Institute of Freshwater Ecology

SEDIMENT ANALYSIS - DRUMORE LOCH SSSI

Principal Investigators:

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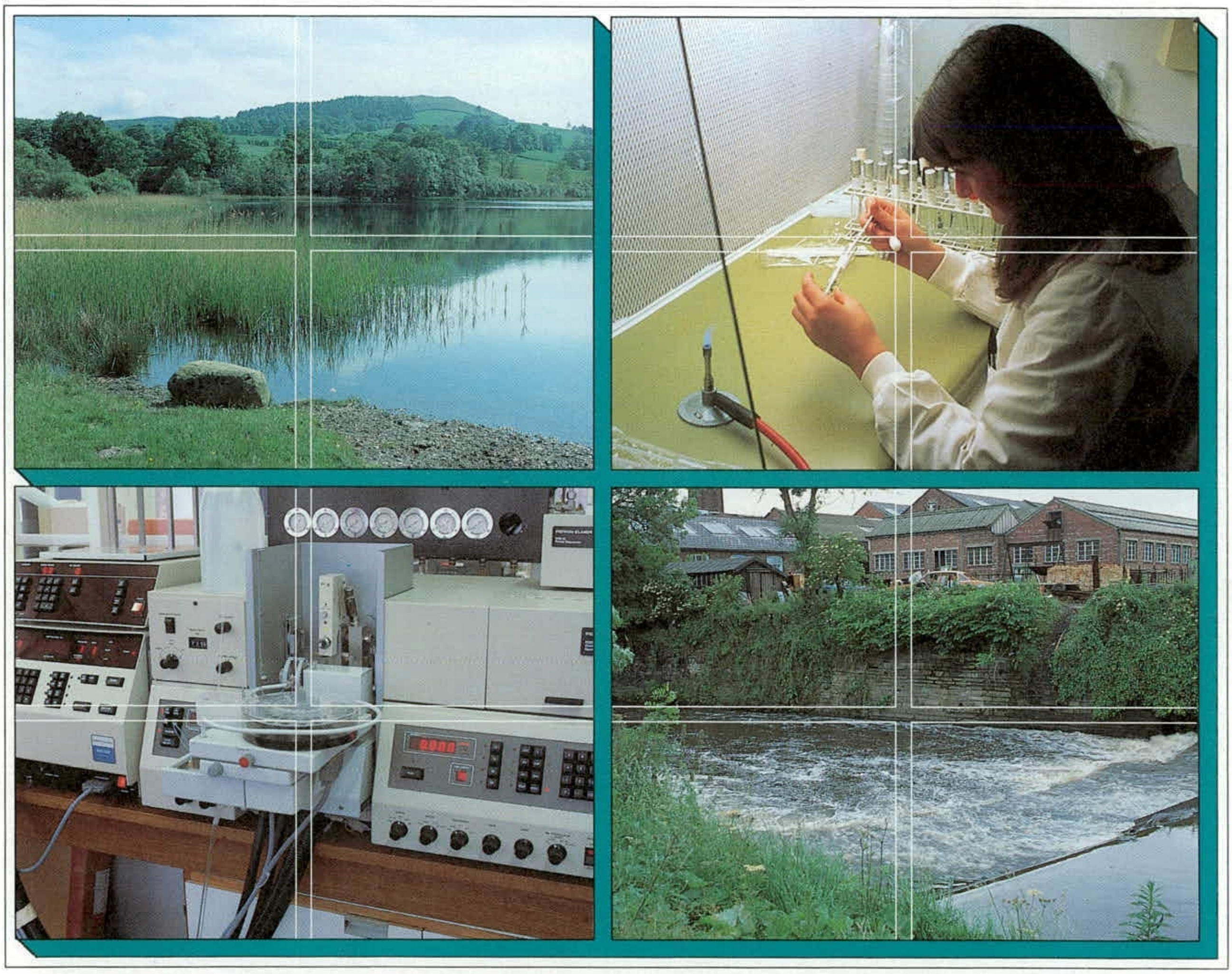
Report to Scottish Natural Heritage (May 1995)



Natural Environment Research Council

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Contents

Summary

A limnological survey of Drumore Loch was carried out on 11 April 1995 in response to concerns expressed over the possible enrichment of the loch - as suggested by a decrease over the last deacde, in the diversity of the macrophytic flora, and especially a reduction from five to two in the number of *Potamogeton* species. The loch was notified as an SSSI in 1985 on account of its diverse aquatic macrophyte community and because it was one of the few naturally mesotrophic lochs in Tayside Region.

The present field and laboratory work focused mainly on nutrients, especially phosphorus (P), and involved the sampling and analysis of the (five) feeder streams and the loch outflow, in addition to the open water of the loch and its surface sediments. Special thought was given to the dispersion of sampling points in the loch in order to assess whether a group of in-loch cages used for the rearing of rainbow trout (*Oncorhynchus mykiss* Walbaum) is a major source of enrichment. In this connection too, a pair of sediment cores was incubated at *ca* 6^0C, while another two cores were kept at 22^0C, to obtain some indication about the P release potential of these deposits.

The results are compared with physical and chemical data collected in 1984, and the current sediment P levels measured in Drumore are discussed in relation to data from other waters.

P levels in the water column are considerably lower than those measured *in summer* 1982 but a check has still to be made as to the units in which the earlier data are expressed.

P levels in the mud are generally high and, on the basis of a review of information from *ca* 35 Scottish loch basins, there are few other sites which yield values higher than the 0.6%-0.8% P of sediment dry weight at the Drumore cages site. Somewhat lower values were found at the two sites situated either side of the cages, but even the 2 sites situated towards the east end of the loch and furthest from the cages yielded values of 0.1%-0.2%; such values are considered by some workers to be typical of eutrophic muds.

Introduction

This study investigates concerns over the possible enrichment (eutrophication) of Drumore Loch which was notified as an SSSI in 1985 on account of its diverse macrophyte community including five species of *Potamogeton*. A recent survey recorded only two of these, including *P. crispus* which is known to tolerate rich conditions in any event. Over the same period the loch has manifested an increase in *Elodea canadensis* which is a eutrophic indicator. Details of the causes of enrichment - and even the extent of eutrophication - have yet to be established, and other factors are likely to have contributed to the shift in the dominant macrophyte species. For example, *Potamogeton* plants were removed in the late 1970s and early 1980s to facilitate water skiing. Nevertheless, Scottish Natural Heritage suspect that a major nutrient source is a group of in-loch cages which have been used for the rearing of some 10-16 tonnes Rainbow Trout (*Oncorhynchus mykiss* Walbaum) *per annum*over the last 12 years - although production has been reduced considerably due to tainting of the fish. Forest Enterprise tree planting and probable application of phosphate fertiliser (albeit by hand) would also enrich the loch.

The main objectives of the study as stated by SNH are as follows:

- to determine the extent to which sediments under the fish cages are P-enriched compared with sediments elsewhere in the loch (it is understood the cages have not been moved around the loch);
- to determine the extent to which P-rich sediments occur around the cages;
- to gain a general indication of whether conditions in the loch may lead to the release of P to the water column from these sediments and hence contribute to enrichment of the overlying waters;
- to obtain an indication of how the level of nutrients (P) in the sediments of Drumore Loch compares with those obtained from other similar standing waters.

In summary, the first two objectives were achieved by means of a spatial survey of sediment P content. The third objective was addressed firstly, by comparing in-loch levels of soluble P (and the dissolved fractions of other nutrients) with values obtained from analyses of the sediment interstitial waters, the feeder streams and the loch outflow, and secondly by incubating sediment cores at different temperatures and measuring the concentrations of soluble P in the overlying water at various time intervals. Literature on sediment P was summarily reviewed in order to place the Drumore results in context.

The study site

Drumore Loch lies at an altitude of 340 m a.s.l. Its surface area is 4.88 ha. Depths recorded by the present series of 5 echo-soundings along the mid-line of the loch and passing from the deepest (west, dam) end (**Figure 1**), are 3.5 m at site 1 (midway between the dam and the fish cages); 3.2 m at site 2 (the fish cages); 2.5 m at site 3 (opposite boathouse); 1.5 m at site 4 (at the point more or less midway along the loch where it starts to narrow), and 1.25 m at site 5 (in the middle of the narrow section at the east end). A mean depth of 1.2 m is calculated from a formula incorporating loch surface area and depth data of the type just presented (Lyle and Bailey-Watts 1993).

A single, but comprehensive survey of the loch, inflows and outflow chemistry was carried out by the Freshwater Fisheries Laboratory (Pitlochry) in August 1982. The data stemming from that survey provide a valuable benchmark with which to compare some of the findings of the present study: it corresponds to the early days of cage rearing of fish at this site, although it refers to a summer as opposed to the wintertime when the latest work was done. All those years ago, the system was slightly to moderately alkaline; pH figures ranged from 7.40 to 8.09 units - corresponding to alkalinity levels of 37 and 70 mg $CaCO_3$ l^{-1} respectively - over inflows and the loch. Conductivity values of *ca* 100 to 130 $\mu S\ cm^{-1}$ are in keeping with these findings. Samples taken from near, and at a distance from, the fish cages showed no significant differences, neither did the samples taken from the loch surface and near the sediment. Nevertheless, a reasonably rich environment is suggested by the FFL nutrient results. The following ranges of values (all $\mu g\ l^{-1}$, with phosphorus expressed as P, and nitrogen as N) were obtained ((i) for 5 inflows and (ii) for a total of 5 samples taken from open water and from the outflow):

total P - (i) 10-33 (ii) 31-92; *total soluble P* - (i) 4-7 (ii) 11-18; *soluble reactive P* - (i) 5-11 (ii) 6-11; *particulate P* - (i) 3-29 (ii) 17-81.

total Kjeldahl N - (i) 111-369 (ii) 374-675; *Kjeldahl N in filtered sample* - (i) 111-369 (ii) 374-675; *total soluble N* - (i) 144-326 (ii) 429-572; *nitrate N* - (i) 90-230 (ii) 110-140; *ammonia N* - all values less than 10, excepting 2 loch figures of 10 and 21; *particulate N* - (i) 15-200 (ii) 47-273.

Investigative methods

Fieldwork was completed in one day - 11 April 1995. The following work was done, following an echo-sounding depth survey on a central transect passing from west (dam end) to east:

at each of 5 sites on the central transect:

- for the analysis of nutrient (mainly P) content of the near-sediment water and the uppermost 5 cm of sediment, two cores were taken with a Jenkin Surface Mud Sampler; this corer secures an essentially undisturbed sample of at least the uppermost 15 cm of sediment, plus overlying water; the total core tube length is 50cm; surface and near-sediment water temperatures were recorded, and a small sample of water was taken from *ca* 2 cm above the sediment.

*at a single open water site with a total depth of 3m (**Figure 1**)*:

- a plastic drainpipe was used to obtain duplicate water samples integrated over the top 2m of the column (and thus, fairly representative of most of this shallow loch), for the analysis of nutrients and phytoplankton chlorophyll and a cursory examination of the algal species;
- weather conditions and the appearance of the water were recorded;
- depth variation in temperature, dissolved oxygen content, electrical conductivity and pH was recorded with a 'Windermere Profiler';

the Jenkin Sampler was used to collect 6 cores for the P release incubation experiments.

Th analytical methods used for assessing P levels in the sediments and the loch and inflow waters, and procedures for the determination of phytoplankton chlorophyll and the assessment of algal species and their abundance, have been documented elsewhere (see e.g. Bailey-Watts, May, Kirika and Lyle 1992a).

Results

General physical conditions

A westerly wind of Beaufort Scale force 3 to 4 prevailed, although surface water movement on this small loch was often slight. Not surprisingly, the shallow water body was more or less well-mixed; the surface water temperature was 8.9°C at all sites, although near-sediment values were often 0.1 or 0.2 of a degree Celsius higher. The water was reasonably clear, with a greenish hue. Secchi disc readings were 3.1 m, i.e. well in excess of the likely mean depth of the loch. Assuming that the euphotic zone is three times the Secchi disc value, energy losses incurred by planktonic and attached algae, and rooted plants through respiration, would only approach the energy gained through photosynthesis, at a depth of approximately 9 m which is at least double the maximum depth of Drumore. Even in the absence of information obtained about the nature of the bottom of the loch (see below), but assuming the sediments were suitable for rooted vegetation, a rich macrophytic flora would be expected. Indeed, so much of the floor of the loch was carpeted with *Elodea* that this plant often fouled the Jenkin corer closing mechanism.

The 'Windermere' depth profiles also confirmed the more or less complete vertical mixing of the loch; over a 3-m column in mid-loch (site 3) , the temperature at six 0.5-m intervals varied by only 0.11 of a Celsius degree, the dissolved oxygen saturation by <2% (around a mean value of 108%), conductivity by <0.25 μS cm^{-1} (126.50 μS cm^{-1}) and pH by 0.25 units (7.49). However, the precision of recording with this instrument has enabled some definite trends in the distribution of these features with depth (**Figure 2**).

Spatial variation in sediment phosphorus content

The weight of total P (i.e. phosphorus in all forms - inorganic and organic, particulate and dissolved) in the top 5-cm deep, 7-cm diameter 'discs' of sediment ranged over almost an order of magnitude, from *ca* 2,500 μg (2.5 mg) to 18,000 μg (18.0 mg). However, it is the values obtained from the cage site (2) that account for much of this variation (**Figure 3a**). Moreover, while the duplicate core values plotted for this site differ appreciably, they are both significantly higher than any of the other (7) values. Otherwise, P levels decrease in a more or less consistent manner from the dam end of the loch eastwards. Some of the variation can be accounted for by differences in the water content of the cores; for example, the lowest P value in **Figure 3a** (for the single core collected at site 4) corresponds to the highest water content (*ca* 95.5% by weight - **Figure 3b**), while the high P valued determined for the cage site relates to the lowest water content (*ca* 92%).

Sediment P content expressed on a dry weight basis facilitates better comparison with data from other sources (see below). The pattern of P content in the Drumore samples (**Figure 4**) mirrors that described by the weight data. The 2 sites nearest the outflow exhibited the lowest values i.e. *ca* 0.20% P of sediment dry weight, while sites 1 and 3 (situated either side of the cages) each gave duplicate values of approximately 0.25% and 0.35%. Considerably higher values of 0.56% and 0.83% were obtained from the two cores collected at the cage site.

The total amounts of P in the sediment just described are unlikely to change in the short term. This may contrast with the situation regarding the levels of soluble P and especially the soluble reactive component (SRP); SRP can be released from, or adsorbed by, sediments depending on seasonally, even diurnally, varying temperature, pH and dissolved oxygen, and the burrowing/grazing activities of invertebrates, and wind-induced disturbance of the deposits (Bostrom, Jansson and Forsberg 1982). Nevertheless, data on the amounts of e.g. SRP, in the sediments are useful, and **Figure 5** shows how the levels of this fraction of P (which is so ecologically important on account of its immediate bioavailability) varied over the loch. Expressed on a specific areal basis the values ranged from *ca* 1 mg m^{-2} to nearly 8 mg m^{-2}. The spatial pattern is similar to those described for TP, except that the site immediately to the east of the cages, as well as the cage site itself, are considerably richer than the other sites. The corresponding TSP dataset is somewhat similar except that the values are 2-3 times greater than those shown for SRP, and sites 2, 3 and 4 appear to be richer than sites 1 and 5. Expressed in the same units as those of SRP in **Figure 5**, TP values in **Figure 3a** range from 500 mg m^{-2} to 4,500 mg m^{-2}, that is, some 500 times the levels of SRP.

The potential for release of phosphorus from the sediments

An indication of the relative likelihood of phosphorus (in SRP form) being released from the sediments and thus, contributing to the enrichment of the loch water, has been gained mainly by examining the levels of SRP in the following: the five main inflows (i.e. excluding 3 ditches entering the loch), the open water column (including the near-sediment zone), the outflow, and the sediment interstitial water. A further indication of the potential for P release was gained from the core incubation experiments.

That the loch - and most probably the sediments - may 'generate' P, is suggested by the nutrient data in **Table 1**. The concentrations of TP are considerably higher in the loch and its outflow (which itself is representative of open water), than in the feeder streams. The main contrasts are due to the particulate P fraction (the difference between the TP and the TSP values in the Table); this is likely to comprise phytoplankton, zooplankton and possibly, re-suspended sediment. Nevertheless, even at the early spring time of the present sampling, the SRP concentrations in the loch and the outflow are significantly higher than the stream levels.

That biological acitivity is involved, is suggested by the contrasts between the inflows and the loch as regards silica (SiO_2). In contrast to the situation with P, the levels of SiO_2 are far higher in the streams than in the loch. (SiO_2 is utilised by a number of plants including grasses as well as algae (Bailey-Watts 1976a). In many waters, however, the major decreases in this nutrient are due to its uptake by diatoms (Bailey-Watts 1976b; Bailey-Watts, Smith and Kirika 1989). In Drumore Loch it is likely that species associated with shallow (or at least illuminated) sediments and the surfaces of higher plants, are very important. A cursory examination of the phytoplankton samples (to which the $chlorophyll_a$ values in **Table 1** correspond) show that diatoms were dominant, although certain other silica-containing algae such as chrysoflagellates were also prominent.

Table 2 shows that the concentrations of both TSP and SRP in water taken from within 2 cm of the surfaces of the sediments were much the same (on this sampling occasion) as those shown for the water column in **Table 1**. The concentrations of these two P fractions in the sediment pore waters were very much higher, and (as illustrated using the SRP results in **Figure 6**) especially so in the cores taken from site 2 beneath the cages and from site 3. Plainly therefore, there is a very sharp gradient in SRP concentration from the high values in the deposits to low values in the overlying water; this would contribute to a flux of SRP from the sediments into the water column above.

Whether, and at what rates, SRP was moving out of the sediments on this occasion is unknown. A variety of factors need to be taken into account in interpreting the results of P release experiments conducted under laboratory conditions. However, **Table 3** shows that P in the form of SRP and as dissolved organic P (which, together with SRP constitutes TSP) is released. The values in this Table show that some P is released even in the 'cold' (6-7°C in this case). Higher rates of release can be induced, however, at a very good summer temperature (25-26°C). Certainly, the accelerated reduction of oxygen that would occur under the higher temperatures would enhance the mobility of SRP.

Discussion - placing the Drumore results in context

This section compares Drumore Loch with other waters on the basis of P levels expressed as percent of sediment dry weight. The Drumore values ranged from 0.20% to 0.83%. The highest values were associated with the cages, while the 2 sites to either side of the cages each gave somewhat lower values of 0.25% and 0.35%, and the two sites furthest away from the cages and to the eastern end of the loch yielded values of 0.20%.

Of the lochs for which the present author's have sediment P data, only Loch Shiel - and then only the sampling sites under smolt rearing cages there - yielded values higher than 0.83% (Bailey-Watts, Gunn, Kirika and Lyle (1993). Most of the other data obtained so far give values similar to those found at sites 4 and 5 in Drumore. Values from a total of 20 sites situated under, and at various distances from, the cages in the relatively shallow, western basin of that loch, ranged from 0.10% to 2.0%. Most of these values (see also Bailey-Watts and Kirika 1991 for Loch Eye data) came within the range 0.10% to 0.20%, however. It is interesting in this connection that the surveys of Bostrom, Jansson and Forsberg (1982) define this range as typical of 'eutrophic muds'. Samples of sediment from some 20 locations in the mud zone of Loch Leven (i.e. corresponding to the area of the loch that is ≥ 3m deep), yielded values ranging from 0.06% to 0.25% (Bailey-Watts and Kirika 1994), with no consistent relationship between these values and water depth, which ranged from 3 m to 20 m. An earlier, less comprehensive study (Bailey-Watts, May and Kirika 1991) recorded a range of 0.10% to 0.40%. Most of these values too, came within the range 0.10% to 0.20%, and and a mean figure of 0.14% is calculated from the uppermost 5 cm of the Loch Leven mud core analysed by Farmer, Bailey-Watts and Kirika (1994). In terms of sediment P levels, Drumore Loch overlaps with an enormous variety of other lochs. A pair of cores was taken from a total of 32 Scottish loch basins during the period May to August 1992 (Bailey-Watts, May, Kirika and Lyle (1992a, b). Fourteen P values came in the range 0.1% to 0.2% and included St Johns and Branxholme Easter. Somewhat richer waters such as Davan and Kilconquhar yieded values between 0.2% and 0.3%, while the base rich Blairgowrie systems yielded values between 0.3% and 0.4%. The 'urban' Linlithgow Loch, and the Loch of Cliff (Unst, Shetland Isles) which has fish cages (Bailey-Watts 1990), gave values between 0.4% and 0.5%.

The data used to put the Drumore findings in a broad context are likely to include those for 'other similar standing waters' as itemised in the original aims of the study. Nevertheless, a more extensive examination than has been possible so far, is needed of the actual nature of these waters as regards area, depth, catchment type and the physical and chemical characteristics of the sediments.

A very preliminary comparison has been made between the inflow and loch water P levels measured during the present (April 1995) study and those obtained in August 1982 and referred to above.

In summary , P levels are considerably lower now. **However, Karen: I have not been able to check with FFL whether their figures are actually expressed as 'P' (which I think they are), or as 'PO_4'. This would make a difference!**

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FIGURES

Figure 1. Sketch map of Drumore Loch indicating the locations of the 5 inflows which were sampled at a point near their confluence with the loch; and the 5 in-loch sampling sites where sediment samples were taken. Sediment for the phosphorus release experiments, and water for nutrient and chlorophyll analysis were taken from site 3. The fish cages are located at site 2.

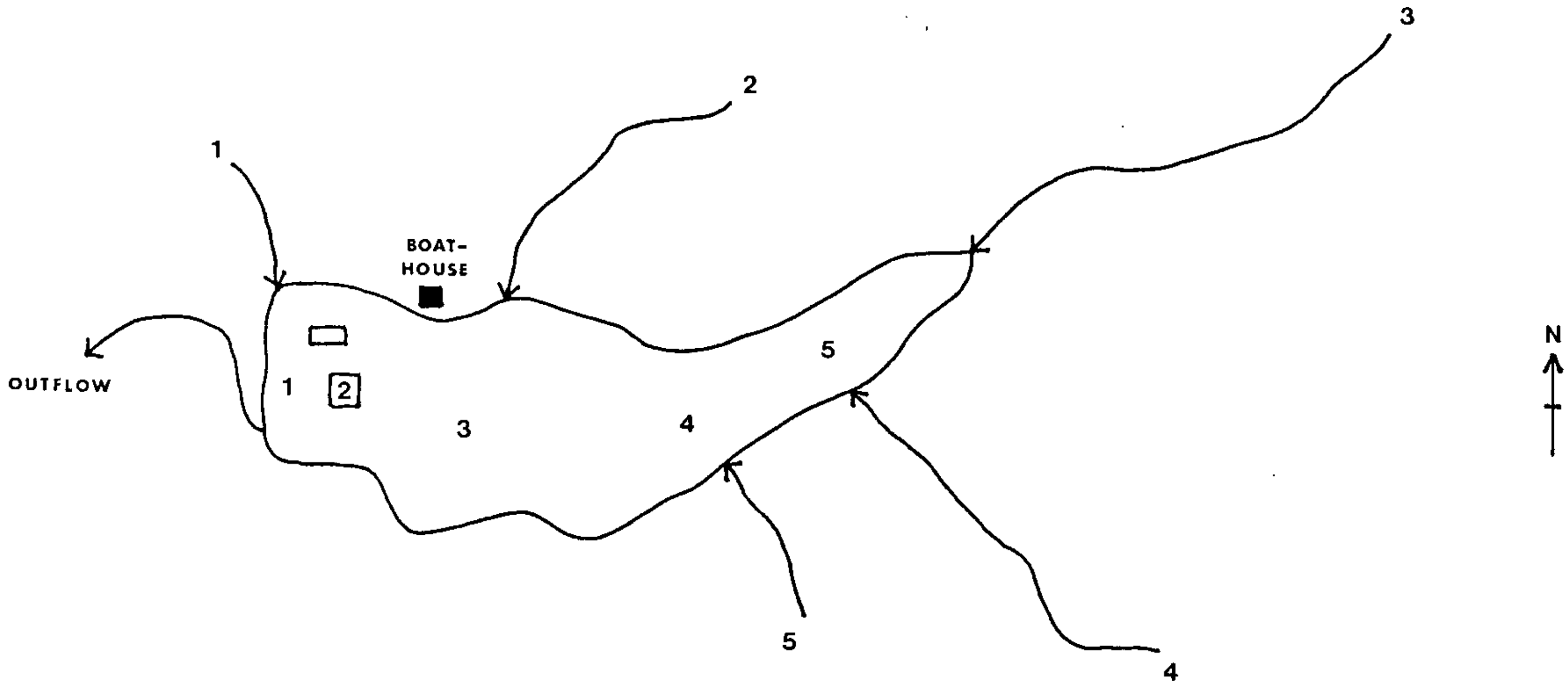

3
2
1
BOAT-
HOUSE
OUTFLOW
1
2
3
4
5
5
4
N

Figure 2a. Variation in water temperature with depth.

Drumore Loch 11.4.95

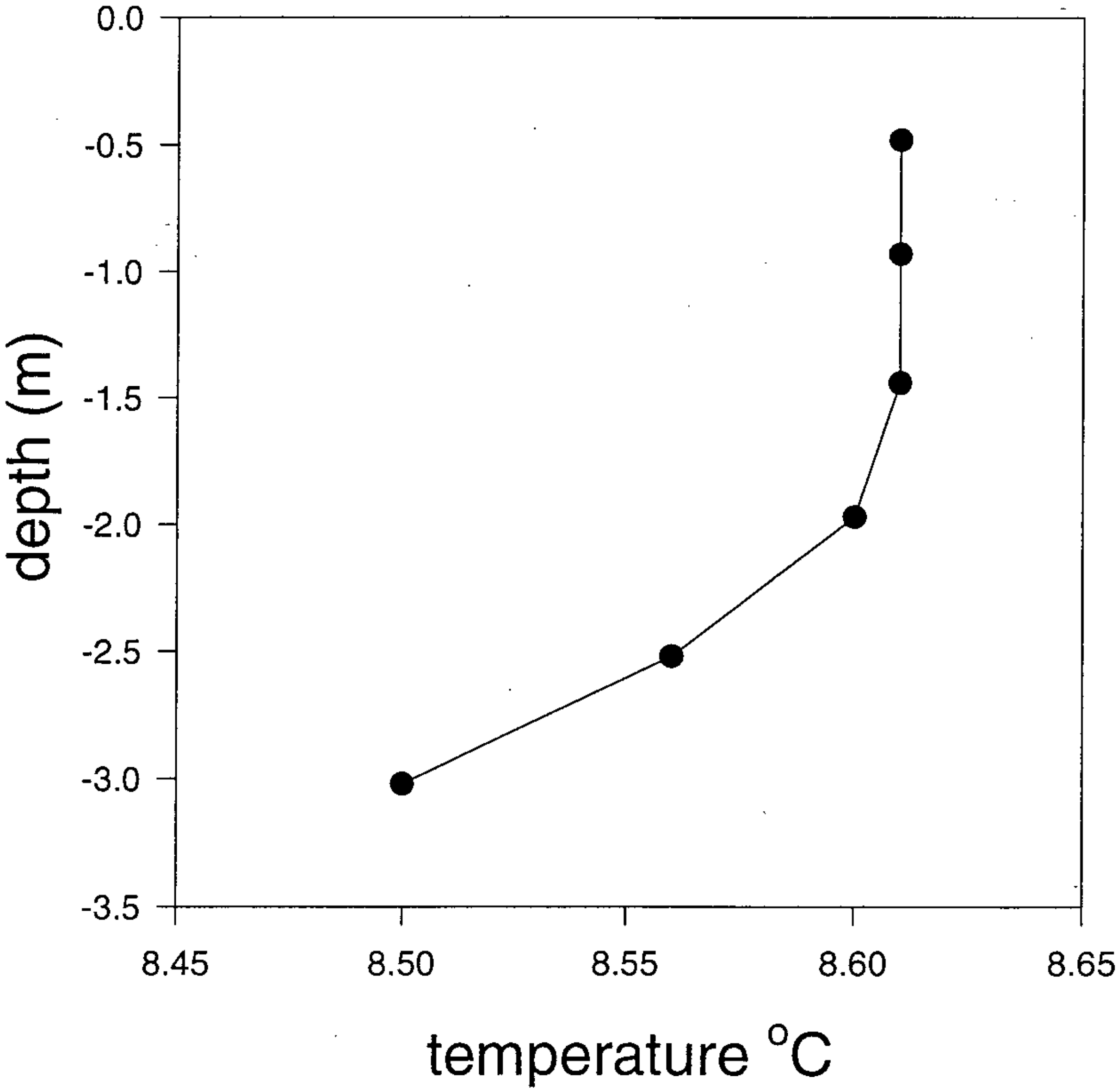


Figure 2b. As Figure 2a for the percent saturation of dissolved oxygen.

Drumore Loch 11.4.95

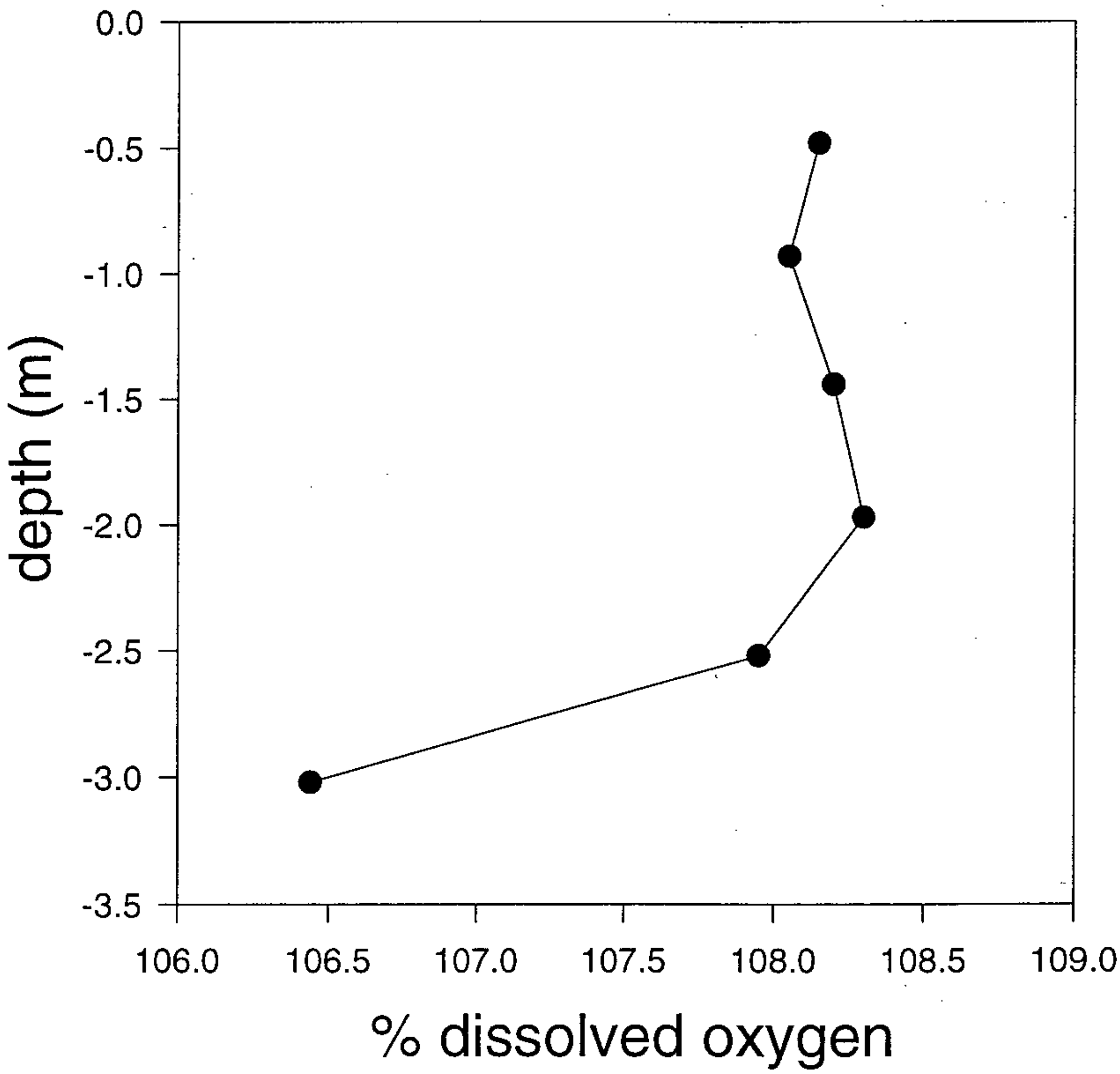


Figure 2c. As Figure 2a for conductivity.

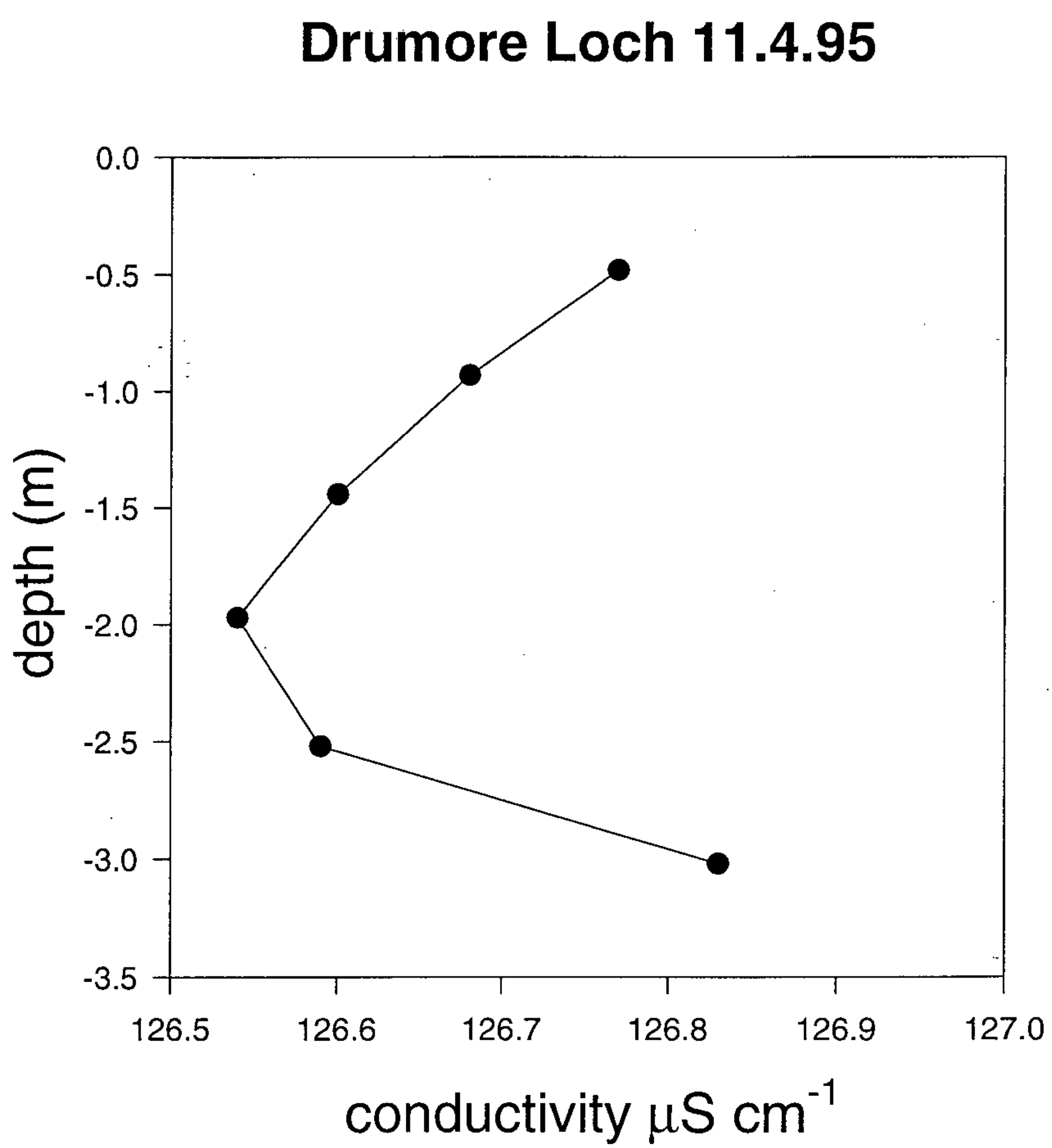

Drumore Loch 11.4.95
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
depth (m)
126.5
126.6
126.7
126.8
126.9
127.0
conductivity µS cm-1

Figure 2d. As Figure 2a for pH.

Drumore Loch 11.4.95

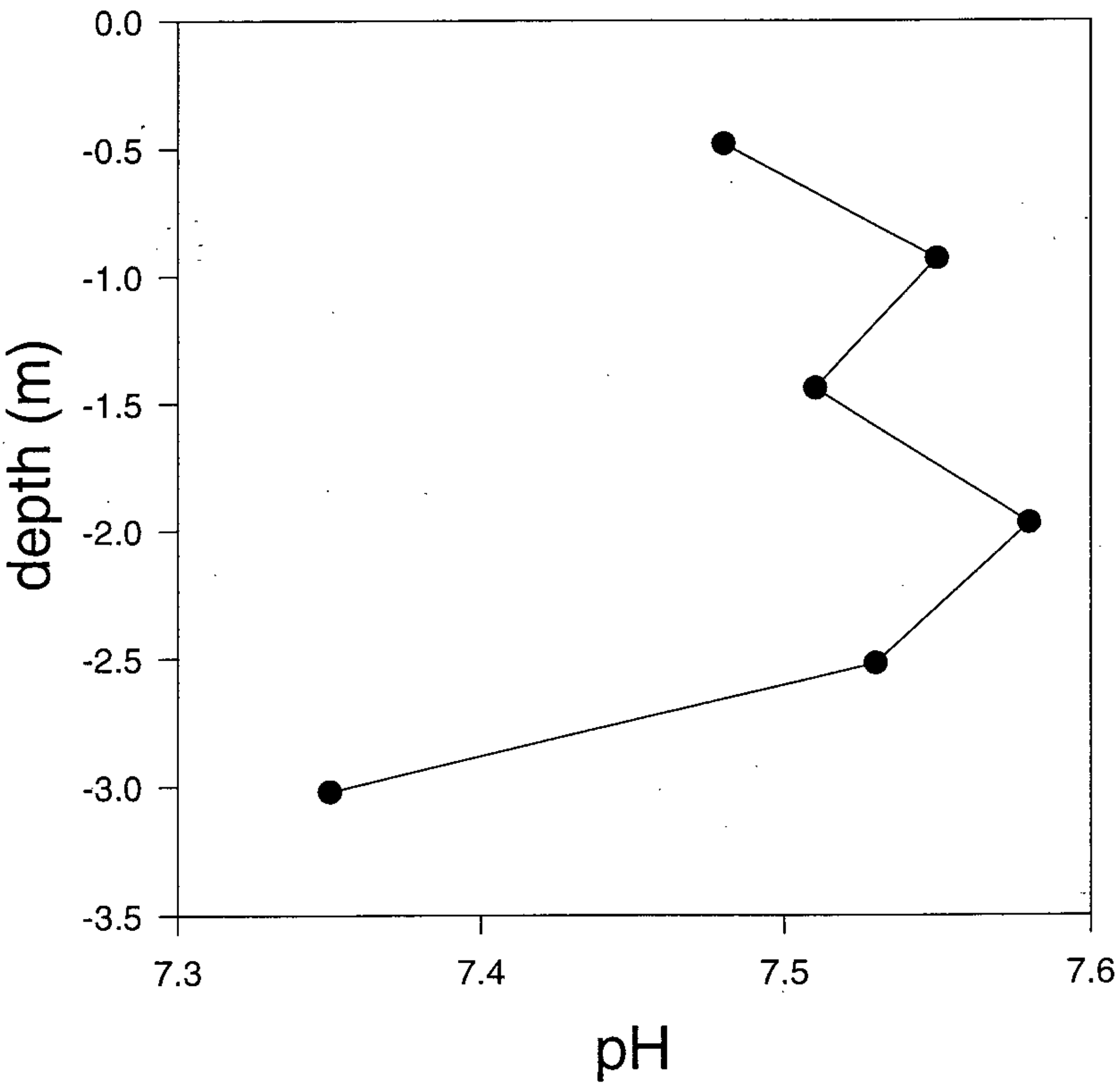
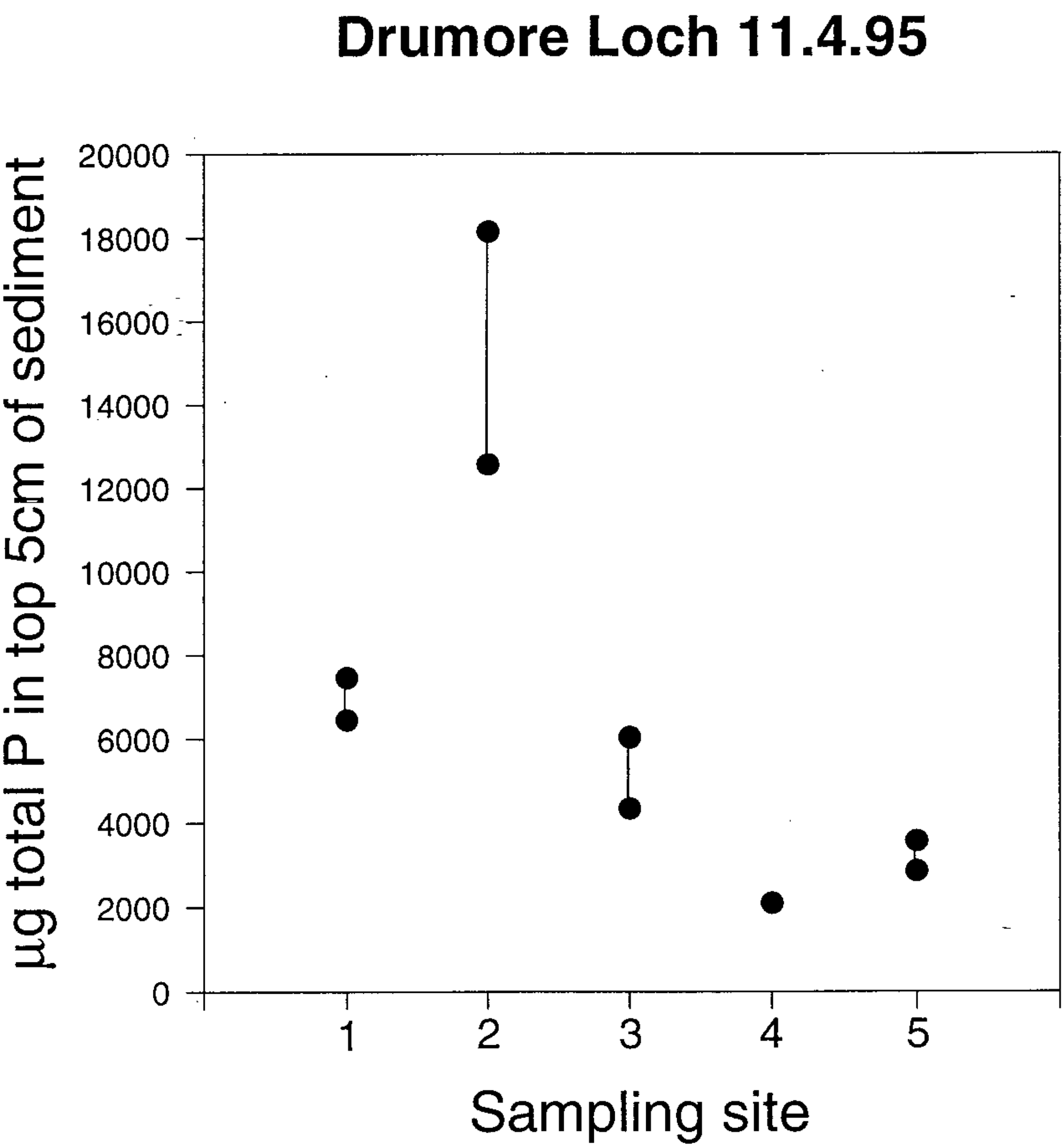
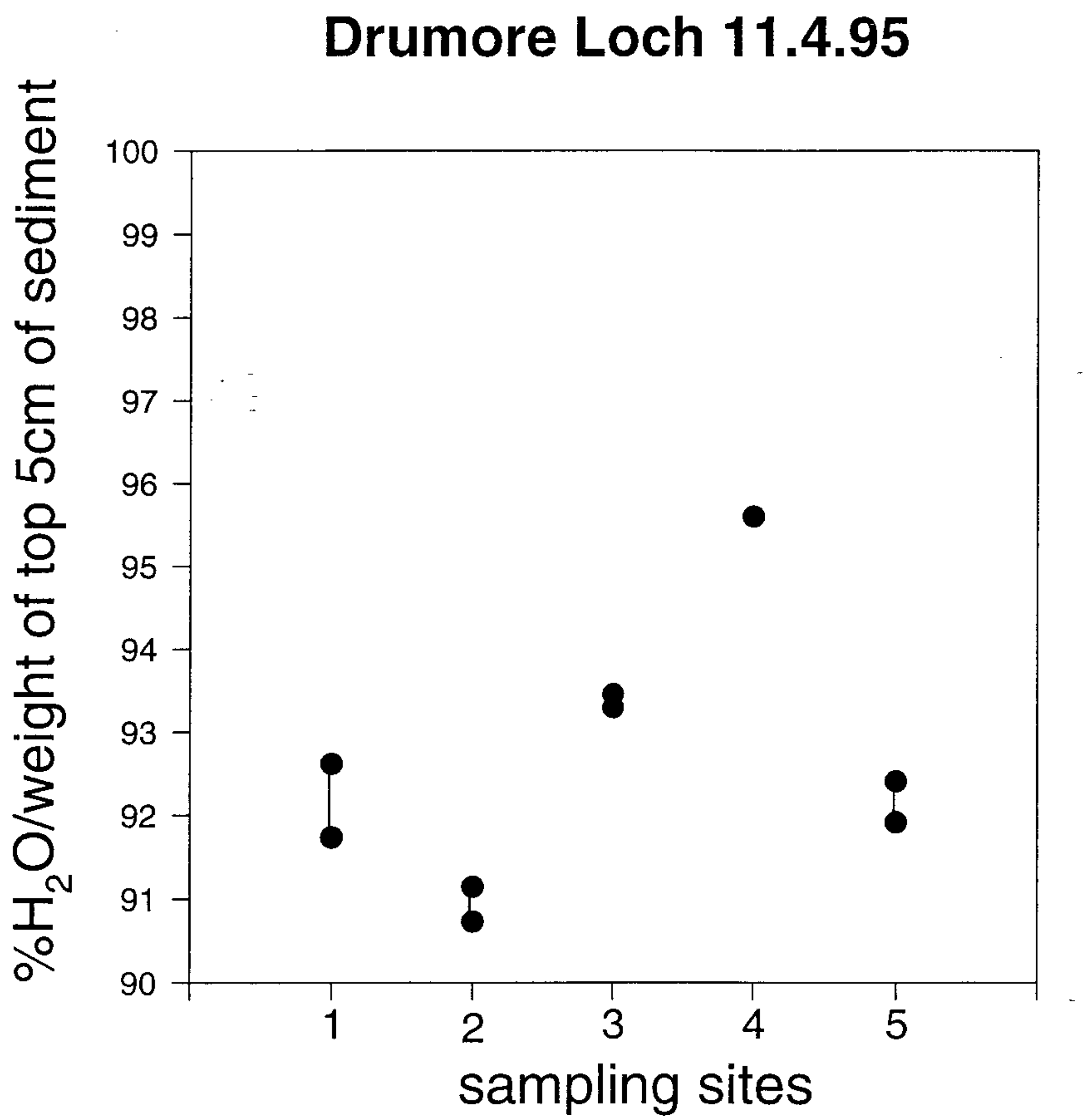


Figure 3a. The weight of total phosphorus in the top 5 cm of each of the two Jenkin mud cores (diameter 7 cm) collected from sites 1, 2, 3 and 5 (passing from west to east along the centre of the loch); the fish cages are at site 2. Only one core was secured at site 4.



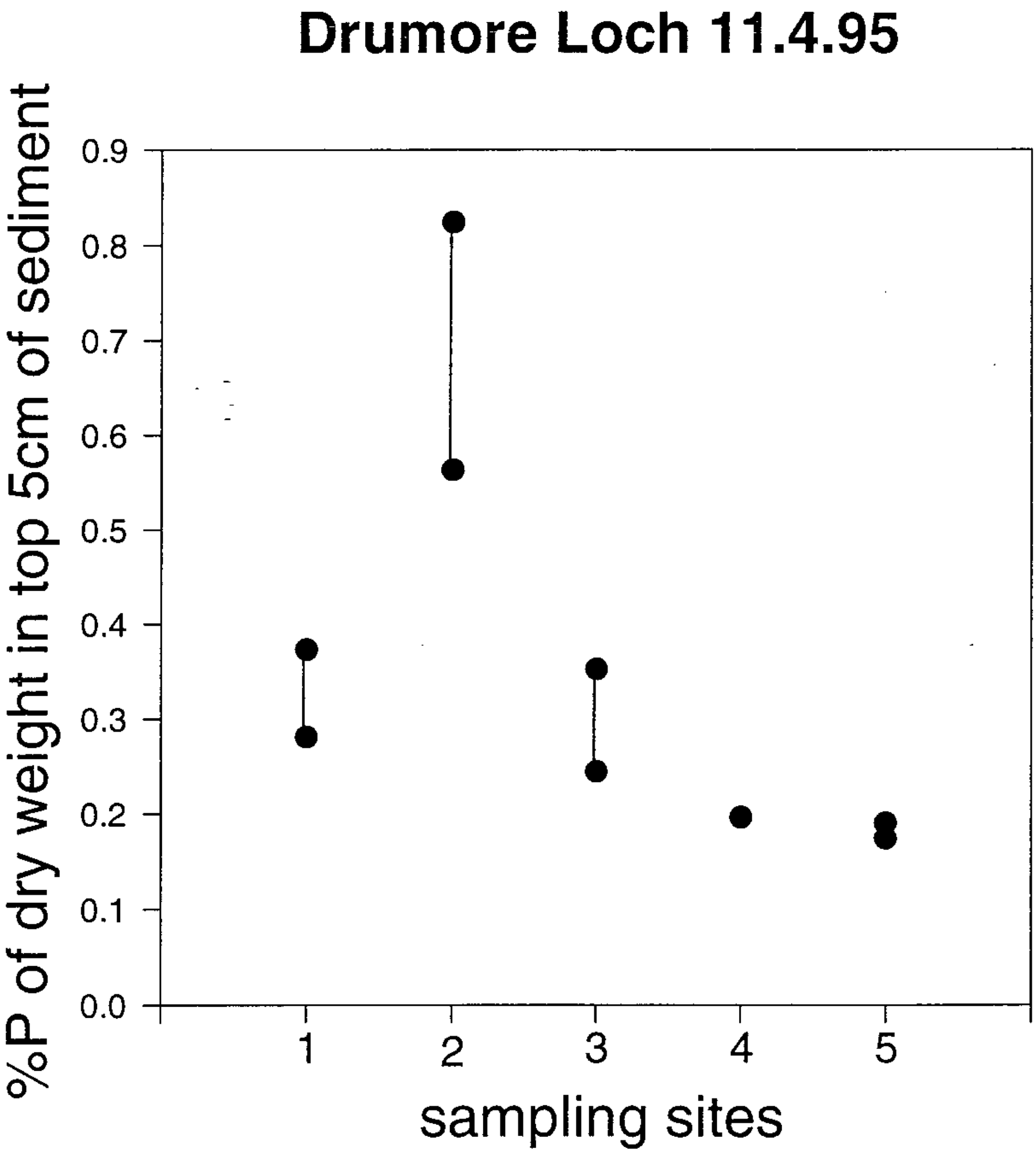
Drumore Loch 11.4.95
µg total P in top 5cm of sediment
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1
2
3
4
5
Sampling site

Figure 3b. As Figure 3a for the water content of the sediment.



Drumore Loch 11.4.95
%H2O/weight of top 5cm of sediment
100
99
98
97
96
95
94
93
92
91
90
1
2
3
4
5
sampling sites

Figure 4. As Figure 3 for sediment P expressed as percent of dry weight.



Drumore Loch 11.4.95
%P of dry weight in top 5cm of sediment
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
sampling sites

Figure 5. As Figure 3 for the amounts of soluble reactive phosphorus (SRP) in the sediment, expressed per square metre of mud surface.

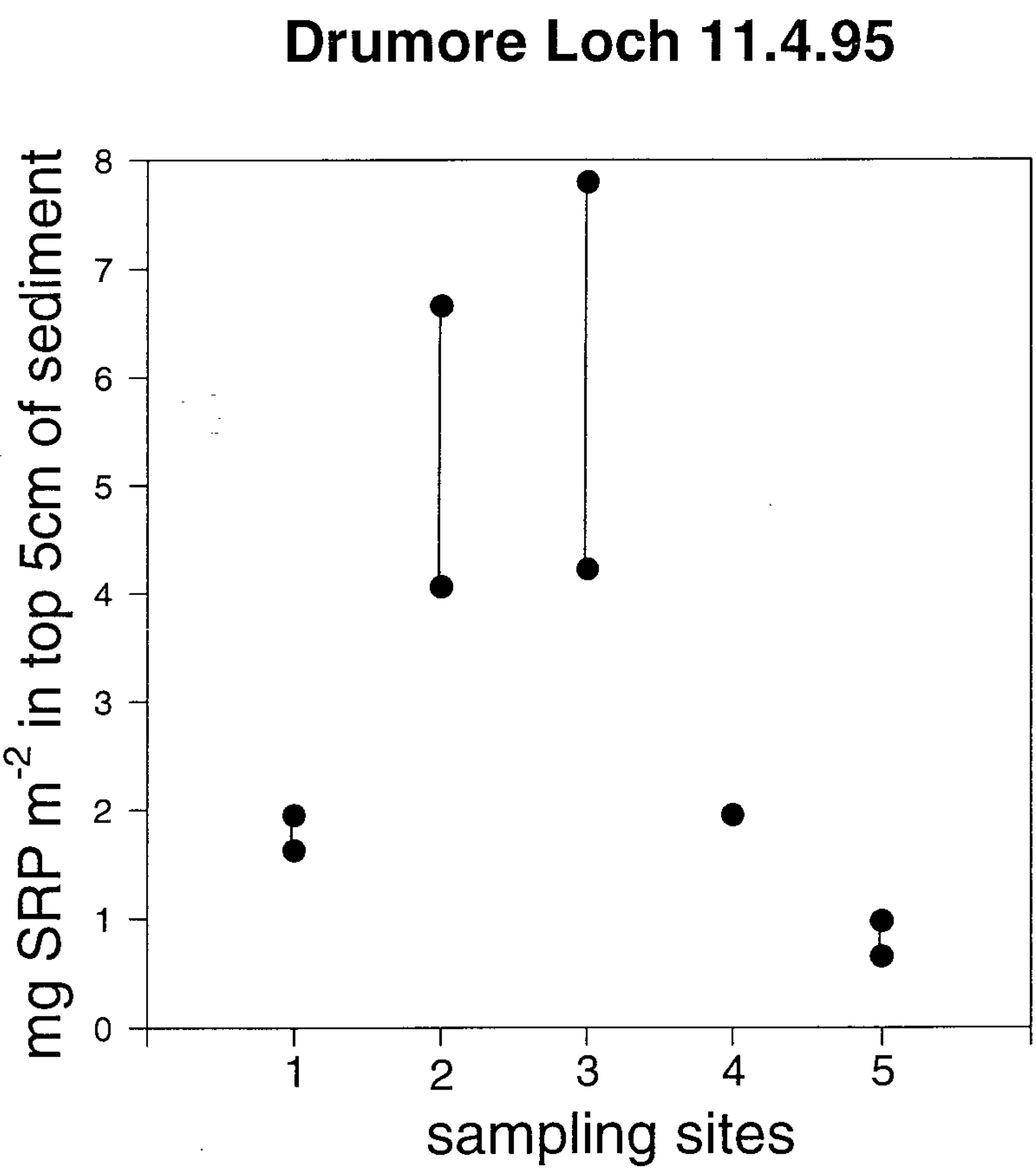

Drumore Loch 11.4.95
mg SRP m-2 in top 5cm of sediment
0
1
2
3
4
5
6
7
8
1
2
3
4
5
sampling sites

Figure 6. As Figure 3 for the concentrations of soluble reactive phosphorus (SRP) in the sediment pore water, and water taken from within 2 cm above the sediment surface.

Drumore Loch 11.4.95

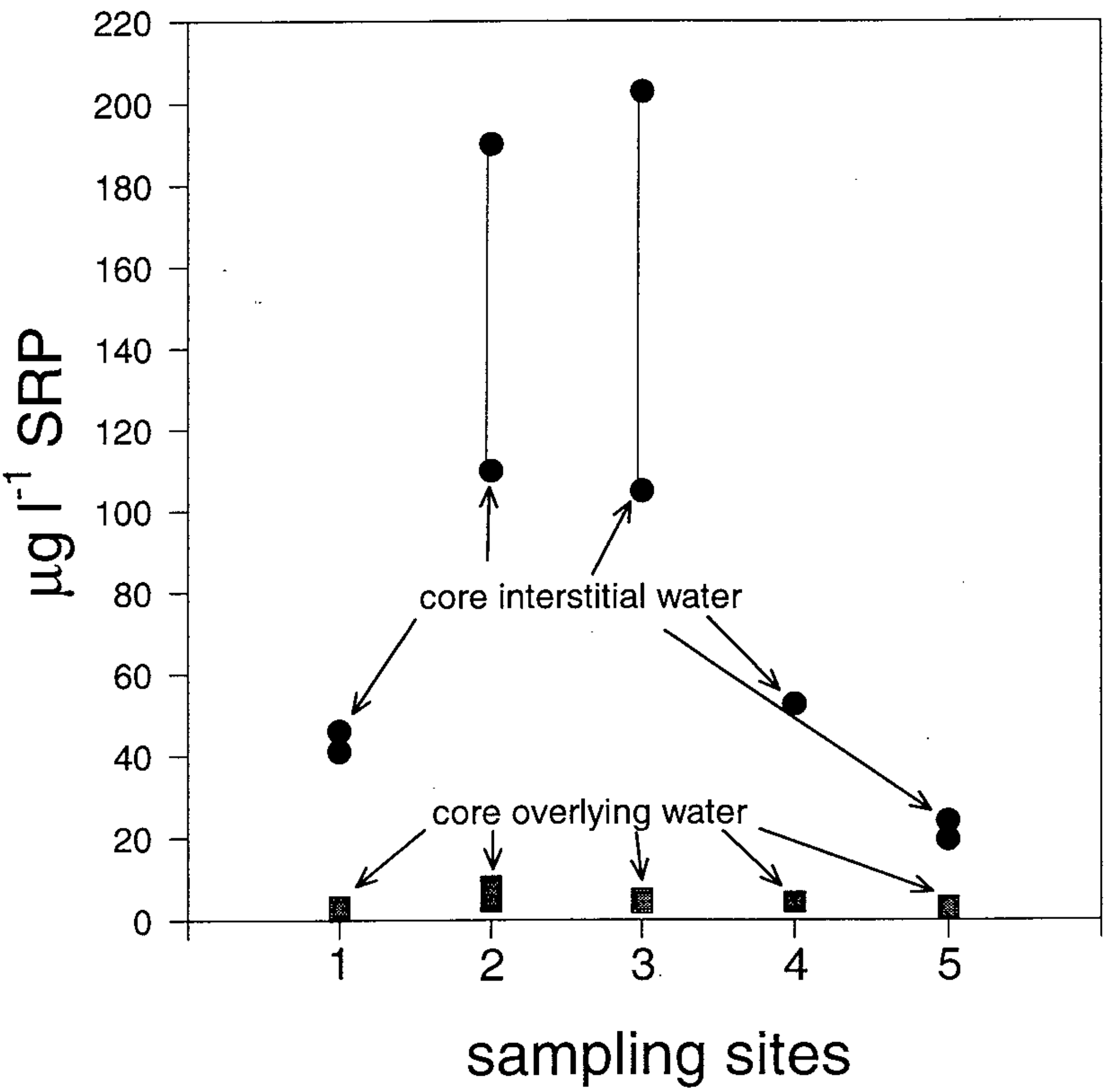


Table 1 (upper). Results of the analyses of total phosphorus (TP), total soluble phosphorus (TSP), soluble reactive phosphorus (SRP) and soluble reactive silica (SiO_2) in open water in the loch, the outflow, and the inflows, and the chlorophyll$_a$ levels measured in open water.

Table 2 (lower). As Table 1 for TSP and SRP in the sediment pore water and water overlying the sediment; Figure 6 displays the SRP data.

Site	Total P µgP/l	Total Soluble P µgP/l	Soluble Reactive P µgP/l	Soluble Reactive Silica $mgSiO_2/l$	Chl.*a* µg/l
Openwater	22.4	12.5	3.9	0.93	8.6
Outflow	21.1	12.2	3.3	0.94	12.0
Inflow 1	6.3	4.5	1.8	5.09	
Inflow 2	4.5	2.5	1.0	4.95	
Inflow 3	5.2	3.1	2.6	5.58	
Inflow 4	5.6	4.2	2.4	6.29	
Inflow 5	5.2	3.2	2.7	6.67	

Core	overlying water		interstitial water	
	Soluble Reactive P µgP/l	Total Soluble P µgP/l	Soluble Reactive P µgP/l	Total Soluble P µgP/l
1A	3.3	13.0	41.0	199.5
1B	2.2	11.7	46.0	185.5
2A	4.4	12.3	190.0	494.0
2B	8.2	18.0	109.8	362.3
3A	5.1	11.6	202.8	403.5
3B	4.0	11.6	104.8	392.0
4A	4.3	12.8	52.5	429.0
5A	3.2	12.5	24.0	297.0
5B	2.8	11.1	19.5	269.0

Table 3. The results of the P release incubation experiments using a pair of cores taken from site 3, showing the concentrations of TSP and SRP in the water overlying the cores, at the start of the experiment (11 April) and on the subsequent dates shown; 'cold' refers to a temperature of 6-7°C, while 'warm' denotes a temprature of 25-26°C.

Date	Core	overlying water	
		Soluble Reactive P μgP/l	Total Soluble P μgP/l
11.4.95	3A	5.1	11.6
11.4.95	3B	4.0	11.6
20.4.95	Cold 1	6.6	12.8
20.4.95	Cold 2	7.2	17.3
20.4.95	Warm 1	15.3	24.5
20.4.95	Warm 2	8.0	16.7
21.4.95	Cold 1	5.9	13.5
21.4.95	Cold 2	6.2	15.9
21.4.95	Warm 1	15.0	26.5
21.4.95	Warm 2	16.4	28.7
30.4.95	Cold 1	8.9	13.9
30.4.95	Cold 2	6.3	12.6
30.4.95	Warm 1	25.0	32.9
30.4.95	Warm 2	23.5	31.6