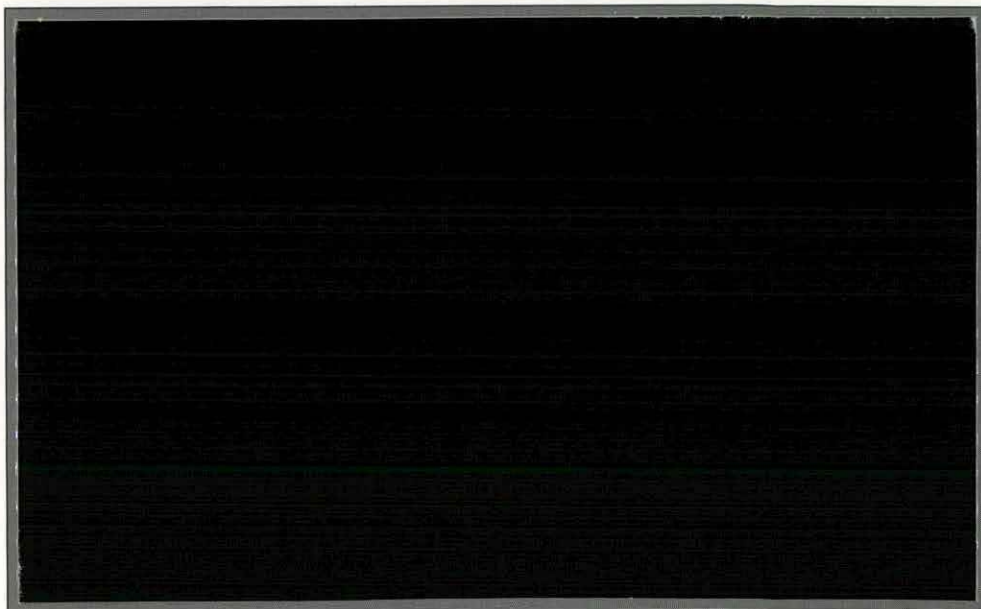


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Institute of Freshwater Ecology
Edinburgh Laboratory, Bush Estate, Penicuik
Midlothian, EH26 0QB, Scotland
Telephone 031 445 4343; Fax 031 445 3943

**Nutrients and Phytoplankton of the Loch of Cliff,
Unst, Shetland**

Project Manager: A E Bailey-Watts

Interim Report to Fish Farm Development Ltd.
Ardrishaig, Argyll (December 1990).

Principal Investigators: A E Bailey-Watts, BSc, PhD, MIWEM
A Kirika

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NUTRIENTS AND PHYTOPLANKTON OF THE LOCH OF CLIFF,
UNST, SHETLAND: RECONNAISSANCES PRIOR TO FISH CAGE INSTALLATION

Introduction

This report presents the findings from (i) work on water and plankton samples collected in December 1989, and April and August 1990, and (ii) the visit to the Loch of Cliff in August 1990, when vertical profiles of physical and chemical features of the water and sediments were measured. It thus updates on the progress presented in the report submitted in December 1989⁽¹⁾, but, like that report, compares the results with conditions recorded during an NERC survey of Shetland freshwaters in 1974.

Methods

Fieldwork

Profiles of temperature, dissolved oxygen, conductivity, pH, and light attenuation, were recorded with sensors incorporated into a 'Windermere Profiler', which also contains a depth transducer - all coupled to a 'Husky' data logger. The precision of the various instruments is indicated by the data which are tabulated below. On this occasion, an additional measure of water clarity was obtained by lowering a black-and-white, quartered, Secchi disc (25 cm in diameter) into the water, and recording the depth at which it could no longer be seen.

Water for nutrient and phytoplankton analyses was collected by dipping the sample bottles below the surface and allowing them to fill. Samples were taken from the intended cage site in the centre of the main basin of the loch (C, where the water is ca 5.5 m deep), and from the middle of the Arm of Quoys (Am, ca 3.5 m) on all three occasions, and additionally on 2 August 1990, from the entrance to the Arm (Ae, ca 4.5 m) as this is where the outflow pipe from the hatchery used to discharge. A single core of sediment was taken at each of the three sites, with a Jenkin Surface Mud Sampler. Cores ranging in length from 15 cm to 20 cm were obtained. The water collected in December and April was posted to the Edinburgh Laboratory of IFE for analysis. The water samples taken during the August field visit were placed in a cool box immediately after collection. Water filtered through Whatman glass-fibre discs (GF/C grade - nominal pore-size 1.2 μm) was used for dissolved nutrient analysis, and unfiltered subsamples were prepared for particulate chemistry and phytoplankton analysis; the phytoplankton samples were fixed with Lugol's Iodine. Water immediately overlying the sediment was siphoned out of the core tubes and saved for nutrient analysis. The sediment was then extruded out of the top of the core tube and removed a centimetre at a time; the 1-cm slices were transferred to polythene bags and kept cool during transport back to Edinburgh.

Laboratory work

The filtered samples were used for determinations of:

- *nitrate* ($\text{NO}_3\text{.N}$) by hydrazine reduction
- *total dissolved phosphorus* (TDP) by acid digestion; this converts all forms of P to the soluble reactive state, which was then

measured by acid molybdate complexing

- *soluble reactive P* (SRP - the form of P most readily taken up by algae) by acid molybdate complexing without prior acid digestion
- *soluble un-reactive or dissolved organic P* (see later) by calculating the difference between the levels of TDP and SRP
- *soluble reactive silica* (SRS as SiO_2) by molybdate complexing and reduction with ascorbic acid.

Aliquots of unfiltered water were used for measurements of:

- *total phosphorus* (TP) by the procedure used for TDP
- *particulate P* (ie the P in algae and other suspended particles including detritus) by calculating the difference between the concentrations of TP and TDP
- *total silica* (TS as SiO_2) by sodium bicarbonate digestion; this converts diatom and any other algal silica to SRS which was then measured as above
- *algal silica* by calculating the difference between TS and SRS
- *total phytoplankton abundance* as chlorophyll *a* concentration by absorption spectroscopy; this was done with centrifuge-cleared, methanolic solutions of the pigment, obtained by steeping GF/C pads (with trapped algal material from measured volumes of water) in the solvent overnight in a dark cabinet maintained at ca 4 °C; the equation of Talling and Driver ^[2] was used to convert the absorbances read at 665 nm to concentrations of chlorophyll *a*
- *phytoplankton species composition and cell numbers* by microscopic examination of the iodine-fixed material; the cells were concentrated by sedimentation in graduated glass cylinders (200 ml); aliquots of the usually, 20-fold concentrate were introduced

into a Lund nanoplankton counting chamber for enumeration; in essence, for small organisms requiring examination under high power magnification (eg 500 x), the chamber is moved by means of the microscope stage controls, and cells are counted at each 'random' point within mini-quadrats delimited by a square on a graticule incorporated in one of the viewing eyepieces; larger (and usually rarer) forms, are more conveniently assessed under lower magnifications, (e.g. 50 x, 100 x) by 'surveys' of the whole chamber, or longitudinal transects of it

- *the size distribution of the phytoplankton*; the greatest dimension of each of 30 randomly-chosen algal individuals was measured with a Vickers Image-shearing module; together with the information on the abundances and types of organisms, the size information gives valuable clues about aspects of the physical nature and chemical characteristics of the waterbody in which they develop, and about the other organisms (e.g. zooplankton) that are present.

Mud from each core slice was subsampled for wet-weight, dry-weight, and total P determinations, and for centrifuging to obtain interstitial water for TDP, SRP and SRS analysis as for the overlying water. Exchanges between sediment particles and interstitial water, of inorganic P especially, but to some extent those of inorganic SiO_2 too, are controlled very much by ambient oxygen and 'redox' levels. Phosphate ions are likely to be rapidly adsorbed under the conditions of handling the mud as described here. As a consequence the concentrations of P in the interstitial water as reported below, are almost certainly underestimates of the actual levels. Ideally, the core slicing and sub-sampling should

be carried out under an inert atmosphere of argon; this was not possible during the Cliff expedition, although means of achieving this in the future are being considered.

Results

Profiles

The ranges of values over depth (Table 1) indicate that the water was reasonably homogeneous from top to bottom; in keeping with the generally calm conditions that prevailed at the time, however, there was some evidence of a trend in temperature with slightly warmer water at the surface at sites Ae and Am. Between-site differences were also minor, and the strong overlaps of the ranges of the determinands indicate a fair degree of similarity between different parts of the loch.

As to oxygenation, the concentrations listed in Table 1 represent nearly 100% saturation for the prevailing temperatures, although there were slight decreases in concentration with depth; near the bottom at sites C and Ae, values are some 0.5 mg l^{-1} lower than the corresponding surface figures, while a difference of just over 1 mg l^{-1} was recorded at Am. Favourably alkaline pH values (overall range 7.61 to 7.92) and conductivities in keeping with a maritime situation, were recorded.

The patterns of light attenuation at the three sites were also very similar (Figure 1). The intensity of light within the photosynthetically active radiation band (PAR, 400 nm to 700 nm wavelength) is reduced to 1% of the surface value at ca 3.5 to 4.0 m depth - these figures corresponding to the Secchi disc readings of 2.3 to 2.5 m.

Nutrient concentrations in the water column

The concentrations of $\text{NO}_3\text{.N}$ and SRP were generally low with values of a few tens of micrograms of N per litre, and SRP levels of less than $5 \mu\text{g l}^{-1}$ being typical (Table 2). These reflect an oligotrophic-to-mesotrophic environment, although the values represent the pools of nutrients that are potentially still available to planktonic and/or rooted plants for further growth ie not what is already incorporated into these organisms. By contrast, dissolved SiO_2 levels are reasonably high, as are the excursions of the values - equivalent to *ca* $5 \text{ mg SiO}_2 \text{ l}^{-1}$. If diatoms are the cause of these shifts in silica, some $100 \mu\text{g P l}^{-1}$ and possibly $1 \text{ mg NO}_3\text{.N l}^{-1}$ would have been utilised at the same time. Supplies of N and P of this order in the Loch of Cliff are unlikely, however. In the absence of further information, it must be concluded that changes in silica are probably controlled primarily by physical and chemical processes, and not diatoms or other silica-utilising organisms - in the plankton at least. Indeed, while diatoms are relatively prominent at times (see below) their populations often suffer considerable losses through sinking on to the sediments, so the levels recorded in the water column are very moderate - as indicated by the diatom silica values in Table 2.

Table 2 indicates how much phosphorus is present - in total (TP) and in other forms, including particles (PP) and dissolved organic material (TDP-SRP). PP levels are low, and as these represent the P in all of the suspended matter - of which phytoplankton is but one component - it is plain that algal levels are also low (see below). Indeed, in August 1990, TDP exceeded PP by far, and the dissolved organic component possibly

associated with humic acids derived from peat, comprised 60 to 65% of TP.

While P is the most common nutrient limiting phytoplankton growth in temperate freshwaters, N is often 'short' in summer. The low ratios of nitrate-N to phosphate-P recorded in August 1990 (e.g. 3:1 to 6:1 by weight) suggest that this is the case in the Loch of Cliff.

Sediments

Much of the wind-driven and waterborne materials entering a lake basin, and the remains of chemical and biological material formed within the lake, may become incorporated into the sediments. As such, the deposits can supply valuable information about the overlying water and the catchment; what is more, the information is not as specific (as are the data on water samples) to the instant of sampling. However, the analysis of sediment cores is difficult, with one of the hallmarks being the considerable variability in physical and chemical texture between sites even within the same area of lake bottom; conclusions about differences between the three sites sampled in the Loch of Cliff therefore, as opposed to the character of the open water deposits there as a whole, should be interpreted with caution. The core analyses cover water content, the concentrations of phosphorus and silica in the interstitial water, and the total phosphorus content of the sediment.

While the range in water content is only 13%, i.e. 77% to 90% by weight, the depth profiles suggest that the deposits at site Ae are the most uniform of the three over depth (Figure 2); moreover, the material at Ae

appears to be slightly, but consistently, wetter than the cores taken elsewhere. In other respects the values for percentage water by weight, are generally similar to organic deposits in lakes elsewhere.

Concentrations of phosphorus in the sediment interstitial water, vary considerably with depth into the mud. Even in the surface layers, the values can be well in excess of the levels determined in the overlying water, where very similar values were recorded at all three sites.

At almost any depth in the mud, concentrations of hundreds of micrograms per litre were measured. Yet, for reasons outlined in 'Methods', these are likely to underestimate the interstitial P levels. So, no single site is consistently richer than another over the whole depth of core (Figure 3a). The values here refer to the inorganic component of the soluble P (ie SRP) and this represents some 60% to 70% of the total soluble P (ie TDP).

Contrastingly, the changes exhibited by silica (Figure 3b) do appear to differ between sites - with particularly distinct profiles below ca 3 cm into the sediments. As with soluble P, however, the SiO_2 concentrations in the interstitial water are considerably greater than the values found in even the immediately overlying water. The concentrations there also appear to be more or less identical at all three sites.

Plainly, the interstitial pools of P and SiO_2 are of potential significance to the functioning of the phytoplankton in the overlying water. The nutrient concentrations are not only high, but often increase with depth into the muds. It is these concentration gradients that could 'drive' the nutrients out of the sediments, although redox potential and degree of

wind-induced mixing (water movements) will influence the rate of release. It is worth considering, however, by how much the nutrient concentrations would be elevated in the overlying water, in the event of all the P and SiO₂ from say, the uppermost 5 cm of sediment being rapidly released.

Concentrations of 100 µg SRP and 20 mg SiO₂ are typical of these upper layers. If these also represent the water comprising 85% by weight of the deposits, (say 80% by volume) the pore water in the 0 to 5-cm layer contains 4 mg P m⁻² and 800 mg SiO₂ m⁻² (i.e. some 4.5 kg P and 900 kg SiO₂ over the whole loch). If these amounts were mixed into the overlying water (total volume of 3.4 x 10⁶ m³) the concentrations would be raised by 1.3 µg P l⁻¹ and 0.26 mg SiO₂ l⁻¹. These are both rather minor amounts, and what is more, are likely to overestimate considerably the impacts of the sediments, since the calculations assume that all the nutrients in the pore waters to 5 cm depth are suddenly released - and this is unlikely. As in many other situations, however, when sediment release is suspected, it is likely to increase the concentrations in shallow overlying waters much more significantly. The apparent anomaly is explained by the fact that the fluxes of material from sediment particles, rather than the standing stocks in the pore waters, are important; so, by dissolution of e.g. diatom remains in the case of SiO₂, and dissolution and desorption of soluble ions in the case of P, quite massive amounts of material can be exchanged between the solid phase and the interstitial water and, thence, the overlying water. To assess, whether, for P at least, the potential for such changes is likely in the Loch of Cliff, results on the total amounts of P in the sediments can be examined.

On a dry weight basis, the nutrient comprises small fractions of 1% of the

sediment (Figure 4) with values in the upper 2 cm at Am and Ae, and the top 3 cm at C being distinctly higher than those in deeper layers. Only at site Am is there a consistent trend of decreasing P content from the surface to even 5 cm depth, and thereafter, none of the profiles exhibits any consistent or major pattern. Nevertheless, there is some indication that, overall, the deposits at Ae are the richest in P. The organic matter and mineral contents of the sediments have not been determined, but casual observations suggest that the sites do not differ markedly in these respects; so, the lower P values as expressed here, at Am and C are probably not explained by, for example, correspondingly higher contents of relatively dense mineral material. While the P contents may appear small, the sediment represents a considerable sink of the nutrient. If a value of 0.15% P is taken to be the average for the uppermost 1 cm, and the dry matter (comprising 20% of the sediment volume) has a relative density of 1.1 g cm³, a slice of 1 square metre of this thickness will contain 11 g P m⁻² (i.e. 12.3 tonnes in the whole loch - many thousands of times the amount of P in the pore water). If this amount were released into the overlying water column, the concentrations there would be raised by 1.08 mg P l⁻¹. This is an extraordinarily high figure, and one unlikely to occur since only a small fraction of the P in the sediment is likely to be labile and easily solubilised; nevertheless, if only 1% of this were mobilised, concentrations in the water above would rise by *ca* 11 µg l⁻¹ - so illustrating the enormous potential of the sediments as a source of P.

Phytoplankton

While samples have been taken only at 4-monthly intervals, total algal biomass appears to be very moderate, with chlorophyll *a* levels usually

below $5 \mu\text{g l}^{-1}$. Table 4 gives the pigment values, and information on the approximate abundances (plus or minus 50% for the numerically dominant forms, and plus or minus 200% for the rarer individuals) of phytoplankton within four, operationally-determined, size classes. Major features are (a) the numerical predominance of a wide taxonomic variety of small algae ('nanoplankton') at 6×10^3 to $12 \times 10^3 \text{ ml}^{-1}$ and (b) the occasional importance *vis-a-vis* biomass, of diatoms such as *Diatoma* and *Aulacoseira* at a few hundreds per millilitre, and the large dinoflagellate *Ceratium* and the colonial green *Botryococcus*, albeit at only one or two individuals per millilitre. Figure 5 displays two examples of the size distribution of the phytoplankton assemblages, and these highlight the numerical importance of small forms ($< 5 \mu\text{m}$, for example).

DISCUSSION AND CONCLUDING REMARKS

The water and sediment chemistry give but a vaguest indication that the Arm of Quoy's sector is richer in nutrients than the main basin. The slightly greater difference in oxygen content between the near-bottom layer and the surface at Am, could also suggest greater enrichment there. In all respects, however, the state of the loch is good, and appears to be little different in respect of pH and conductivity, for example, from conditions recorded during our 1974 surveys. The algal information gathered so far, also suggests an intrinsically fairly nutrient-poor water. Nevertheless, diatom species such as *Asterionella* indicate that the environment is not ultra-oligotrophic.

The loch could be quite sensitive to any Man-induced changes. Thus, alterations to land use, or other developments in the catchment, should be carefully monitored - indeed thoroughly discussed at an early planning stage. The catchment area (27.3 km²) is some 24 times that of the surface area of the loch itself (1.1 km²); this is a high ratio. Being also shallow (3.05 m mean depth), the loch will be relatively susceptible to changes in nutrient burdens - whether these originate from the surrounding land or enter the water directly in connection with the feeding of fish in mid-water cages (recently installed - October 1990). A watching brief needs to be maintained.

Plainly, the potential of the sediments to enrich the overlying water is considerable, and in the event of a warm, calm spell of weather, releases of P can be expected. Then, the consequences will depend very much on prevailing flushing regimes. If water residence time is lengthened, any increases in nutrients may be rapidly manifested as algal 'blooms'. Contrastingly, under conditions of short residence time (i.e. rapid flushing), such biological developments are unlikely, and indeed, any P released from the deposits may be removed from the loch in water passing down the outflow.

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- [2] Talling, J.F. and Driver, D. 1963. Some problems in the estimation of chlorophyll *a* in phytoplankton. In: Proceedings, Conference on *Primary Productivity Measurement, Marine and Freshwater*, Hawaii 1961, pp. 142-146. U.S. Atomic Energy Commission, TID-7633.

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T A B L E S

Table 1: Variation with depth in water temperature, conductivity and pH at 3 sites in the Loch of Cliff on August 2nd 1990.

		Ranges of values recorded					
sampling site and total depth	no. of depths at which readings were recorded	sampling depth (m)	temperature ($^{\circ}$ C)	dissolved O ₂ (mg l ⁻¹) at ambient temperature	conductivity (μ S cm ⁻¹) at ambient temperature	pH	
main basin (site C) - 5.5m	10	0.83-5.40	17.18-17.21	9.56-9.93	291.0-291.2	7.87-7.92	
Entrance to Arm (site Ae) - 4.5 m	9	0.86-4.26	17.63-17.75	9.33-9.94	293.4-293.6	7.77-7.98	
Middle of Arm (Site Am) - 3.5 m	8	0.51-3.06	17.53-17.84	8.93-9.97	295.8-297.0	7.61-7.92	

Table 2: Overall ranges in the concentrations of inorganic and other fractions of nutrients in the Loch of Cliff water samples collected from the cage site (C - December 1989, April and August, 1990) and the middle of the Arm site (Am - April and August 1990 only).

Determinands	Site C	Site Am
a. inorganic forms		
µg nitrate-N l ⁻¹	9-92	28-36
µg phosphate-P l ⁻¹	2.4-11.3	3.0-5.1
mg silicate-SiO ₂ l ⁻¹	1.84-6.46	1.44-5.94
b. other fractions		
µg total P l ⁻¹	13.8-29.3	20.3-24.8
µg particulate P l ⁻¹	2.4-9.6	4.9-7.6
µg soluble organic P l ⁻¹	6.9-9.0	9.7-14.8
mg diatom SiO ₂ l ⁻¹	0.21-0.80	0.19-0.22

Table 3: Chlorophyll *a* concentrations ($\mu\text{g l}^{-1}$) as an indicator of total phytoplankton abundance, in the Loch of Cliff; main basin (site C) and the middle of the Arm (site Am)

Date	Sampling Site C	Sampling Site Am
13.12.89	2.1	-
8.4.90	6.1	5.0
2.8.90	3.5	4.8

Table 4: Phytoplankton in the Loch of Cliff: pigment values at the open water site (cage C) and in the middle of the Arm (A), and the numbers of algae and the dominant types for site C.

Sampling date	December 1989	April 1990	August 1990
Chlorophyll <i>a</i> concentration ($\mu\text{g l}^{-1}$)	2.1 (C)	6.1(C) 5.0(A)	3.5(C) 4.8(A)
approximate algal abundance (n ml^{-1}) and dominants:			
relatively large forms ($> \text{ca } 50 \mu\text{m}$ counted - under 40x magnification)	20 narrow (1-2 μm) <i>Planktothrix</i>	50 narrow (1-2 μm) <i>Planktothrix</i>	7 <i>Ceratium hirundinella</i> , <i>Botryococcus braunii</i>
forms of <i>ca</i> 20-50 μm - counted under 100x magnification	300 <i>Aulacoseira italica</i>	600 <i>Diatom elongatum</i> , <i>Synedra</i> and <i>Fragilaria</i> species	30 <i>Asterionella formosa</i>
forms of <i>ca</i> 10-20 μm - counted under 250x magnification	300 <i>Monoraphidium curvata</i> , <i>Rhodomonas</i> sp.	600 flagellates of various algal groups	-
forms of $< 10 \mu\text{m}$ counted under 500 x magnification	6000 chrysophytes including flagellates and non-motile forms	12000 chrysoflagellates, cyanobacteria and chlorococcalean (green) algae	12000 chlorococcalean algae and cyanobacteria

FIGURES

Figure 1

Light (PAR) attenuation in the L. of Cliff
cage site (◦), Arm entrance (◊) and mid-Arm (▲).

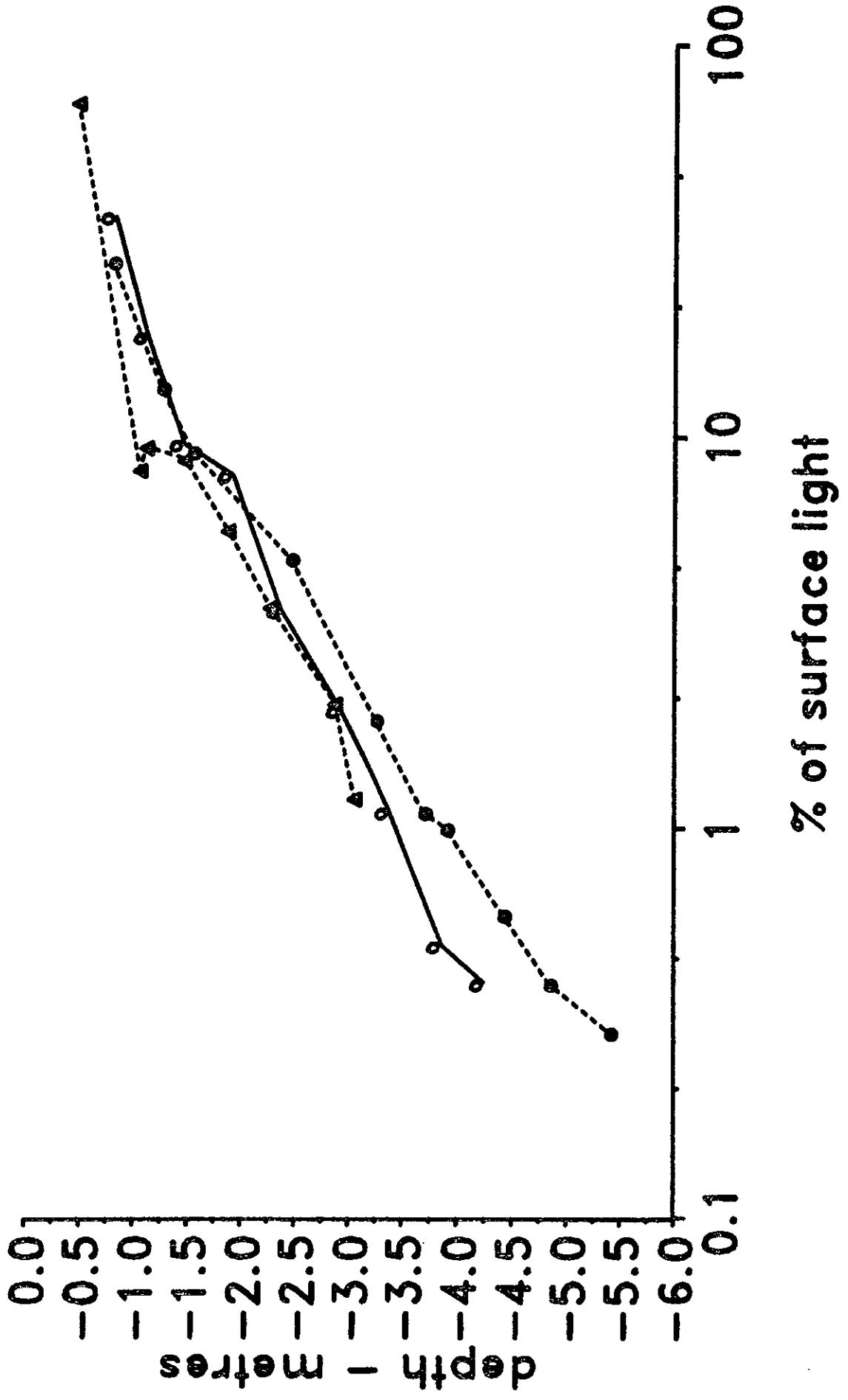
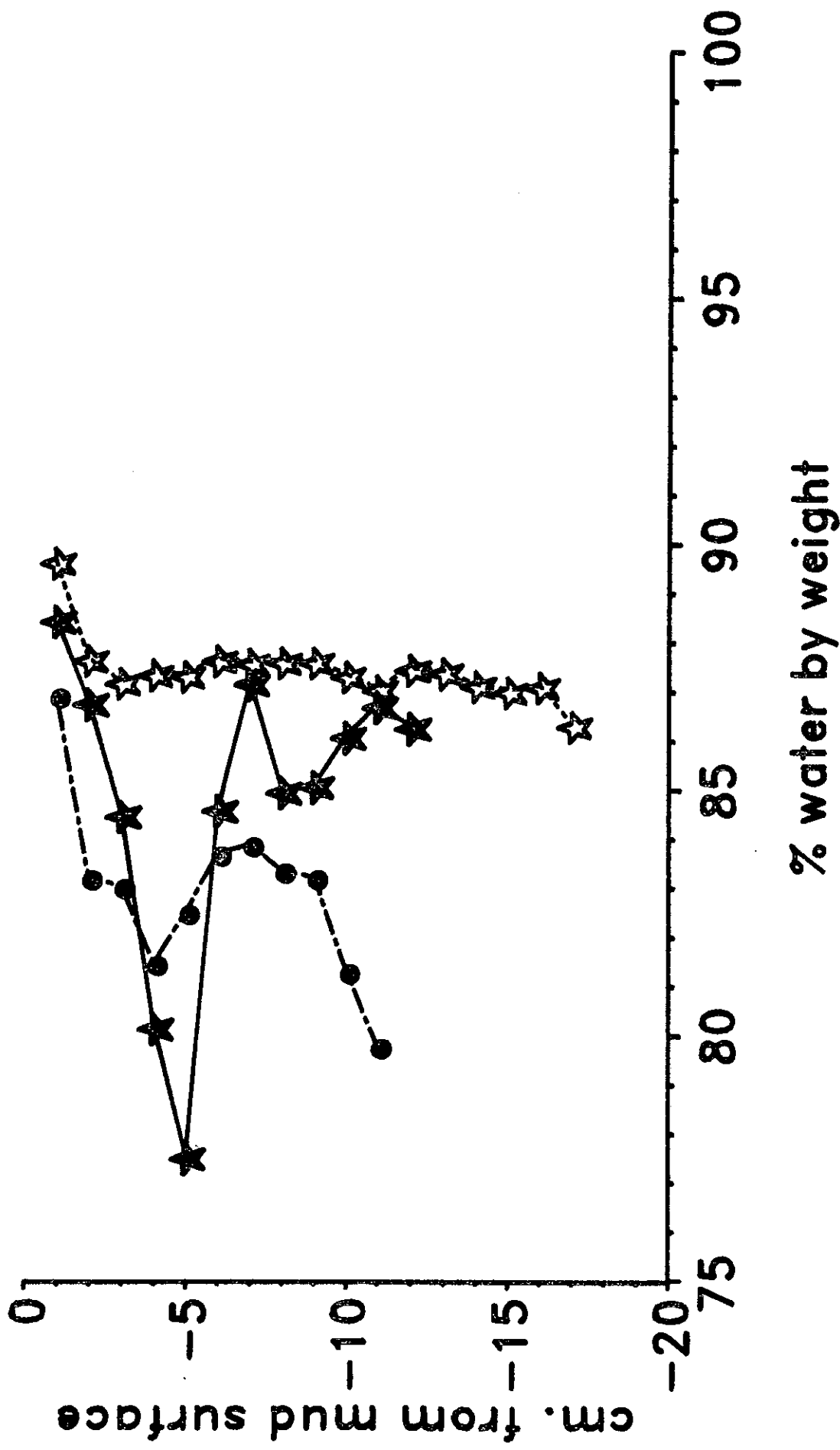
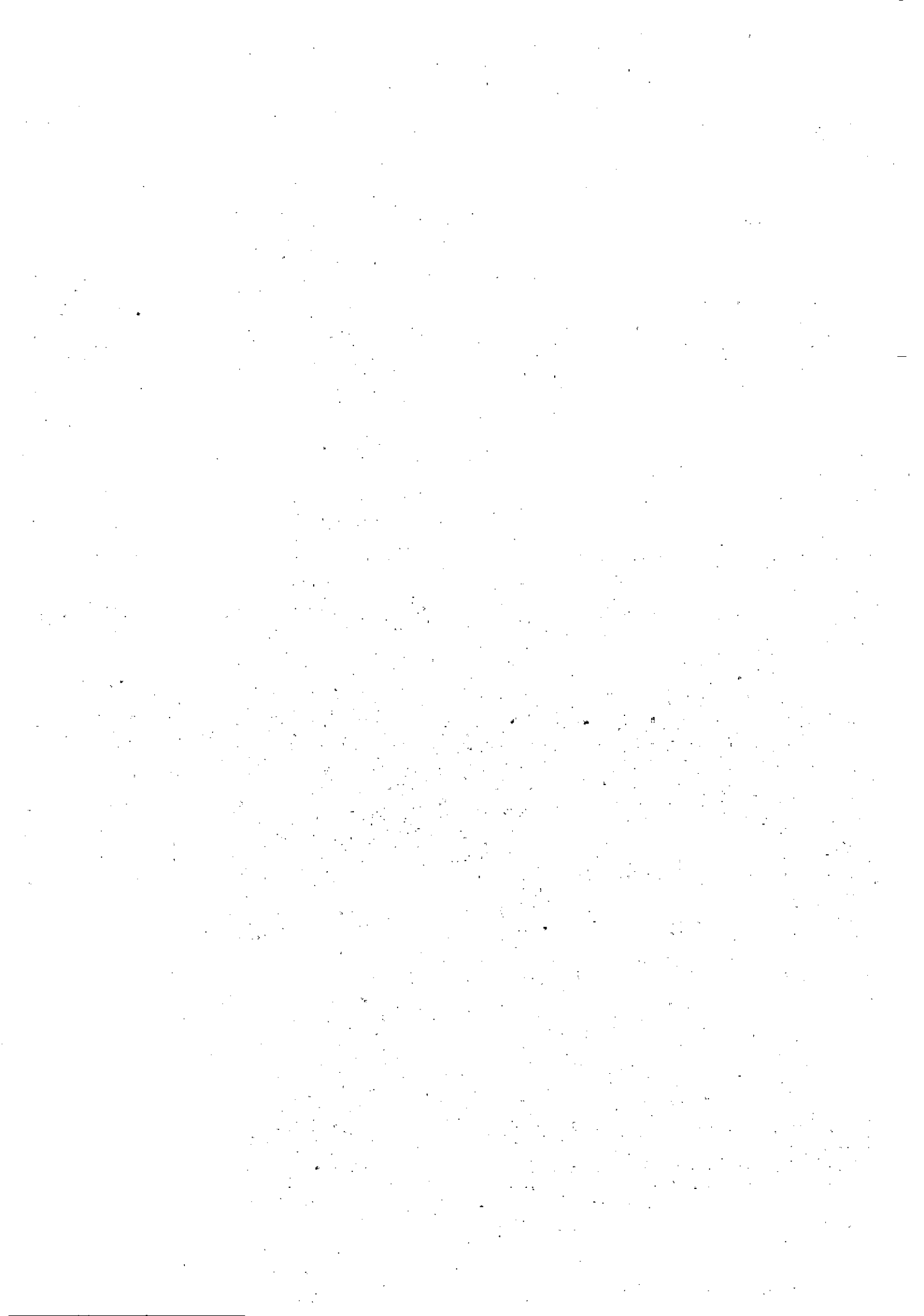


Figure 2

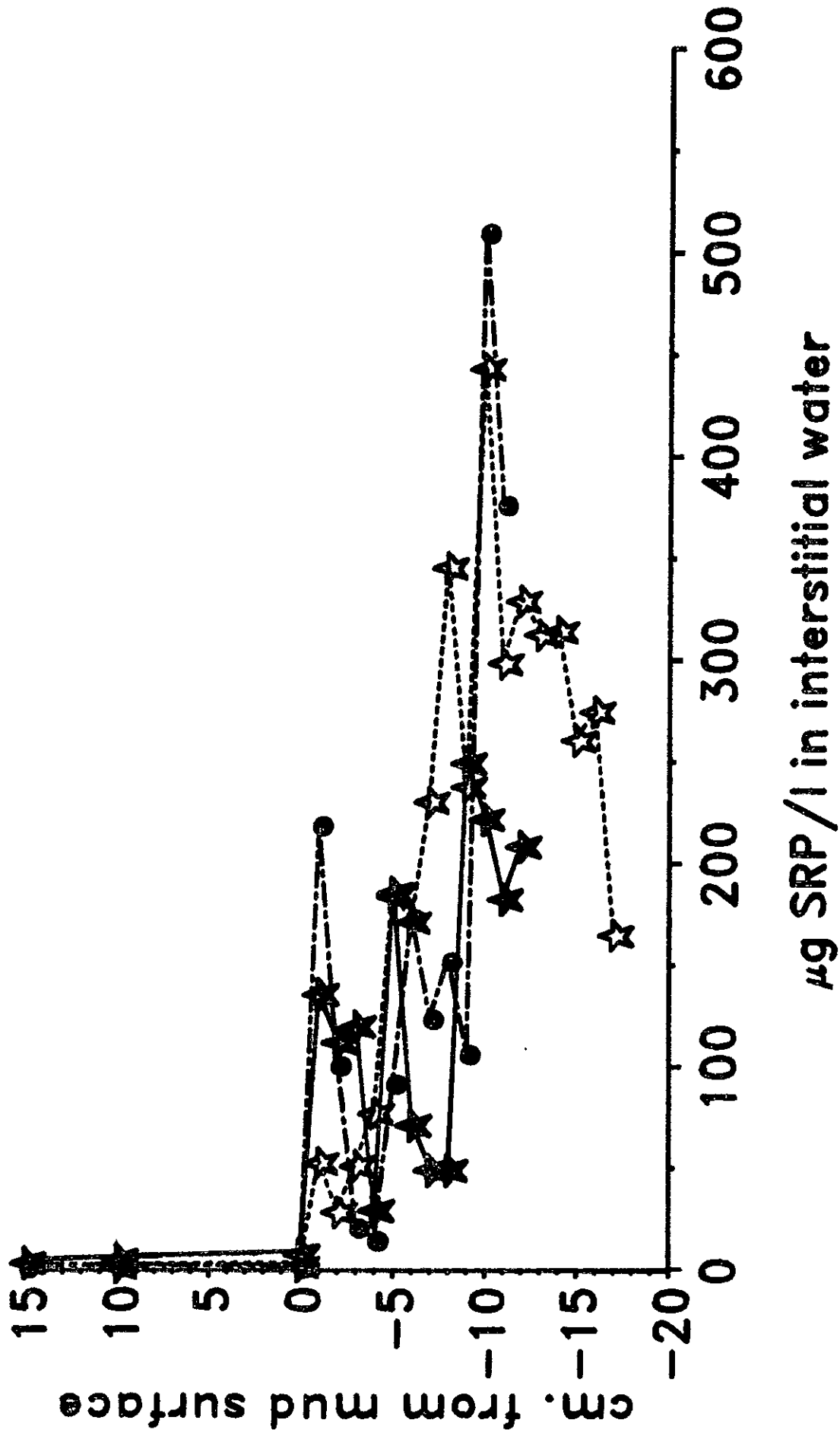
L.Cliff sediment water content Aug.1990:
cage site (●), Arm entrance (☆) and mid-Arm (★).





L.Cliff sediment SRP Aug.1990:

cage site (●), Arm entrance (☆) and mid-Arm (★).



L.Cliff sediment silica Aug.1990:
cage site (●), Arm entrance (☆) and mid-Arm (★).

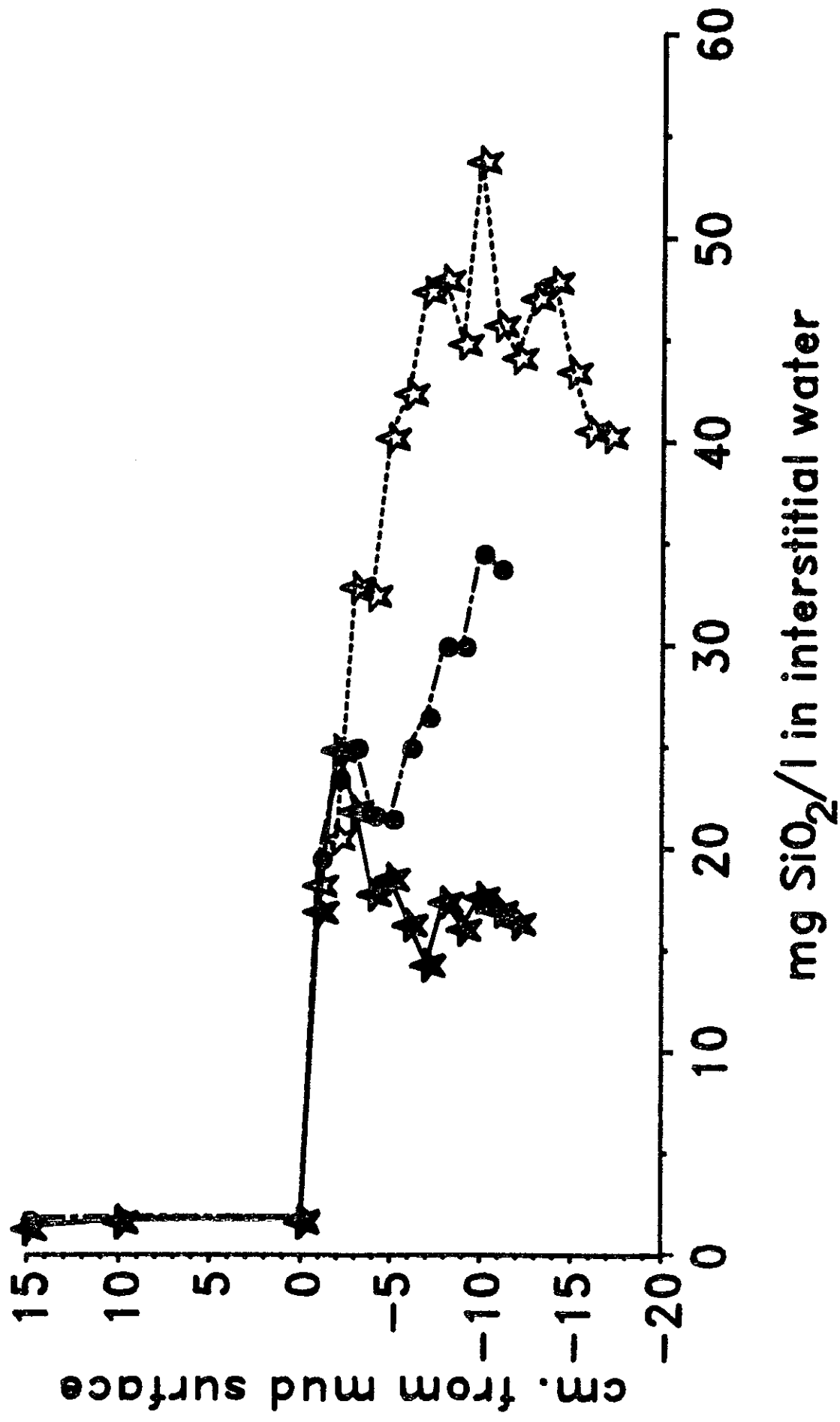
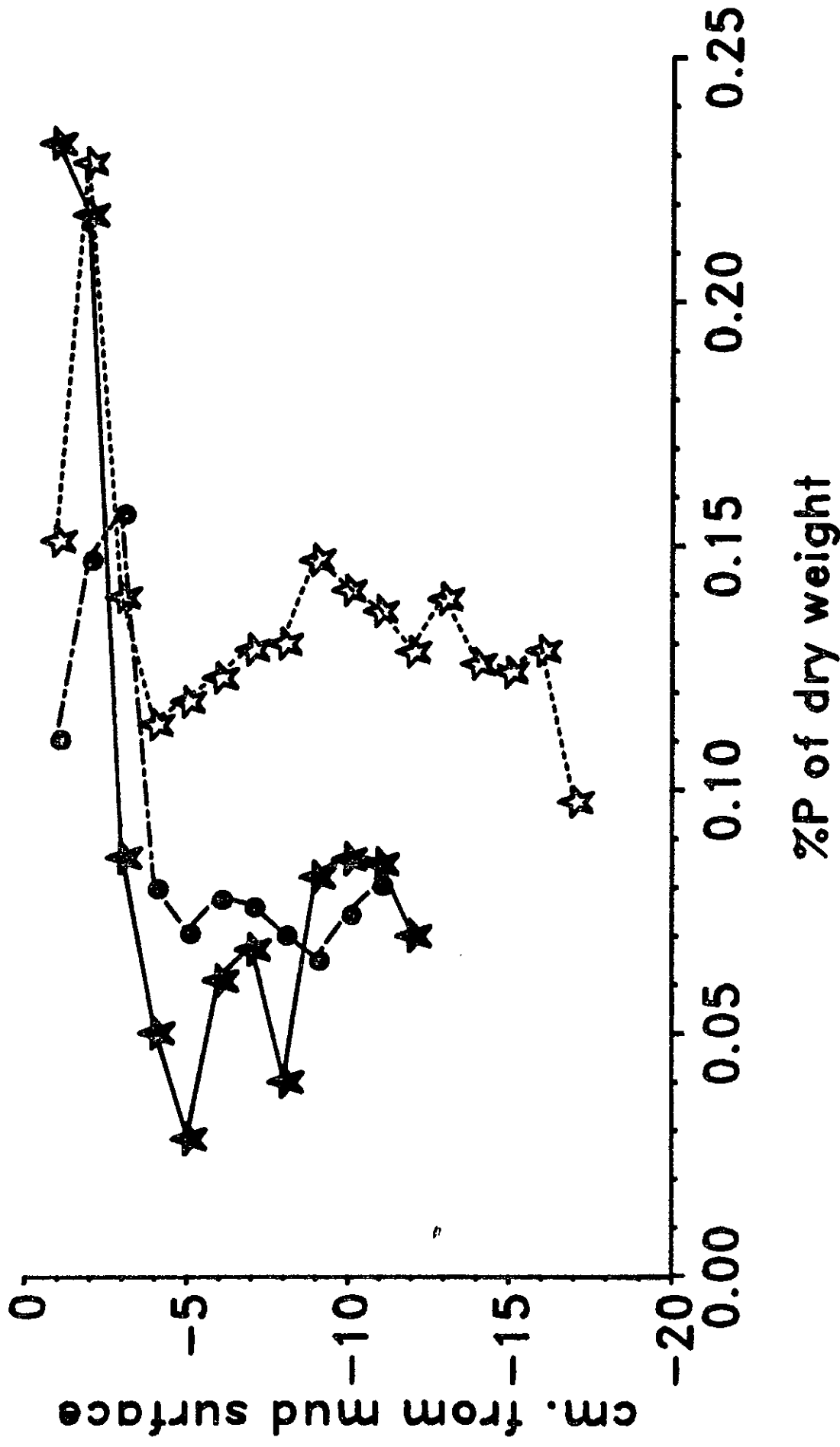


Figure 4

L.Cliff sediment phosphorus Aug.1990:
cage site (●), Arm entrance (☆) and mid-Arm (★).



**Size distributions of Loch of Cliff phytoplankton
Dec.89 (•), and Aug.90 (◦).**

