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International Council for
the Exploration of the Sea

C.M.1974/L: 13
Plankton Committee

PRELIMINARY STUDIES WITH A LARGE PLASTIC ENCLOSURE

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Introduction

The use of plastic enclosures in aquatic ecology provides time series data of changes within a particular body of water rather than changes at a single position, or in the neighbourhood of a drogue. There are two main artificialities which are introduced. Enclosures prevent the lateral mixing of populations and this could be an important process in maintaining the general equilibrium of these populations in the open sea. Since the question of the relevance of spatial heterogeneity and dispersal to population stability needs elucidation, the basic experiment with "bags" is to determine the importance of diffusion by studying the consequences of its removal. The second artificiality comes from the "wall effect" due to fouling on the interior of the bag. This cannot be eliminated and we need to determine the effects on the interior of the system. Both these problems are related to the size of the bag, through changes in the ratio of volume to surface area. Small bags in the sea, such as those used by Strickland and his colleagues (McAllister et al 1961; Antia et al 1963) can be used to follow the relatively rapid changes in a phytoplankton bloom. At the other extreme, large columns, 45 m diameter and 11 m deep, stretching from surface to bottom, have been used in fresh water in Blelhan Tarn (Lund 1972). The flora and fauna inside remain reasonably similar to those outside for periods of 18 months.

We wished to study changes at several trophic levels in an inshore but relatively marine, rather than estuarine, environment. This meant we had to live with tidal excursion and some wave action. Both of these preclude the type of structure used in Blelhan Tarn. Further, we are particularly interested in exchange and recycling processes between the water and the bottom, thus we wish to isolate the bag from the bottom but collect the "fall-out" for concurrent experiments at the mud surface. We also wanted to follow the flow of energy inside the bag from primary production to its final removal from the system and to compare it with the outside water column which had been studied in previous years (Steele and Baird, 1972). These factors, together with cost, led to the design of an enclosure which was used for preliminary studies in Loch Ewe during April and May 1973. The aims were to find how the bag operated as a structure and for how long the contents of the bag, particularly the zooplankton, would function as an ecosystem similar to the populations outside the bag. The results, although not replicated, may be of value to others involved in this type of development in inshore or estuarine environments.

Experimental Design

For this experiment we wanted to enclose a water column and used a cylindrical enclosure of 3 m diameter and 17 m depth. It was moored in 30 m of water.

The final design was a completely closed system so that at the top the cylinder finished about one metre below the surface and a funnel (46 cm diameter) protruded from the surface and was used for sampling. The bottom of the bag was conical, reducing to 46 cm diameter and a replaceable bottom bucket was used to collect the settlement material (Fig. 1). The bag was held in place inside a semi-rigid frame by elastic strops located radially at one metre intervals down the length of the bag. The semi-rigid frame consisted of metal rings, one at the top holding a flotation ring and three at the bottom, connected by seven ropes, the whole being held rigid by 112 kg weights at the end of each rope (Fig. 1).

The bag was constructed using polyethylene reinforced with nylon mesh, with light transmittance of 95%.

The sampling programme inside the bag and out was as follows. Profiles of nitrate, nitrite and ammonia; phosphate; silicate, salinity; temperature; chlorophyll and phaeopigment were measured every day. Zooplankton hauls were taken every second day and particulate carbon and nitrogen, C^{14} production, light meter readings and heterotrophic production were carried out every five days. The settlement was collected once per week. Radiation, wind speed and direction were recorded continuously.

The bag was filled initially by pumping *into* the top, then, with the bottom open, a volume equal to that of the bag was pumped *out* of the top in an attempt to fill the bag with subsurface plankton populations.

During the course of the 45-day experiment, there were a number of severe storms with winds exceeding 150 km/hr and waves of 2 m. During one of these storms on 1 to 2 May, the top of the bag ripped. The tears were repaired as far as possible two days later but the bag cannot be considered a completely closed system from then on since some leakage could occur in the top 3 m. Although the salinity results show that some exchange occurred at the surface, the chlorophyll *a* and zooplankton data show that the water exchange was probably fairly small.

Changes of temperature in the bag were similar to those outside, implying relatively efficient heat exchange with the outside, and resulting in comparable density changes, Fig. 2. The main feature here is the complete vertical homogeneity at the end of the storm (4 May) in both environments. As will be seen, this had a considerable effect on the biota.

Results

The vertical chlorophyll profiles, Fig. 3, show two main periods occurring in both the bag and outside water. From 15 April to 3 May outside and 15 April to 4 May inside, a bloom started at the surface and was followed by a midwater maximum at 5 m. The storm conditions on 1 and 2 May which broke down stratification in both systems, started a second cycle, from 4 May onwards, with a general trend from a small surface maximum to a large midwater peak at 10 m during the period 15-22 May outside, corresponding to a peak in radiation, followed by a similar peak 17-26 May inside.

Although this is a general trend, there are marked fluctuations within it. The changes outside the bag could be attributed to lateral movements but the changes inside are not explicable, even by leakage. Since any leakage occurred near the surface or possibly at the bottom of the bag, midwater peaks could not be included by exchange with the outside. These changes in chlorophyll form the best proof that the bag was responding in a manner not very different from the outside environment.

The primary production (per m^2 of water surface) in the bag was significantly less than that outside. In part this was due to exclusion of the top 1.5 m by the neck of the bag. There was also some production below 15 m outside the bag since the 1% light level in this area is usually found at 20-25 m. The maximum reduction in production, on 9 May, was associated with a heavy growth on the outside of the bag which significantly decreased light inside the bag. At the beginning and after the outside was cleaned, light levels inside and outside did not differ significantly. In general, the decreased production within the bag does not seem to have led to significantly lower chlorophyll concentrations inside the bag or to decreases in herbivore populations.

The numbers of the larger zooplankton in the bag are significantly different from those outside (Fig. 4). For the larger animals there was only one occasion when total numbers inside were less than those outside. The species compositions were qualitatively similar throughout the whole period with two species *Acartia clausi* and *Pseudocalanus elongatus* forming the major parts of the copepod populations and two other species making up the remainder. However, in the bag there was a switch at the 2 May with *Acartia* being replaced by *Pseudocalanus* which was the species responsible for the later large populations in the bag. The qualitative similarity in species composition indicates that, during the period of the experiment, there was no drift to a completely different community as happened in tanks on shore in Loch Ewe (Trevallion *et al*, 1973). The differences support the conclusions from the chlorophyll data that, except possibly around 2 May, there was no significant exchange of water between the bag and the outside.

Differences were also found in the small mesh collections which showed larger numbers of nauplii in the bag after 28 April. Since there were many gravid females in the bag during the first two weeks, it is possible that the nauplia increase was from eggs produced during the first few days of the bag. However, if as according to Corkett (1970) the developmental time Nauplius 1 to Adult of *Pseudocalanus minutus* is 35 days at 12°C, the dramatic population increase in 250 µ mesh caught copepods cannot be totally explained in this way.

Although total numbers were small, there were significantly more euphausids in the bag than outside but, since these were at the furcilia stage, they can be considered as herbivores. The other major difference was in numbers of animals which could be considered as predators (ctenophores, medusae and *Sagitta spp.*). Except for the first day of sampling, there were significantly fewer in the bag than outside. There may be problems in sampling these animals adequately with a small slow-moving net but the difference indicates that predation on the copepods in the bag probably was at a much lower level than on the natural populations outside. This could account for the survival of a much larger number of nauplii and to a larger adult population. The reasons for the small numbers of predators is not clear. It may have resulted from avoidance during filling of the bag but the one sample on 16 April suggests that "inside" and "outside" were the same. Another possibility is that these organisms do not survive well in the bag, although the numbers tend to increase with time. This aspect of population survival is a main problem for future studies.

A further problem is the decrease in numbers of copepods at the end of the experiment. One feature of the settlement data (to be discussed in the next section) is the marked increase in 'crustacean fragments' in the second half of the experiment. This material is not normally found in settlement collections outside the bag (Steele & Baird, 1972) and suggests that, in the absence of predators, there may have been natural mortality.

The detrital material settling out of the bag water column was collected once per week and a string of three settlement jars was used to collect settlement material outside the bag over the same period.

The most interesting aspect is the change in composition of the settlement material during the course of the experiment. For the first 25 days the settlement material contained about 85% faecal pellets and small amounts of crustacean fragments and benthic diatoms, and was very similar in composition to the material collected outside the bag (Steele & Baird, 1972). However, after about 25 days the percentage faecal pellets dropped to about 50%, the crustacean fragments increased from 5 → 25% and the percentage benthic or sessile diatoms also increased (10 → 20%). About 5% pelagic diatoms were recovered ungrazed (Fig. 5).

This change in the settlement composition within the bag follows the zooplankton peak (8 May) and its subsequent decline and would suggest that about this time events in the bag were being influenced by wall effects, and/or the lack of predators.

The other striking difference between the inside and outside settlement material is the percentage primary production carbon recovered as settlement faecal material. During the course of the experiment, a string of settlement jars was used to collect settlement material. Outside the bag about one-third of the production was recovered as faecal pellets whereas inside the recovery is as low as 2% and ranges up to 22% only toward the end of the experiment (17-25 May) when the zooplankton numbers had declined. It is unlikely this is due to inefficient collection since there was no evidence of material sticking to the sides of the cone. One possible explanation is the reworking of the faecal pellets by the zooplankton and there is some evidence to support this idea in that in bad weather the material in the bucket was partially resuspended and on one occasion when the bucket was changed there were large numbers (almost 20 times the natural density) of zooplankton in the bucket.

Further experiments are in progress in Loch Ewe using four enclosures to investigate the effects of pollutants. This work is part of a joint programme (Controlled Environment Pollution Experiment) with laboratories in the US and Canada, and similar experiments are also underway at Saanich Inlet on Vancouver Island.

Conclusions

Considering the extremely adverse weather conditions, the bag performed reasonably well. Improvements in design are required and a more sheltered site would be an advantage but the general conclusion is that enclosures of this size can be operated without too great difficulty in marine environments. The main problem was deciding what exchange had occurred when the bag ripped. For this and for possible exchanges at other times the biological, rather than the physical, data prove better indicators.

Both chlorophyll measurements and zooplankton counts indicate that, except for a short period around the beginning of May, the bag contained separate populations which were adequate representations of marine conditions even though the dominant zooplankton species differed. Because of the marked changes immediately after 2 May, it may be better to regard these trials as two, successive, experiments. This is particularly the case for the observed decline in zooplankton numbers at 2 May which could have resulted from inadequate feeding as shown by the feeding experiment. The later outburst in the zooplankton population would suggest that this was not a dominant effect for the second part of the trial but more experimental work is required in future studies.

The large numbers of zooplankton in the bag, while implying generally good survival of the herbivores, also raise questions about the low numbers of predators. At present, the most likely cause appears to be escape of these organisms when the bag was filled but this is a second major problem for future work.

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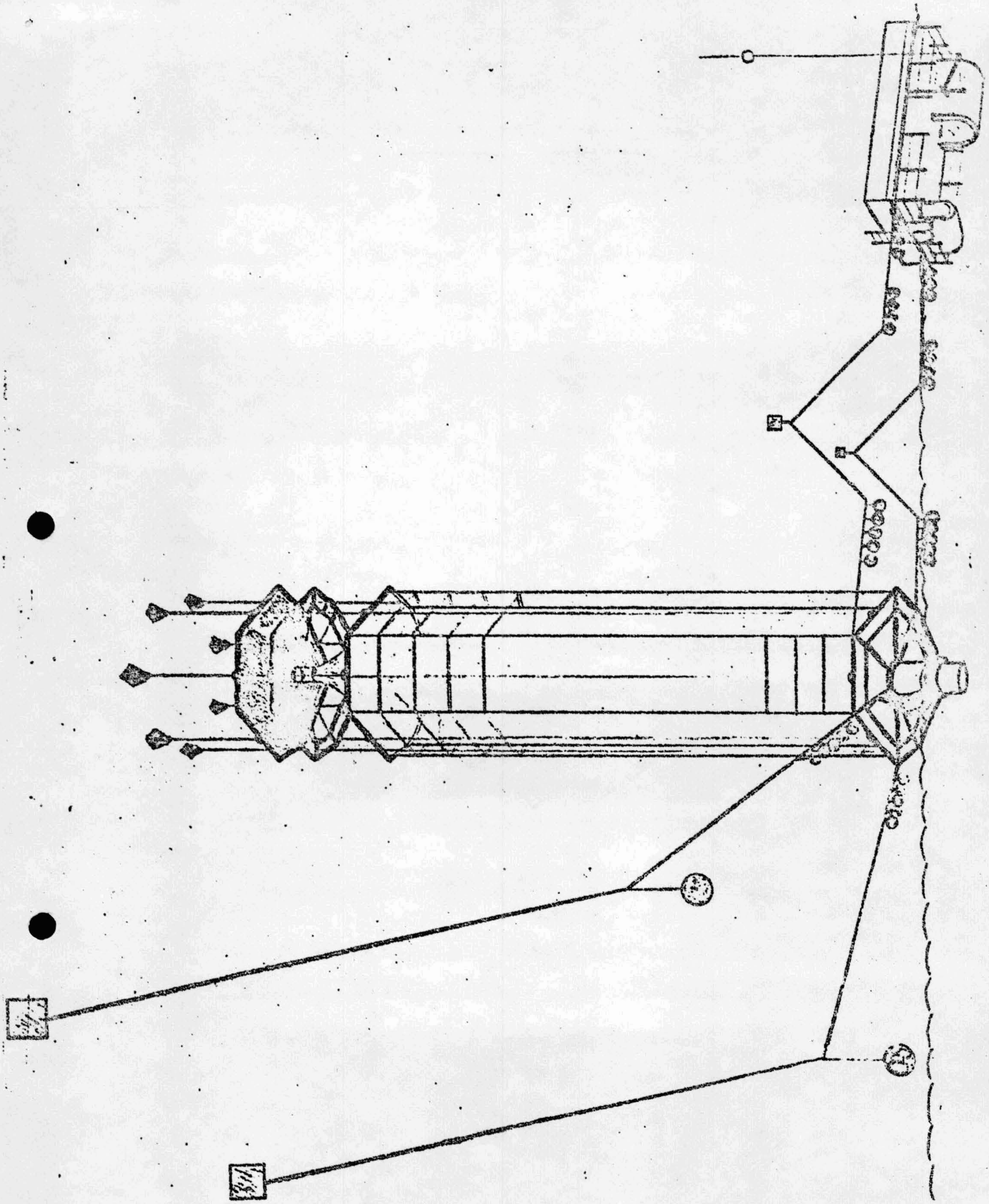

Fig. 1 Diagram of the bag and raft.

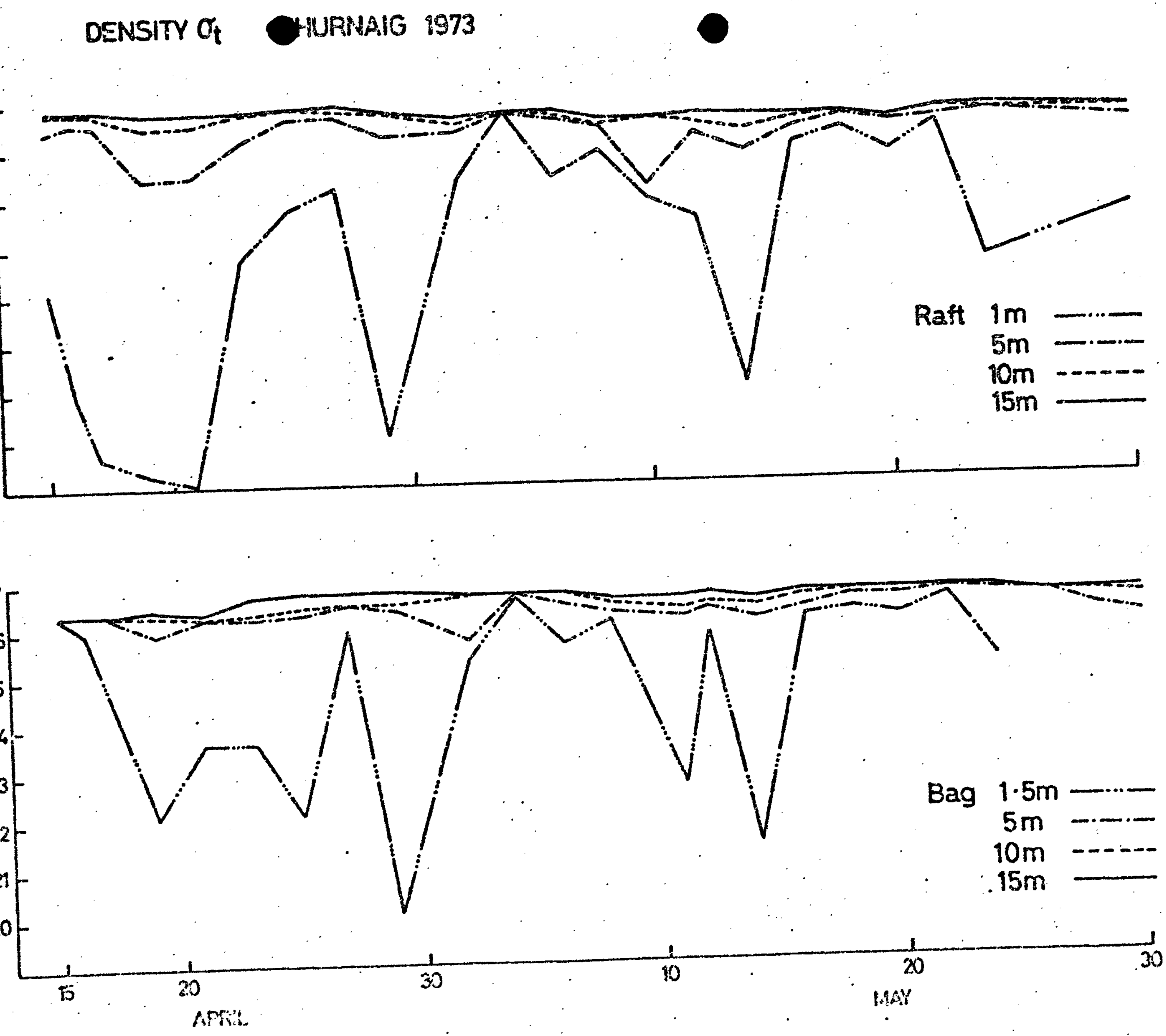

Fig. 2 Density changes in the bag and outside water.

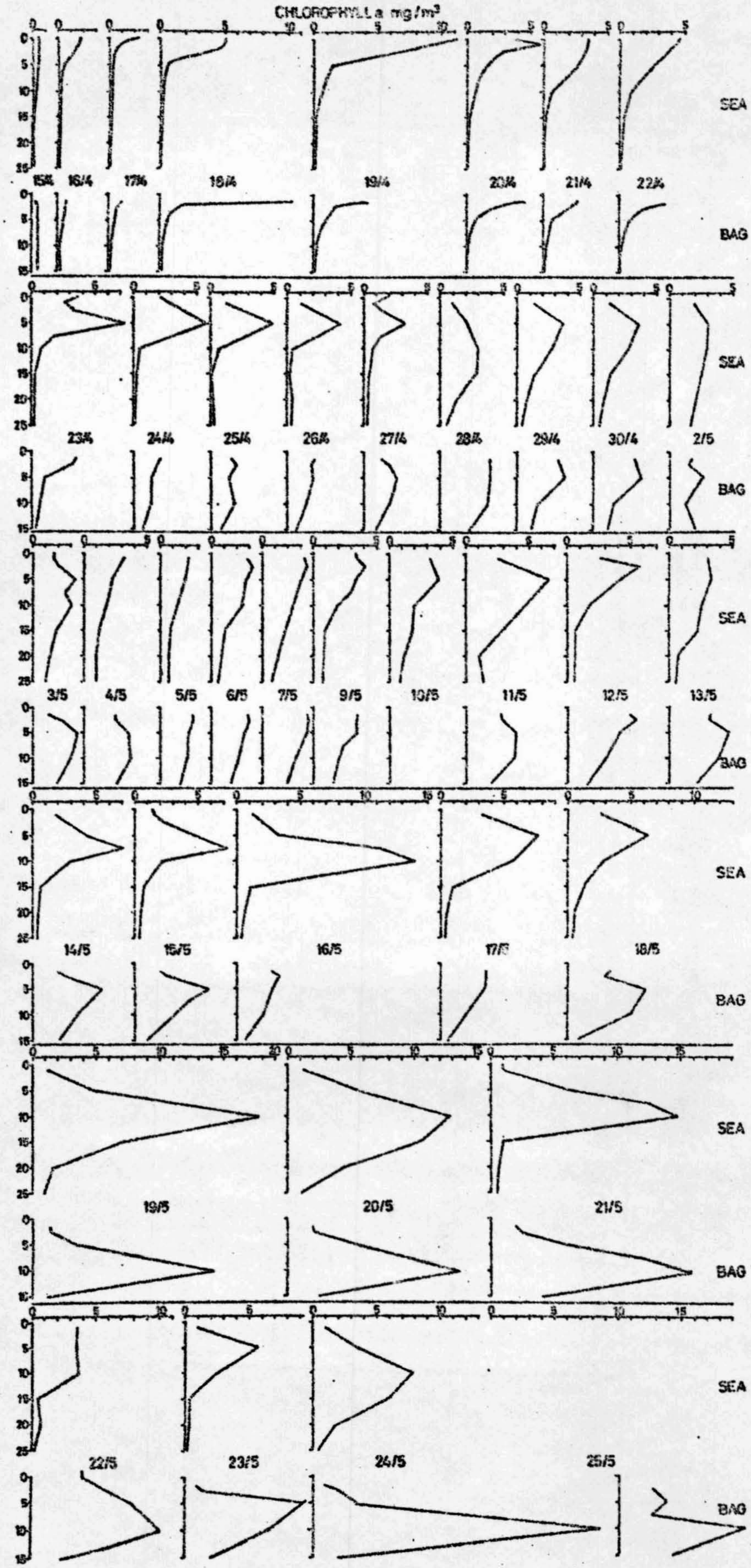

Fig. 3 Vertical profiles of chlorophyll a in bag and outside water.

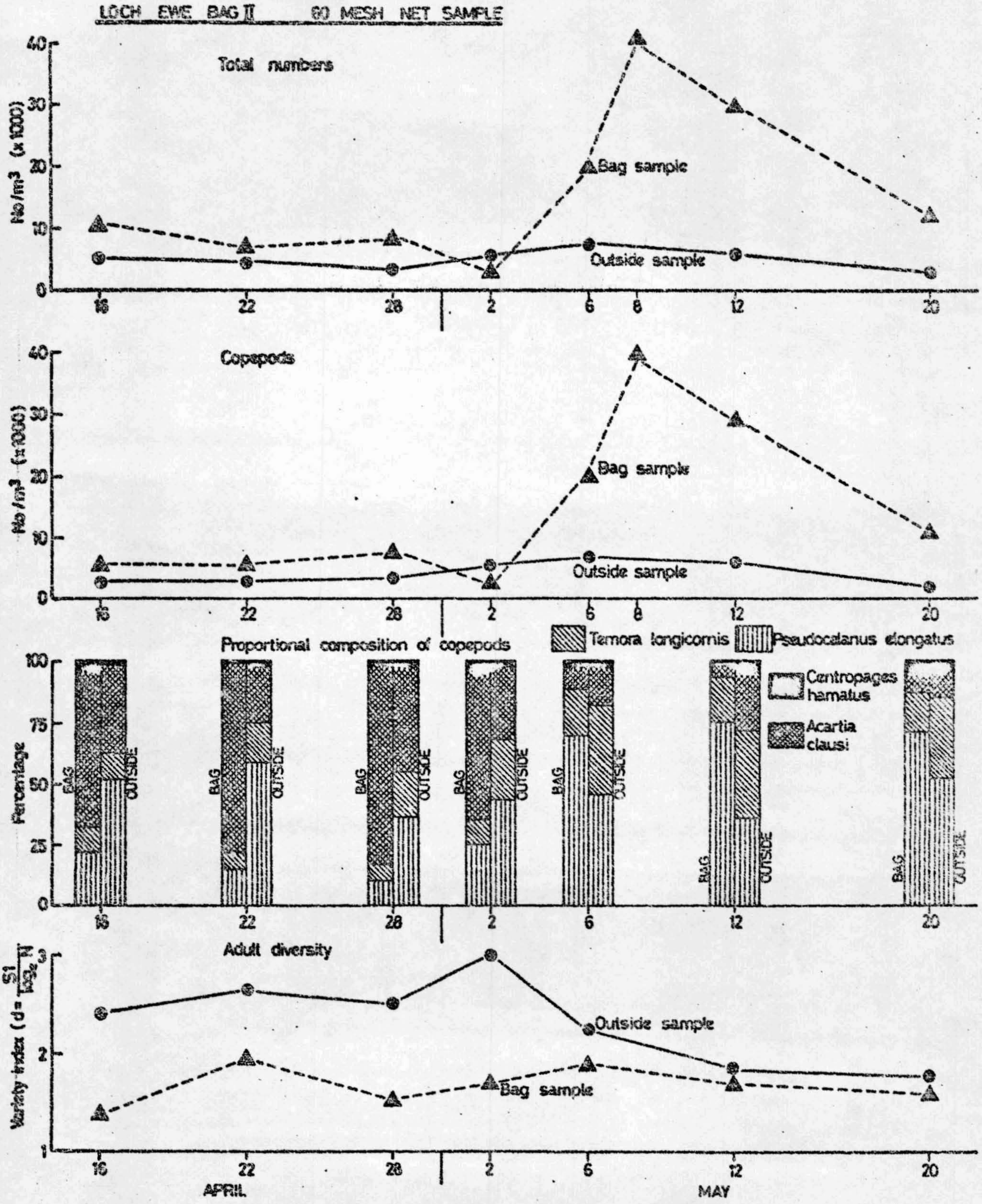

Fig. 4 Zooplankton (250 µ mesh net) numbers and species in bag and outside.

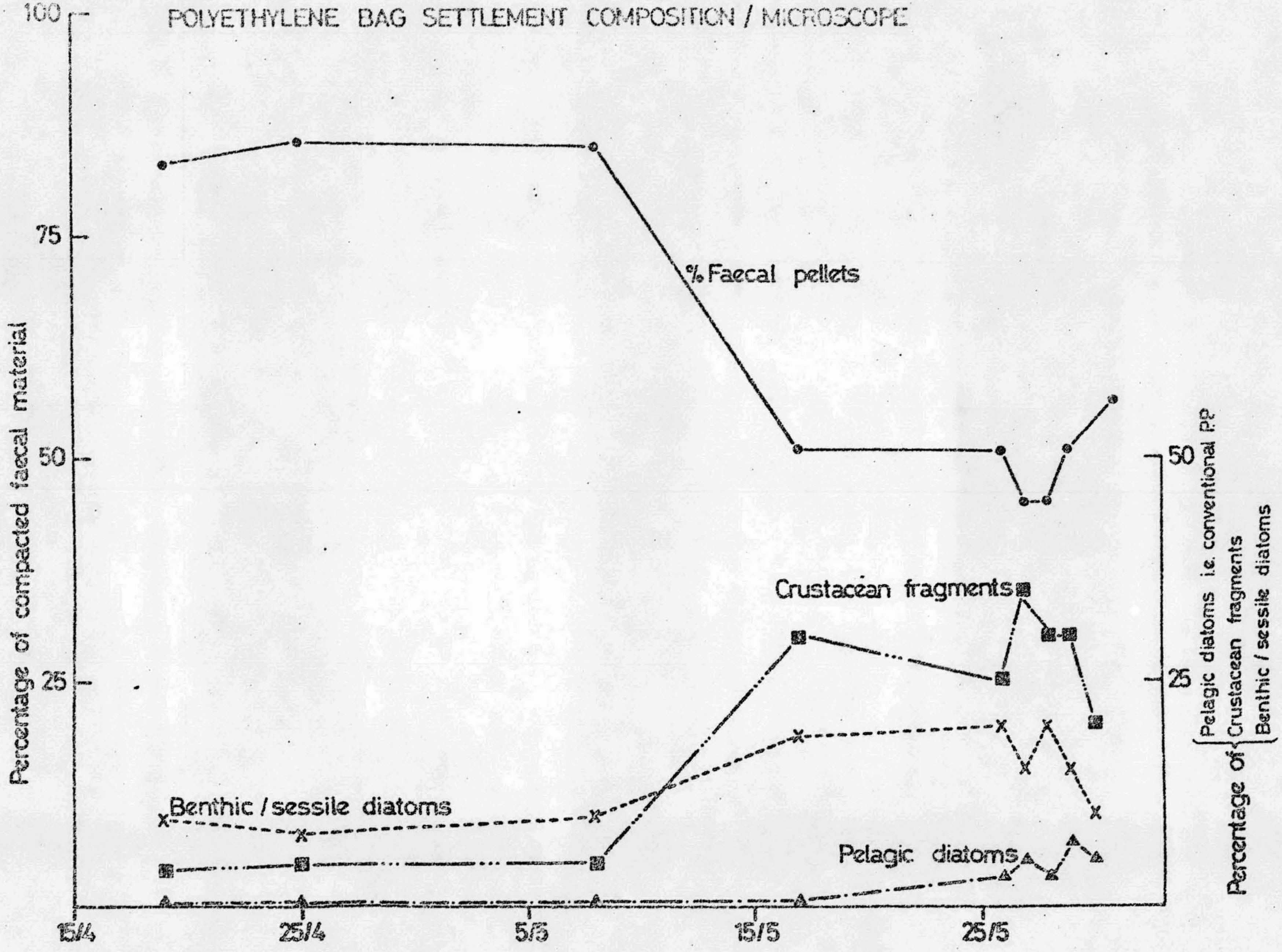

Fig. 5 Composition of the bag settlement material.