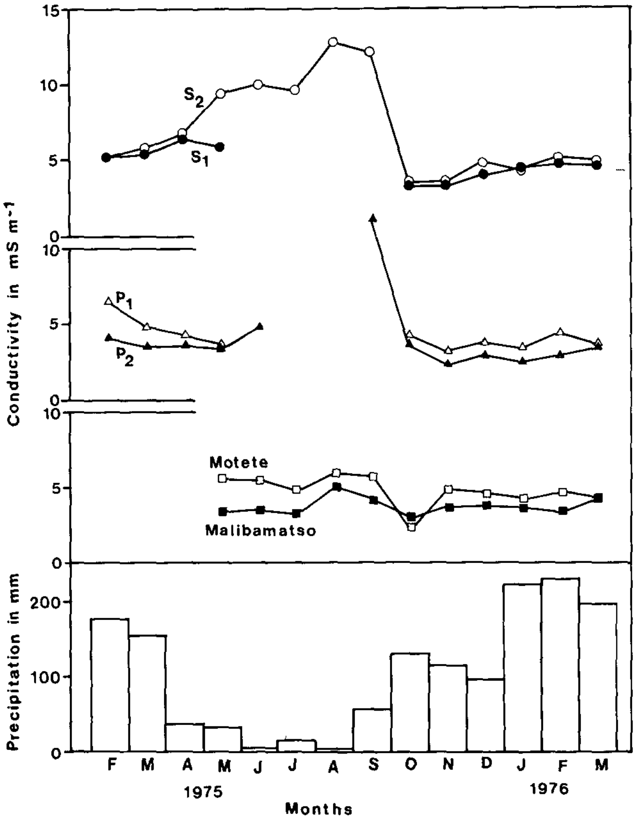

Figure 5

Variations in the ionic content of stream 1 (S_1), stream 2 (S_2), pool 1 (P_1), pool 2 (P_2), the Motete and Malibamatso Rivers during the study, together with the monthly precipitation quantities.

Large day-to-day variations occurred, and the productivity was almost three times higher on the 14th December, compared with 13 December 1975. This variation was attributed to the overcast conditions on 13 December where the irradiance was almost a third of that recorded on 14 December. The low productivities measured in March 1976 were attributed to the heavy downpours and consequent flushing of the streams, ridding them of their pelagic biota. Water temperatures also followed a seasonal pattern and ranged from 1,7 to 21,5°C (Figure 6). Differences of up to 10°C were recorded between the water temperatures measured at the beginning and end of the incubation periods (Figure 6), which were attributed to the shallowness of the waters and high incident solar radiation at times.

Phytoplankton productivity in the pools was almost an order of magnitude higher than in the streams with a maximum of 355 mgC m^{-2}.d^{-1} measured in Pool 2 on 14 December 1975 (Figure 7). A seasonal trend was discernable with higher rates during the summer months. Large day-to-day variations occurred (Figure 7), where for example the productivity increased from 25,5 to 143,7 mgC m^{-2}.d^{-1} between 21 and 22 October 1975 in Pool 1. Temperatures varied between 1,7 to 17,5°C (Figure 7) with higher temperatures generally being recorded at the end of the incubation period, compared to the beginning. When water was present in the pools, an ice layer of varying thickness (maximum measured was 250 mm) was usually present during the winter months.

The dissolved oxygen content of the waters was mostly close to saturation, but increases of up to 15% above saturation were measured during periods of high productivity in the pools. The productivity of the benthic community was three times higher than that of the phytoplankton during the same period in Pool 1 and five times higher in Pool 2 (Table 5).

Discussion

The average mineral composition of the Lesotho basalts has an ionic dominance order of Si > Al > Ca > Fe > Mg > Na > K (Nixon, 1973). Although minerals have different mobilities after the weathering of rocks, the above dominance order resembles that of the freshwaters. However, the composition of the surface waters of the bog was very similar to the composition of the leachable ions from the soils and peat deposits. This indicates that the minerals in the freshwaters are of edaphic origin and belong to the rock-dominated group of waters, according to Gibbs (1970). The high ammonia concentrations measured in the

TABLE 4
CHEMICAL ANALYSES OF SOIL-WATER SAMPLES FROM THE BOG IN LESOTHO

(WS = southern face sample on rock rubble 0,3 m deep, NS = northern face sample on rock rubble 0,25 m deep, ES = eastern face surface sample, EB = eatern face sample on rock rubble 0,3 m deep, BT = surface sample near top-end of bog, and BB = surface sample at bottom end of bog)

Sample	pH	Na	K	Ca	Mg	Fe	Cl	SO_4	NO_3-N	NH_3-N
		mg/200 g								
WS	6,39	5,2	9,5	26,5	6,6	2,5	1,7	41,7	1,31	1,47
WB	6,61	5,7	2,5	21,8	6,32	3,7	0,84	30,3	0,94	0,53
NS	6,5	7,5	3,6	26,0	7,6	1,24	0,71	21,3	1,4	0,86
NB	6,65	7,6	2,5	23,5	7,08	4,67	0,51	15,1	1,25	0,5
ES	6,21	4,9	8,5	17,3	5,07	3,0	2,64	20,7	1,43	0,87
EB	6,6	7,2	3,3	17,8	5,8	4,9	0,57	19,9	1,13	0,15
BT	6,7	16,8	38,5	35,5	14,8	39,2	0,69	120,5	5,24	34,27
BB	5,93	5,6	11,7	22,5	7,5	9,3	6,36	123,8	3,1	16,3

TABLE 5
PRODUCTIVITY OF THE BENTHIC MACROPHYTE AND ALGAL COMMUNITIES IN POOLS 1 AND 2

Date	Productivity of Benthic Community in mgC $m^{-2}.d^{-1}$ Pool 1	Pool 2
13-5-75	—	99,1
14-5-75	—	380,6
18-11-75	168,8	—
19-11-75	135,3	—
13-12-75	321,7	360,9
14-12-75	634,7	828,2
27-1-76	134,8	101,0
17-2-76	510,9	332,4
18-2-76	502,4	563,3
24-3-76	87,7	94,9
25-3-76	67,0	180,9

— Community not present in pool

soil leachate are in accordance with acid peaty soils, where low rates of nitrification are common due to the absence of nitrifying bacteria (Pearsall, 1952).

Variations in the mineral content of the surface waters (Figure 5) were inversely related to the precipitation, where a correlation coefficient of $r = -0,77$ was calculated between the ionic content of Stream 2 and the monthly precipitation. The quantity of leachable ions is, therefore, dependent on the volume of water received by the bog as precipitation. Natural and anthropogenic sources influence the mineral content of precipitation. The domination of Ca and SO_4 (Figure 4) in the wet fallout of continental areas is well established (Wolaver and Lieth, 1972). Continental aerosols and anthropogenic sources appear to have influenced the composition of the precipitation collected at the bog.

The pools can be classified according to their productivities and P-contents as mesotrophic whilst the streams were oligotrophic according to the classification of Wetzel (1983). No statistical relationship could be found between solar radiation and primary productivity in the waters. This is clearly shown in Figures 6 and 7 where daily variations of up to five times were measured without much variation in solar radiation between consecutive days (e.g. October and November). On other occasions solar radiation appeared to directly influence the phytoplankton, as recorded in December in the streams and pools (Figures 6 and 7), where higher irradiances on 14 December resulted in higher productivities. Temperature appears to be the most important factor influencing production rates where a significant correlation coefficient $(p = 0,05)$ was calculated between the water temperatures at the end of the incubation period and phytoplankton productivity in Pool 2. Temperature explained 43% of the variation in Pool 1, and 31 and 24% of Streams 1 and 2 respectively.

The higher productivities measured in the pools as compared to the streams was attributed to the longer residence times of the water in the former. This together with the high rates of production, which were recorded for the macrophyte and epiphytic algal benthic communities, resulted in their mesotrophic character. Large populations of zooplankton were sometimes observed, where one count gave 60 *Paradiaptomus lamellabis*, 15 *Simocephalus vetulus*, 10 *Chydorus sphaericus*, 5 Nematoda and a few water mites per litre of water. The zooplankton populations were, however, vulnerable to the

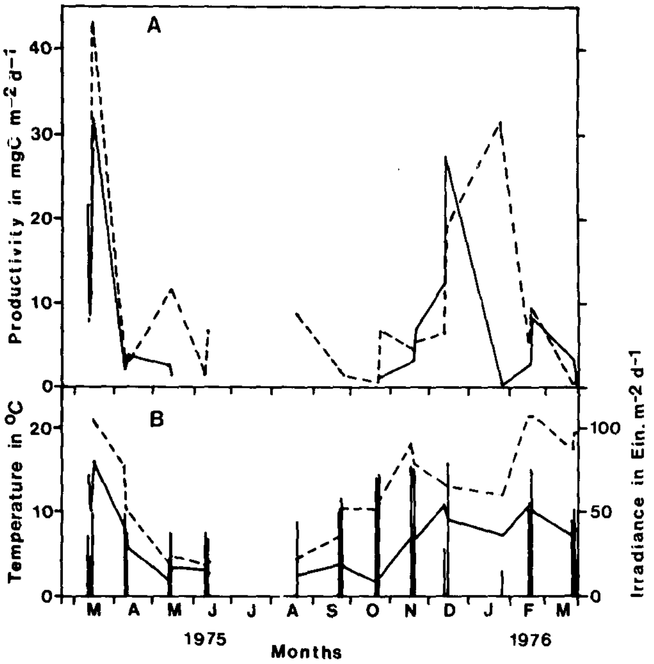

Figure 6
A. Phytoplankton productivity during the study period in stream 1 (solid line) and stream 2 (broken line). B. Water temperature at the beginning (solid line) and the end of the incubation periods (broken line) in stream 2, as well as the solar radiation (vertical solid lines) during the study period.

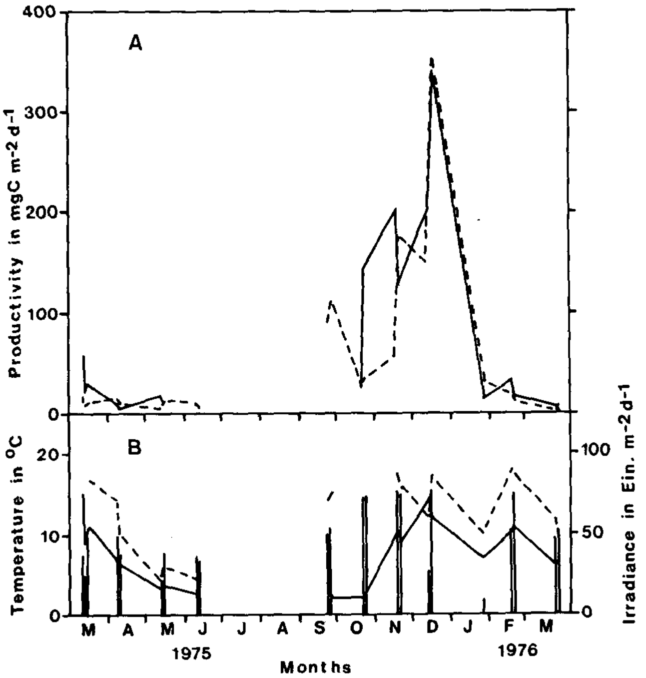

Figure 7
A. Phytoplankton productivity in the pelagic zone of pool 1 (solid line) and pool 2 (broken line) during the study. B. Water temperature at the beginning (solid line) and end (broken line) in pool 2, as well as the solar radiation (vertical solid lines) as measured during the study.

Figure 8
A semi-protected area on the bog showing the extent of grazing on the unprotected area.

Figure 9
Deep gully erosion on a bog.

flushing of the pools during heavy rainfalls.

The harsh climatic conditions and changeability of the weather were seen as the factors which influence the physical and biological properties of the lentic and lotic waters of these high-altitude bogs the most. An overriding factor is the precipitation, where the hydrology and water status of the bogs were entirely dependent on it. Heavy rainfalls resulted in flushing of the streams and when surface water flow occurred, even the pools were flushed. The rooted macrophytes with epiphytic algae were the only "permanent" inhabitants of the pools. The flushing of the surface waters had an influence on the productivity as well as on the chemical composition and ionic content of the waters (Figures 5, 6 and 7). During the dry winter months the pools and most of the streams dried up completely, with only a trickle of water leaving the bog.

The water leaving the bog is of excellent quality, being low in ions and clear, as are those of the other streams and rivers of this mountainous area. When compared to the TDS content of 85 mg ℓ^{-1} of the Orange River (Keulder, 1979) and the 800 mg ℓ^{-1} of the Vaal River (Grabow, 1986) this is a valuable asset to Lesotho and every effort should be made to protect these bogs. Unfortunately severe signs of erosion can already be seen, which is attributed to extensive overgrazing by livestock of the Basothu people as well as the apparent increase in numbers of burrowing ice-rats (*Otomys sloggetti*). The livestock removes the vegetation cover (shown in Figure 8 is a semi-protected area on a bog giving some indication of the extent of overgrazing) and through their trampling, mechanically break up the soft peat. The ice-rats inhabit the drier areas of the bogs where they burrow and dig up large areas of soil and peat, and in so doing, create suitable areas for erosion. The sheep and goats tend to form footpaths, especially along the edges of the bogs and a deep erosion trench has already formed around the edge of the study area bog. The erosion gullies have increased in size during the past few years, an example of which is shown in Figure 9, which was taken at the bog adjacent to the one studied. Damage has already been done to this important catchment area and conservation measures are needed to control human activities, movement and grazing by animals and possibly the spread and activities of the ice-rats. Such actions would be of incalculable value to Lesotho and the effective utilisation of these water resources, especially in view of the Lesotho Highlands Water Project. Care should be taken during the construction phases of this latter project, to limit unnecessary environmental damage to a minimum.

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References

BROCK, E.S. and YAKE, W. (1969) A modification of Maucha's ionic diagram to include ionic concentration. *Limnol. Oceanogr.* **14**(6) 933-935.

CARTER, C.A. (1965) Basutoland as a source of water for the Vaal basin. *Die Siviele Ingenieur in Suid-Afrika*, October, 217-228.

COETZEE, J.A. (1967) Pollen analytical studies in East and southern Africa. In: *Palaeoecology of Africa* 3, E.M. van Zinderen Bakker Sr. (Ed.), Balkema, Cape Town, 146.

COMMISSION OF ENQUIRY INTO WATER MATTERS (1970) Report No. RP 34/1970, Government Printer, Pretoria, 170.

GIBBS, R.J. (1970) Mechanisms controlling world water chemistry. *Science* **170** 1088-1090.

GOLTERMAN, H.L. (1969) *Methods for chemical analysis of fresh waters.* Blackwell Sci. Publ. Oxford and Edinburgh, 172.

GRABOW, W.O.K. (1986) Water quality assessment and control in South Africa. *SA J. Sci.* **82** 342-346.

GROBBELAAR, J.U. (1974) Primary production in the freshwater bodies of the sub-Antarctic island Marion. *S. Afr. J. Antarct. Res.* 4 40-45.

HANSARD (1979) No 6, 12-16 March, column 433. Government Printer, Pretoria.

JACOT-GUILLARMOD, A. (1962) The bogs and sponges of the Basutoland Mountains. *SA J. Sci.* **58** 179-182.

KEULDER, P.C. (1979) Hydrochemistry of the upper Orange River catchment. *J. Limnol. Soc. sth. Afr.* **5** 39-46.

KINGDOM OF LESOTHO (1986) Lesotho highlands water project. Feasibility study. Ministry of Water, Energy and Mining. Main Report. 12-8.

NIXON, P.H. (1973) Perspective. In: *Lesotho Kimberlites*, P.H. Nixon (Ed.), Lesotho National Development Corporation, 300-318.

PEARCE, R.O. (1973) *Barrier of Spears.* Howard Timmins, Cape Town, 304.

PEARSALL, W.H. (1952) The pH of natural soils and its ecological significance. *J. Soil Sci.* **3** 41-51.

SCHULZE, B.R. (1979) Climate of South Africa Part 8. Weather Bureau, Department of Transport. Republic of South Africa. 330.

SHAND, N. (1963) Report on the hydrological investigation in the mountain area of Basutoland. Consulting and Chartered Civil Engineer, Cape Town, 28.

STAINTON, M.P., CAPEL, M.J. and ARMSTRONG, F.A.J. (1974) The chemical analysis of fresh water. *Environment Canada,* Miscellaneous Special Publication No. 25, 120.

STOCKLEY, G.M. (1974) Report on the Geology of Basutoland. Basutoland Government, Maseru, 114.

THE CAPE TIMES (1986) SA share in Lesotho water project 12, 2 pc, 4.

VAN ZINDEREN BAKKER, E.M. (1955) A preliminary survey of the peat bogs of the alpine belt of northern Basutoland. *Acta Geographica* **14** 413-422.

VAN ZINDEREN BAKKER, E.M. Sr. and WERGER, M.J.A. (1974) Environment, vegetation and phytogeography of the high-altitude bogs of Lesotho. *Vegetatio* **29** 37-49.

WOLAVER, T.G. and LIETH, H. (1972) *US precipitation chemistry.* Chapel Hill, 75.

WETZEL, R.G. (1983) *Limnology.* Saunders College Publishing, Philadelphia, New York, etc. 767.