THE DEVELOPMENT OF TECHNIQUES FOR THE CULTIVATION OF LAMINARIALES IN THE IRISH SEA.

A thesis submitted for the degree of Doctor of Philosophy in accordance with the regulations laid down by Liverpool University.

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Dedicated to my parents, for their support and encouragement.

SUMMARY

The main aim of the work was to develop a method of cultivating large brown algae in the open sea. This was successfully achieved using *Alaria esculenta* and *Laminaria saccharina*. A third species, *Saccorhiza polyschides*, was found to be less suitable because it was easily dislodged from the artificial substratum by wave action.

Cultivation took place on horizontal ropes suspended 1-10m below the sea surface. A simple system of buoys and weights proved effective in maintaining the depth of the ropes. The system usually survived winter storms.

The method involved culture of the young stages of the plants on string under controlled conditions, usually for 20-40 days. Short lengths of the string were then inserted into the rope in the sea during winter and spring. Groups of plants grew both on the string and on the rope itself at the point of attachment. The plants grew rapidly during spring and early summer. Winter seeded *Alaria* stopped growing in late May/early June, while spring seeded plants continued to grow until mid July. *Laminaria* continued to grow until early September when it was harvested. Spring seeded *Saccorhiza* grew slowly during August and was also harvested in September.

In *Alaria* and *Laminaria* production was higher in winter seeded plants than in spring seeded ones. A depth of 2m was found to be suitable for growth of winter seeded plants. By seeding at depths of 3, 5 and 10 m (the latter rope raised to 2m after 6 weeks) diatom growth was inhibited, resulting in increased survival of spring seeded plants, but production was still lower than from winter seeded ones. Winter seeded *Saccorhiza* groups were removed by wave action when 1 - 2m in length.

Production levels of 1.125 kg dry weight/m of rope by 10 groups of *Alaria* seeded at 5 cm intervals and 2.8 kg dry weight/m of rope by 5 groups of *Laminaria* seeded at 10 cm intervals were obtained. These levels were higher than the maximum observed by natural colonisation of the experimental ropes, and there were indications that they could be substantially increased by seeding the plants at very high densities. Production levels attained by *Saccorhiza* were much lower.

The organic content of the weed was 68 - 74% of dry weight for *Alaria*, 61 - 65% for *Laminaria*, and 52 - 60% for *Sacchoriza*. Preliminary experiments suggest that all three species could be stored by ensilage.

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1. INTRODUCTION

The energy crisis of the 1970's caused the developed world to rethink its energy policies. Although immediate problems have been postponed by the discovery of many hitherto unknown fossil reserves, new sources of energy will still be required in the long term. Environmental issues such as toxic emissions from oil-based fuels and the possible dangers of nuclear power generation reinforce this need. Fuels such as ethanol, methanol and methane could ultimately reduce the demand for fossil fuels, since they are relatively clean-burning and can also be used in the manufacture of chemicals and plastics. The E.E.C. therefore instigated a comprehensive programme of research into the production of various forms of biomass from which these fuels can be made. Most of this research involves terrestrial crops or aquatic plants grown in land based tanks or ponds, but land in the E.E.C. countries is already heavily used. It has been estimated that without drastic changes in land use, no more than 5% of Europe's energy could be produced from land based biomass (Dalsager, 1982). However, there are large areas of relatively unused sea around the E.E.C. countries which could be used for the cultivation of marine algae. It is known that large brown algae can be successfully fermented to produce methane (Chynoweth et al, 1978, Asinari et al 1981). Production by seaweeds in temperate waters can be extremely high (Mann, 1973), and it has been shown that production can be improved by cultivation (Hasegawa, 1971). Successful cultivation for food of Laminaria species similar to those found in North European waters has been carried out in China since 1952 (Tseng, 1981a). Much research has been carried out since the 1950's to improve cultivation techniques. The most successful methods have involved simple vertical or horizontal rope structures suspended a few metres below the surface of the sea (Cheng, 1969). More than one million tonnes fresh weight (equivalent to 275,000 tonnes dry weight) of *Laminaria japonica* was cultivated in this way in China in 1978-79 (Tseng, 1981a).

Large scale cultivation of *L. japonica* for food has also been carried out more recently in Japan (Hasegawa, 1971, 1976) and experimental cultivation has been carried out in Russia (Sarochan and Buyantlina, 1981, Buyantlina, 1981).

In the United States attempts have been made to cultivate the giant kelp *Macrocystis pyrifera* as an energy source on complex large scale structures which incorporate a system for pumping up nutrient - rich water from a depth of 300m or more (Wilcox, 1977, North et al 1982). However, these attempts have been largely unsuccessful, and the technique has been much criticised, particularly for the high costs involved (Budiansky, 1980). Furthermore, although *Macrocystis* is an exceptionally productive genus, its introduction into European waters would be a highly controversial step. It would almost certainly grow well in local conditions and there is much concern over its potential effect on inshore fisheries and shipping (Boalch, 1981). For these reasons it was decided that the present work should investigate the cultivation of local species on simple rope structures. A similar approach is being used with *Laminaria groenlandica*, *L. saccharina* and *Cymathere triplicata* as a food source in Canada (Druehl, 1980, 1982) and with *L. digitata*, *L. saccharina* and *Alaria* esculenta as a source of alginate in Norway (Indegaard and Jensen, 1982).

There may be some advantages to cultivation in European waters. Large scale fertilization of the algae, which is extensively employed in China (Cheng, 1969) should not be necessary, and summer temperatures, which are too high for growth of L. japonica off much of the Chinese coast (Cheng, 1969) should also present few problems. Unlike China, however, Europe would not have the combined advantages of cheap labour and a relatively high priced product. This necessitates a high biomass yield combined with low costs. Bearing this in mind, three fast growing species were selected for investigation: Alaria esculenta, Laminaria saccharina and Saccorhiza polyschides.

Alaria is relatively small, normally weighing up to about 100g (fresh weight), but Lewis (1971) found it growing at densities of up to 175 plants per $0.25m^2$ in the Isle of Man, and reported a mean growth rate of up to 8cm/week. It is known to be capable of tolerating exposure to extreme wave action.

Laminaria is rather larger. Parke (1948) reported specimens up to 2.5 kg fresh weight and found individual growth rates of up to 17.5 cm/week.

Saccorhiza is the largest of the three species investigated. Single plants weighing up to 22 kg fresh weight have been reported (Black, 1948). Norton and Burrows (1969a) found individual growth rates of up to 14.5 cm/week for the frond. The young stages of Saccorhiza develop rapidly under ideal conditions (Kain, 1969), and it is often the first large alga to appear on cleared areas of rock (Jones and Kain, 1967, Kain, 1975, Harkin, 1981).

The main aims of the present work were to develop a method of artificially "seeding" these algae onto ropes, and to investigate the effects of plant density, time of seeding and depth upon production.

Since most of the available sea area in Europe is exposed to strong wave action, the experiments were carried out in an exposed region on the South-West tip of the Isle of Man.

The experiments all started between November and April, because large numbers of sporing plants were available at this time, and the main growth period for the Laminariales is in the spring and early summer. The plants were harvested during the summer.

It was desirable that cultivation should be carried out at a shallow depth so that the plants would be subject to high light intensities, but it was thought that if the ropes were too shallow many of the plants would be removed by wave action. A constant depth of 2m below the sea surface was chosen for most of the experiments, but the effect of a range of depths of 1-5m on production was also investigated.

Since any artificial seeding method is likely to be expensive, the possibility of "reseeding" ropes by leaving some plants on the ropes over the winter period was investigated.

Some work was also carried out on the moisture content and organic content of the weed, and on the possibility of ensilage and drying as means of storage.

The work was carried out as part of a joint project with Professor J.G Morley at the Wolfson Institute of Interfacial Technology at the University of Nottingham. Professor Morley investigated the engineering and technical aspects of artificial substrates and harvesting methods (Morley, 1983).

2. THE STRUCTURES AND SITE

The experimental structures consisted of pairs of buoyed vertical ropes anchored to the bottom by concrete blocks, suspended between which were the 60m long horizontal ropes upon which the experiments were performed (Fig. 1). The design was such that the vertical ropes could be positioned in the sea first and the horizontal ropes shackled on later. The concrete blocks were then towed apart so that there was a certain amount of tension in the system. The depth of the horizontal ropes was determined by the length of rope on the supporting buoys which were attached at intervals along it.

Some early experiments (1980-81) were carried out using 10mm diameter sheet polypropylene rope, but the majority (1981-82, 1982-83) were performed using 12mm spun polypropylene which is more fibrous and might therefore provide a better surface for the attachment of spores and holdfasts. Polypropylene was chosen because it is cheap, strong and does not decay. It is slightly buoyant in seawater, so that the attachment of small weights beneath the buoys was necessary to keep the horizontal rope in position.

The positions taken up by the horizontal ropes under various conditions are shown in Fig. 2. The depth of the rope was extremely stable when only small amounts of algae were present. However, since the algae concerned are denser than seawater, large amounts produced a series of vertical bows in the rope. The depth reached by these bows was dependent upon the weight of algae, the tension in the rope due to current, the distance between supporting buoys, and the height of the tide. There was potentially up to about 6m of

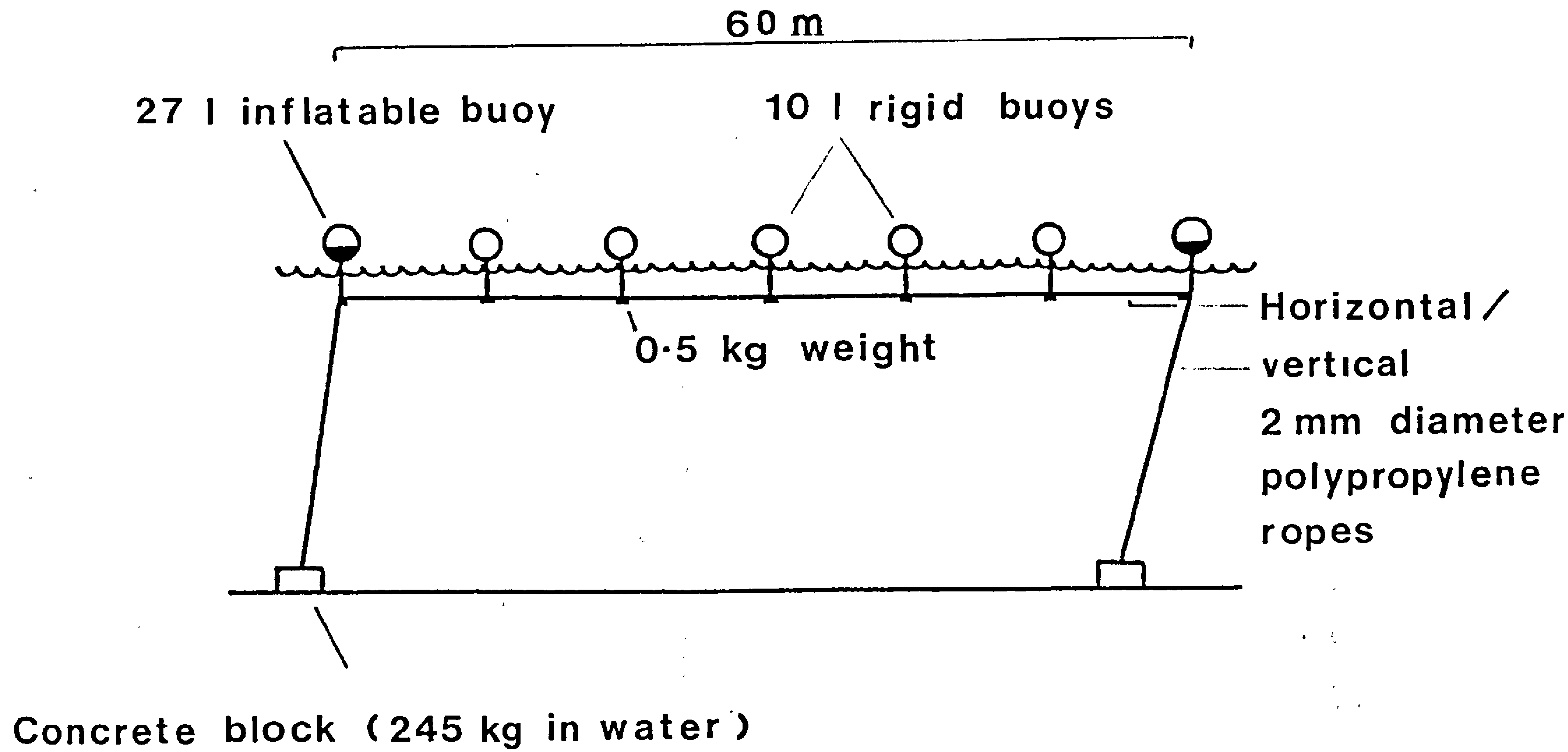


Fig. 1 The structures used for field experiments in 1982-83.

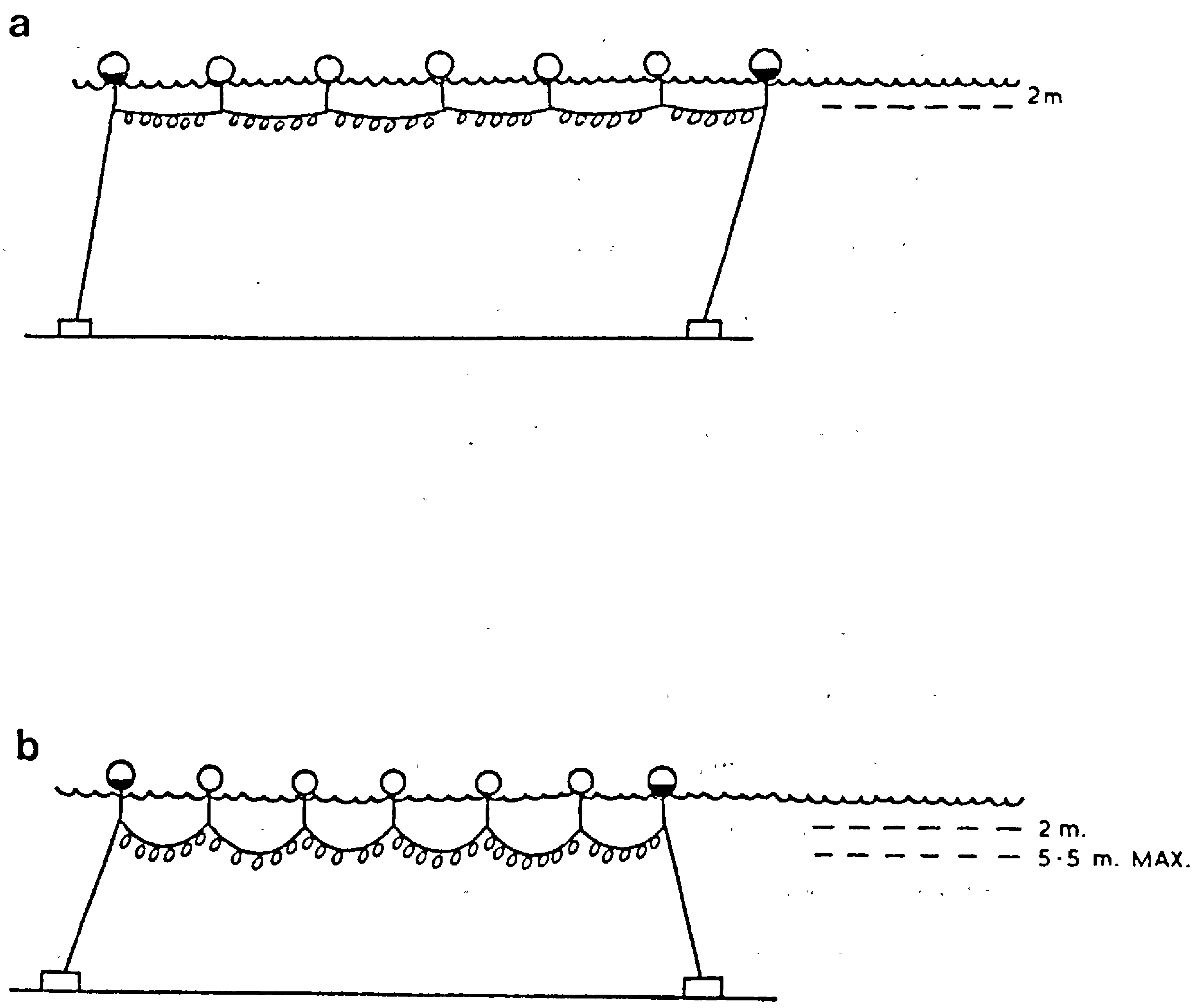


Fig. 2 The effects of tides and currents upon heavily colonised structures;
a) High tide, strong current.
b) Low tide, no current.

slack rope on each vertical rope at low water. However, since slack water did not coincide with low water but was three hours before it, and the structures were arranged with the horizontal ropes stretched across the direction of current flow (Figs. 3, 4), downwards bowing was less of a problem than it might otherwise have been. Despite this, bowing at slack water in the summer of 1982 was occasionally such that a rope originally placed at a depth of 2m could in parts attain a depth of 7m. The same rope at high tide with a ½ knot current running would have a maximum depth of 3-4m, as shown in Fig. 2(a). Bowing rarely occurred before June, and then only on ropes with a high degree of natural colonisation in addition to any cultivated plants.

The ropes used in 1982-83 had more frequent buoys so that the bows were smaller. These are the ropes shown in Figs. 1 and 2.

In 1982, when five litre collapsible buoys were used, a strong current combined with large quantities of algae on the ropes occasionally caused the whole structure to be pulled beneath the surface. The buoys collapsed at depth due to the increased pressure, so that once submerged the structures remained so. This proved to be a problem during the summer of 1982, when up to ten extra buoys had to be added to each rope. In 1983 ten litre hard-shelled buoys were used, and the vertical ropes were kept clean of algae to reduce the drag. None of the structures was submerged at any time.

The concrete blocks used in 1980-81 and November 1982 weighed only 140 kg (85 kg in water) and several of the structures moved up to about twenty metres in currents of 1 knot or more when large amounts of algae were present. Blocks of 410 kg (245 kg in water) were used from January 1982 and no movements were observed.

Although wave action occasionally turned the blocks over, leading to chaffing of the vertical ropes on the edge of the concrete and subsequent loss of the ropes, it did not move the structures over any appreciable distance.

Rust frequently caused the galvanised shackles attaching the vertical ropes to the concrete blocks to come loose, and several ropes were damaged or lost because of this in 1981 and 1982, despite carefully wiring the shackles with 1mm galvanised wire. In 1983 some vertical ropes were spliced directly to the concrete blocks. When shackles were necessary they were used in pairs. They were heavily greased, wired with 3mm galvanised steel wire and checked, and replaced if necessary, every two to three months. Although one shackle from a pair was occasionally found to be loose, the other was always tightly fastened, so that no ropes were lost due to loosening shackles in 1983.

Loosening of the shackles at the junction of the horizontal and vertical ropes was comparatively rare. However, the vertical rope frequently became frayed by rubbing on the edge of the thimble. Several ropes came loose in this way, as shown in Fig. 4, but they were all quickly reconnected using new vertical ropes.

Almost all of the field work was carried out in Bay Fine, 1 km south of Port Erin Bay on the Isle of Man (Fig. 3,4). This bay has a depth of 12-15m at lowest astronomical tide, with a maximum spring range of 5.95m. It is exposed to winds from the south west through to north. Currents of up to about 1½ knots are common at spring tides and run parallel to the coastline except in the southernmost corner of the bay where there is frequently an eddy (Fig. 3).

In 1981, one structure was placed in Perwick Bay (Fig. 3) a south facing bay of similar depth to Bay Fine. This site proved difficult to reach, however, and no further work was carried out there.

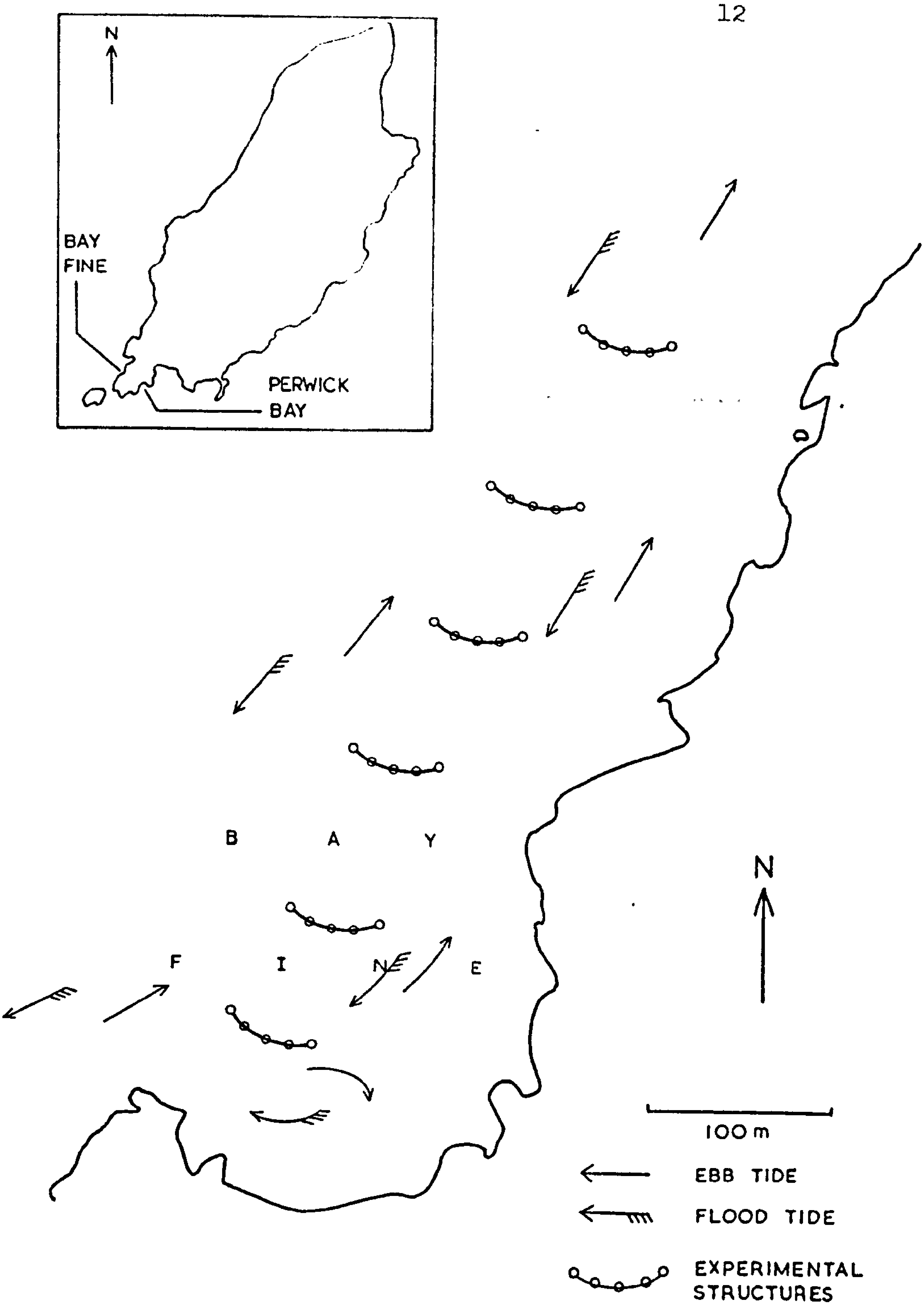


Fig. 3 - A map of Bay Fine showing tidal flows and typical positions of experimental structures. Inset - a map of the Isle of Man showing the positions of Bay Fine and Perwick Bay.

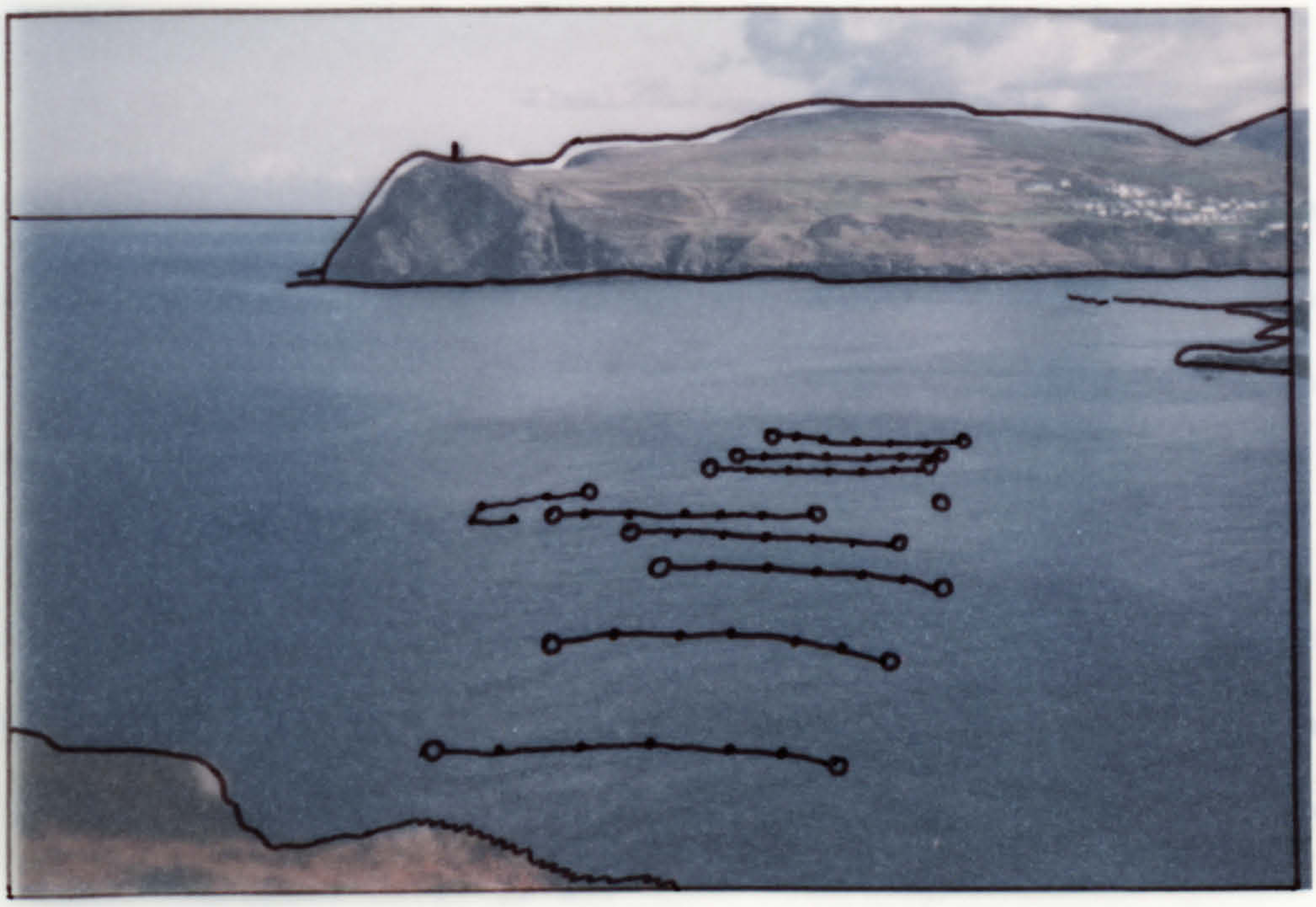


Fig. 4 - A photograph of Bay Fine taken in 1983, showing experimental structures in place. The relationships of the buoys are shown on the overlay. Note that one horizontal rope has broken free at one end.

Fig. 4 – A photograph of Bay Fine taken in 1983, showing experimental structures in place. The relationships of the buoys are shown on the overlay. Note that one horizontal rope has broken free at one end.

3. SEEDING METHOD

3.1 INTRODUCTION

A variety of seeding methods have been developed for *Laminaria religiosa*, *L. angustata* and *L. japonica* cultivated on ropes in China and Japan. The earliest widely used method in China involved transplantation of individual sporelings, grown on nursery ropes in the sea, onto vertical or horizontal ropes (Tseng 1964). However, more recently in both China and Japan sporelings have first been raised in the laboratory on thin string. In China short lengths of this string are attached to nursery ropes until the sporelings are 10-15cm long, when they are transferred to the main ropes as previously (Tseng 1981a). In Japan, however, short lengths of string are attached directly to the main ropes, and the sporelings thinned to desirable densities when they reach 10-15cm in length (Hasegawa 1971, 1976).

It was realised that these sorts of methods would be labour intensive, and therefore expensive, so two similar methods were investigated. The first involved culture on long lengths of string which were subsequently wrapped around the horizontal ropes. Culture took place outdoors in order to minimise costs. The second method involved the attachment of sporing adult plants to the ropes, to determine if spores from these would settle in sufficient quantities to colonise the rope.

However, most of the work involved a method similar to that described by Hasegawa. It was therefore necessary to develop a reliable culture technique. One of the more obvious requirements was a suitable type of string. The Chinese use a natural material made from palm fibre. The Japanese also use a natural material, cremona (Hasegawa 1976). Both of these types of strings are very fibrous, providing a good surface for the settlement of spores and attachment of the young stages of the algae. Neither type of string was readily available, however, so some trial cultures were performed on sisal, a very fibrous natural string. These were only partially successful, and seemed to indicate that the sisal was toxic. It was suspected that this might also apply to other natural fibres, so experiments were carried out on a variety of natural and synthetic fibres using Saccorhiza polyschides and Laminaria saccharina cultures to determine which was the most suitable. Although it might be suspected that synthetic fibres would be too smooth for effective attachment of spores and the young stages of the algae, Baik (1977) found that free floating gametophytes of Laminaria japonica attached well to braided poly-vinyl alcohol twines.

The early cultures were carried out in white light at 45-50 $\mu E\ m^{-2}\ s^{-1}$ at 10°C. Many of them suffered from contamination by unicellular green algae, which was occasionally severe enough to kill all of the developing gametophytes. Changing the medium at frequent intervals had relatively little effect since large amounts of green algae grew on the strings themselves. Schonbeck (1976), who encountered similar problems whilst culturing fucoids in white light at 48-68 $\mu E\ m^{-2}\ s^{-1}$, reduced the growth of some contaminants by diluting the culture medium ten times without reducing the growth of the cultured plants, but contamination by small green algae and diatoms was still a problem.

It was suspected that reducing the light levels might be beneficial for the present work. In an investigation of the effects of light intensity on photosynthesis, King and Schramm (1976) tested seven species of green algae, most of which showed rates of photosynthesis much lower than 1/3 of Pmax at an irradiance of 50 μE m^{-2} s^{-1}. The two laminariales tested, L. digitata and L. saccharina, showed photosynthesis rates of about 1/3 and 1/2 Pmax respectively at the rather lower irradiance of 10 μE m^{-2} s^{-1} in winter. Furthermore, they seem to have used adult Laminaria plants, and young stages would be expected to have lower compensation and saturation points because of their monostromatic structure (Kain, 1966). Cosson (1975) found the maximum cell division rate in L. digitata male and female gametophytes to be at 5 and 10 μE m^{-2} s^{-1} respectively, with a marked inhibition at 15 μE m^{-2} s^{-1}. Kain (1969) found the saturation points for growth of small sporophytes and the maturation of gametophytes of both L. saccharina and Saccorhiza to be 8.7 - 10.4 μE m^{-2} s^{-1} at 10°C. Norton and Burrows (1969a) reported the saturation points for the growth of sporophytes of 100 cells or less and the development of gametophytes of Saccorhiza to be 7.0 μE m^{-2} s^{-1} or less at 10°C. Lewis (1971), also working at 10°C, found the saturation point for the maturation of Alaria to be 14.8 - 17.4 μE m^{-2} s^{-1}.

In view of these figures experiments were set up to compare contamination at a lower light level of 15 μE m^{-2} s^{-1}, which should allow rapid development of all three species, with that at 50 μE m^{-2} s^{-1}. On completion of the experiments, however, it was found that the quantum meter was faulty and that the true irradiances were 10 and 45 μE m^{-2} s^{-1}.

It was thought that using green light instead of white might further reduce the growth of green algae, as has been demonstrated with <u>Ulva pertusa</u> (Kageyama and Yokohama, 1977). The experiments were therefore carried out using both green and white light.

In Japan transfer of the strings to the sea usually occurs when there are sporophytes of 1mm or more in length (Hasegawa 1971, 1976). Baik (1977), in a study of the attachment to strings and subsequent growth in culture tanks of free living cultures of <u>L. japonica</u>, showed that cultures of mature gametophytes attached better than cultures of sporophytes or mixtures of both. Sporophytes did attach to the string initially but subsequently fell off. In view of these facts field experiments were designed to investigate production from cultures transferred to the sea at a range of ages from less than 6 days, when no sporophytes or fertile gametophytes would be present in any of the 3 species investigated, to about 60 days, when numerous sporophytes of greater than 1cm in length would be present.

Further experiments were performed to determine whether sporophytes grown in moving water would be more firmly attached to the string, thus helping to prevent them from being washed off in rough seas.

It was realised that any seeding method is likely to be expensive. However, if a few adult plants left on the rope after harvesting could subsequently provide sufficient spores to recolonise the rope, artificial seeding would be unnecessary after the first year. Although losses over the winter seem inevitable, plants left on the rope should not represent a significant loss with <u>Alaria</u> or <u>Laminaria</u> since production in the second year of growth is high (Lewis 1971, Parke 1948). The possibility of reseeding was investigated at the end of the summer of 1982.

3.2 LABORATORY CULTURE EXPERIMENTS

3.2.1 METHODS

All cultures were grown in a medium slightly altered from that of Kain (1964). 1mM of KNO_3, 5µM of Fe Cl_3, 100µM of K_2HPO_4 and 5ml of 12-vitamin solution was added to each litre of sterilised seawater. The medium was changed every 7-10 days. Germanium dioxide was added for the first week of culture in order to prevent contamination by diatoms (Lewin 1966). Until July 1982 2ml of saturated GeO_2 solution per litre of medium was used, as described by Luning (1981) with no obvious inhibitory effects on the cultures. However, Markham and Hagmeier (1982) demonstrated slight inhibition of growth in <u>L. saccharina</u> at concentrations 1/40 of this, so from July 1982 the amount used was reduced to 0.5ml sat. sol. per litre.

Spore suspensions were prepared by rinsing freshly collected fertile plants in seawater to remove as many surface contaminants as possible, then leaving them overnight in a black plastic bag at 10°C, after which they were placed in sterilized seawater for one hour. The resulting spore suspension was left in a measuring cylinder for a further hour to allow any large particles to settle out.

All light measurements were carried out using a Crump quantum meter (cat. no. 550). White light was supplied by Thorn 65/80W white fluorescent tubes, and green light by Thorn 65/80W green fluorescent tubes in conjunction with a green cinemoid (no. 24) filter. The wave band of the resulting green light was 470-570nm.

A temperature of 10°C was used for all experiments.

To find the most suitable type of string, tests were performed on three natural fibres (jute, sisal and cotton) and three synthetic fibres (terylene, polypropylene and an unwoven fibre film). After soaking in sterilized water for one week in an attempt to leach out any toxins, 10cm lengths of string were placed on crystalising dishes containing 50ml of culture medium. Since the polypropylene and fibre film were less dense than seawater they had to be held in place with small plastic clips. Six replicates of each type of string were innoculated with L. saccharina spores and two with S. polyschides. One ml of spore suspension was added to each dish. The dishes were exposed to continuous white fluorescent light at 45 $\mu E\ m^{-2}\ s^{-1}$ for 21 days, after which each string was cut into three sections and counts of the numbers of sporophytes per cm of string made using a binocular microscope. Observations were also made on the amount of vegetative gametophyte growth.

To investigate the effects of different light regimes, deliberately contaminated cultures of Laminaria were grown in white and green light at 10 and 45 $\mu E\ m^{-2}\ s^{-1}$. The experiments were performed during the summer when Alaria, Sacchorhiza and L. saccharina were infertile, so L. digitata was used. This has a similar development to L. saccharina (Kain 1969).

Fifty ml. of culture medium, 1 ml of spore suspension and 0.5ml of contaminated medium from a previous experiment were added to each of twelve crystallising dishes under each light regime. Cover slips were placed in the crystallising dishes so that observations could be made with a microscope. After 44 days the amount of green algal contamination on the bottom of the dishes and floating as a scum on the surface of the water was observed, and the condition of the Laminaria was noted.

3.2.2. RESULTS

3.2.2.1 STRING TYPE

Green algal contamination occurred in most of the dishes, but was not sufficient after 21 days to have any severe effect on the cultures.

Table 1 shows that natural fibres were generally less suitable for culturing purposes than synthetic. Sisal appeared to be toxic to Saccorhiza but not to Laminaria. In some trial cultures sisal had appeared to prevent the development of Laminaria gametophytes completely, while a later culture of Alaria esculenta had produced large numbers of sporophytes. It therefore seems that the toxicity of sisal is variable, perhaps due to variations in the inherent toxicity of different batches of string or to contamination by toxic substances during production or transport. It is not clear whether there are any differences in the susceptibility of the species concerned.

Jute appeared to be extremely toxic to Saccohiza and inhibited sporophyte production in Laminaria without apparently affecting vegetative gametophyte growth.

The only apparent toxic effect by the synthetic fibres was that of terylene on Saccorhiza. Only small numbers of gametophytes appeared, but it is not clear whether maturation of the gametophytes and/or sporophyte development were affected.

All three natural fibres were found to rot in seawater,

String type	No. of sporophytes / cm.						Gametophyte cover					
	L.s.			S.p.			L.s.			S.p.		
	N	$\overline{x}$	±S.D.	N	$\overline{x}$	±S.D.	Dense	Light	Nil	Dense	Light	Nil
Synthetic: fibre film	18	31.1	38.6	6	17.7	14.0	18	0	0	6	0	0
terylene	18	39.7	38.5	6	0.7	1.0	18	0	0	0	5	1
polypropylene	18	19.1	17.9	6	11.2	11.8	18	0	0	6	0	0
Natural: cotton	18	6.1	5.2	-	-	-	18	0	0	-	-	-
jute	18	0.2	0.5	6	0.0	0.0	18	0	0	0	0	6
sisal	18	55.0	49.6	6	0.0	0.0	18	0	0	2	0	4

Table 1 - mean and standard deviations of the number of sporophytes/cm ($\overline{x}$) and observations on the gametophyte cover on 3.3cm lengths of string innoculated with Laminaria saccharina (L.s.) or Saccorhiza polyschides (S.p.) for 6 different types of string after culture for 21 days in white light at 45 µE m^{-2} s^{-1} and 10°C

particularly the cotton which disintegrated so much after 21 days that no results could be gained for Saccorhiza.

The choice of string for later experiments was thus limited to the fibre film and the polypropylene. Observations under a low power microscope revealed that the former was quite rough and fibrous, while the latter had a smooth surface. The fibre film was therefore chosen on the assumption that it would provide a better surface for the attachment of young plants.

3.2.2.2 LIGHT REGIME

Table 2 shows that under white light at both photon flux densities green algal growth was so great that no Laminaria sporophytes survived after 44 days, although there was less contamination at the lower irradiance. Contamination under green light was much reduced compared to that under white light, and was particularly low at 10 $\mu E\ m^{-2}\ s^{-1}$. Healthy sporophytes were present. Although the sporophytes in green light at 10 $\mu E\ m^{-2}\ s^{-1}$ were larger and more numerous than those in 45 $\mu E\ m^{-2}\ s^{-1}$ (green light) this cannot be attributed solely to the reduced numbers of green algal cells, since there were several dishes at the higher light intensity in which no green algae were observed, yet the Laminaria sporophytes were no larger or more numerous than in the more heavily contaminated dishes. Despite this, it is clear that use of green wavelengths instead of white reduced green algal contamination at both photon flux densities, and that in conjunction with a reduction in photon flux density from 45 to 10 uE $m^{-2}\ s^{-1}$ it was an effective means of controlling the contamination without severely affecting the development of Laminaria.

Light regime	Unicellular green algae: Water surface	Unicellular green algae: Bottom of dish	*Laminaria* sporophytes
White 45 $\mu E/m^2/s$	dense growth on all 12	dense growth on all 12	0
White 10 $\mu E/m^2/s$	dense growth on 1 light growth on 5	dense growth On 6 light growth on 6	0*
Green 45 $\mu E/m^2/s$	light growth on 3	dense growth on 2 light growth on 3	10-100/cm^2 up to 750 cells
Green 10 $\mu E/m^2/s$	none	light growth on 1	100-1000/cm^2 up to 10^4 cells

* Some small dead sporophytes observed

Table 2 - Estimations of numbers and maximum sizes of *L. digitata* sporophytes and observations on the amount of green algal growth in the 12 crystallising dishes after 44 days of continuous white or green (470-570nm) light at 10 and 45 $\mu E\ m^{-2}\ s^{-1}$. Temp = 10°C.

Grandy (in preparation) has since demonstrated a similar reduction in green algal contamination of red algal cultures using green light instead of white.

3.2.3 THE DEVELOPED CULTURE TECHNIQUE

Since the synthetic fibre film is slightly less dense than seawater, it was necessary to devise a frame to suspend the string below the surface of the culture medium (Figs. 5 & 6). The frame was made of steel covered with polythene tubing. The string was wrapped 100 - 140 times around it, after which it was placed in a polythene dish containing seven litres of culture medium with GeO_2 added as described earlier, and left for 24 hours for the string to become fully soaked. Fifty ml. of spore suspension was then added. This was prepared using sporing tissue from 5 - 10 (*Laminaria* and *Saccorhiza*) or 15 - 20 (*Alaria*) adult plants. No counts of spore numbers were made but when a noticeably poor suspension was made a fresh one was added a day or two later.

The cultures were exposed to continuous green light at a photon flux density of 15 $\mu E\ m^{-2}\ s^{-1}$. This is higher than the experimental value of 10 $\mu E\ m^{-2}\ s^{-1}$ which proved effective at inhibiting green algae, but is still rather lower than the value of 45 - 50 $\mu E\ m^{-2}\ s^{-1}$ which allowed them to grow rapidly. The medium was changed every 7 - 10 days.

Since only one culture room was available, the temperature had to be a compromise chosen with regard to the individual needs of the three species. Burrows (1961) reported that gametophytes of *Laminaria saccharina* grew almost equally well at 5 and 10°C,

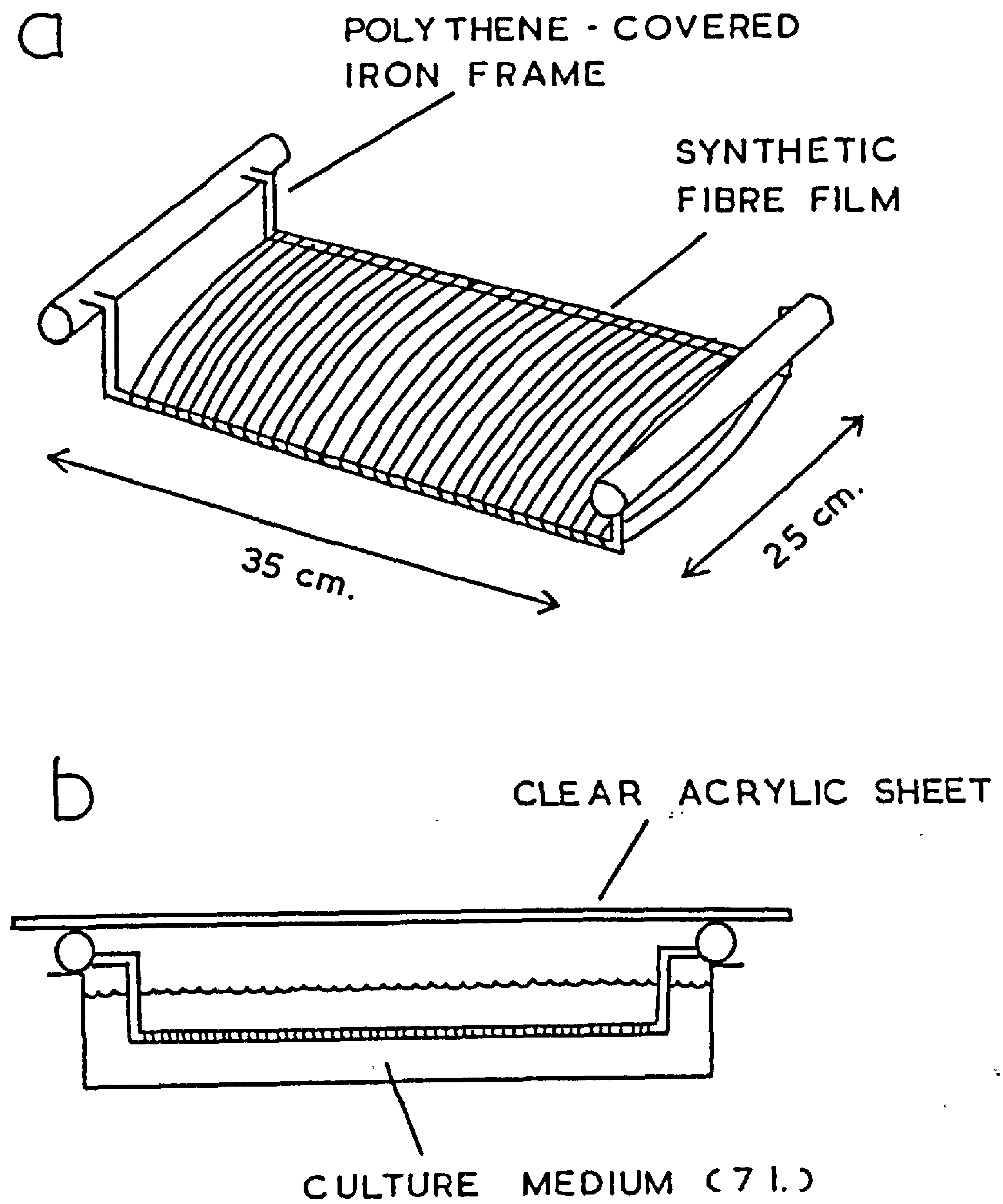
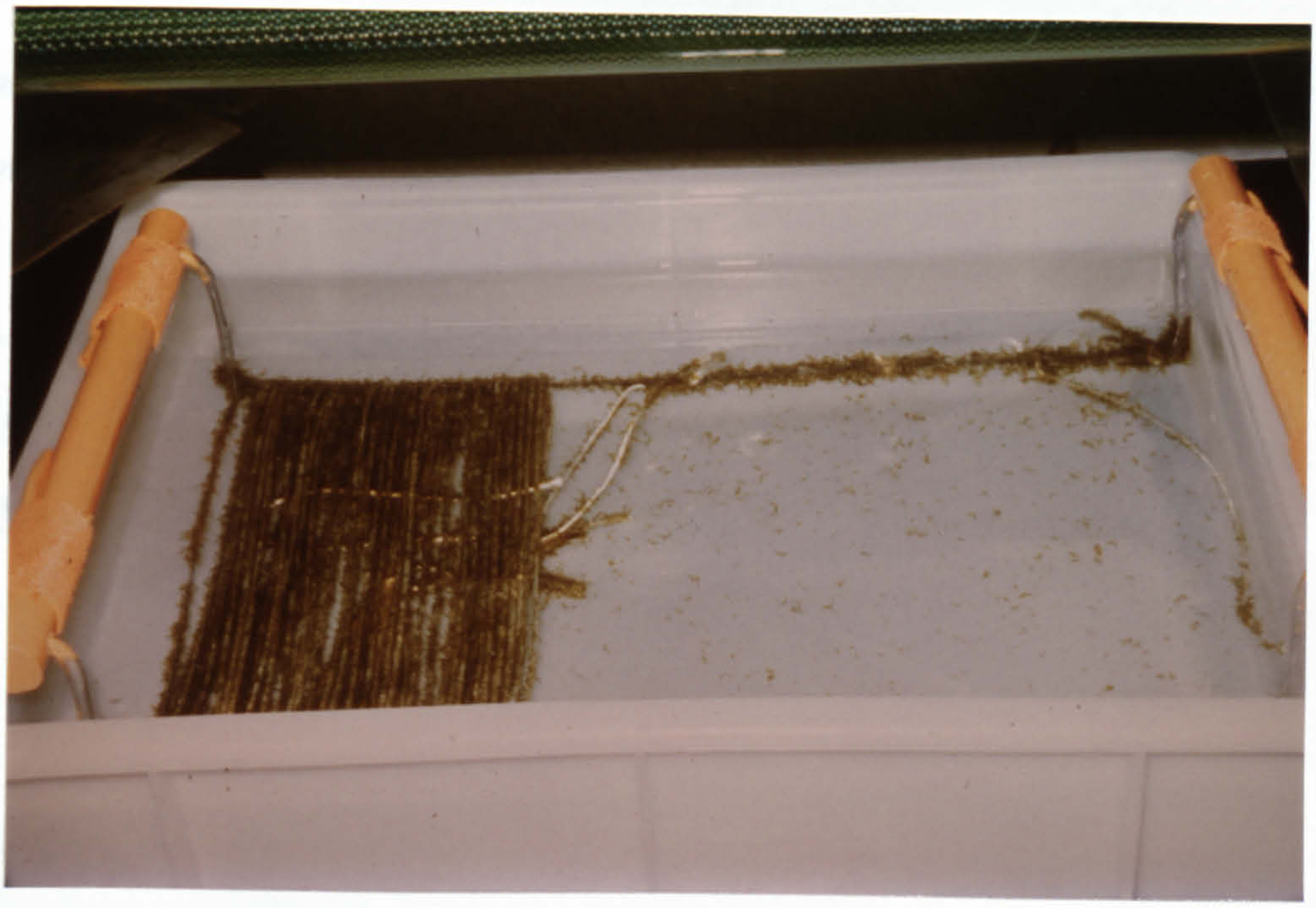


Fig. 5 - The system used to hold the string in place during culture of the young stages. a) The supporting frame with string wrapped around. b) The frame in situ with the string suspended in the culture medium.

a



b

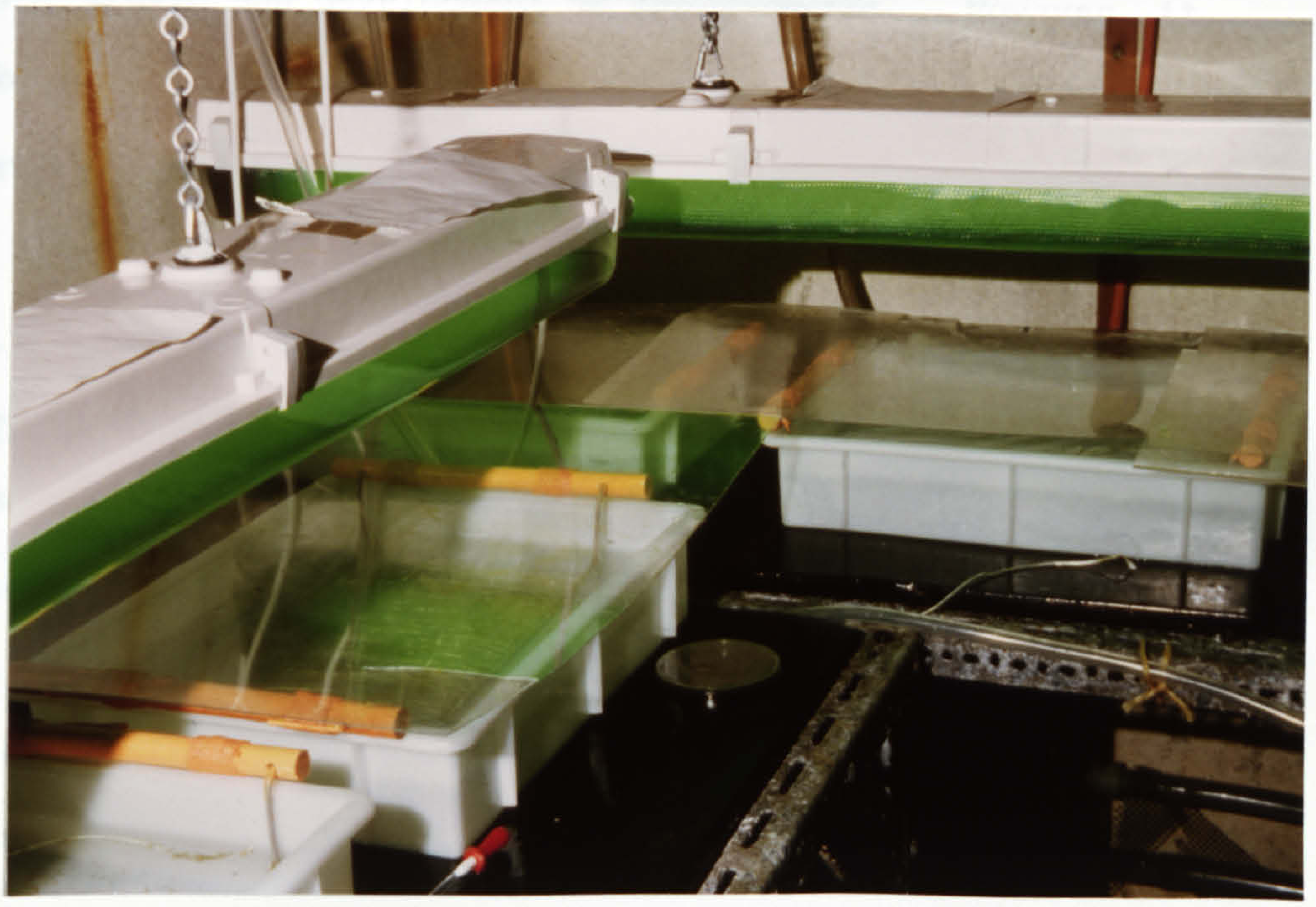


Fig. 6 - The apparatus for culturing algae on string. a) Frame with 56 day old Saccorhiza culture. b) The culture room.

although Kain (1969) found a slight reduction in the rate of development and also in the growth of young sporophytes at the lower temperature. Sundene (1962) reported only slightly slower growth of small sporophytes at 4°C than at 5 - 15°C in Alaria esculenta. Norton (1970) pointed out that zoospores of Saccorhiza polyschides can germinate to produce gametophytes at temperatures of 2 - 26°C, but Norton and Burrows (1969a) showed that the gametophytes developed much more slowly at 5°C than at 10°C, and Kain (1969) showed that sporophytes of up to 100 cells grew more slowly at 10°C than at 17°C and much more slowly at 5°C. In view of these facts a temperature of 10 - 12°C would probably have been ideal for growth and development of the cultures. However, it was thought that this might result in too great a temperature drop upon transfer to the sea, since surface temperatures in Manx waters can be 5.5°C or less during late winter/early spring (Slinn, unpubl.). Although Burrows (1961) reported that Laminaria saccharina sporophytes can be transferred from 10°C to 5°C at any stage during at least the first 6 months of their life without any significant change in growth rate, nothing was known about the effects of temperature drops upon Alaria or Saccorhiza. A temperature of 8 - 10°C, which was about 1 - 3°C above mean sea temperature, was therefore used for culturing (Fig. 7 - Seawater temperatures recorded at Port Erin breakwater, Isle of Man, from Slinn, unpublished †). The greatest drop in temperature experienced by any set of strings upon transfer to the sea was 3.1°C in February 1983.

† 1981 figures published as monthly means (Slinn in prep.).

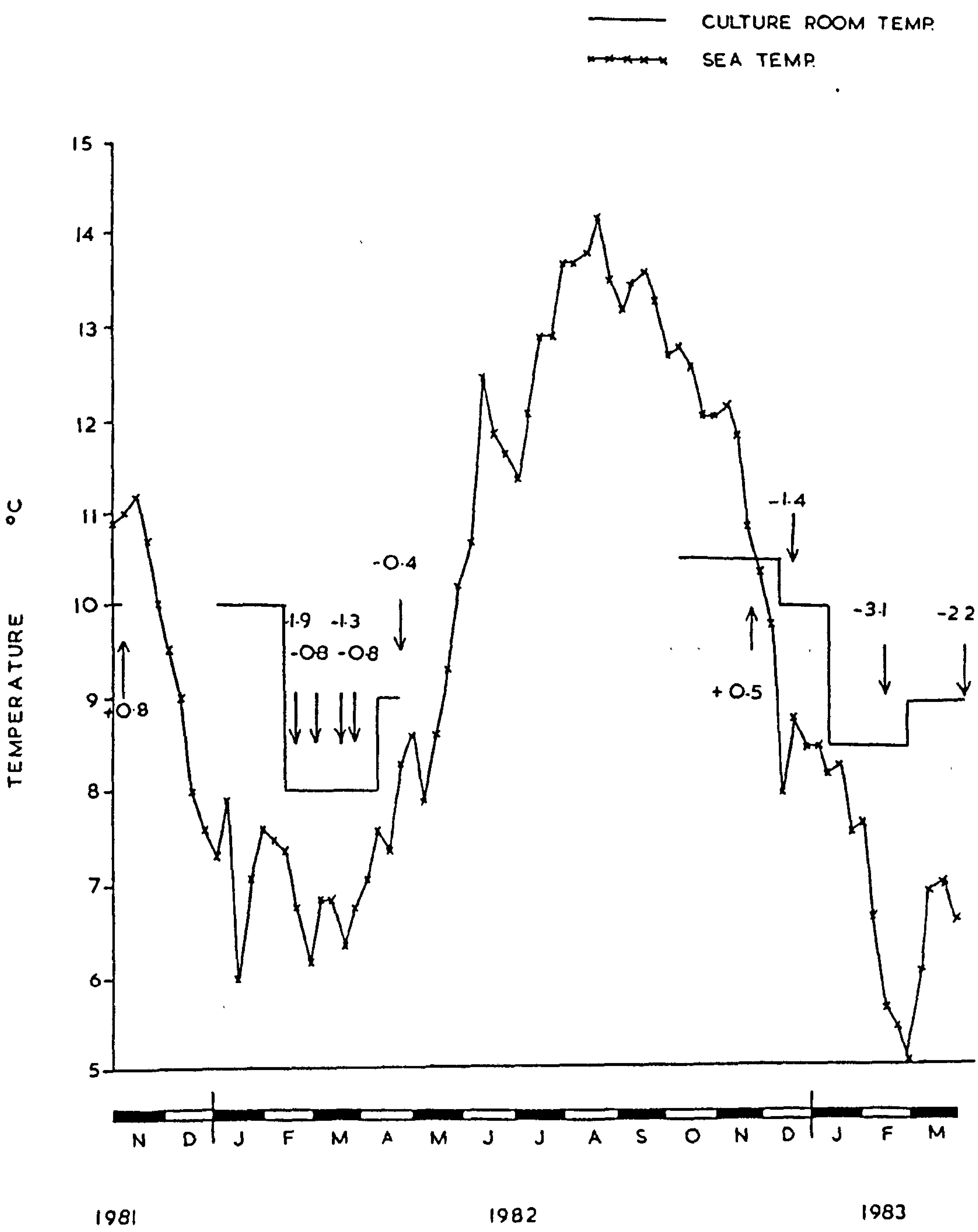


Fig. 7 - Variation in weekly mean sea temperature and culture room temperature. Difference between culture room temperature and sea temperature on each day on which strings were transferred to the sea is indicated by arrows. Seawater temperature was measured at the breakwater, Port Erin, from Slinn (unpublished).

Under these conditions healthy cultures with little contamination were obtained (Fig. 8). Growth and development of all three species was satisfactory, but consistent differences between the species were observed. After 20 - 40 days, Laminaria saccharina produced very little gametophyte growth but large numbers of healthy individual sporophytes (Fig. 8b). Alaria esculenta produced some dense balls of gametophytes which then produced many sporophytes clumped together. Saccorhiza polyschides produced quite large quantities of both gametophytes and sporophytes (Fig. 8a) although not in such dense patches as Alaria.

Occasionally there was noticeably less growth on the bottom layer of strings than on the top layer of the same frame, although there was usually little difference. However, when the string was to be placed in the sea it was cut along both edges of the frame and the resultant 25cm lengths from the top layer only were used.

Some of the cultures were aerated using a small airstone in one corner of the dish. Aeration commenced 24 hours after the addition of the spore suspension. There was no noticeable difference in either number or size of plants produced in the still and moving culture media.

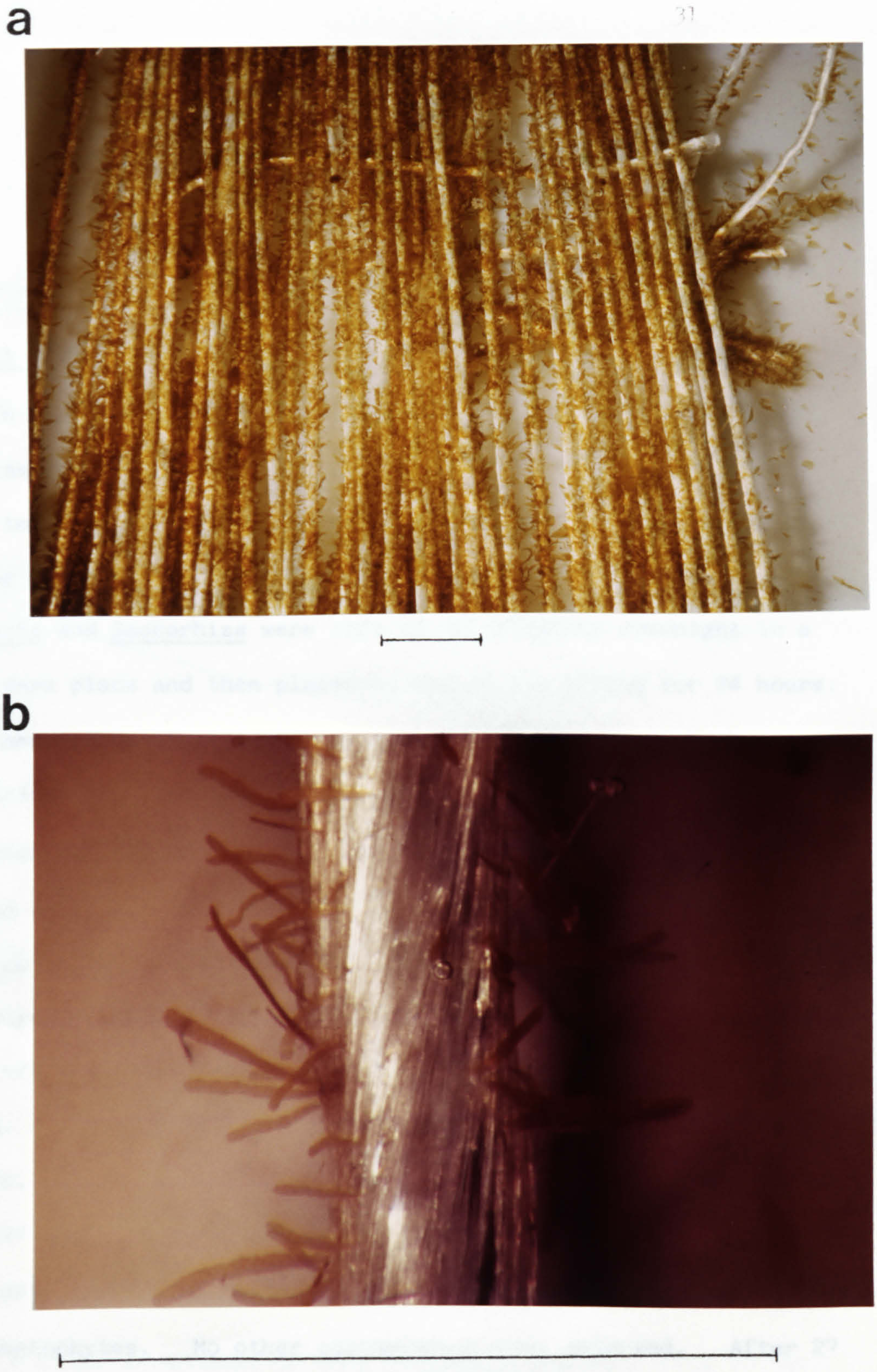


Fig. 8 - Algal cultures. a) Saccorhiza polyschides, 56 days old.
b) Laminaria saccharina 30 days old. Scale bars = 1cm.

3.3 FIELD EXPERIMENTS

3.3.1 METHODS

3.3.1.1 LONG STRING METHOD

In March 1981 100m of sisal string was wrapped around each of two plastic coated wooden frames, which were then placed in 230 litre tanks through which seawater was running at two litres/minute. A glass wool filter was used to reduce contamination. Sporing Laminaria and Saccorhiza were left to dry slightly overnight in a cool, dark place and then placed on top of the string for 24 hours. The frames were left outdoors with no temperature control or artificial light source, but sheltered from direct sunlight and rain. The water temperature ranged from 5.5 - 10°C and the light levels reached a maximum at midday of about 1000 lux (roughly equivalent to 19 $\mu E\ m^{-2}\ s^{-1}$) on bright days and 340 lux (5.7 $\mu E\ m^{-2}\ s^{-1}$) on dull days. Despite later results in the laboratory demonstrating toxic effects of sisal many gametophytes appeared on both sets of string. They were very slow to develop. No sporophytes, zygotes, eggs or gametophytes with more than two cells were observed after 27 days. Filamentous diatoms grew quickly on the strings but were easily washed off with a seawater hosepipe without dislodging the gametophytes. No other contaminants were observed. After 27 days (April 7) 25m of each string was wrapped around a 25m section of each of three ropes set at depths of 0, 1, and 2m in Bay Fine, and a further rope at 2m depth in Perwick Bay. It was necessary to tie the string to the rope at intervals of one to three metres since the two did not remain in contact (Fig. 9b, c). In situ

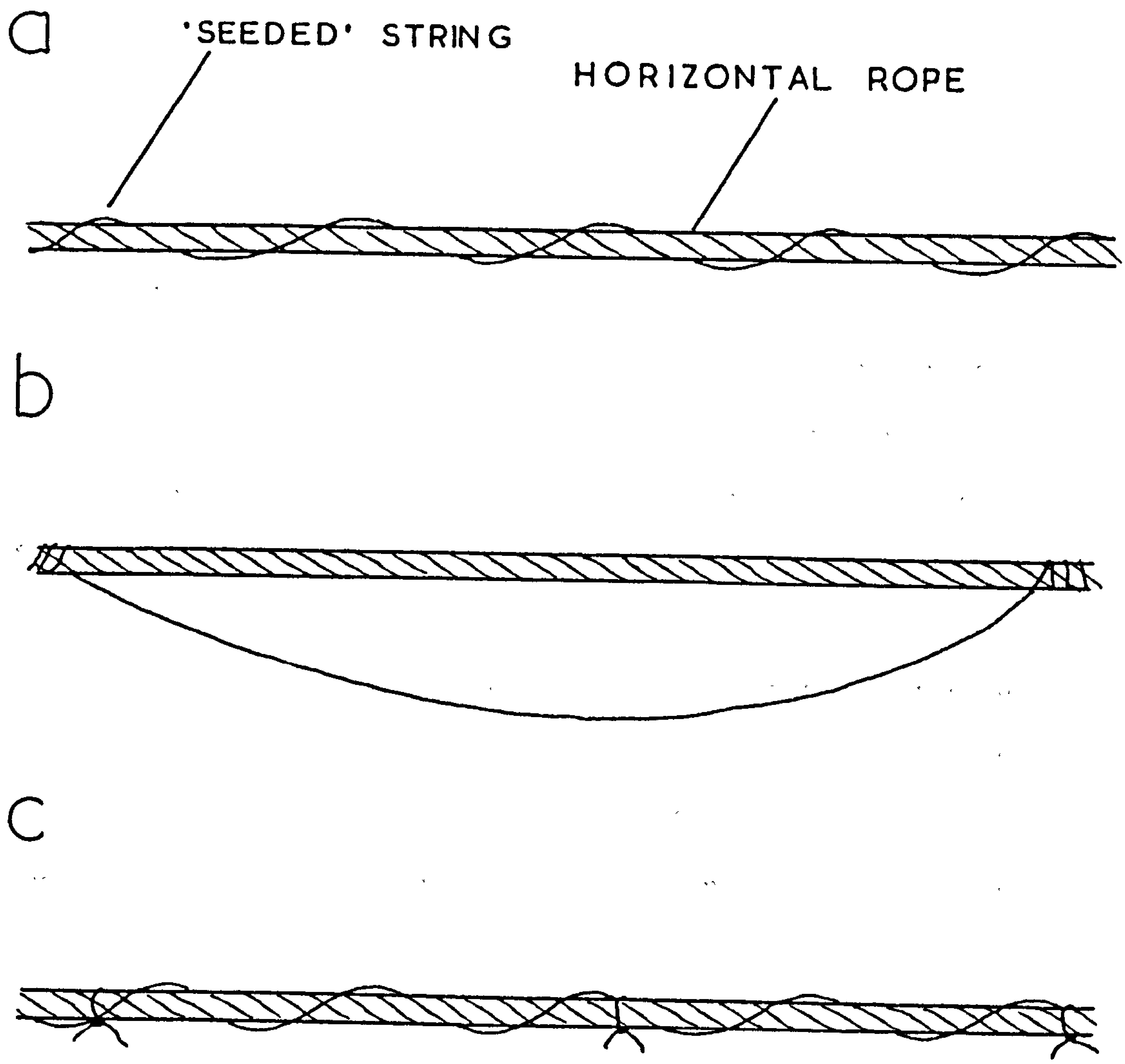


Fig. 9 - The attachment of long lengths of seeded string to the ropes. When it was simply wrapped around the rope (a) large portions quickly became unwrapped (b). The string therefore had to be firmly tied to the rope at frequent intervals (c).

observations were made by divers during April, May and June 1981, including counts of numbers of plants and notes on the approximate size of the plants.

3.3.1.2 ATTACHMENT OF SPORING ALGAE

Mature Laminaria and Saccorhiza plants were collected by divers and tied to horizontal ropes at intervals of 1, 3 and 5m using polypropylene string (Fig. 10). It was known that large numbers of plants would occur naturally on the ropes, so the sporing plants were attached with 1m gaps at one end of the rope and 5m gaps at the other so that if the method was successful it would be expected that the plants would be much more numerous at one end than the other. The ropes and attached plants were left out of water in a cool dark place overnight to encourage spore release and placed in the sea the following day at a depth of 2m.

On November 5th 1981, two such ropes with sporing Saccorhiza, one with sporing Laminaria and a control rope with no attached algae were placed in Bay Fine, and a further rope with sporing Laminaria was added on December 3, 1981. The ropes were spaced 50m apart with the control rope in the middle, the two Saccorhiza ropes on one side and the two Laminaria ropes on the other. Unfortunately, during February 1982 both Laminaria ropes were lost due to loosened shackles at the bottom of the vertical ropes.

On April 2 1982, in situ counts were made by divers of the numbers of Alaria, Laminaria and Saccorhiza plants on each of the four sections between the supporting buoys on the remaining ropes.

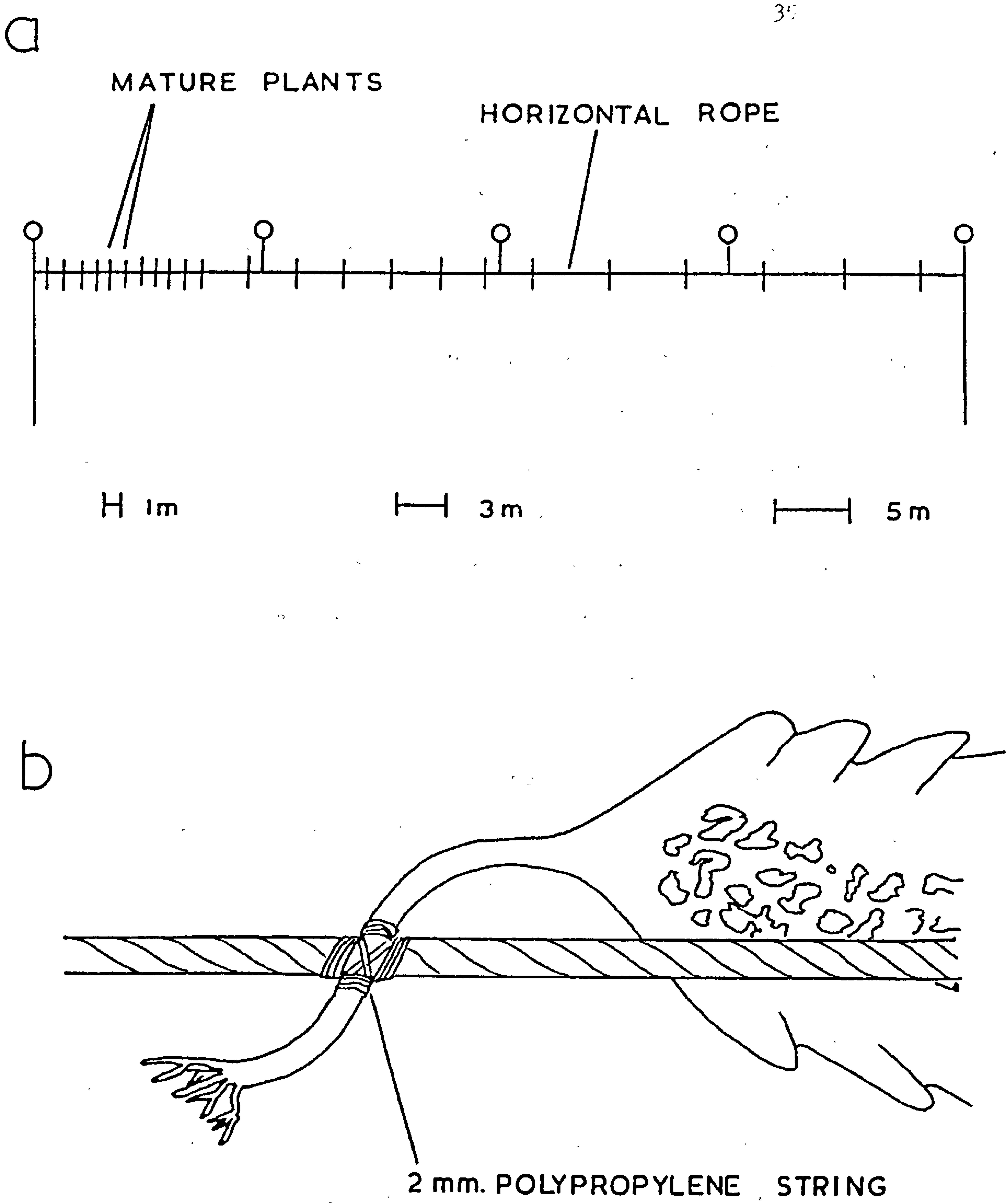


Fig. 10 - The attachment of sporing thalli to the ropes. Eleven plants were attached at 1m intervals, seven at 3m intervals, and five at 5m intervals as shown (a). The plants were attached by lashing the stipes firmly to the rope a few cm above the holdfasts. (b).

3.3.1.3 SHORT STRING METHOD

The method of attachment of the strings to the ropes was devised during a trial experiment which started on November 5 1981 using seventy 30cm lengths of string on which *Alaria esculenta* gametophytes had been grown for 21 days. No sporophytes were observed on these strings during culture. Sisal was used because the results of the laboratory culture experiments were not yet known. The strings were attached to the rope from a small boat. They were inserted into the lay of the rope (Fig. 11) in order to avoid having to tie knots which might have rubbed off the algae. One person was required to twist open the rope, and a second person to pass the piece of string through. This proved impossible while the rope was attached to both vertical ropes because of the tension caused by the current and by the boat drifting. The horizontal rope was therefore attached to only one vertical rope and the boat then moved steadily towards the other. The rope was payed out slowly while the strings were inserted into it at about 80cm intervals and then attached to the second vertical.

By February 3 1982, 45 groups of 1 - 30 plants up to about 15cm in length had grown. In some cases much of the string had rotted or been worn away and the plants were growing mainly on the rope at the point of attachment of the string. In others there were large numbers of plants growing on the string, although these were lost later as the sisal disintegrated. The rope had held the strings tightly in position and none of them appeared to have moved or been lost. This method of attachment was therefore thought to be satisfactory and was used in all experiments involving short strings.

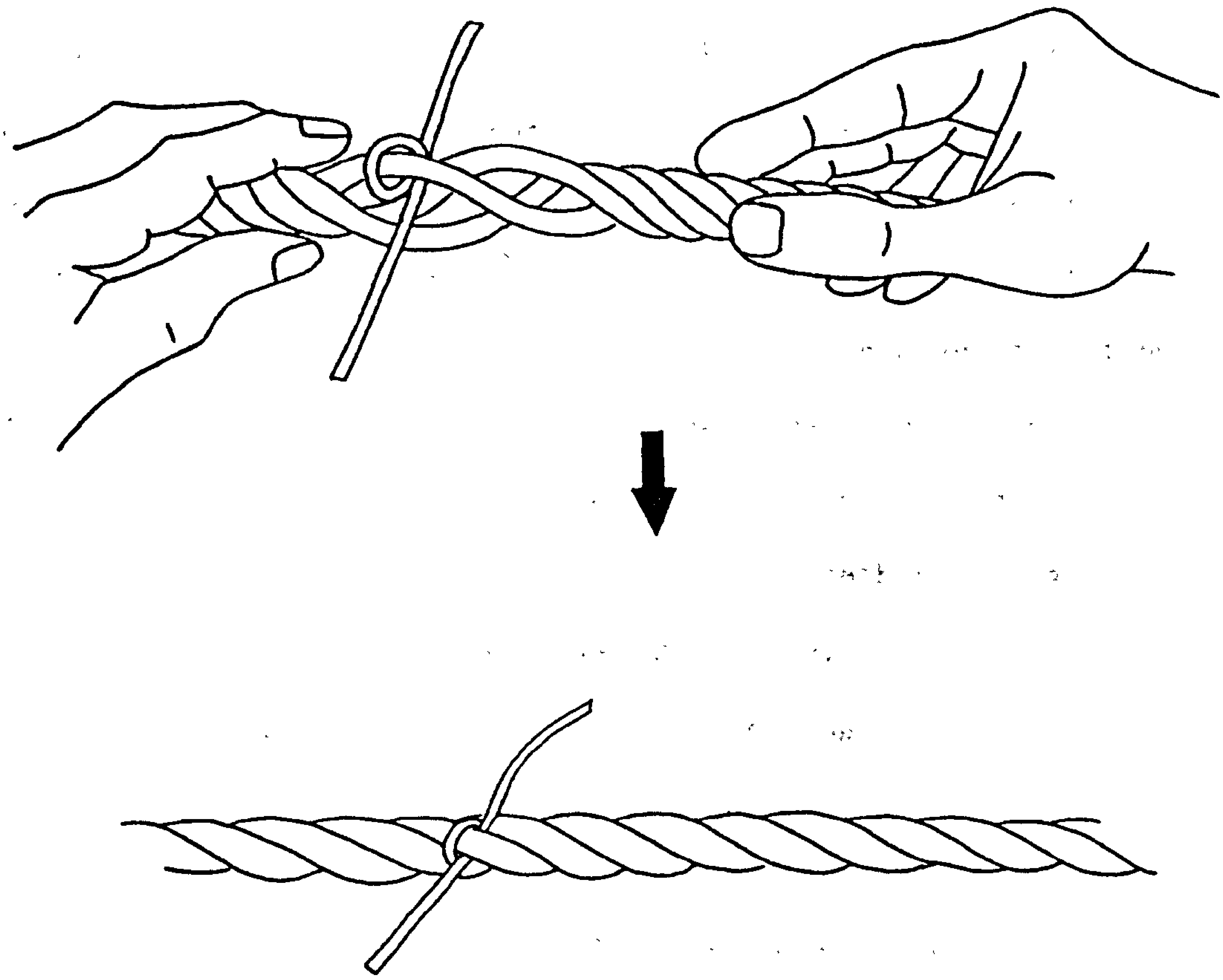


Fig. 11 - Insertion of short lengths of seeded string into the ropes.

In the following experiments culture was carried out on fibre film as described in section 3.1.4. The strings were always spaced at 1m intervals on ropes set at a depth of 2m.

To investigate the effect of the age of the cultures at the time of seeding, it was intended that cultures be set up every two weeks from Feb 10 until early April in 1982, and a batch of ten strings from each culture be transferred to the sea every week. Cultures of different ages would therefore have been seeded at the same time and usually on the same rope, enabling comparisons to be made. However, frequent strong winds prevented regular collection of sporing algae and only three sets of cultures were started, on Feb 10, on which date it proved impossible to find sporing Laminaria, February 24 and March 17. The bad weather also gave few opportunities for placing strings in the sea, with the result that only a small fraction of the original seeding programme was put into effect.

To test the effects of water movement during culture. many of the cultures were duplicated using the same spore suspension but with gentle aeration to produce water movement of about 1 - 2cm s^{-1}. Batches of ten of these strings were placed in the sea on the same ropes and on the same day as the non-aerated equivalents.

Frequent observations were made on the plants by divers. They were harvested during the summer when they appeared to be deteriorating badly at the tips. They were removed from the ropes and taken in plastic bags to the laboratory where the number of plants and fresh weight of algae from each string were determined. The dry weight content of each species at each harvest was determined by drying a sample of 400 - 1000g (fresh weight) taken from as many individual plants, or portions of plants in the case of Laminaria and Saccorhiza, as possible. The samples were dried at 80 - 90°C for 48 - 72 hours. The dry weight of the harvested algae was then calculated.

3.3.1.4 RESEEDING

At the end of the summer of 1982 three ropes were left in the sea, each bearing ten groups of Laminaria, or twenty of Saccorhiza or Alaria. The groups chosen contained quite high numbers of large plants, and were situated at one end of the rope so that if reseeding occurred it would be expected to be heavier at one end of the rope, since all the ropes were stretched across the direction of the predominating tidal currents. Observations were made over the following winter and spring, and in July 1983 counts were made of the number of plants of each species on each metre section of rope.

3.3.2. RESULTS

3.3.2.1 LONG STRING METHOD

The seeding strings maintained very little contact with the horizontal rope, despite being tied to it at 1 - 2m intervals. Furthermore, since it was sisal it rotted easily and often snapped. By mid-June none of the four seeded ropes bore any string at all.

The number of young sporophytes of Laminariaceae on the surface rope and string were counted on June 11, after more than nine weeks in the sea (Fig. 12). No attempt at identification to species was made. The plants were small, mainly 3 - 5cm in

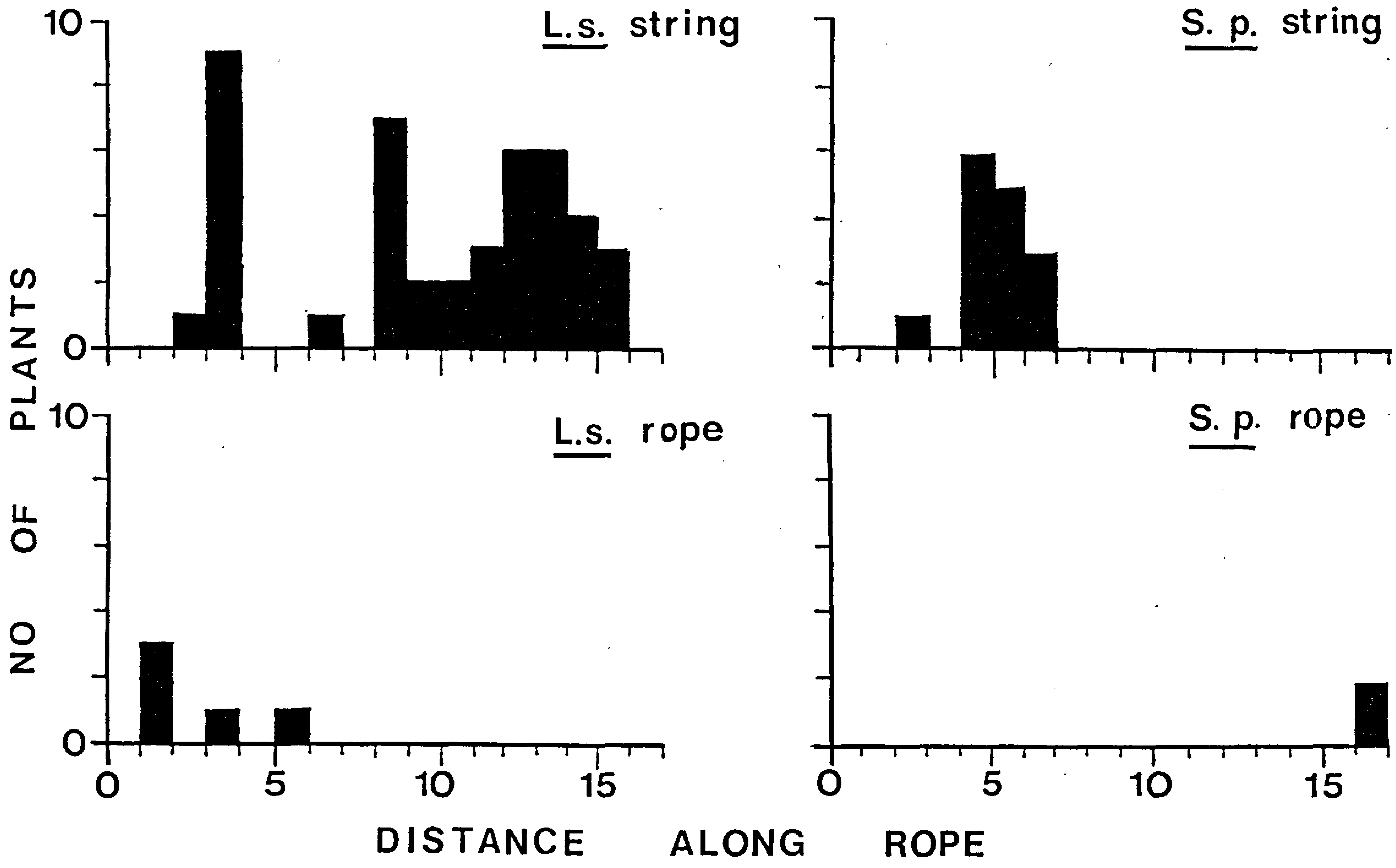


Fig. 12 - The number of sporelings of laminariales attached to 1m sections of the rope or string in 'long string' experiments after 2 months in the sea. This rope was set at a depth of 0m.

length, but occasionally up to 10cm. It can be seen from Fig. 12 that there were more plants on the string than on the rope, suggesting that the plants were there as a result of seeding and not natural colonisation, but that they were few in number. There were only about 2.5 plants/m on Laminaria seeded string and fewer still on Saccorhiza seeded string. Since the rope was floating at the sea surface it is possible that excessive turbulence during rough weather removed many young plants or that desiccation during calm weather killed some. However, it was observed while diving that the ropes and strings at 1 and 2m depth also bore negligible numbers of plants. It is unlikely that the low temperature of the culture tank and the sea could have delayed development sufficiently to explain this†, particularly with Laminaria. One possible explanation is that toxins from the string, the frame or the seawater system inhibited proper development of the young plants. It is also possible that rotting of the strings resulted in loss of plants as surface fibres disintegrated or were lost. Both of these possibilities could be overcome by culturing the plants on fibre film under more controlled conditions. This would still leave the possibility that the loose attachment of the string to the rope causes loss of plants by allowing the two to rub together. To overcome this the seeding string would have to be payed out very carefully, keeping the length of the string exactly equal to that of the rope, and tied much more frequently.

† Rising from about 7 to about 10°C from early April to early June (figures from Slinn, unpublished).

3.3.2.2 ATTACHMENT OF SPORING ALGAE

Most of the sporing Saccorhiza plants remained attached to the horizontal ropes for several months. Only three or four were lost from each rope by April 2nd. They remained healthy looking until at least early December, but by March most of the fronds had been entirely lost and the stipes and holdfasts were heavily covered with epiphytes, mainly filamentous brown algae with some Ulva and Cladophora.

Section	Control Rope		Ropes with sporing Saccorhiza thalli			
			1		2	
	S.p.	L.s.	S.p.	L.s.	S.p.	L.s.
1	27	69	203	9	37	200
2	69	59	68	15	83	94
3	59	59	16	25	117	64
4	77	30	278	100	124	78

Table 3 - the numbers of Saccorhiza polyschides (S.p.) and Laminaria saccharina (L.s.) observed on April 2nd 1982 on each of four 15m long sections of three 60m horizontal ropes placed in the sea on November 5th 1981, with and without attached sporing Saccorhiza. Section 1 - 1m gaps between attached algae. Section 4 - 5m gaps. (See Fig. 10).

Table 3 shows the numbers of the two major colonisers on the two ropes bearing attached Saccorhiza and on the control rope after 21 weeks. There were more Saccorhiza plants on both experimental ropes than on the control, with up to 278 plants per 15m on rope 1 compared to a maximum of 77 on the control rope. However, there were also considerably more Laminaria plants on rope 2 than on the control, demonstrating that natural colonisation can be very variable even over relatively short distances. Furthermore, it can be seen that on both ropes there were fewer young Saccorhiza plants where the attached thalli were at 1m intervals than where they were at 5m intervals, and that there were only 37 plants on a 15m section of rope 2 bearing eleven attached thalli at 1m intervals. The tidal currents ran perpendicular to the horizontal ropes, rendering it unlikely that spores could be released at one end of a rope and transported to the other. It is therefore improbable that much of the colonisation was due to the attached algae.

Even the maximum density of sporelings achieved, 18.5/m over 15m, is not particularly high, and overall the sporelings were patchily distributed and of very low density. It is possible but unlikely that the algae chosen were of low fertility. It is more probable that the zoospores were removed from the area by currents before they had a chance to settle. If this is the case, this method of seeding is very unlikely to be suitable, particularly for Laminaria and Alaria for which high densities of plants are desirable.

3.3.2.3 SHORT STRING METHOD

When successful, this method produced distinct groups of plants, as shown in Figs. 13 - 16. Unlike the sisal, the fibre film did not disintegrate and the plants were able to develop on the free floating part of the string, the horizontal rope at the point where the string was attached, or both.

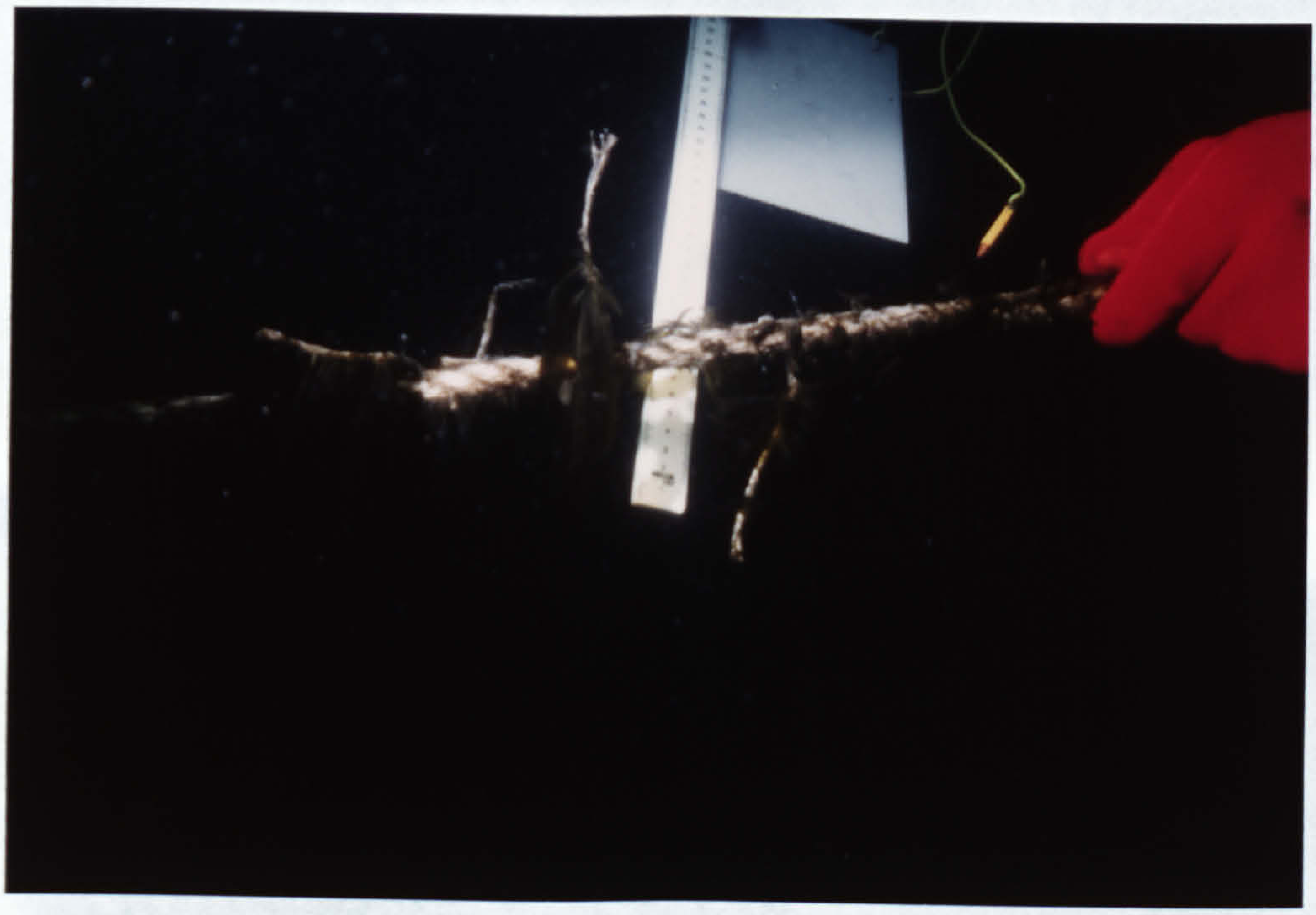


Fig. 13 - Alaria esculenta plants growing on strings seeded 10cm apart at 2m depth on November 5 1982, photographed on March 10 1983.

a

b

Fig. 14 - Alaria esculenta groups seeded 1m apart at 2m depth on March 26 1982, photographed on July 13 1982.
a) In a steady current of about 0.3 m/s with no swell.
b) In a steady current of about 0.3 m/s with a slight swell.

Fig. 15 - Alaria esculenta groups (A.e.) seeded 1m apart on November 5 1981, photographed on April 19 1982 in calm conditions with no current. Some naturally colonised Saccorhiza polyschides can be seen (S.p.).

a

b

Fig. 16 - Laminaria saccharina groups seeded 1m apart at 3m depth on April 5 1983 being harvested on September 8 1983.
a) Groups weighing about 90-300g dry weight. The holdfasts were attached to the strings only.
b) Two larger groups. The one in the foreground weighed 460g dry weight. One group can be seen attached directly to the rope.

Groups of *Saccorhiza* contained 1 - 34 plants, but usually fewer than 15. *Saccorhiza* is relatively weakly attached to substrata, despite the large size of its holdfast, and groups were frequently removed by wave action when the plants reach about 1m or more in length. Groups attached only to the string rarely survived until the harvest. Often, when large numbers of plants developed in one group, some of them were attached only to other plants and not to the rope or string. This must have increased the drag forces on the group without increasing the overall strength of attachment to the substrata, but it is not known if any more large groups than small ones were lost because of this.

Laminaria groups consisted of 1 - 97 plants. They were relatively strongly attached and only three groups (10%) were entirely removed by wave action. When a large group formed, the holdfasts intertwined to form a tangled mass which was often attached to the rope at some point. This greatly increased the strength of attachment, particularly when the holdfasts completely encircled the rope. Groups attached in this way had to be harvested with a knife, while those attached only to the string could easily be pulled off by hand. Attachment of the holdfasts to the rope also prevented excessive movement of the groups which could eventually cause the string to snap. Snapping was a problem in later experiments when large groups of plants were sometimes attached only to the string.

Groups of *Alaria* consisted of up to 225 plants (typically 50 - 180) and were very strongly attached. The holdfasts formed tangled masses similar to those of *Laminaria* and, because of the large numbers of plants involved, were almost always attached at some point to the horizontal rope.

The plants were harvested on the following dates when they were deteriorating noticeably at the tips:

Alaria:

February seeded	}	harvested	July 2
March 1 seeded	}		
March 26 seeded	-	"	August 13
April seeded	-	"	July 27

Laminaria: " August 13

Saccorhiza:

March seeded	-	"	August 13
April seeded	-	"	July 27

At Port Erin, Alaria stops growing in late May/early June, and the frond then rapidly degenerates (Lewis, 1971). Natural populations of Laminaria saccharina grow slowly during the summer (Parke 1948). However, they may carry on photosynthesising at a high rate and accumulate organic storage materials, as has been suggested for L. longicruris (Chapman and Craigie, 1977, Gagne & Mann, 1981) and in L. hyperborea (Kain, 1979). Black (1954) reported that the storage materials mannitol and laminaran reached a maximum in L. saccharina in the summer. Saccorhiza grows most rapidly in June - July (Norton 1970) and it is doubtful whether it accumulates any organic reserves (Jensen et al, in prep.). Although cultivated Alaria plants seeded in the spring may continue to grow for a month longer than natural populations (see chapter 5), it seems likely that in 1982 Alaria was harvested rather later than it should have been, so that the production levels recorded may be somewhat low. It is also possible that, despite the severe damage observed at the ends of the plants, the Laminaria and/or Saccorhiza plants may have still been growing in August, when they were harvested. The Laminaria plants may have been accumulating sufficient storage material to increase the total organic content despite erosion, although analysis of naturally colonised plants on the ropes suggests this was unlikely (chapter 7). In any case, the plants would have to have been harvested in early September in order to avoid the autumn gales, and there was unlikely to have been a large increase in the total organic content in that time.

Some groups were lost when adjacent ropes tangled, while others which appeared to be relatively large were left on the ropes as part of an experiment.

When mean values for plant numbers or weights were required, they were usually calculated only from the harvested groups, ignoring those which were lost or failed to grow. The figures therefore give an idea of the potential production from each species, assuming that the reliability of the seeding technique can be improved, and that losses due to wave action can be minimised. Statistical analysis of differences in plant numbers and weights under the different treatments was performed using the non-parametric Mann-Whitney rank correlation test as described by Meddis (1975), since normal distributions could not be assumed.

Table 4 - The number of groups and total number of plants ($\pm$ 1 S.D.) grown from sets of 10 strings for *Alaria*, *Laminaria* and *Saccorhiza* seeded at 2m depth in 1981 after various lengths of time in aerated or unaerated culture. Each set of figures represents the same culture seeded at different ages.

* = groups left on the rope as part of a reseeding experiment.

? = groups lost by rope tangling.

† = 7 groups were lost when the boat rubbed against the rope during harvest.

Results of Mann - Whitney tests to compare numbers of plants in groups from aerated and non-aerated cultures:

X = no difference at 5% level of significance.

✓ = difference at significance level indicated.

L. saccharina	Mar 19, 23 days	X (nearly significant at 5% level).
A. esculenta	Feb 17, 7 days	✓ 5%
	Mar 26, 30 days	X
	Apr 22, 57 days	✓ 2%

		Date	Age (Days)	Aerated: No. of Groups	Aerated: Mean No. of Plants	Non-aerated: No. of Groups	Non-aerated: Mean No. of Plants
Laminaria	i)	Mar 1	5	0	0	0	0
		Mar 19	23	8	54.8 ± 28.0	9	5.9 ± 4.6
		Mar 26	30	10	*	-	-
		Mar 22	57	0	0	0	0
	ii)	Mar 26	9	0	0	-	-
		Apr 22	36	0	0	-	-
Alaria	i)	Feb 17	7	10	67.1 ± 26.6	10	97.0 ± 27.6
		Mar 1	19	-	-	10	43.1 ± 17.6
		Mar 19	37	-	-	10	?
		Apr 22	71	-	-	10	67.7 ± 12.8
	ii)	Mar 1	5	0	0	0	0
		Mar 19	23	10	*	10	*
		Mar 26	30	10	125.6 ± 41.8	10	152.1 ± 41.3
		Apr 22	57	10	137.3 ± 37.5	10	88.2 ± 39.4
	iii)	Mar 26	9	10	41.8 ± 37.4	-	-
		Apr 22	36	10	48.5 ± 28.1	-	-
Saccorhiza	i)	Feb 17	7	10	*	10	*
		Mar 1	19	-	-	0	0
		Mar 19	37	-	-	6	3.3 ± 2.2
		Apr 22	71	-	-	†3	13.3 ± 2.5
	ii)	Mar 1	5	0	0	0	0
		Mar 19	23	2	2.5	5	?
		Mar 26	30	6	5.0 ± 3.3	0	0
		Apr 22	57	9	10.8 ± 6.1	-	-
	iii)	Mar 26	9	0	0	-	-
		Apr 22	36	6	20.0 ± 9.7	-	-

Table 4

3.3.2.3.1 Effects of Aeration

If water movement during culture resulted in stronger attachment of the young sporophytes to the string, larger numbers of plants would be expected in groups grown from aerated cultures than in those from unaerated ones. Table 4 shows that this may be the case with *Laminaria*. A mean of only 5.9 plants per group was obtained from a non-aerated culture compared with 54.75 per group from an equivalent aerated one. A Mann-Whitney test revealed no significant difference at the 5% level, due mainly to the fact that one of the groups from the aerated culture contained only two plants, while the other seven groups contained 36 - 97 plants each (Appendix 2). It is possible that this group originally contained many more plants, but that the majority were lost during rough weather. Ignoring this group, the Mann-Whitney test showed a significant difference at the 0.2% level. However, this was the only set of figures obtained for *Laminaria*, so that no firm conclusion can be drawn.

One of the aerated *Saccorhiza* cultures (culture no. i in Table 4) dried up a few days after the first medium change when an increase in pressure in the aeration system caused most of the water to be splashed out of the tray. Very few plants survived, so the number of comparable sets of aerated and non-aerated *Saccorhiza* strings was considerably reduced. Of the *Saccorhiza* strings which were placed in the sea, a great many bore no algae at all. This was probably due mainly to plants being removed by wave action, rather than a failure to grow. Ten of both the aerated and non-aerated groups were selected for use in the reseeding experiment because of their relatively large size and good attachment, but the number of plants in the group were not counted. Comparison of the number of plants from the aerated and non-aerated cultures which were harvested (Table 4) gives no strong evidence of any difference. However, even quite a large difference could easily have been masked by the many losses, particularly if large groups were more prone to removal by wave action than small ones.

The first aerated Alaria culture (no. i in Table 4) dried out in a similar way to the Saccorhiza one. Again few plants survived, and the number of comparable aerated and non-aerated strings was much reduced. However, almost all of the strings bore groups of algae, aiding comparison considerably. It can be seen from Table 4 that in two cases there were more plants in the non-aerated groups than in the aerated ones. With culture i), seeded on February 17, there was a mean of 97 plants per group from the non-aerated cultures, compared to only 67 from the aerated ones. This difference was significant at the 5% level according to the Mann Whitney test. With culture ii), seeded on March 26, there was no significant difference between the aerated and non-aerated cultures, but the latter bore a mean of 152 plants per group, the highest from any set of strings, compared to only 125.6 from the aerated ones.

Only on the strings from culture ii) seeded on April 22 were there more plants from the aerated cultures, with a mean of 137 per group compared to 88 from the non-aerated strings. This difference was significant at the 2% level. Taking all three sets of equivalent aerated and non-aerated strings together gives means of 110 and 112.4 plants per group respectively, and it must be concluded that aeration had no significant effect upon the number of plants grown.

Table 4 shows that further groups of Alaria plants were harvested, bearing 42 and 48.5 plants per group (iii, aerated) and 43 and 68 plants per group (i, non-aerated), again suggesting that aeration had little effect. However, the cultures were not prepared from the same spore suspension and were of different ages, either of which could greatly affect the number of plants.

Groups from 10 aerated and 10 non-aerated cultures seeded on March 19 (Table 4, culture ii) were left on the rope to investigate reseeding. The number of plants in these was not counted, but no obvious difference could be seen while diving. The groups were roughly the same size as the groups from the same culture seeded on March 26, which contained more plants than any others. These observations therefore support the conclusion that there was no significant difference in the number of plants grown from aerated and unaerated cultures.

It was observed whilst diving that within a few days of being placed in the sea all the strings were competely bare to the naked eye, even though many of them had originally been covered with sporophytes up to 1cm in length (Figs. 6 and 8). Markham and Hagmeier (1982) observed that young L. saccharina sporophytes exposed to GeO_2 were very brittle and tended to break into pieces when touched, which might explain the disappearance of the sporophytes from the strings. However, in the present work the plants were only exposed to Ge for the first week (before sporophytes were produced), and since Markham and Hagmeier (1982) also reported that most germanium effects can be reversed by reducing the Ge/Si molar ratio, it seems unlikely that the sporophytes would have been adversely affected. It is most likely that the plants were simply removed from the string by wave action due to insufficient strength of attachment. In either case, the adult plants which were harvested must all have developed in the sea from gametophytes or from microscopic sporophytes on the string, and it seemed very unlikely that attachment at such an early stage could have benefited greatly from gentle water movement. Since there was a great deal of water movement in the sea during winter and spring, the subsequent appearance of large numbers of sporophytes, particularly with Laminaria and Alaria, suggests that water movement may be necessary for adequate attachment, but at greater rates than 1 - 2cm s^{-1}. As this was impractical with the aeration system used, particularly with the risk of the cultures drying out, all cultures in 1983 were unaerated. The results are discussed more fully in Chapter 4, but again there was no evidence that Alaria was adversely affected by lack of aeration. Twenty groups of plants seeded in February 1983 produced a mean of over 170 plants per group (Appendix 4) which is rather more than the maximum of 137 per group obtained using aerated cultures in 1982 (Table 4). Losses of Saccorhiza in 1983 were extremely heavy, and were almost all incurred when the plants were about 1m or more in length. However, with Laminaria a mean of 22.6 plants per group from 8 groups was the maximum achieved in 1983 (Appendix 5), compared to 54.15 using the aerated culture in 1982 (Table 4).

It is possible, therefore, that microscopic Laminaria plants can benefit from gentle water movement during culture by becoming more strongly attached to the string.

3.3.2.3.2 Effect of Age of the Cultures

Insufficient results were gained to make any meaningful comparisons between groups of plants seeded on the same date after varying lengths of time in culture (Table 4). However, strings from a number of individual cultures were seeded after various lengths of time, and enough results were obtained from these to enable some conclusions to be drawn.

Except with Laminaria, results involving groups from aerated and non-aerated cultures were lumped together.

3.3.2.3.2.1 Alaria

It can be seen from Table 4 that every string placed in the sea produced a group of plants except for those bearing 5 day-old cultures seeded on March 1, none of which bore even a single plant at any stage. It can also be seen that strings from the same culture seeded after 23, 30 and 57 days produced groups with very large numbers of plants, ruling out the possibility that the culture was unhealthy or contained only small numbers of gametophytes. It is also unlikely that the survival of the plants was linked to sexual development of the gametophytes, since Lewis (1971) reported that Alaria gametophytes took 14 - 16 days to produce sporophytes at 10°C and in the present work, 7 day old cultures seeded on February 17 produced large numbers of plants. Furthermore, ten strings bearing a 19 day old culture which were seeded on the same rope on the same day as the 5 day old cultures produced a group of plants in each case (Table 4, culture i). The weather conditions at the time of transfer to the sea or shortly afterwards can not therefore explain the lack of production by the 5 day old strings, unless the young cultures were much more susceptible to the stresses, such as desiccation and temperature changes, which occur upon transfer to the sea. Unfavourable weather conditions on March 1 would explain why the 19 day old cultures produced fewer plants than strings from the same culture seeded both earlier and later than this. The difference between the culture room temperature and sea temperature was only 0.8°C on March 1 (Fig. 7), and there was no rain, but the amount of direct sunlight, air temperature and wind velocity were not recorded.

Fig. 17 shows the number of plants and dry weight of groups seeded from a single culture at 7, 19, and 71 days. Further strings had been seeded on day 37 but were lost when the rope tangled with another. It can be seen that the weight of the 71 day groups was rather less than that of both the 7 and 19 day groups, even though they contained only slightly fewer plants than the 7 day groups and more than the 19 day ones. Fig. 18 shows a similar effect with a second culture. Groups seeded after 57 days weighed much less than those seeded after 30 days, although they contained only slightly fewer plants. Groups seeded after 23 days, which were left on the rope to investigate reseeding, were of roughly similar overall size to the 30 day plants and it seems likely that they contained similar numbers of plants. A third culture (culture iii in Table 4) produced groups of plants averaging 109g dry weight from 41.8 plants per group when seeded after 9 days (March 26) but only 47g dry weight from 48.5 plants per group when seeded after 36 days (April 22). Thus, with all three cultures, strings seeded after a long time in culture produced groups weighing considerably less than those from strings

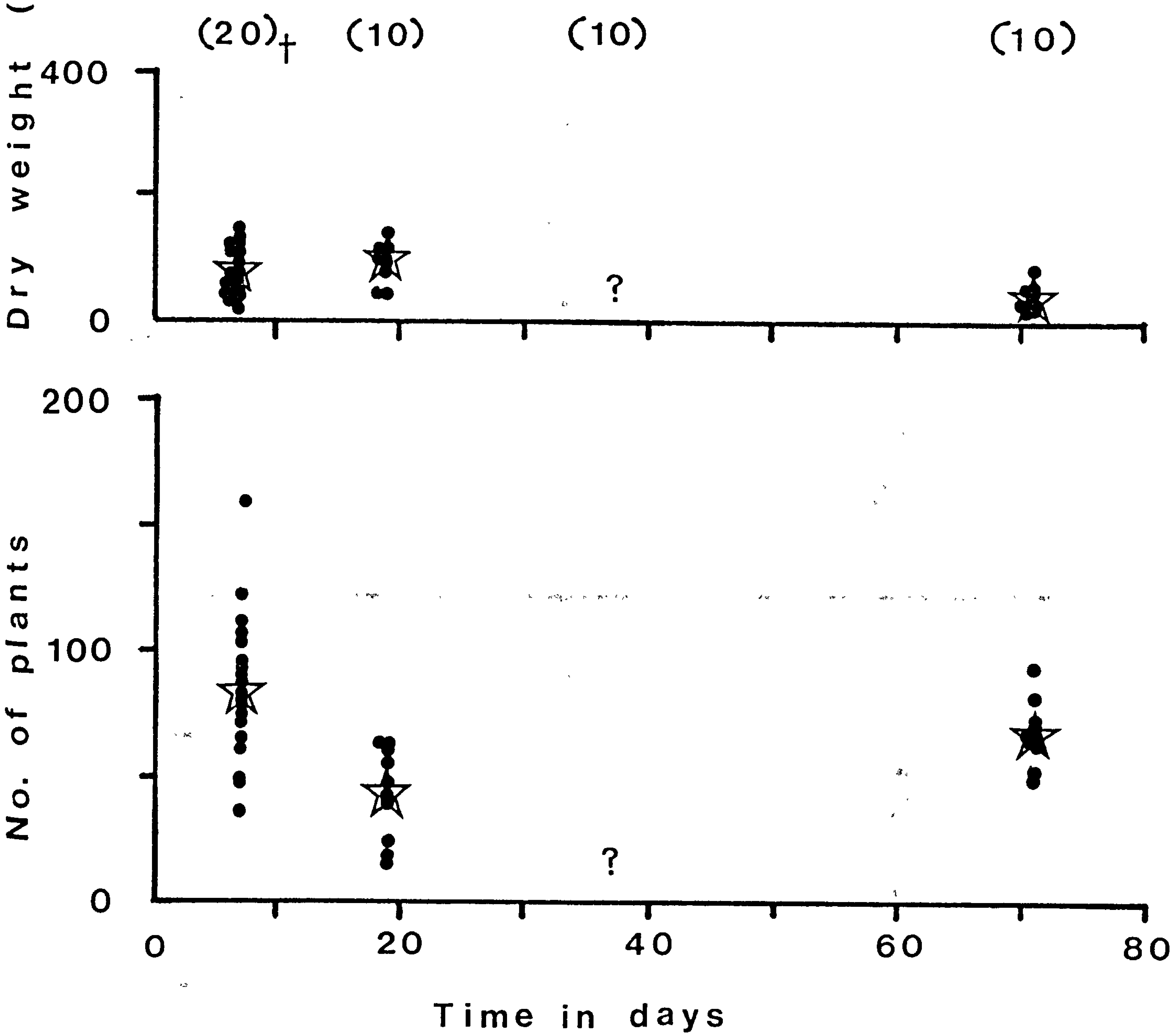


Fig. 17 - Dry weight (top) and no. of plants (bottom) for each group of Alaria plants produced from sets of 10 or 20 (†) strings seeded after varying lengths of time in culture. Day 0 = Feb 10 1982.

☆ = mean value.

? = groups lost when adjacent ropes tangled.

(10) = no. of groups grown.

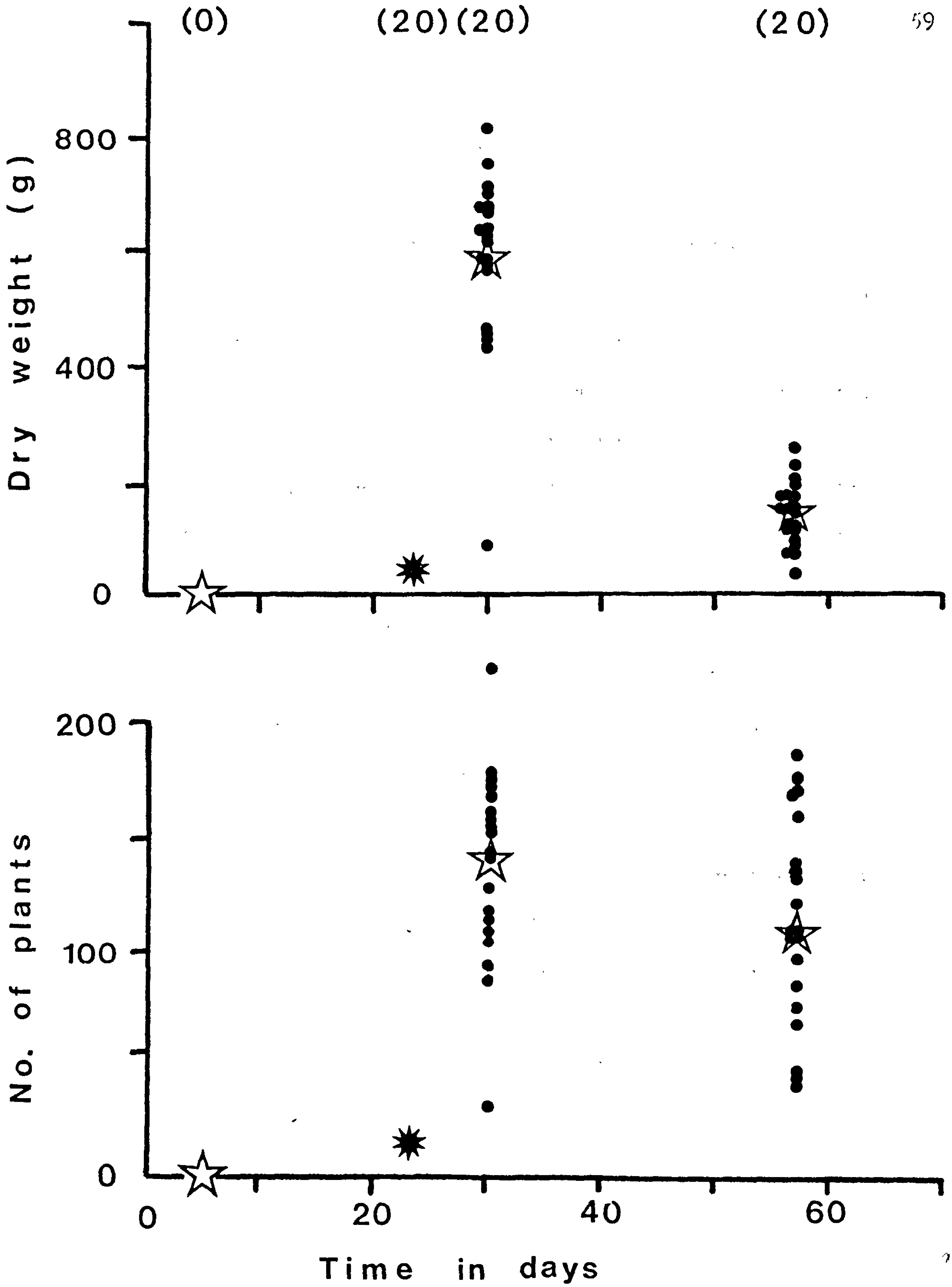


Fig. 18 - Dry weight (top) and no. of plants (bottom) for each group of Alaria plants produced from sets of 10 or 20 strings seeded after varying lengths of time in culture. Day 0 = Feb 24 1982.

☆ = mean value.

(10) = no. of groups grown.

✸ = groups left on the rope as part of a reseeding experiment.

seeded earlier, even though they contained similar numbers of plants.

Since the number of plants in individual groups varied widely both within and between batches, density effects might have had an important bearing upon plant weight. Effects such as inhibition of growth and self thinning have been described from a wide range of higher plants (Harper 1977, Kays and Harper 1974), but only rarely from large algae. However, Cousens and Hutchings (1983) reported density effects from several subtidal algae including Saccorhiza polyschides. In the present work, a plot of mean plant weight against number of plants per group was used to aid comparison between treatments (Figs. 19 and 20). Although there is some evidence of density effects, it can be seen clearly that the age of the culture seemed to have a more pronounced effect upon mean plant weight. It is unlikely that the age of the culture itself is directly responsible, however. A more probable explanation is the time available for growth of the later seeded plants; since the fast growth period for these plants generally finishes in about May or June (Lewis 1971). This is supported by the fact that groups from the latest seeded strings for each culture (57, 71 and 36 day cultures in Figs. 19a, 19b and 20 respectively) which were all seeded on April 22, all showed roughly similar weight/number relationships, while earlier seeded groups usually had a somewhat higher mean plant weight. In addition a thick growth of diatoms was observed on the rope and strings during April and early May, and this may have delayed development to some extent. This would have had a less pronounced effect on earlier seeded plants, since some of them would have grown sufficiently to avoid much of the

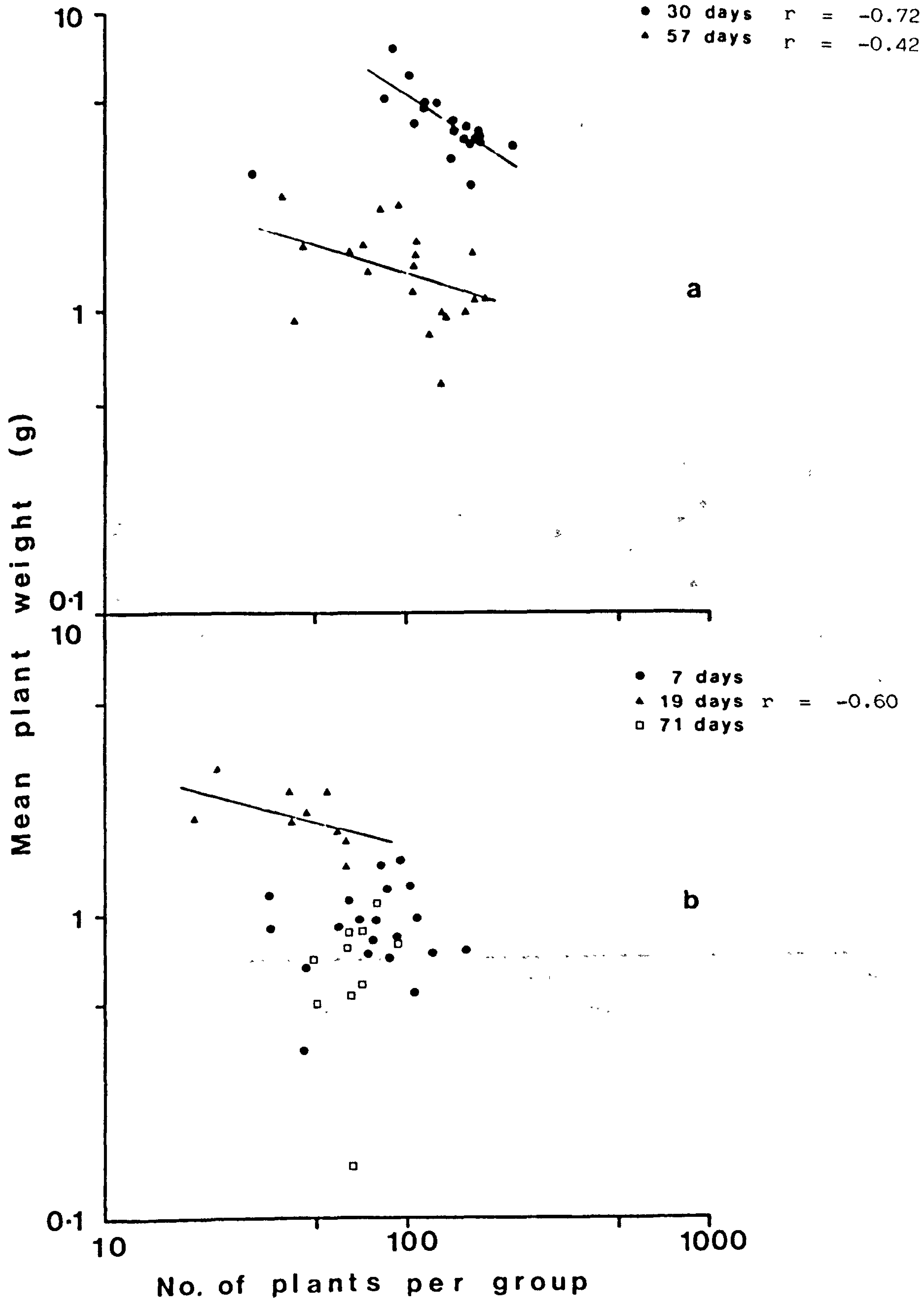


Fig. 19 - Mean plant against no. of plants for groups of Alaria seeded after 7 to 71 days in culture, with fitted regression lines.
a) Culture started on Feb 24 1982. The extreme left "30 day" group was omitted from the regression calculation.
b) Culture started on Feb 10 1982.

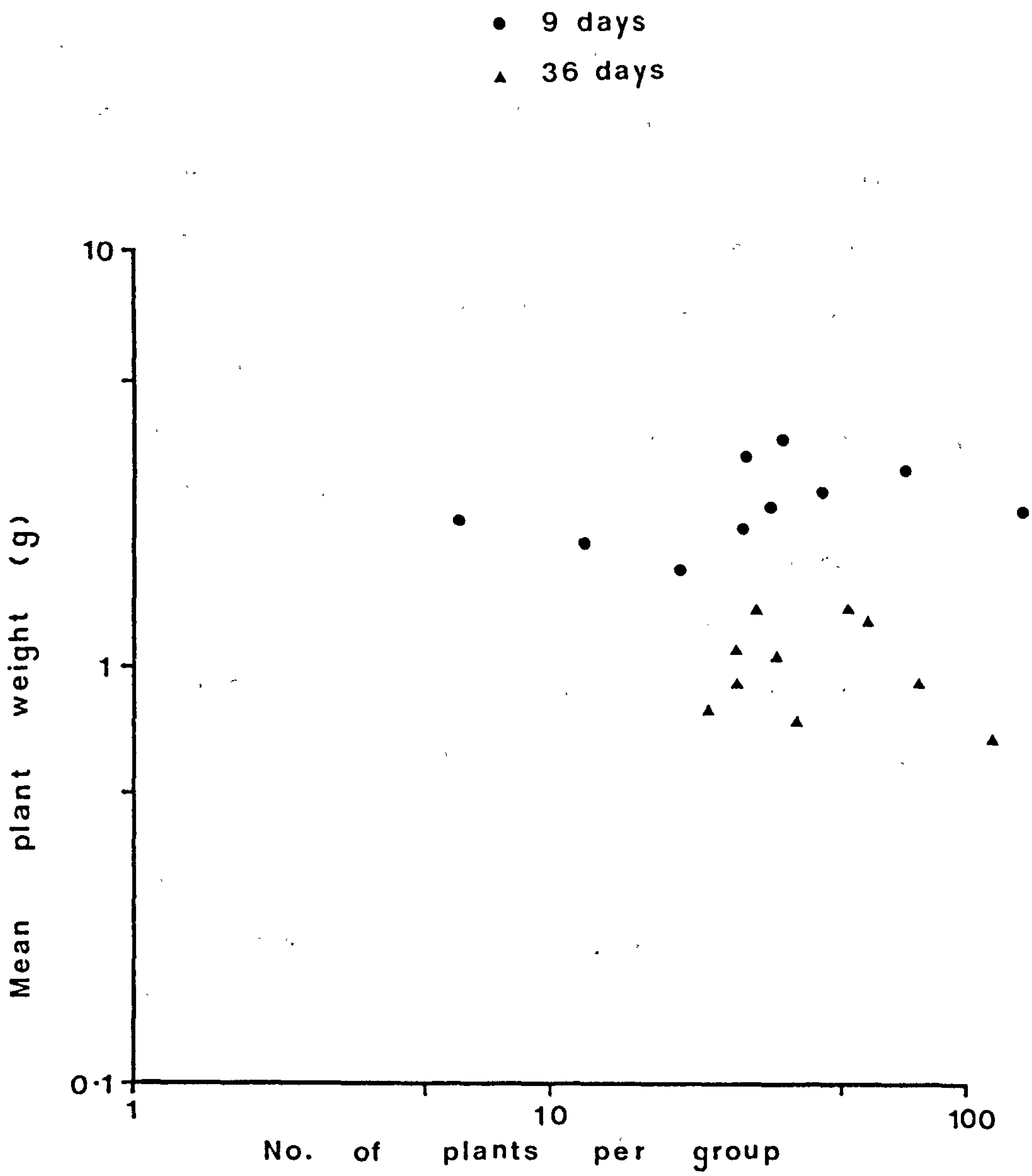


Fig. 20 - Mean plant weight against number of plants per group for <u>Alaria esculenta</u> groups seeded after 9 and 36 days in culture. Culture started on March 17 1982.

diatom cover.

The mean plant weight of the groups ranged from about 0.35 to about 8g dry weight. In three of the four cases where the majority of groups grew to a mean plant size of more than 1g dry weight, there was a negative relationship between mean plant weight and numbers, i.e. at higher densities the mean plant weight was lower (all plants in Fig. 19a, and 29 day plants in Fig. 19b). This was most pronounced with the 30 day groups (Fig. 19a), which contained quite high numbers of plants and which grew well, the majority of groups reaching a mean plant weight of over 3g. It is to be expected that when production is very low because of lack of growing time or poor conditions, the effects of density will be relatively minor, as with the 7 and 71 day plants in Fig. 19b.

3.3.2.3.2.2 Laminaria

It can be seen from Fig. 21 that, as with Alaria, no plants were produced from 5 day old cultures, but it is not known if this was a result of the age of culture since strings from the same culture seeded on day 57 also bore no plants, while thirty strings seeded on days 23 and 30 produced a total of 27 groups. A further culture seeded after 9 and 36 days in culture (Table 4) was similarly unsuccessful, although in this case there had been some difficulty in obtaining a good spore suspension and there was little growth on the strings even during culture. The three groups of plants missing from the 23 day old cultures were removed from the rope by wave action when they were about 50 - 100 cm in length, but none of the other failed strings bore plants at any time. The 5 day old cultures were seeded on the same day as the 5 day Alaria

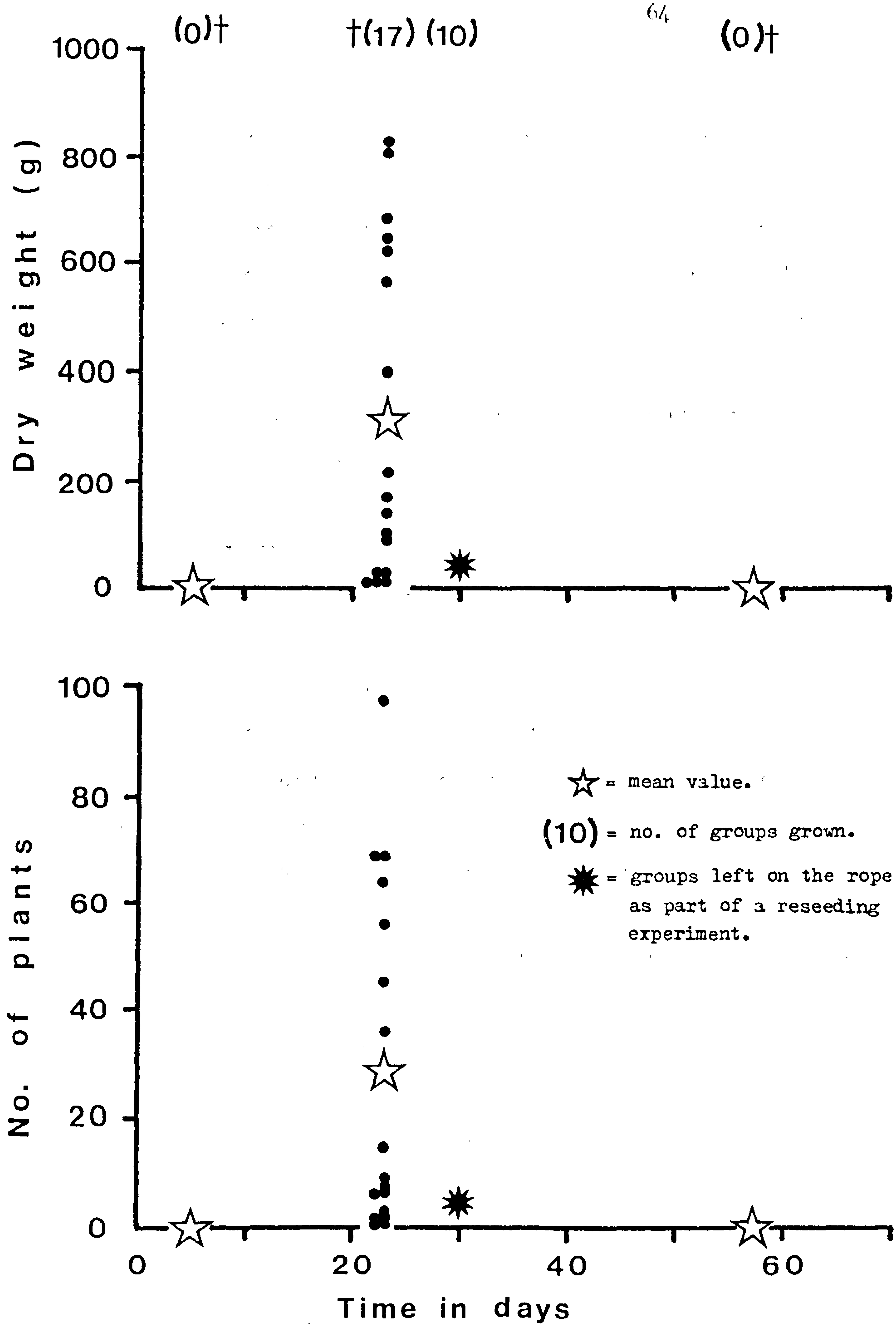


Fig. 21 - Dry weight (top) and no. of plants (bottom) for each group of Laminaria plants produced from sets of 10 or 20 (†) strings seeded after varying lengths of time in culture. Day 0 = Feb 24 1982.

cultures and may likewise have been susceptible to adverse weather conditions because of their age. The reason for the failure of the 57 day old cultures, seeded on April 22, is unknown. The thick layer of diatoms in the spring may have had some influence, but is unlikely to have killed all the plants in what was undoubtedly a healthy culture. It may be that Laminaria is more susceptible to poor conditions during transfer to the sea, or to rough weather immediately following transfer, than is Alaria.

A plot of mean plant weight against number of plants per group (Fig. 22) suggests that there was no effect of density with plant numbers ranging from 1 - 97 per group. However, taking only those groups with seven or more plants gives a correlation coefficient of -0.72, which is significant at the 1% level. Since this is a highly significant result it must be assumed that growth in the very small groups was inhibited in some way, or that at some stage the larger plants were removed from the rope, perhaps by strong wave action or the string rubbing against the rope, leaving only late-developing plants. However, the effect of density was only slight, the mean plant weight dropping from about 20g dry weight at 7 plants per group to about 10g at 100 plants per group. This probably reflects the relatively small size of the plants, due to the fact that the plants were only in the sea for 25 weeks. In later experiments mean plant weights of 30 - 50g were regularly obtained with Laminaria.

3.3.2.3.2.3 Saccorhiza

Table 4 shows that once again, although 7 day old cultures produced large groups of plants, 5 day old cultures seeded on March 1

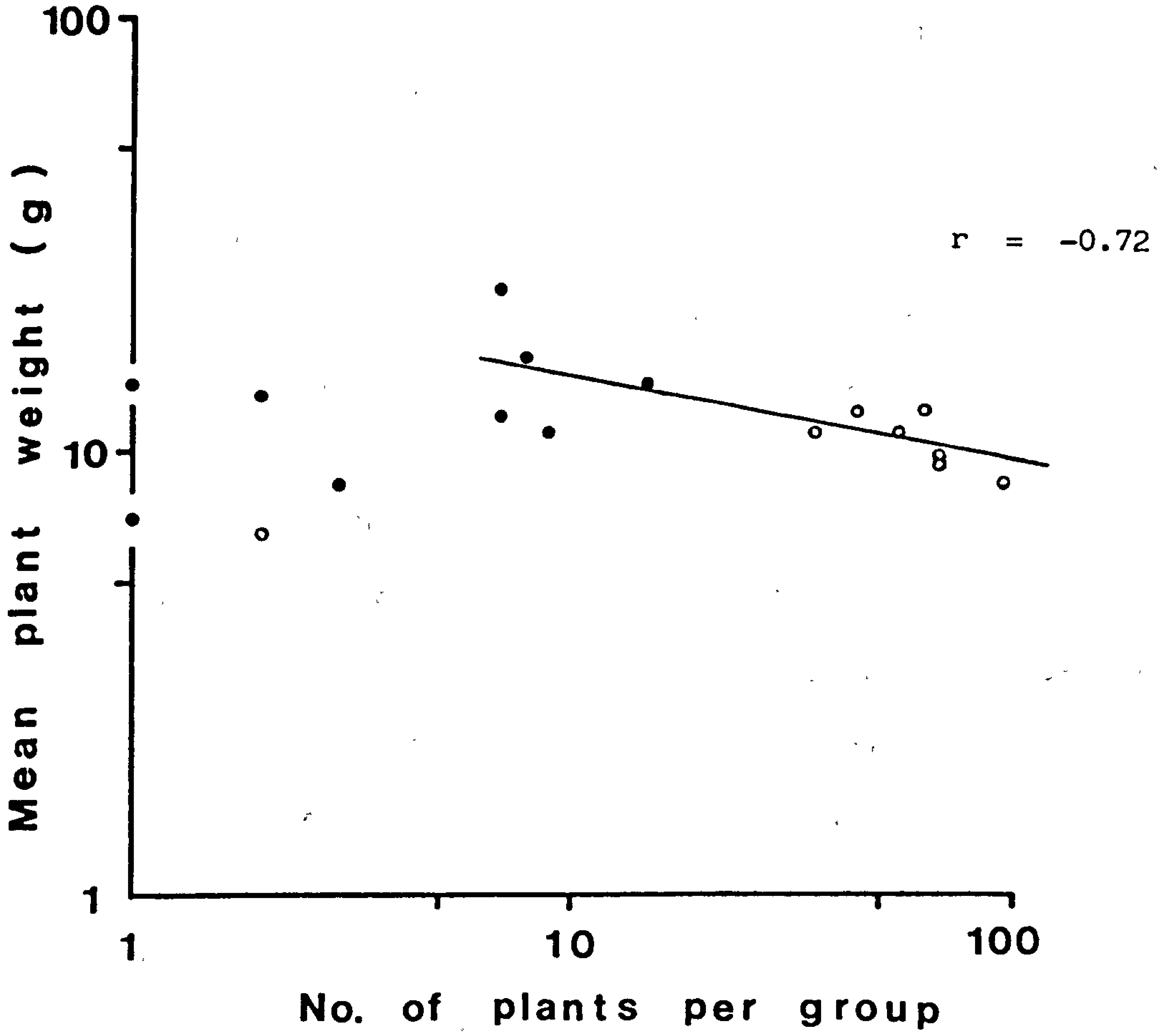


Fig. 22 - Mean plant weight against no. of plants for groups of <u>Laminaria</u> seeded after 23 days in culture. Culture started on Feb 24 1982.

were completely unsuccessful, no plants having been observed on the strings at any time. When strings from the same culture were seeded on three further occasions many groups of plants were produced. Strings bearing a 19 day old culture seeded on the same day as the 5 day strings appeared to be equally unsuccessful, but it is not known whether the plants simply failed to grow, or were removed by wave action at a later stage. If the plants failed to grow, it would seem likely that conditions during or shortly after transfer on March 1 were detrimental, and that Saccorhiza was more susceptible than the other two species.

Figs. 23 and 24 show that, as with Alaria, production from the older groups was very low compared to that from the younger ones, although the number of plants in the former groups was much higher. This again suggests that the reduced length of time for growth and/or the spring diatom outburst had an important effect upon growth. The increased numbers of plants from older cultures might simply be the result of the large amounts of gametophytes on the string, or they may be due to calmer weather in the period following transfer, resulting in fewer losses.

Fig. 25 shows that, while earlier seeded groups had mean plant weights varying from 15 to 128g (dry weight), the latest seeded strings from each culture, which were all seeded on April 22, produced groups with mean plant weights of less than 10g. This confirms that production from the later seeded plants was very poor. It can also be seen from Fig. 25 that a density effect was apparent in three cases, although it only appeared to be severe in the 30 day plants, in which production was high, and which contained up to 10 plants per group.

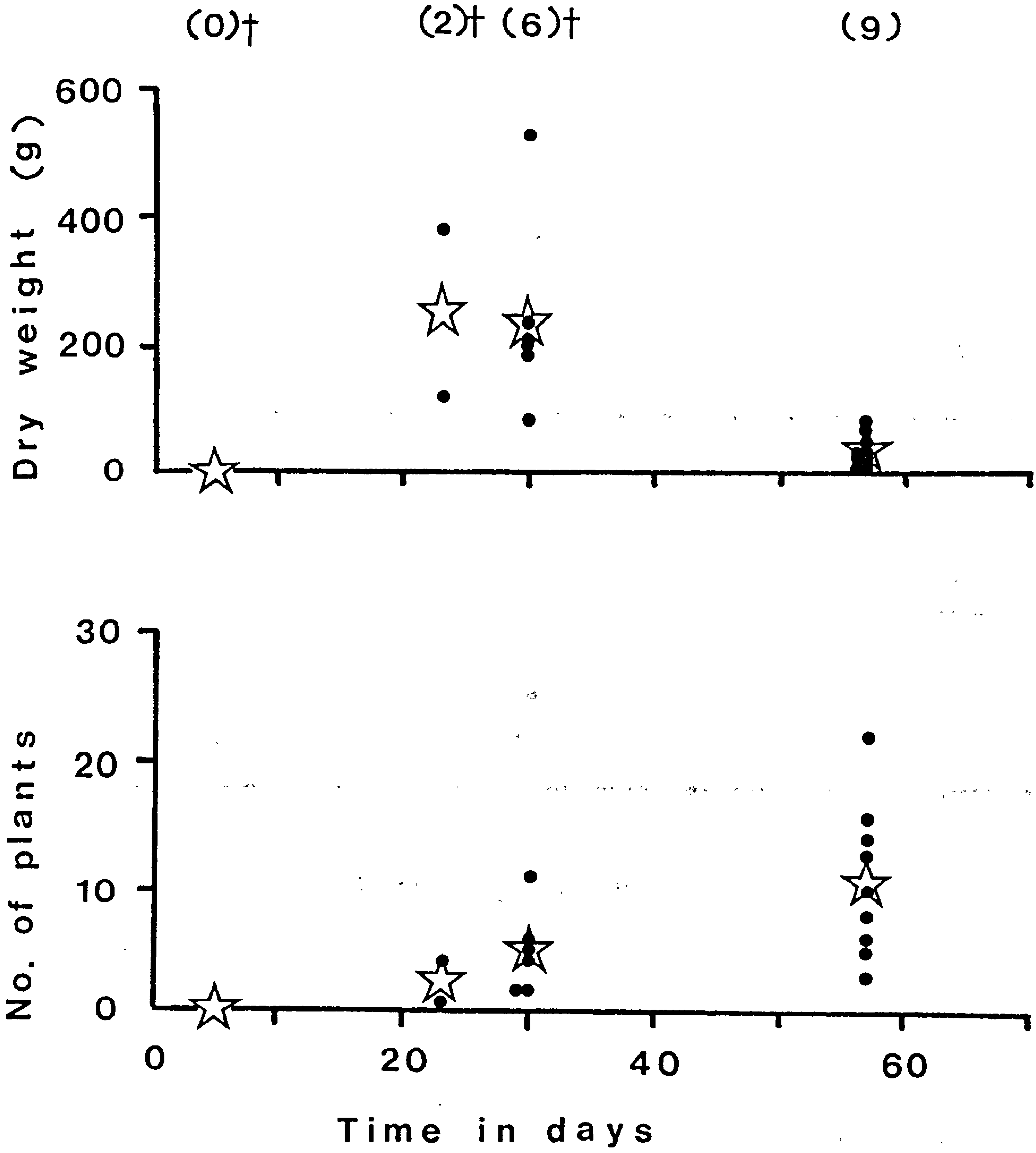


Fig. 23 - Dry weight (top) and no. of plants (bottom) for each group of Saccorhiza plants produced from sets of 10, or 20 (†), strings seeded after varying lengths of time in culture. Day 0 = Feb 24 1982.

☆ = mean value.

(10) = no. of groups grown.

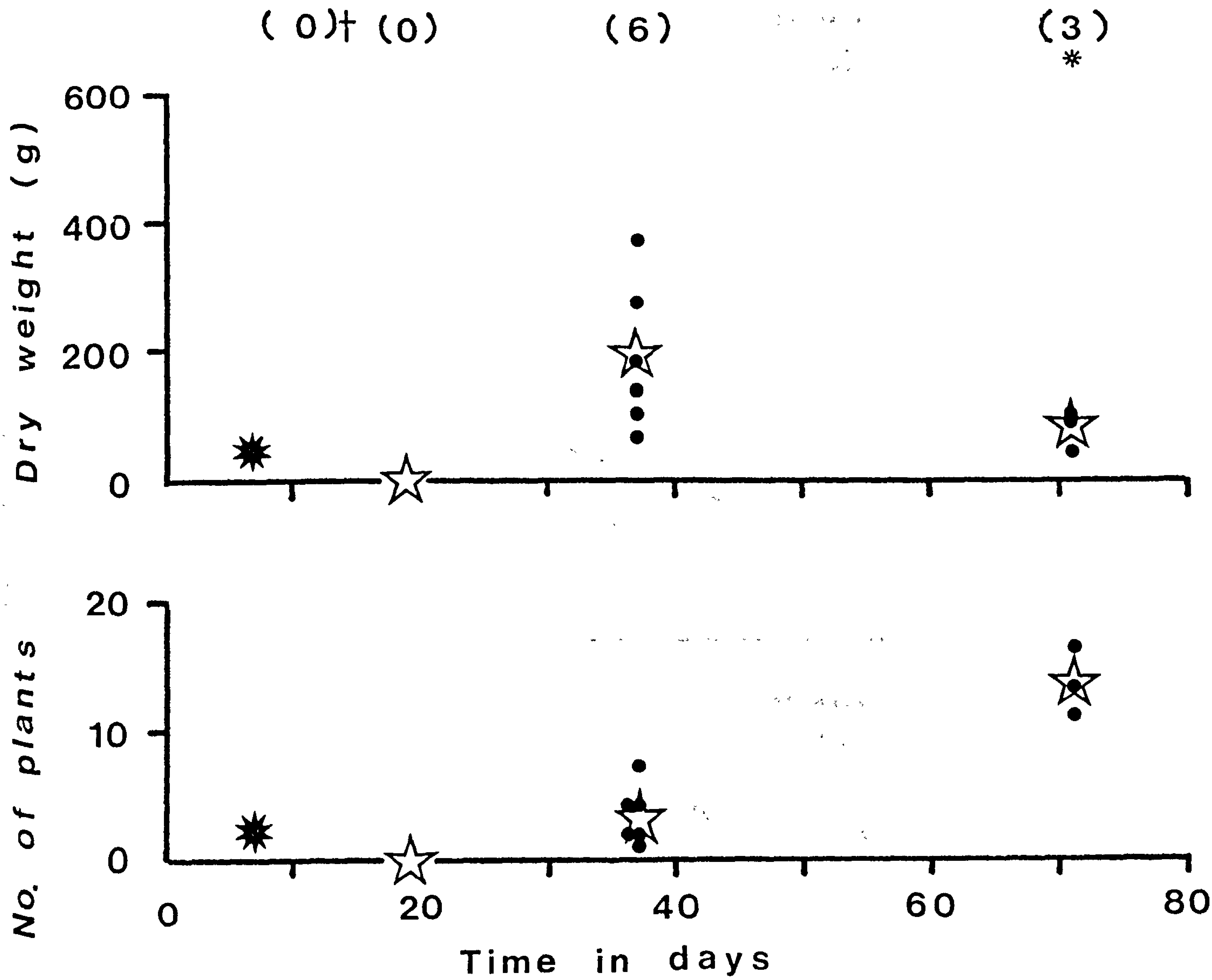


Fig. 24 - Dry weight (top) and no. of plants (bottom) for each group of *Saccorhiza* plants produced from sets of 10 or 20 (†) strings seeded after varying lengths of time in culture. Day 0 = Feb 10 1982.

* - 10 groups of plants were produced but 7 were lost when the boat rubbed against the rope during the harvest.

☆ = mean value.

(10) = no. of groups grown.

✸ = groups left on the rope as part of a reseeding experiment.

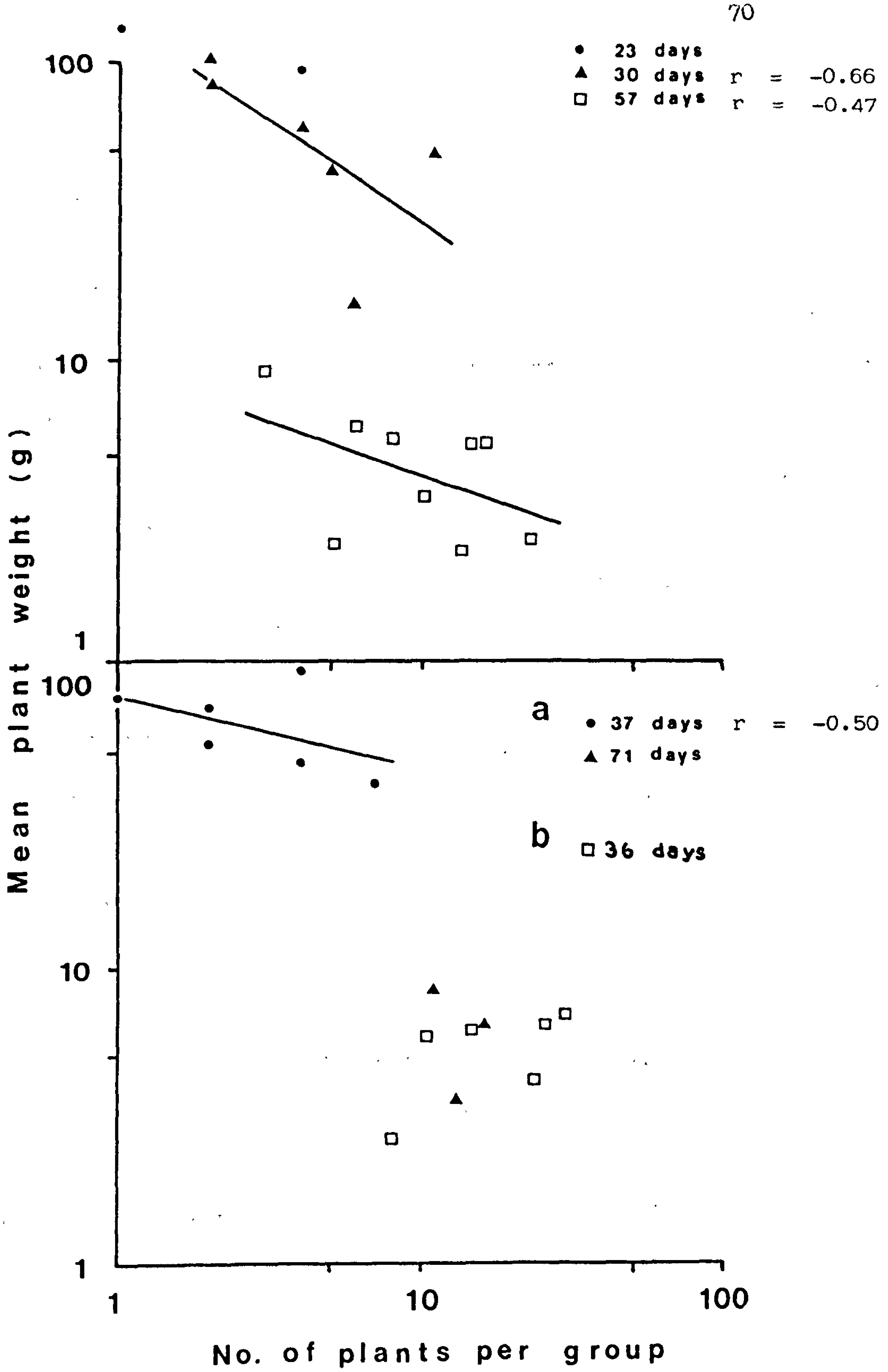


Fig. 25 - Mean plant weight against no. of plants for groups of <u>Saccorhiza</u> seeded after 23 - 71 days in culture plotted on a log/log scale, with fitted regression lines.

top - culture started on Feb 24th 1982.
bottom - culture a) started on Feb 10th 1982.
- culture b) started on Mar 17th 1982.

3.3.2.4 RESEEDING

The ropes bearing the *Saccorhiza* and *Alaria* groups were lost during the autumn gales, but the one bearing the *Laminaria* groups survived. Of the original ten groups containing about 100 plants, only seven groups totalling 37 plants remained in the spring of 1982. These plants were healthy and had grown considerably by early July. Almost all of them developed large conspicuous sori between November 26 1982 and February 3 1983. When the rope was removed on July 1 1983 to count the numbers of plants colonising it, large numbers of *Saccorhiza* plants fell off the rope, but *Laminaria saccharina*, *L. hyperborea* and *Alaria* remained firmly attached. Fig. 26 shows the numbers of plants found on the rope. Colonisation by all four of the major species was lower than expected after observing other naturally colonised ropes. The total of 145 *L. hyperborea* plants was fewer than observed on some one metre portions of vertical ropes, and there was a total of only 84 *L. saccharina* plants compared with totals of 217, 149 and 446 observed on horizontal ropes on April 2 1982 (Table 3). Furthermore there is no evidence of increased numbers of *L. saccharina* in the region of the attached groups. In fact it seems more likely that the presence of the groups actually reduced colonisation, perhaps by a scouring action similar to that suggested for kelp on rocky bottoms by Velimirov and Griffiths (1979). It is not known to what extent the poor results were due to insufficient numbers of spores being released from the reseeding plants, or to the thick growths of small algae and hydroids present on the rope making settlement and development of the young plants difficult. Although it might be possible to compensate for the former by having large numbers of "reseeding" ropes in any particular area of sea, thus effectively increasing the concentration of spores, the latter would be very difficult to control. Since it has also been shown that attaching sporing plants to the ropes was unsuccessful, it is concluded that such a method of reseeding is unlikely to be feasible.

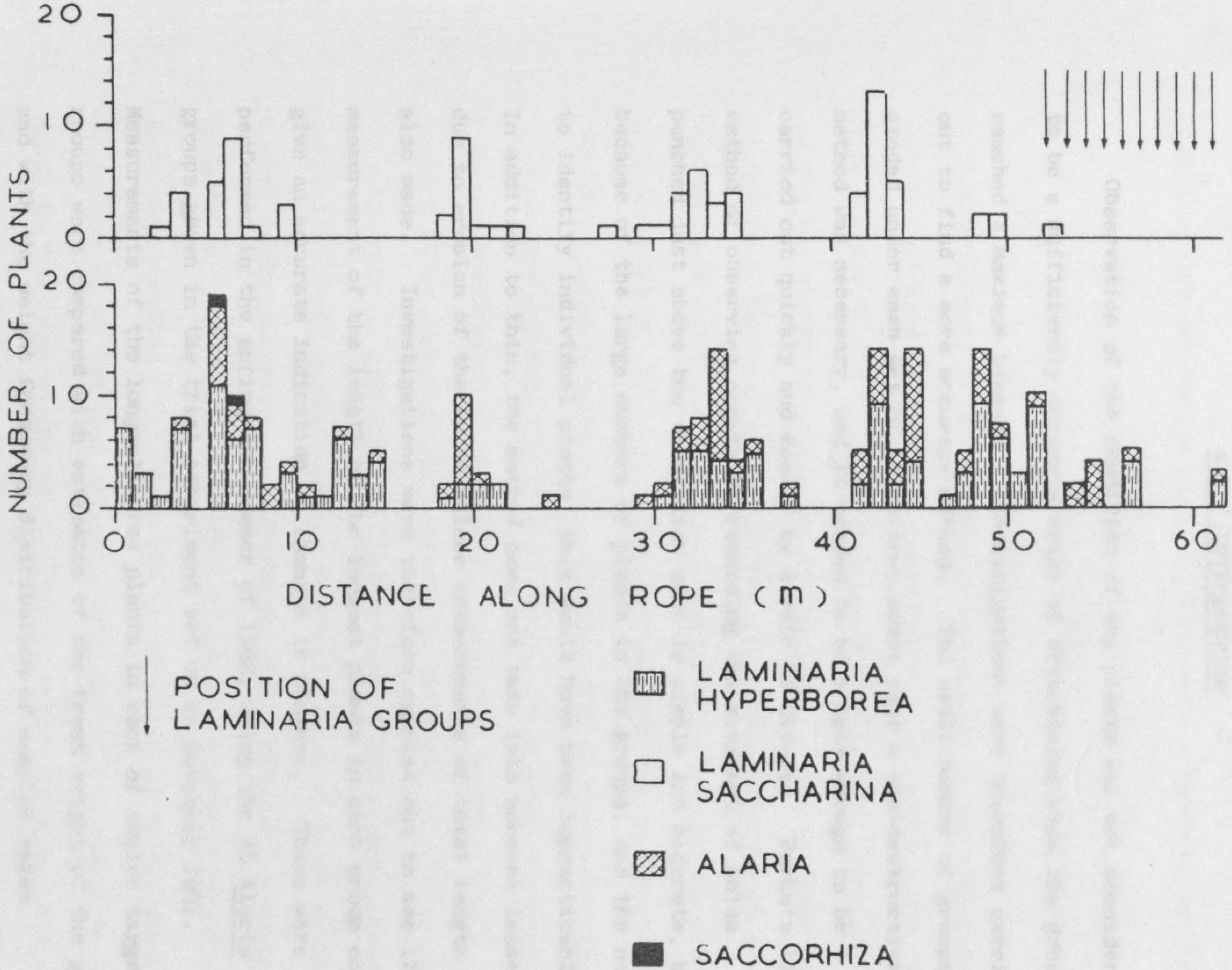


Fig. 26 - Numbers of young Laminariales found on a horizontal rope at 2m depth on July 1st 1983 after 10 groups of L. saccharina had been left on from the previous summer.

4. DETERMINATION OF HARVESTING TIME

4.1 INTRODUCTION

Observation of the condition of the plants was not considered to be a sufficiently accurate means of determining when the groups reached a maximum biomass. Investigations were therefore carried out to find a more accurate method. The small number of groups seeded under each set of conditions meant that a non-destructive method was necessary, and it needed to be simple enough to be carried out quickly and easily by a pair of divers. Parke's (1948) method of observing growth by recording the movement of holes punched just above the transition zone is simple and accurate, but because of the large numbers of plants in the groups, and the need to identify individual plants, this would have been impracticable. In addition to this, the method does not take into account losses due to erosion of the frond unless measurements of total length are also made. Investigations were therefore carried out to see if measurement of the length of the longest plants in each group could give an accurate indication of changes in biomass. These were performed in the spring and summer of 1982, using the 45 *Alaria* groups grown in the trial experiment set up in November 1981. Measurements of the longest three plants in each of twelve tagged groups were compared with estimates of the fresh weight of the groups, and with the weight frequency distribution of samples taken periodically from the remaining groups.

Information on the growth of *Laminaria* and *Saccorhiza* was also desired so that the approximate time at which the maximum biomass occurred would be known for subsequent experiments, but there were no trial groups upon which investigations could be carried out. Observations were therefore made on growth in naturally seeded plants growing on the ropes, using Parke's hole punching method.

4.2 METHODS

Measurements of the lengths of the plants in the tagged *Alaria* groups were made by a pair of divers using a 2m ruler. One diver held the end of the ruler against the rope while the other gently teased the plants out until the longest three could be measured. It was found by trial and error that three plants from each group was the most which could easily be measured. Most of the plants were attached to the rope, but a few were attached to the string and therefore appeared to be a few cm longer than they actually were. No allowance was made for this since any errors would be constant from one measurement to the next. Individual groups were identified by numbered tags attached to the rope.

In order to estimate the fresh weight of the groups, random samples of three untagged groups each containing at least eleven plants (with one exception, containing eight) were periodically removed, and the length and weight of each plant was carefully measured, enabling a length/weight relationship to be calculated. The ratio, Z, of the mean weight of the rest of the plants in a group to the total weight of the longest three plants was also calculated. Using the length/weight relationship, the measured lengths of the longest three plants were converted into estimates of their fresh weights, and the fresh weights of the groups then estimated using the following formula:

$$W_g = W_3 + (W_3 \times Z \times (N-3))$$

where W_g = weight of the group

W_3 = total estimated weight of the 3 longest plants

N = number of plants in the group

Whenever possible, the three sample groups were collected on the same day as the length measurements were made. When this was not possible the weights of the groups were estimated by interpolation between values calculated using the length/weight relationship and Z ratio from the sample dates immediately preceeding and following the length measurement. In some cases it proved impossible to find all twelve of the tagged groups because of the large amounts of naturally seeded algae growing on the ropes, and interpolation between previous and subsequent estimated weights was used for calculation of mean values.

Comparison of changes in measured lengths and estimated weights of the tagged groups involves a certain amount of circular argument, since the lengths of the longest plants were themselves used in the estimation of the fresh weights. For this reason, the length changes were also compared with changes in the weight frequency distribution of the sampled groups.

Whenever time allowed, field measurements were made of the length of the longest three plants in each of the sampled groups before they were removed, and then compared to the values measured in the laboratory. Estimates of their fresh weights, calculated as described earlier, were also compared with measured values, although such comparisons again involve a certain amount of circular argument, since each group itself contributed towards the calculated length/weight relationship and Z value for the particular date.

Observations on individual naturally colonised Laminaria were made by punching holes in the fronds, 5 cm from the transition zone, and recording their subsequent movement. New holes were punched when the old holes neared the end of the blade. The total length of each plant was also recorded. The ends of the Saccorhiza plants proved to be very delicate and sometimes broke off when touched. The plants were treated very gently, however, and the ends would probably have been lost very quickly without being handled, so the lost tissue was ignored. It was thought, nevertheless, that movement of punched holes would provide the more important indication of growth in this species, since erosion of the frond does not necessarily reduce the biomass because the proximal part of the frond, the stipe and the holdfast may still be increasing in weight. Individual plants were recognised by 30 cm long coloured ribbons tied around the stipes, but were frequently missed because of the large amounts of growth on the ropes. A total of ten Laminaria plants were tagged on two adjacent ropes. These were measured seven times between June 30 and September 14 1982. Because of the large variation in size of the Saccorhiza plants, sixteen large (over 150 cm long on June 1) and ten small (under 150 cm long on June 30) plants were selected. The large plants were measured six times between June 1 and July 21, and the small ones six times between June 30 and August 27.

4.3 RESULTS

Fig. 27 shows the length/weight relationship of the sampled *Alaria* groups on six occasions from March 26 to June 16. Plants greater than and less than 2g were treated separately since there was some evidence that the true relationship was a slight curve. Even above 2g weight, however, there was still not a simple log/log relationship, since the heaviest plants were frequently to the left of the regression line, and therefore not as long as would be predicted from the regression equation. This was probably due mainly to the continued growth of large plants, resulting in increased width and thickness, while erosion prevented large increases in length, and to growth of reproductive sporophylls, which grow largely during late winter and spring (Lewis 1971). There appears to be very little correlation between length and weight above about 30 - 40g in weight, or about 100 - 150 cm in length. As a result the weight of the long plants measured in the tagged groups is likely to be considerably overestimated.

Fig. 28 shows the variation in the Z ratio from March to June. It has been assumed that this would be roughly constant at any one time, but this may not be true, particularly for groups containing widely varying numbers of plants. Even if it is, the ranges of values encountered were quite large, and considerable errors may have been incurred since only three groups were sampled on each date.

Table 5 shows the field measured and lab measured lengths of the longest three plants in sampled *Alaria* groups. It can be seen that the field measurements were almost always underestimated.

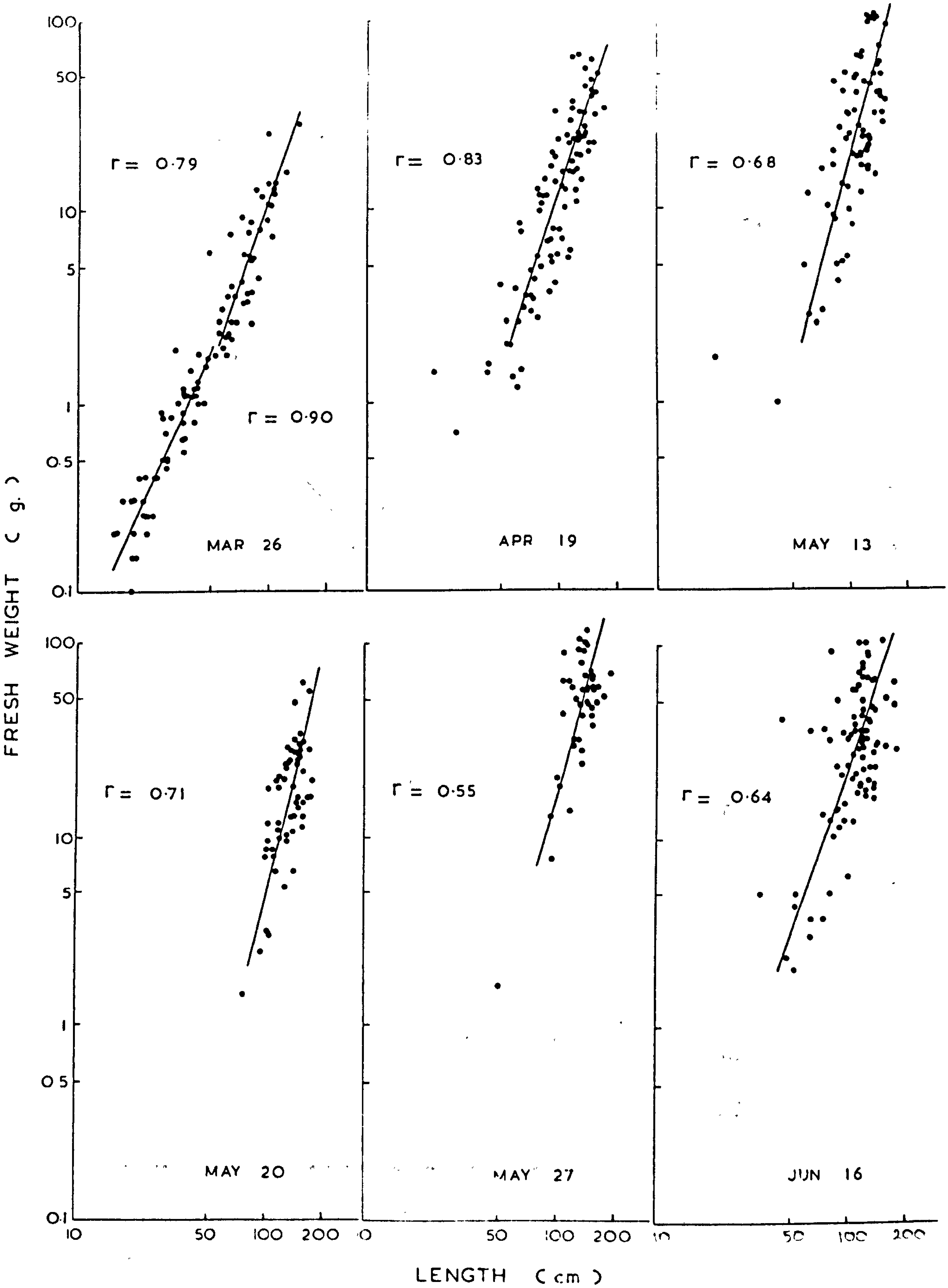


Fig. 27 - Weight against length of Alaria plants seeded in Nov 1981, measured on 6 occasions during 1982, with fitted functional regression lines. Three groups were sampled on each date. Plants weighing less than 2g fresh weight were ignored except on March 26 when they were regressed separately.

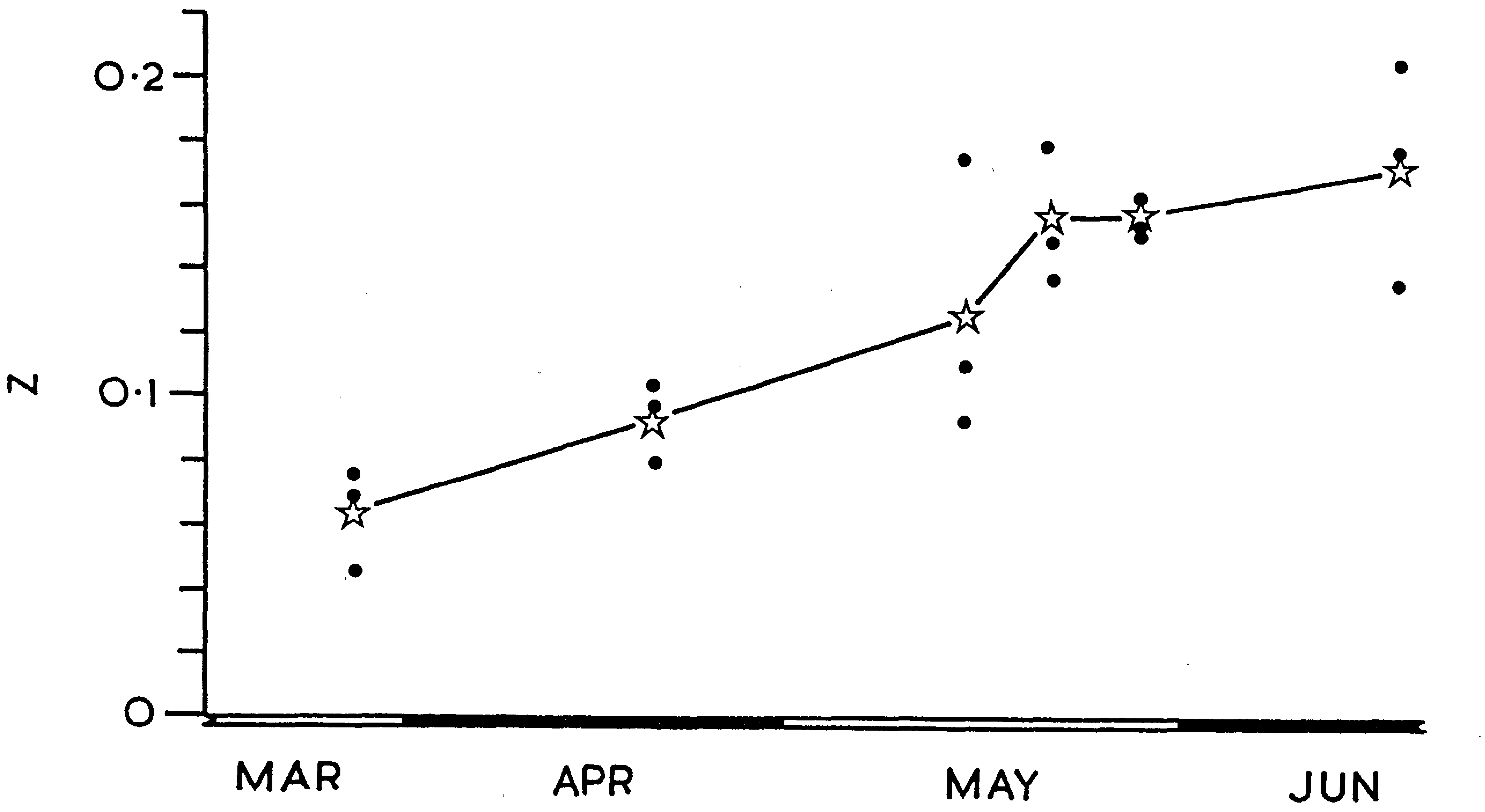


Fig. 28 - Z, the mean weight of the plants other than the longest three expressed as a fraction of the total weight of the longest three plants in a group, as calculated from 3 sampled groups on 6 occasions. ☆ = mean values.

LONGEST PLANT			2ND LONGEST PLANT			3RD LONGEST PLANT		
ESTIMATED LENGTH (cm)	ACTUAL LENGTH	% ERROR	ESTIMATED LENGTH (cm)	ACTUAL LENGTH	% ERROR	ESTIMATED LENGTH	ACTUAL LENGTH	% ERROR
140	141.5	- 1.2	120	121	- 0.8	103	107	- 3.7
100	105.5	- 5.2	96	104.5	- 8.1	87	99.5	- 12.6
99	98.5	+ 0.5	77	80.5	- 4.3	75	79.0	- 5.1
143	148.0	- 3.4	143	148	- 3.4	119	143	- 16.7
147	150.5	- 2.3	143	146.5	- 2.4	131	138.5	- 5.4
166	170	- 2.3	154	160	- 3.7	153	152.5	+ 0.3
149	144	+ 3.5	119	124	- 4.0	113	119	- 5.0
153	156.5	- 2.2	149	153	- 2.6	148	152	- 2.6
135	136	- 0.7	133	133	0.0	127	127.5	- 0.4
153	169.5	- 9.7	154	163	- 5.5	151	152.5	- 1.0
160	155	+ 3.2	153	153	0.0	150	142.5	+ 5.3
182	177	+ 2.8	181	164	+10.4	180	156.0	+ 15.4
190	194	- 2.1	160	167.5	- 4.5	152	159.5	- 4.7
144	149.5	- 3.7	132	134	- 1.5	128	131	- 2.3
135	132	+ 2.3	132	124	+ 6.5	132	122.5	+ 7.8
Mean value		3.0	Mean value		3.8	Mean value		5.9

Table 5 - Field measurements, carried out by divers, actual lengths, subsequently measured in the laboratory, and % error of field measurements for the longest three plants in sampled groups of Alaria in 1982.

This is because to pull the plants too taut would have snapped the ends off, particularly with the larger plants which were eroding at the tips. Table 5 also shows that the longest plants were measured most accurately, with a mean error of 3.0%, the second longest plants slightly less accurately (3.8%) and the third largest rather less accurately (5.9%). This trend reflects the ease with which the plants could be distinguished from the rest of the group.

Table 6 shows the estimated and actual weights of the sampled groups on five occasions. It can be seen that there was a lot of variation in the accuracy of individual estimates. There was a tendency for groups with high numbers of plants to be overestimated and those with low numbers to be underestimated, which was probably due to differences in the relative sizes of the smaller plants in the groups (the Z ratio). Despite this, a rough indication of the weights of the groups was given. The total estimated weight of the fifteen groups was 10,031g, which compares well with the measured value of 9,917g.

Fig. 29a shows the lengths of the longest plants and the estimated weights of the tagged Alaria groups. It must be remembered that the weight estimates of the tagged groups were probably less accurate than those shown in Table 6 due to the fact that the length/weight ratio and Z value for the latter were obtained from the groups in the table themselves. Despite this, it can be concluded from Fig. 29a that Alaria reached a maximum biomass in late May to early June, agreeing with impressions gained while diving and with previous work on local natural populations (Lewis 1971). The weight frequency distributions of the sampled groups, shown in Fig. 30, suggest a peak biomass between May 20 and

Date	N	Real Wt. (g)		Estd. Wt. (g)	
Mar 26	47	169		220	
	33	102	346	81	337
	14	75		36	
Apr 19	29	508		308	
	26	536	1564	340	1307
	38	520		659	
May 13	24	718		444	
	43	1076	2383	1239	1906
	8	589		223	
May 27	14	730		642	
	17	821	2401	1341	2883
	14	850		900	
Jun 16	12	725		410	
	14	885	3223	443	3598
	63	1613		2745	
	Total	9917		10031	

Table 6 – Comparison of measured and estimated weights on various dates of groups of Alaria seeded in November 1981. Estimated weight was calculated as described in Chapter 4. The total of each set of three figures is given.

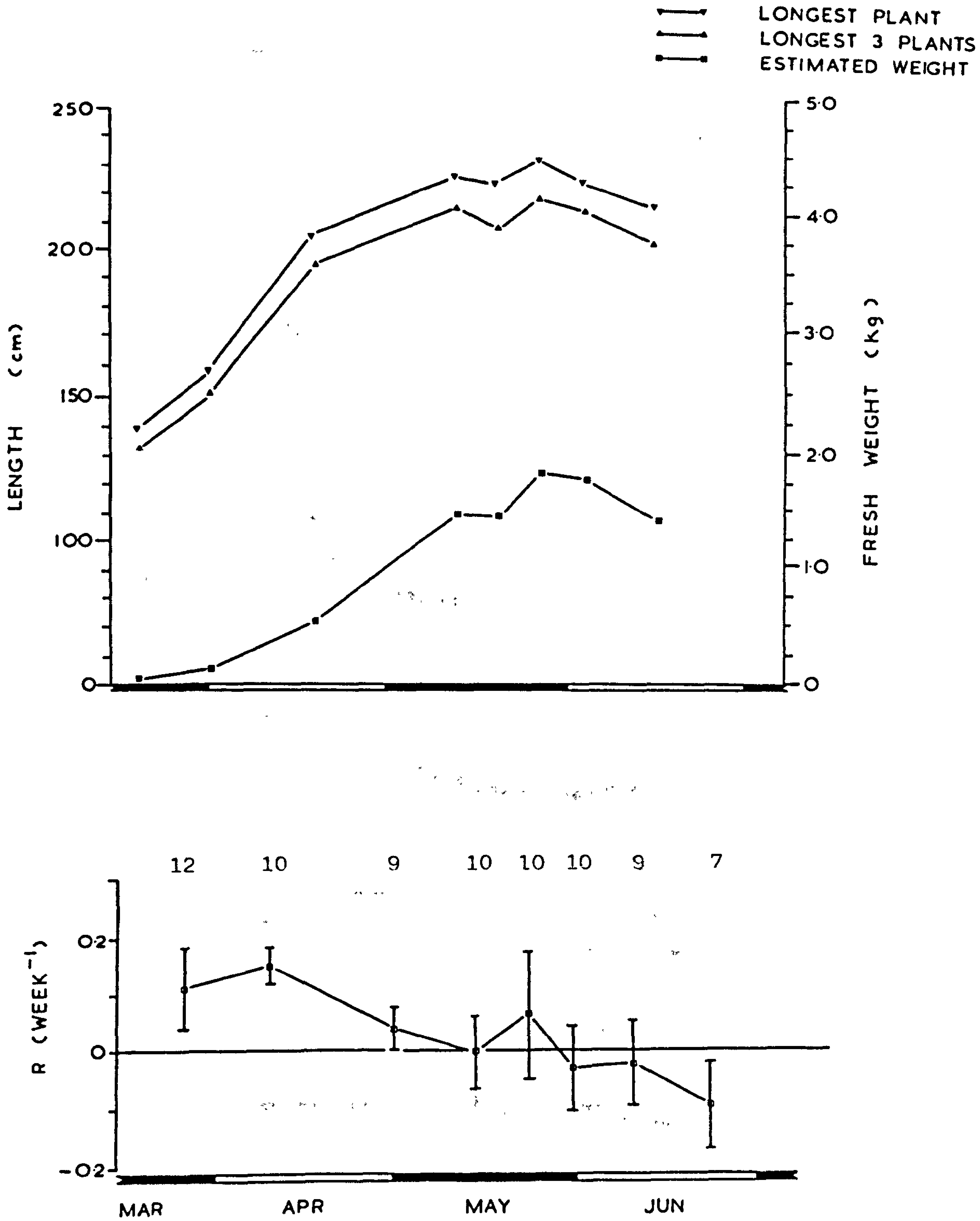


Fig. 29 - a) Mean estimated weights of 12 groups of Alaria with mean lengths of the longest 3 and the longest single plant in each group from March - June 1982. The groups were seeded in Nov 1981 at 2m depth.

b) Mean relative growth rate (R) of the longest single plants in each group with 95% confidence limits. N is given above each point.

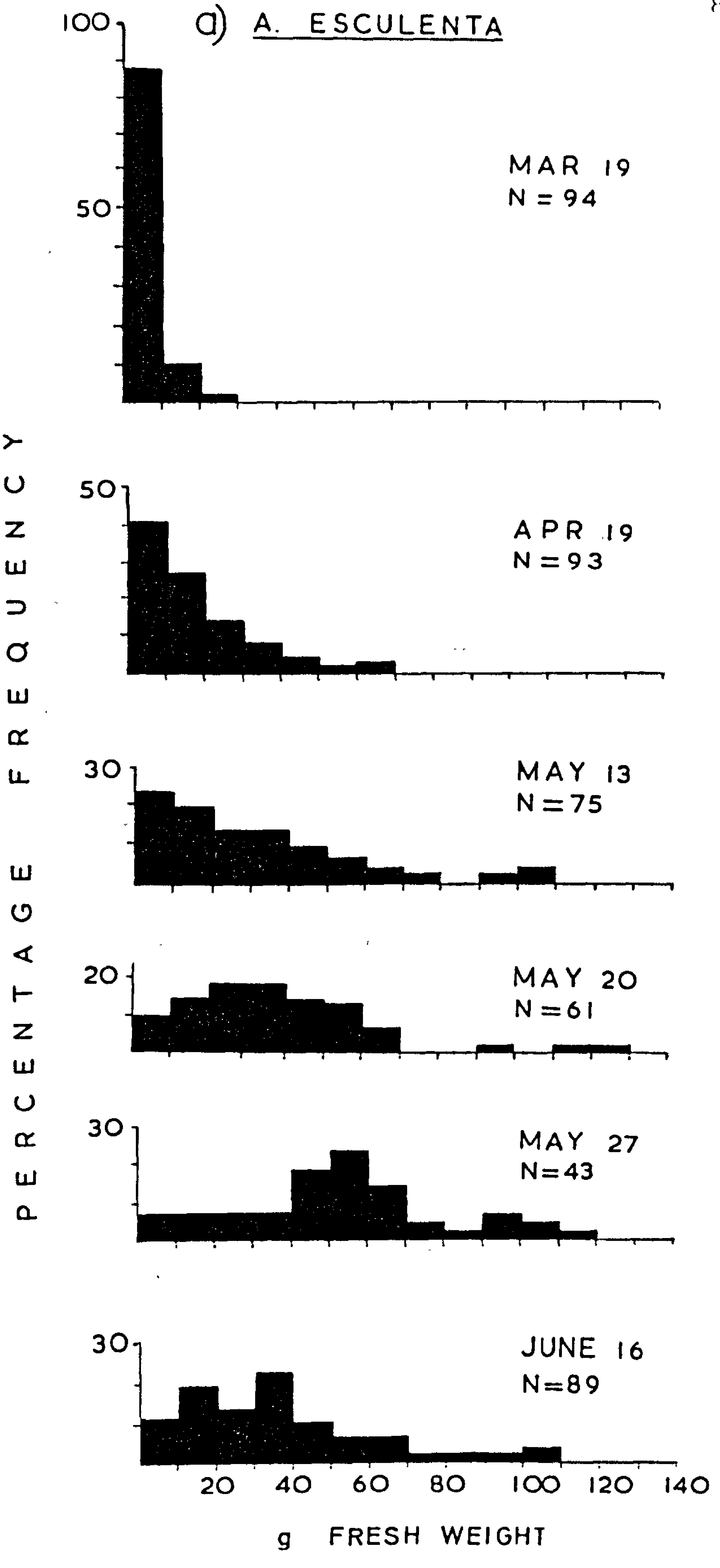


Fig. 30 - Fresh weight composition from March - June 1982 of samples of 3 groups of Alaria seeded in November 1981 at 2m depth.

June 16. Fig. 29a also shows that the lengths of the longest three plants varied in a similar way to the weight of the tagged groups. This means that changes in the weight/length relationship and in the contribution of the smaller plants to the weight of the groups were relatively unimportant, and that measurement of the length of the longest plants gives an indication of whether total biomass is increasing or not. More importantly, the lengths of the single longest plants alone also varied in the same way as the estimated weights. This was a great advantage, since measurement of single plants, rather than three, was not only more accurate, but also very much faster. Many more measurements would therefore be possible.

Since the plants were of widely varying size it was difficult to gauge the significance of any change in mean length. For this reason consecutive length measurements of individual tagged plants were converted into the relative growth constant R, described by Ricker (1958) as the "instantaneous growth rate". It is calculated using the following equation:

$$R = \frac{\log_e l_t - \log_e l_o}{t}$$

where l_t = length at time t.

l_o = length at time 0.

t = time in weeks

The mean and 95% confidence limits of the R values were plotted on the mid point between the dates of the two measurements, as shown in Fig 29b.

Movement of punched holes and changes in total length of Saccorhiza and Laminaria are shown in Figs. 31, 32 and 33. A few Saccorhiza plants were removed from the rope by wave action. Others, and some Laminaria, were missed on certain dates because dense growths of Laminariales and Desmarestia obscured them or filamentous brown algae covered the marker ribbons. Such missing values are indicated by the use of dashed lines between previous and subsequent values. It can be seen from Fig. 31a that the total length of most of the large Saccorhiza plants decreased markedly during June and July. Movement of the holes (Fig. 31b) indicates that some growth occurred during June, and even July, but this was very slow. In June, when about eleven plants were actively growing, the mean rate was 0.7 cm/day. In July there were three or four actively growing plants and seven or eight growing at negligible rates. Fig. 32a shows that, later in the summer, there was little change in the lengths of the small Saccorhiza plants. There was a slight increase in length during early July and a slight decrease in early August. Hole movements (Fig. 32b) again indicate quite slow growth, but faster than the larger plants, with a mean of 1.1 cm/day in July. By early August two plants were growing quite rapidly and four at negligible rates. During further observations on natural colonisation it was found that by June 23, 89% by weight of the Saccorhiza population consisted of large plants (greater than 500g fresh weight). This suggests that the peak of biomass was reached during early – mid June.

Fig. 33 shows that all the Laminaria plants grew quite rapidly throughout July and early August, continuing to increase in

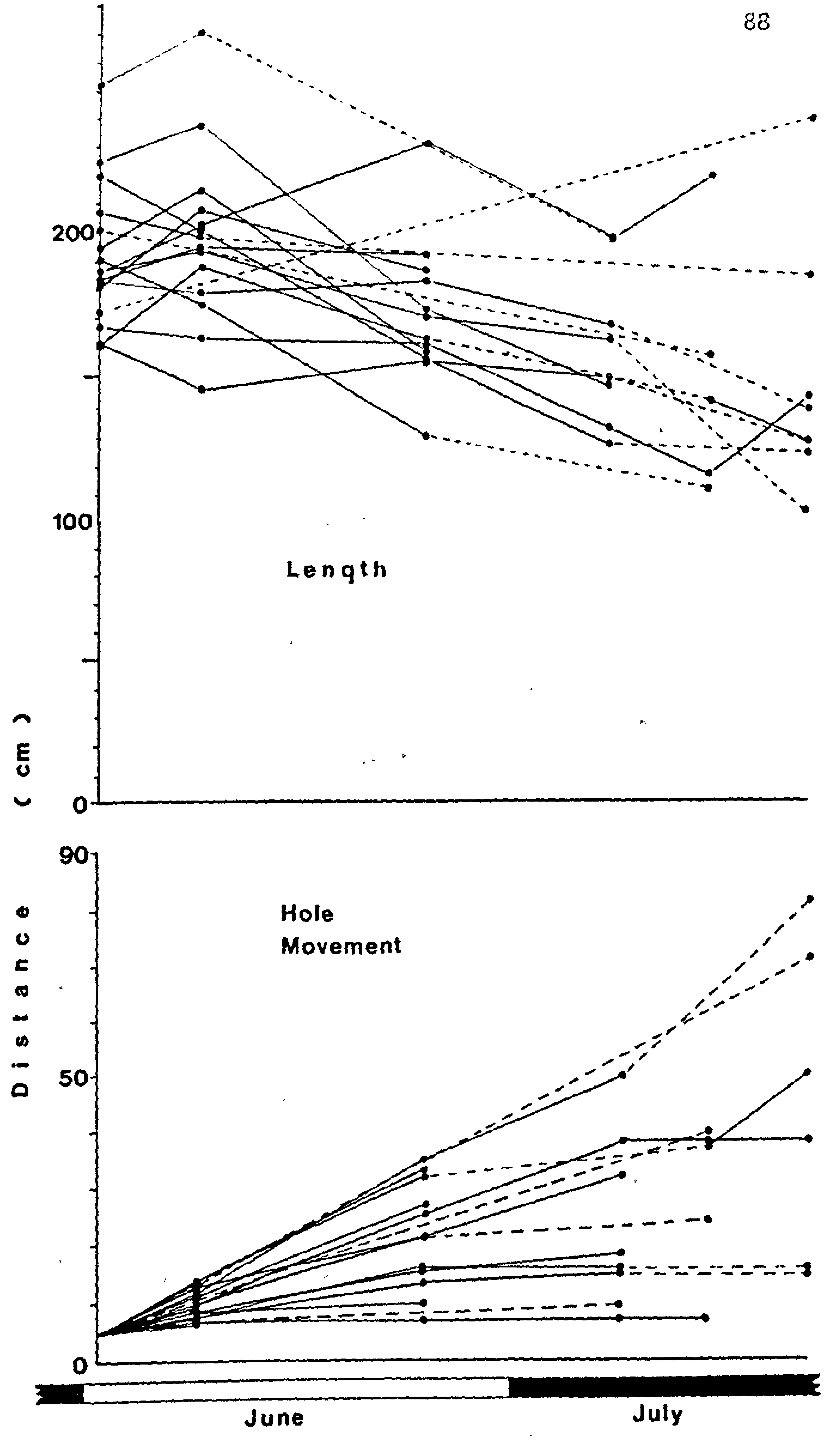


Fig. 31 - Total length (top) and distance from the top of the stipe of holes punched in the frond (bottom) in individual naturally colonised large <u>Saccorhiza</u> plants (more than 150 cm long on June 1) during summer, 1983.

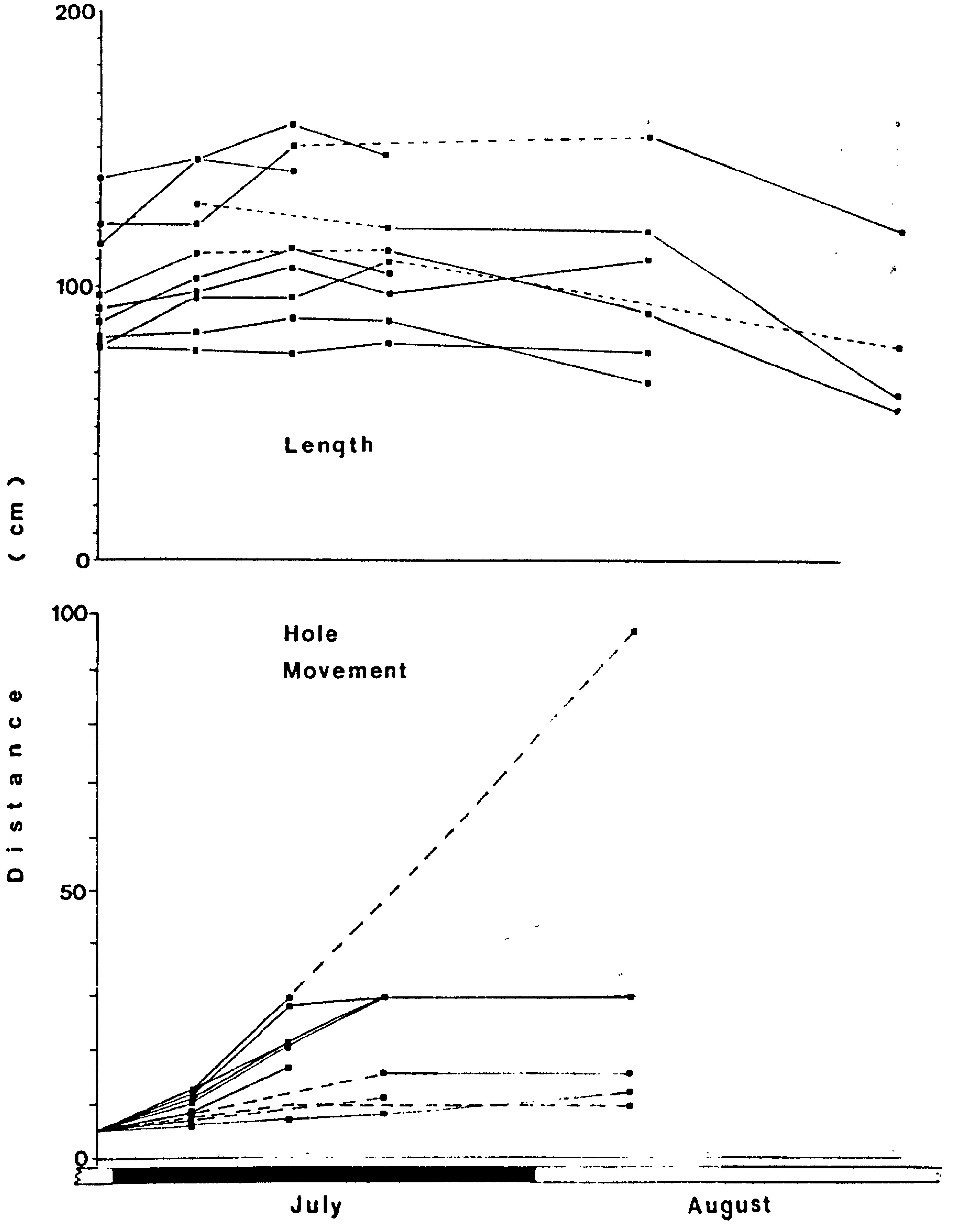


Fig. 32 - Total length (top) and distance from the top of the stipe of holes punched in the frond (bottom) in individual naturally colonised small Saccorhiza plants (less than 150 cm long on June 30) during summer, 1983.

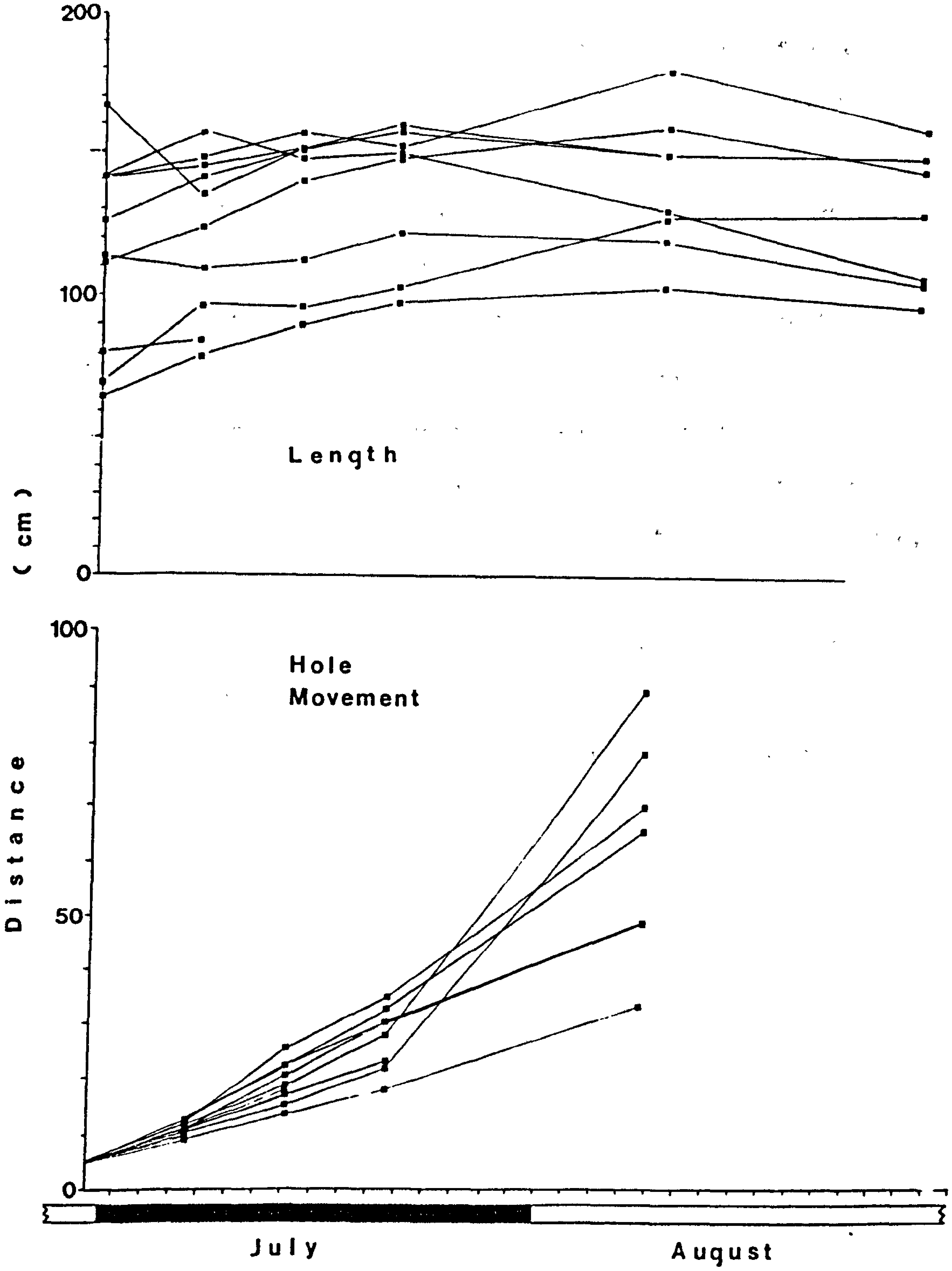


Fig. 33 - Total length (top) and distance from the top of the stipe of holes punched in the frond (bottom) of Laminaria plants during summer, 1983.

length throughout this period. The rate of movement of holes averaged 1.44 cm/day but increases in length averaged only 0.53 cm/day, indicating substantial losses due to erosion. The rate of growth was roughly constant, although there may have been a slight increase in late July/early August.

From the results of these experiments it was decided that in 1983 monitoring of Alaria should commence as soon as the plants were of measurable length, Sacchoriza measurement should commence in about mid-late May, and Laminaria in about June. If late seeded plants were still very small measurements could, of course, be further delayed. This scheme was intended to reduce the amount of overlap of the measuring periods of the three species without missing the period of maximum biomass, so that diving time could be used most effectively and hence large numbers of plants could be measured.

5. EFFECTS OF DENSITY, TIME OF SEEDING AND DEPTH

5.1 INTRODUCTION

The three species under investigation spore mainly during autumn and winter. Young sporelings usually first appear during spring, with rapid growth taking place during spring and early summer. Measurements of underwater irradiance (Luning 1971, Kain 1971, Kain et al 1976) have indicated that all stages of L. hyperborea are below saturation point and frequently below compensation point in shallow waters off the Isle of Man in winter (Kain et al 1976). Norton and Burrows (1969a) suggested that development and growth of Saccorhiza is light limited rather than temperature limited in winter, and it seems likely that the same is true of L. saccharina and Alaria. Since the rope systems used in the present work were at a constant distance below the sea surface, and not subject to periodic increases in depth of water due to incoming tides, it was thought that light might be less limiting than on submerged rock surfaces. This was supported by the appearance in early February 1982, of Alaria sporophytes up to 15 cm in length, from microscopic plants seeded in early November 1981. However, the shallow depths necessary for high light levels would conceivably result in severe losses of plants during winter storms, thereby reducing the total biomass, particularly with Saccorhiza. In order to find out which seeding date would result in the greatest biomass, experiments were set up to compare production of all three species seeded from November 1982 through till April 1983 at a depth of 2m.

In view of the density effects observed in 1982, it was decided to investigate the effects of a larger range of densities by seeding strings closer together. Intervals of 100, 50, 25, 10 and 5 cm between strings were used. This experiment was carried out twice, in November 1982 and April 1983.

Since the depth of 2m at which most experiments were carried out was picked quite arbitrarily, further ropes were set up to compare production at depths of 1, 2, 3, and 5m. Seeding took place in April so that there would be little natural colonisation and the ropes would remain at their intended depths throughout the experiments. Since it was known that diatoms would cover the ropes and strings in the top few metres in April, another rope was seeded at a depth of 10m, where diatom contamination would be minimal, and raised to 2m after six weeks. This is referred to as the 10(2)m rope.

5.2 METHODS

Experiments were set up for each species as shown in Table 7, using ten strings for each set of conditions. It was intended that seeding at 50 and 100 cm spacings be performed monthly from November to March inclusive, but because of bad weather the January seeding had to be abandoned completely and the March seeding was delayed until early April. Fig. 34 shows the format used to set out the strings at various intervals. It can be seen that one string at each spacing, except for 100 cm, had strings at different distances on either side (labelled B in Fig. 34). These strings were harvested with the more densely seeded series of groups in all

PLANNED DATE OF SEEDING	DEPTH (m)	SPACING (cm)	ACTUAL SEEDING DATE
mid - Nov.	2m	100 50 25 10 5	Nov 25
mid - Dec.	2m	100 50	Dec 13
mid - Jan.	2m	100 50	abandoned due to bad weather
mid - Feb.	2m	100 50	Feb 16
mid - Mar.	1m	100 50	delayed until April 5
	2m	100 50 25 10 5	
	3m	100 50	
	5m	100 50	
	10m*	100 50	

* raised to 2m after 6 weeks

Table 7 - Planned seeding scheme for 1982 - 83, with changes forced by weather conditions. Ten strings were used for each species under each set of conditions.

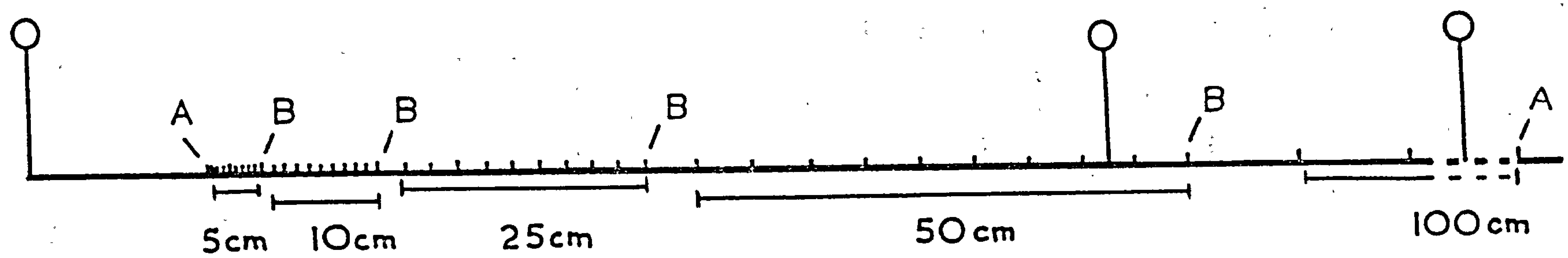


Fig. 34 - The arrangement of seeding strings in the density experiments.

A - The end strings in the series.

B - Strings with adjacent strings at different distances.

cases. Further strings at 5 and 100 cm (labelled A in Fig. 34) had no neighbouring strings on one side. This was inconsequential for the 100 cm strings since this was a relatively wide spacing, but the group from the end 5 cm string would have received rather more light than the other 5 cm spaced groups and was therefore not measured.

Closely spaced strings spent more time out of the water during seeding than 1m spaced ones - up to several minutes at 5 cm intervals - but were repeatedly splashed with seawater until they were submerged.

It was intended that cultures of the same age be used in all experiments. On the basis of the 1982 result thirty days was thought to be sufficient, but delays due to bad weather meant that ages ranging from 31 - 46 days were used.

Growth of Alaria and Laminaria was followed by means of the relative growth rate (R) which was calculated for the longest plant in each group as described earlier. Occasionally the end of a Laminaria plant was pulled off during measurement. The total length including the removed portion was recorded and used to calculate R. The length of the plant after damage was also recorded and used to calculate the subsequent value of R. Growth of Saccorhiza was followed by measuring the total length of the longest plant in each group during the early stages, and by using Parke's hole punching method in the later stages. In 1983 the lengths of the plants were measured with a tape measure which was clipped to the rope adjacent to the holdfasts of the group concerned. This was considerably easier than using a long ruler, and probably more accurate, particularly for the longer Alaria plants which, in 1983, were frequently more than 3m in length. Whenever possible, the plants were measured in a current of 0.15 - 0.40 m s^{-1}. Under these conditions the plants were swept into a horizontal position which made measurement very much easier. In all three species, plants in the 50 and 100 cm spaced groups at 2m depth for each seeding date were measured. The 10(2)m rope was used for measurement of April seeded plants. Due to lack of diving time it had to be assumed that plants seeded at the same time would reach a maximum biomass at about the same time, irrespective of depth of spacing.

Plants were harvested when it had been concluded that the mean value of R had fallen below zero.

5.3 RESULTS

5.3.1 GROWTH AND HARVESTING

The raw data for length measurement are given in Appendix 4. Laminaria groups were sometimes missed but usually all the groups were easily found. Occasionally plants were found to have been badly damaged, usually when one end of a horizontal rope came free and tangled either around itself or around an adjacent rope. Such groups were easily identified by the clean breaks at the ends of the plants. When this occurred the R value was ignored until the plant continued to grow.

Figs. 35 - 38 show the mean and 95% confidence limits for R calculated for Alaria and Laminaria. It can be seen from Figs. 35 and 36a that Alaria seeded in November, December and February all

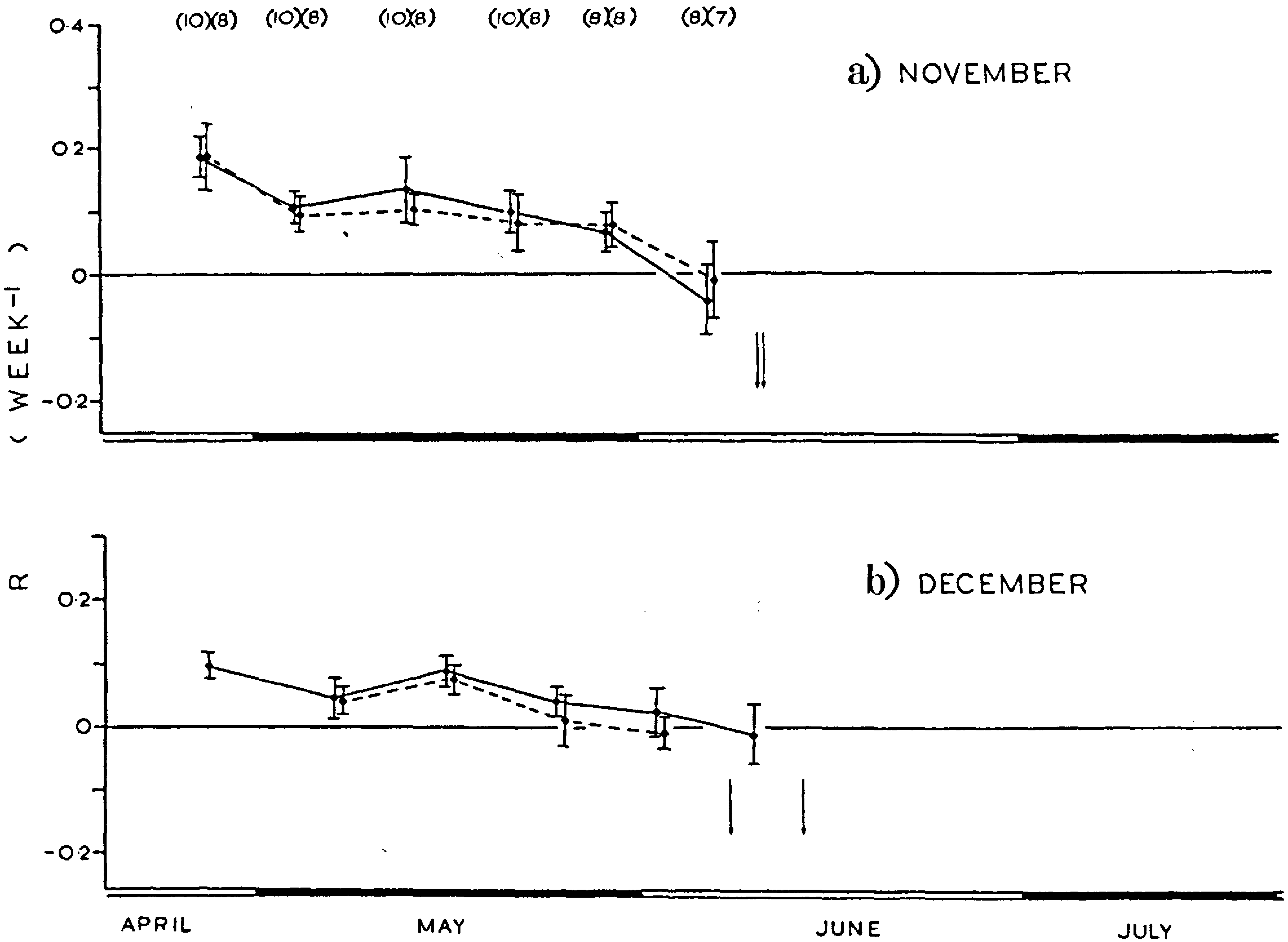


Fig. 35 - variation in the relative growth rate, R, with time for the longest plant in each group of Alaria seeded in November (a) and December (b) 1982. Mean and 95% confidence limits are shown. N is indicated above each point for Nov. plants. N = 10 for all Dec. measurements. Solid line = 100 cm spaced plants. Dashed line = 50 cm spaced plants. Arrows indicate date of harvest.

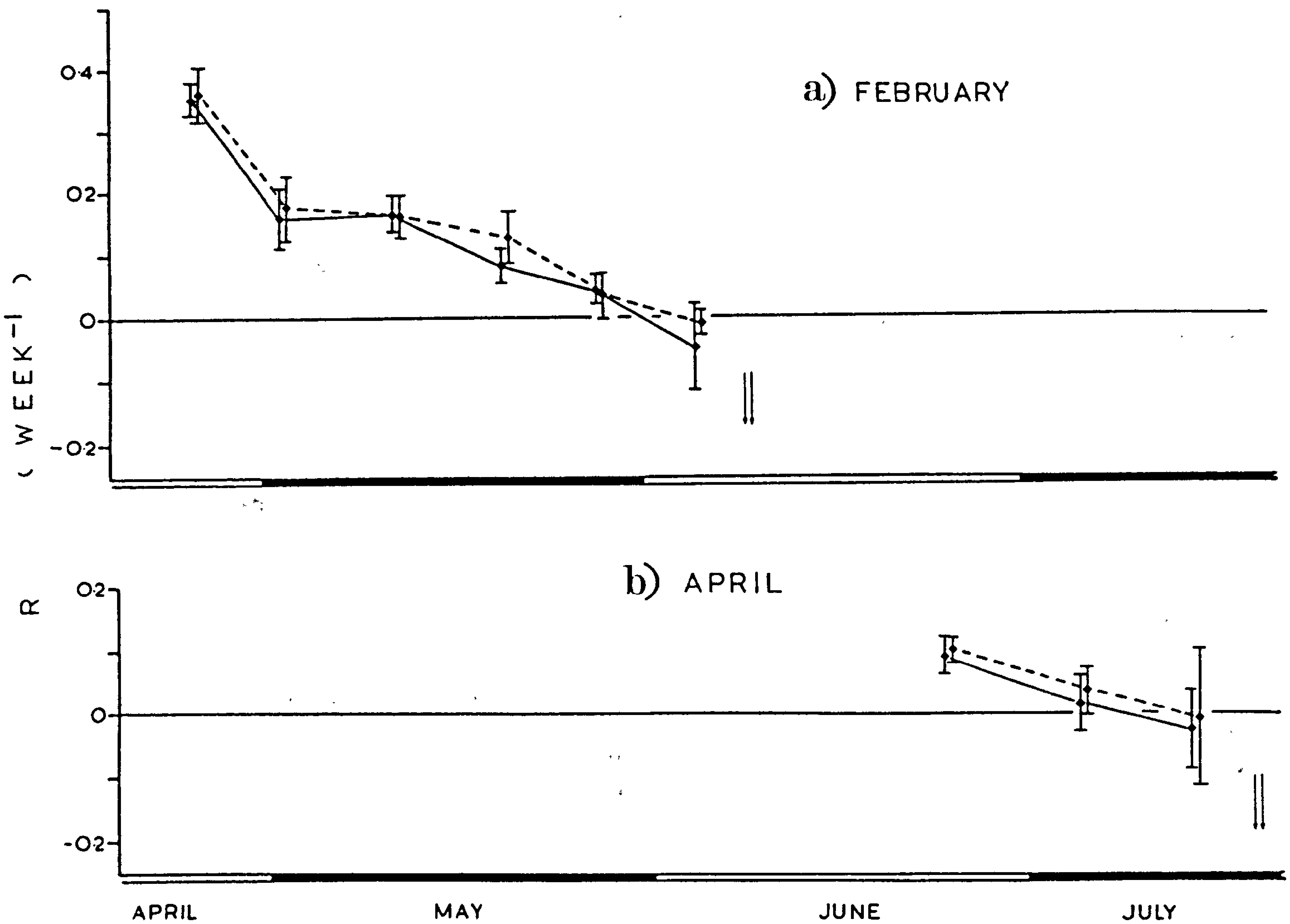


Fig. 36 - variation in the relative growth rate, R, with time for the longest plant in each group of <u>Alaria</u> seeded in February (a) and April (10(2)m) (b) 1983. Mean and 95% confidence limits are shown. N = 10 in all cases. Solid line = 100 cm spaced plants. Dashed line = 50 cm spaced plants. Arrows indicate date of harvest.

Fig. 37 - variation in the relative growth rate, R, with time for the longest plant in each group of Laminaria seeded in November (a) and December (b) 1982. Mean and 95% confidence limits are shown. N is indicated above each point. Solid line = 100 cm spaced plants. Dashed line = 50 cm spaced plants. (Nov. 100 and 50 cm spaced plants combined in August).

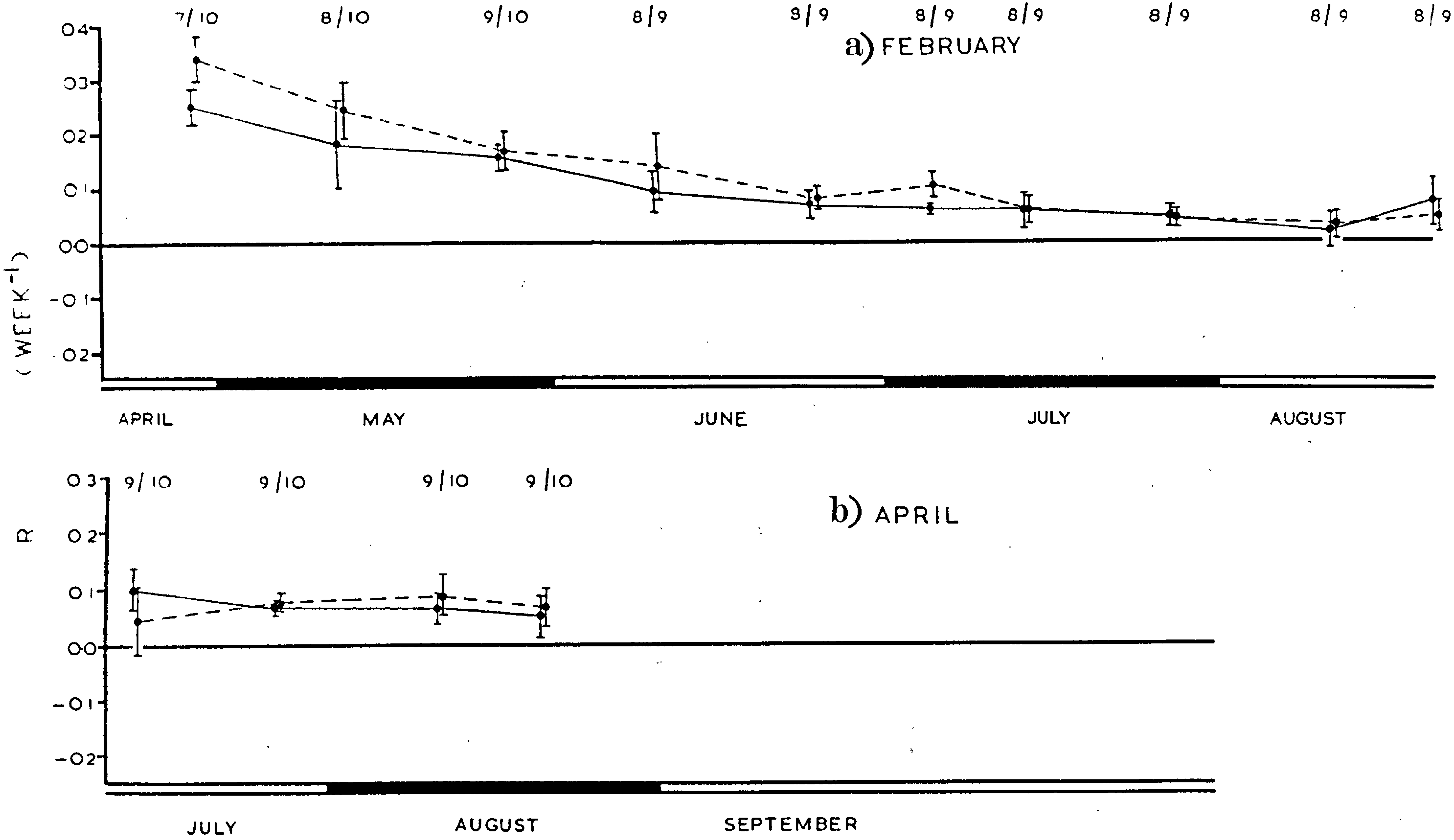


Fig. 38 - variation in the relative growth rate, R, with time for the longest plant in each group of Laminaria seeded in February (a) and April (10(2)m) (b) 1983. Mean and 95% confidence limits are shown. N is indicated above each point. Solid line = 100 cm spaced plants. Dashed line = 50 cm spaced plants.

stopped increasing in length during late May/early June, although the relative growth rates were markedly different. The February seeded plants grew fastest, with an R value in late April of about 0.35, which is equivalent to a doubling time of about 2 weeks. The December seeded plants were slowest with an R value in late April of about 0.1, equivalent to a doubling time of about 7 weeks. These differences in growth rate were reflected in the maximum length attained by the plants (Table 8). Those seeded in February reached almost 300 cm in length while those seeded in November and December only reached about 200 cm. The 50 cm spaced December seeded plants were harvested on June 1 and the 100 cm spaced plants plus all November and February seeded plants on June 8 and 9. It can be seen from Fig. 36b that Alaria seeded in April continued to grow until early/mid July, when the longest plants were about 145 cm in length, and was harvested on July 18 and 20.

Although the 50 cm spaced December plants were harvested before the 100 cm spaced ones, there was no strong overall evidence of a difference in growth rate between the two spacings.

Figs. 37 and 38 show that Laminaria plants continued to grow during the summer until at least late August irrespective of the date on which they were seeded. Growth from about late June onwards was slow, even in those plants which were seeded in April and were still relatively small (Fig. 38b). In late May and early June the November 100 cm spaced plants and December 50 cm spaced plants respectively appeared to have stopped growing, but in both cases this was due to one end of the horizontal rope having come loose and tangled around itself, damaging many of the plants, particularly on the November rope. The damaged plants continued

	SEEDING DATE & INTERVAL		LENGTH (MEAN ± 1 S.D.)	N
Alaria	NOV	50	195 ± 42	8
		100	204 ± 22	7
	DEC	50	216 ± 22	10
		100	202 ± 19	10
	FEB	50	289.5 ± 26	10
		100	293 ± 34	10
	APR	50	145 ± 14	10
		100	144 ± 20	10
Laminaria	NOV	50	154 ± 25	4
		100	154 ± 35	3
	DEC	50	214 ± 41	5
		100	226.5 ± 33	8
	FEB	50	214 ± 29	9
		100	200 ± 38	7
	APR	50	108 ± 12	10
		100	116 ± 20	9

Table 8 – Mean values for the maximum observed lengths of the longest plants in groups of *Alaria* or *Laminaria* seeded in November, December, February and April at 50 or 100 cm intervals.

to grow normally, albeit more slowly in absolute terms, in their shortened condition. Table 8 shows that the December and February seeded plants were the longest, with mean values of 222 and 208 cm respectively, and April seeded were the shortest with a mean of 112 cm. In early September severe storms caused a lot of physical damage to the plants, and removed another 15 - 20 groups completely. Since it was thought that this probably heralded the early onset of the autumn gales, the plants were harvested on September 7 and 8.

Saccorhiza plants from November seeded strings were all lost from the rope when it became tangled in early June, while those from December seeded strings were gradually removed by wave action so that none remained by mid-June. The February seeded strings produced no plants at any stage, so that only plants seeded in April remained by mid-summer. These were still relatively small (100 - 150 cm in length), and actively growing in early August. Only one measurement of the movement of holes was carried out before the storms in early September. This indicated a slow mean growth rate of 2.5 cm/week for 12 plants from August 16 - 23. All of the *Saccorhiza* were harvested on September 8.

Growth of *Laminaria saccharina* and *Saccorhiza polyschides* may be nitrate limited during the summer when ambient levels are low. Chapman and Craigie (1977, 1978) have shown that *L. longicruris* is nitrate limited in the summer in St. Margaret's Bay, Nova Scotia. Chapman et al (1978) showed that *L. saccharina* had a half-saturation constant for nitrate uptake of 1.4 μM. In Manx waters nitrate concentration frequently falls below 1 μM for lengthy periods during the summer (Slinn in prep.). Cultivated

L. saccharina and Saccorhiza plants were more heavily covered with bryozoans than plants in natural populations, which probably reduced their ability to take up nutrients. It is not known why most of the Alaria appeared to stop growing completely in late May/ early June, although this also occurs in natural populations in the Isle of Man (Lewis, 1971). Despite lowering nitrate levels and increasing temperature, Alaria is obviously capable of maintaining growth until at least early July, as shown by the April seeded plants. It is possible that growth in the earlier seeded plants did continue at a slow rate during the summer, but that erosion of the distal tissue was so much faster that the plants appeared to have stopped growing, and that the distal tissue of the later seeded plants, being younger, did not erode until later. The growth rate of the April seeded plants during June and July was quite slow.

5.3.2 EFFECTS ON PRODUCTION AND MEAN PLANT WEIGHT

Figs. 39 - 57 can be found between pages 130 & 148. Raw data for production are given in Appendices 5, 6 and 7.

5.3.2.1 ALARIA

5.3.2.1.1 Density

The mean plant density in terms of numbers per unit length of rope is the product of two factors - the number of plants in each group, and the distance between the groups. All three aspects need to be considered in a study of plant density.

Figs. 39 and 40 show the mean plant weight plotted against the number of plants for all the Alaria groups harvested in 1983. It can be seen that, as in 1982, an increase in plant numbers per group generally caused a decrease in mean plant weight. Groups with low numbers of plants tend to lie below the regression line, suggesting that density effects were lower than with higher numbers of plants, but there was still a negative relationship even when the range of plant numbers was as low as 1 - 19 (April seeded, 2m depth, 50 cm spacing, Fig. 40b). At the highest range (79 - 242 plants/group seeded at 50 cm intervals in February, Fig. 39c) there was a strongly negative relationship but the slope of the regression line was less than -1, which is the gradient representing a constant level of production per group, which means that increasing numbers of plants still resulted in an increase in total production.

Comparison of groups spaced at different intervals was complicated by several factors:

i) The relative sizes of neighbouring groups must affect the influence they have upon each other. This varied within each set of conditions and was not experimentally controlled.

ii) The end 5 cm spaced group in the November experiment was accidently harvested and measured with the others, so that the observed production may be slightly overestimated in this case.

iii) Groups were lost for various reasons (summarised in Table 9). In the November experiment two adjacent 50 cm spaced groups were lost in March or early April. Two 100 cm spaced groups were also lost but this occurred only days before the harvest so the remaining eight would have been unaffected. On the

DATE & DEPTH (m)	SEEDING INTERVAL (cm)	NO. OF GROUPS HARVESTED	FAILED TO GROW	LOST DURING GROWING SEASON	LOST 18 DAYS OR LESS BEFORE HARVEST
NOV 2m	100	8	0	0	2 (May*)
	50	8	0	2 (Mar*)	0
	25	10	0	0	0
	10	10	0	0	0
	5	10	0	0	0
DEC 2m	100	10	0	0	0
	50	10	0	0	0
FEB 2m	100	10	0	0	0
	50	10	0	0	0
APR 1m	100	rope lost† May 20	3	-	-
	50		4	-	-
APR 2m	100	8	2	0	0
	50	6	4	0	0
	25	0	10	0	0
	10	3	7	0	0
	5	7	3	0	0
APR 3m	100	10	0	0	0
	50	10	0	0	0
APR 5m	100	10	0	0	0
	50	10	0	0	0
APR 10(2)m	100	10	0	0	0
	50	10	0	0	0

† - most surviving "groups" were single plants

* - groups removed by rope tangling

Table 9 - The number of Alaria groups harvested from each set of 10 strings seeded in 1982-83 together with the causes of failure or loss of groups.

April 2m deep rope twenty six of the fifty strings failed to produce any plants. Fortunately seven of the most densely seeded (5 cm intervals) and eight of the least densely seeded (100 cm intervals) strings produced groups of plants, allowing some comparisons to be made.

Fig. 39a shows that the spacing interval between the groups seeded in November had a pronounced effect upon mean plant weight. In an attempt to determine the significance of differences between the various spacings, comparisons of regression coefficients and elevations were made using the methods outlined by Zar (1941). This is not a very reliable test when different ranges of x - values are involved, particularly when it is known that the relationship between x and y is unlikely to be constant for all values of x. It would be expected that density would have a minimal effect upon mean plant weight up to a certain number of plants per group, beyond which a more negative log/log relationship would be found (Harper 1977, Kays and Harper 1978). Comparison of regressions revealed little about the effects of density in the November experiment. It can be seen from Fig. 39a that there was little difference in mean plant weight between groups spaced at 100, 50 and 25 cm when there were less than ten plants per group. This is not surprising since such low numbers of plants would not result in a very high overall density even when spaced quite closely together. At 10 cm spacing the overall density seems likely to have been sufficient to have an effect even with such low numbers of plants. No groups spaced at 5 cm intervals contained fewer than ten plants, but it is possible that density effects would have been noticeably more severe than in the 10 cm spaced groups.

With about 50 - 100 plants per group the mean plant weight decreased regularly with decreasing spacing from 100 cm down to 5 cm. It seems reasonable to conclude that the difference between the 25 and 100 cm spaced groups is significant, since both the elevations and coefficients of the regression lines were significantly different. However, there is also some evidence that spacing at 50 cm had the effect of reducing the mean plant weight compared with 100 cm spacing. It can be seen from Figs. 39 and 40 that the difference in mean plant weight between 50 and 100 cm spaced groups was never great, being largest in the November seeded and April (5m deep) seeded plants, negligible in the February and April (2m, 3m, 10(2)m deep) plants and, although significant, only small in the December seeded plants. It can also be seen from Fig. 40b that in the April seeded plants there was no effect of spacing even down to a distance of only 5 cm, due probably to the relatively poor growth of these plants and the low numbers of plants in the groups, but there was generally a reduction in mean plant weight with increasing plant numbers, suggesting that intra-group density effects occur earlier than inter-group. This was expected, due to the close proximity of the plants within a group compared to the distance between groups.

Dry weight per group, number of plants per group and dry weight per metre of rope were plotted against spacing interval for the November and April seeded groups (Figs. 41 and 42). In calculating dry weight per metre, missing groups were ignored since they had been lost only a few days before the harvest. It can be seen from Fig. 41 that, despite the slight reduction in mean plant weight of 50 cm spaced strings seeded in November, the mean production per group was the same as in those seeded at 100 cm intervals, at about 250 g dry weight. Production by more closely spaced groups was considerably lower, although there was no significant difference between 25 and 50 cm spacings according to the Mann-Whitney test. Production by 5 cm spaced groups was very low, at about 50 g dry weight/group, but it can be seen that this is equivalent to over 1100 g per metre of rope, approximately four times that at 1m spacings, and represents the highest production per metre.

Fig. 41 also shows that the number of plants in the groups may also have been affected by the proximity of the strings, the numbers on 5 and 10 cm spaced strings being significantly lower than the numbers on the more widely spaced strings. Although self thinning of dense natural stands of algae has been reported (Schiel and Choat, 1980; Cousens and Hutchings, 1983) it is more likely in this case that it was the result of adjacent strings rubbing together and dislodging young plants. None of the November seeded groups contained more than 100 plants, although up to 242 were found in the February seeded groups (discussed later).

The variously spaced groups had a clear effect upon the amount of natural colonisation on the rope. Unseeded portions and those portions bearing strings at 100 or 50 cm intervals were heavily colonised with large *Saccorhiza*, *Laminaria saccharina* and *Desmarestia* as well as many smaller plants. Colonisation of the rope between the 25 cm spaced groups was only slight, consisting of only a few small *Saccorhiza*, and no naturally colonised large brown algal species were found on the 10 cm or 5 cm spaced sections. It is not clear to what extent this was caused by competition for light or to "scouring" of the rope by the strings and/or groups preventing the growth of young colonising plants.

Fig. 42 shows that despite the very poor production by the April seeded plants, which was nearly the same at 5 and 100 cm spacings, production per metre increased with decreasing spacing up to a maximum of 400 g per metre at 5 cm intervals. There was no apparent reduction in the number of plants at the closer spacings, but numbers were very low in all cases, only three groups containing more than fifty plants. This may have masked any effect of the strings rubbing together.

The mean number of plants per metre was calculated by multiplying the mean number of plants per group by the number of groups per metre of rope. When mean plant weight was plotted against mean plant number a strong double logarithmic relationship in November seeded plants was revealed (Fig. 43). The groups tended to spread out quite widely even in calm conditions, as shown in Figs. 14 and 15, so that once they became quite large the overlapping of plants from several groups probably had a more important effect than the number in each group, particularly at close spacings, and the result approximated to that which would be expected from an even distribution of plants. The wide spread of values for individual groups at each spacing was probably caused in part by variations in the number of plants per group, but also by other environmental factors and genetic variation. The slope of the regression line is less than -1, which means that there was an increase in production per metre up to a density of at least

530 plants per metre. It seems likely that this could have been exceeded by using higher plant densities. The point at which no further increase in production could be obtained is not known.

There was no relationship between mean plant density and mean plant weight in April seeded plants since, as had already been shown, the spacing of the strings had no effect upon growth.

5.3.2.1.2 Time of Seeding

As there were only slight differences in mean plant weight between 50 and 100 cm spaced groups, the results were pooled in order to consider the effects of the time of seeding and depth.

It has already been shown that production by plants seeded in April was low. It was expected that the earlier seeded plants would have grown better due to the increased time available for growth. Fig. 44 compares production per group and numbers of plants per group on the four seeding dates at 2m depth. It can be seen that maximum production was obtained from December and February seeded plants, with the latter slightly more productive, although not significantly so. Although two November and two December seeded groups were lost because of the ropes tangling (Table 9), damage to the remaining plants was minimal and unlikely to have severely affected production. Fig. 44 also suggests that much of the difference in production can be accounted for by differences in the number of plants in the groups. This is shown more clearly by a plot of mean plant weight against plant numbers (Fig. 45), which suggests that the November and December seeded plants produced similar mean plant weights at high plant densities, but that both sets of plants grew better than the February seeded ones, attaining a higher mean plant weight for a given number of plants per group. It is important to note that dense natural colonisation by large brown algae was observed on all parts of the November and December ropes, but none at all on the February rope. This seems unusual since in previous years it was shown that vertical ropes placed in the sea in February, early March and even mid-April often bore large amounts of such colonisation (chapter 6). It is likely that such a difference in colonisation would have had a large effect on the production by the plants, and therefore that in other years the difference in mean plant weight between November or December seeded plants and February seeded ones could be greater. Furthermore, it was observed that the November and December strings bore numerous plants up to 18.5 cm in length on February 16, the day on which the February seeded strings were placed in the sea. It would appear that this size advantage increased the final production, and therefore, in spite of the observations that the February plants had the highest relative growth rate during spring and summer, it seems likely that early seeding can be advantageous for production.

The high production from the February seeded strings was due to the high numbers of plants in the group - a mean of over 170 from twenty groups (Fig. 44). This was significantly higher than the numbers from November (less than 50/group) or December (less than 100/group) seeded strings. If this trend is indicative of a repeatable seasonal effect then the higher production per plant from earlier seeding could be negated by the reduced numbers of plants. However, it is possible that the variation in numbers was caused by the number or viability of gametophytes in the culture or to the particular weather conditions during seeding. The low numbers in the April seeded groups were probably caused by the smothering effects of diatoms.

There was a pronounced difference in morphology between plants seeded in November, December and February. The February plants became very long and narrow, the longest in each group averaging 271.5 compared to 181.25 and 192.7 cm for the November and December seeded plants respectively, while the mean plant weights per cm were very much lower in the February seeded plants and highest in the November seeded ones (Table 10). A link between morphology and the number of plants in the groups is possible since the November plants (shortest and heaviest) were in groups with low numbers of plants, and the February seeded ones (longest and lightest) were in groups with large numbers of plants.

	mean length longest plant (cm)	mean plant weight (g)	plant wt/cm (mg)	mean plant no. per group
November seeded	181.25	4 - 8	22.1 - 44.1	43.1
December seeded	192.7	3 - 5	15.6 - 25.9	96.6
February seeded	271.5	2 - 3	7.4 - 11.0	172.1

Table 10 - the relationship between length of the longest plant and mean plant weight in Alaria groups seeded in November, December and February. Mean numbers of plants per group are also shown.

Schiel and Choat (1980) found a positive correlation between plant length and density in *Ecklonia radiata* and *Sargassum sinclairii*, although they also found a positive correlation between mean plant weight and density which was not found in the present work. However, more likely explanations are environmental conditions such as depth, or degree and type of water movement, which have been shown to affect blade size and morphology in *L. hyperborea* (Svendson and Kain 1971) *L. longicruris* (Gerard and Mann 1979) and *Saccorhiza polyschides* (Ebling and Kitching, 1950, Norton 1969). Sundene (1961) observed that *Alaria esculenta* plants grown in exposed conditions developed narrower blades than those grown in sheltered conditions. Although in the present work the plants spent much time in very similar conditions, it is possible that morphology is linked to conditions prevalent at certain stages in the development of the plants. Genetic differences in the parent material are unlikely to be the cause since fifteen to twenty adult plants were used to prepare each spore suspension.

5.3.2.1.3 Depth

Table 9 shows that the 1m deep rope bore few plants on May 20. This may have been because the rope was floating at the surface for much of the time in the first week after seeding, so the strings were exposed to heavy surf and possibly desiccation. Further weights were added to sink the rope which was subsequently covered by a very dense growth of diatoms. This could have smothered any remaining *Alaria*.

Fig. 46 compares dry weight and numbers of plants in groups seeded at the various depths. It can be seen that, although few April seeded plants survived at 2m depth, survival at 3, 5 and

10 (2)m was much higher, but there were significantly fewer plants at 3m than at 5 or 10m. This was probably because diatoms were less dense on the deeper ropes, although increased shelter from turbulence may also have been a factor. Fig. 46 also shows that production was much higher at 3, 5 and 10 (2)m than at 2m. However, production at 5m was significantly lower than at 10 (2)m and slightly lower than at 3m despite the higher number of plants. A plot of mean plant weight against plant numbers per group (Fig. 47) shows clearly that production by the surviving plants at 2m was very poor considering the low densities involved, and that the mean plant weight was lower at 5m than at 3 and 10 (2)m, at least when there were more than 70 plants per group. Furthermore, the slope of the regression line for the 5m deep plants is about -1 (-1.06), which means that production could not be greatly increased by increasing the number of plants at this depth. The slopes for the shallower depths were less than -1, indicating a less severe density effect.

5.3.2.2 LAMINARIA

Laminaria groups seeded in 1983 can be seen in Figs. 16 and 48.

It can be seen from Table 11 that large numbers of *Laminaria* groups were lost once they had grown to a large size. In most cases the plants were attached only to the string, and not directly to the rope itself, as can be seen from Fig. 16. Wave action and possibly currents caused the string to snap or slip through the holdfasts, which were not as strongly attached as those of *Alaria*. The majority of the losses occurred in storms in early September.

The holdfasts of the three 5 cm spaced groups harvested from the November seeded strings had interwoven to such an extent that

DATE & DEPTH (m)	SEEDING INTERVAL (cm)	NO. OF GROUPS HARVESTED	MISSING GROUPS: FAILED TO GROW	MISSING GROUPS: LOST MORE THAN 18 DAYS BEFORE HARVEST	MISSING GROUPS: LOST LESS THAN 18 DAYS BEFORE HARVEST
NOV 2m	100	3	0	2 (Mar*) 4 (Jun)	1
	50	5	0	3 (Mar*) 1 (Jun)	1
	25	4	0	0	6
	10	5	0	0	5
	5	3	0	0	7
DEC 2m	100	8	0	2 (Jun)	0
	50	2	0	1 (Jun) 3 (Jul)	4
FEB 2m	100	8	0	2 (Jun)	0
	50	8	0	1 (Jun)	1
APR 1m	100	rope lost May 20	10	0	0
	50		10	0	0
APR 2m	100	7	3	0	0
	50	3	7	0	0
	25	0	8	2	0
	10	7	3	0	0
	5	7	3	0	0
APR 3m	100	9	0	0	1
	50	8	0	0	2
APR 5m	100	10	0	0	0
	50	10	0	0	0
APR 10 (2) m	100†	1	0	0	8
	50	0	0	0	10

* - groups removed by rope tangling

† - only 9 strings seeded

Table 11 - The number of Laminaria groups harvested from each set of 10 strings seeded in 1982-83 together with the causes of failure or loss of groups.

it was impossible to separate them accurately, so the total weight was divided by three to give a mean density.

5.3.2.2.1 Density

Mean plant weight was plotted against number of plants for all the harvested Laminaria (Figs. 49 and 50). The maximum number of plants encountered in one group was 41, up to which point density effects were slight, if any. Only in the December seeded 100cm spaced groups (Fig. 49b), which had a relatively wide range of plant numbers and high mean plant weights, was there any strong evidence of a density effect, and even in this case the slope of the regression line is very shallow, indicating that an increase in plant numbers would have led to a substantial increase in production. Furthermore, February seeded groups, with a similar range of plant numbers and mean plant weights, showed no evidence of density effects (Fig. 49c).

Production by the April seeded plants was very low, and consequently there were no obvious effects of spacing (Fig. 50a). It can be seen from Fig. 49a that production by the November seeded plants also appeared to have been poor. However, many of these groups were lost or damaged by wave action (Table 11). In March, five groups spaced at 100 and 50 cm intervals were lost when the horizontal rope came free and twisted around itself. Many other groups at 100, 50 and 25 cm spacings were severely damaged, so that in some cases only 2 or 3 cm of frond remained on any of the plants in those groups. Although these plants were able to continue growing, recovery was extremely slow and they were very much smaller than they would otherwise have been. Some less serious damage was done to the ends of some of the plants in late May when one end of the horizontal rope again came free, although no groups were lost. Many November seeded groups were lost during storms in June and early September. Although there is no evidence that spacing had any effect upon mean plant size, even at 5 cm intervals, as shown in Fig. 49a, it is probable that the damage to the 25, 50 and 100 cm spaced groups caused a significant reduction in production. It is further possible that more large groups than small ones were lost, since greater forces would have been exerted upon the larger groups. Any slight effect of density could therefore have been hidden by the damage and losses, but it is still unlikely that there was any severe reduction in mean plant size caused by the closer seeding intervals. This can be seen clearly in a plot of mean plant weight against mean plant number per metre of rope at each spacing (Fig. 51). Even if the mean plant weight from the 100 cm spaced groups had been ten times greater (twice as great as anything attained in this work), the slope of the regression line would still have been considerably less than -1. It is therefore possible that production could be increased by seeding at plant densities greater than the maximum used here, which was equivalent to 307 plants/m.

Fig. 52 shows the dry weight per group and per metre of rope at the various seeding densities. It can be seen that the mean dry weight of the 10 and 5 cm spaced groups was more than double that of the 25, 50 and 100 cm spaced ones, and was equivalent to 2.8 and 5.4 kg/m of rope respectively. These figures must, of course, be treated with caution, since only five and three groups were harvested from the ten seeded at each spacing. The missing groups were lost only a few days before the harvest, however, (Table 11), and the harvested groups would have been subject to competition from them for almost all of the growth period. There was dense natural colonisation of Saccorhiza immediately adjacent to the 5 cm spaced groups which would have contributed to this competition. It is therefore possible that 5 kg/m or more is a realistic target for production by Laminaria. Taking the total weight of the eight surviving groups at 10 and 5 cm spacings, which were spread over a distance of 1.5m, gives a total production of 2.22 kg, or 1.48 kg/m. This can be taken as a minimum production level, since twelve further groups were lost from the same portion of rope just prior to harvesting.

5.3.2.2.2 Time of Seeding

Fig. 53 compares the dry weight and number of plants in groups from the four seeding dates. It can be seen that production by the April seeded plants was extremely low, with a mean of less than 50g/group, due to the short length of time available for fast growth and/or dense growth of diatoms. Production by the November seeded plants was also low, with a mean of just over 100g/group, but this was due at least in part to the damage sustained in March. Production by December and February seeded plants was significantly higher, with mean values of 0.47 kg from 19 plants per group and 0.38 kg from 12.5 plants per group respectively. There was no significant difference in production between the December and February seeded plants. It can also be seen from Fig. 53 that the numbers of plants per group followed much the same pattern as the dry weight, but there were no significant differences between the

November, December and February groups according to the Mann Whitney test. Nevertheless it is surprising that, as with Alaria, November seeded groups contained relatively few plants compared to those seeded just eighteen days later in December. Although many November seeded groups were damaged or lost, few, if any, individual plants were removed from the groups. However, preferential loss of larger groups may have reduced the apparent numbers of plants in the groups. Differences in the survival of young plants due to the weather conditions in the period following seeding, and differences in the numbers, strength of attachment or viability of the young plants on the seeding strings are also likely to have been responsible for variations in plant numbers.

It is impossible to say for certain from the production figures whether there is any advantage to seeding in November or December compared to February. Comparison of Figs. 49a, b and c suggests not. However, it is important to note that, as mentioned earlier, dense natural colonisation by large brown algae was observed on all parts of the November and December ropes, but none at all on the February rope. As with Alaria it is likely that such a difference in colonisation would have had a large effect on the production by the plants. Furthermore, it was observed that the November and December strings bore numerous plants up to 19.5 cm in length on February 16, the day on which the February seeded strings were placed in the sea, and since winter storms seemed to cause no severe reduction in plant numbers it is possible that such early seeding is advantageous.

5.3.2.2.3 Depth

No plants had grown on the 1m deep rope by May 20 (Table 11) although numerous plants had been observed on the other ropes. This may have been because the rope was insufficiently weighted at first so that it frequently floated on the sea surface and the plants were exposed to heavy surf and possibly desiccation, and when the rope was weighted, so that it sank to a depth of 1m, it was quickly covered with diatoms. Only 31 groups were produced from 50 strings at 2m depth compared to 17 from 20 strings at 3m, 20 from 20 strings at 5m and 19 from 19 strings at 10m.

Fig. 54 compares production and number of plants per group seeded in April at 50 and 100 cm spacing at various depths. Unfortunately, all but one of the groups on the 10 (2)m rope were lost due to wave action in early September. However, it can be seen from Fig. 54 that the number of plants in the groups at 2, 3 and 5m followed the same trend as the number of groups produced. There was a mean of less than five plants per group at 2m depth, which was significantly lower than the values of eighteen and twenty plants per group found at 3 and 5m respectively. Although there were slightly more plants at 5m than at 3m, the difference was not significant.

It can be seen from Fig. 54 that production at 3 and 5m was significantly higher than at 2m. Although no production figures were obtained for the 10 (2)m plants, inferences can be made from the length of the longest plants in these groups which were used for the growth analysis in the summer. These were in the range 87 - 135 cm (mean 112 cm) by August 23. This is quite short and, since there were few plants in most of the groups, production must have been quite poor. Measurements of the plants on the 3 and 5m ropes were not made but they were observed to be larger than the 10 (2)m plants.

The increase in production from the deeper ropes compared to the 2m rope must have been mainly due to the increased numbers of plants in the groups, which were probably caused by the reduced number of diatoms rather than decreased turbulence, since the species grew well when seeded at 2m in December. Comparison of Figs. 50b and c makes it clear that there was little difference in mean plant weight between the plants at 3 and 5m even at the higher densities. Although there appeared to be slightly more bryozoan cover on the plants at 5m compared to those at 3m (section 8.3.2) this is unlikely to have seriously affected the algal production figures.

It is not clear why the 10 (2)m plants should have grown relatively poorly, since the six weeks spent at 10m allowed the plants to develop to several cm in length before being raised to 2m. It is possible that at this stage the plants were rather smaller than those at 3 and 5m and could not grow sufficiently fast to catch up.

Previous workers have shown deep optima for growth in <u>L. saccharina</u> and <u>L. longicruris</u>. Chapman and Craigie (1977) observed faster growth at 9m than at 6m, and only slightly submaximal growth at 18m in <u>L. longicruris</u>, and Boden (1979), in an experiment carried out at 1, 3, 6, 9, 12, 17 and 21m in Maine, U.S.A., found maximal growth at 9m and only slightly submaximal growth at 12m in <u>L. saccharina</u>. In both cases the differences were attributed to increased nitrate concentrations in the deeper water layers. Chapman and Craigie observed a strong thermal stratification at the experimental site (St. Margaret's Bay, Nova Scotia). Although Slinn (in prep.) found slightly more nitrate at 37m than at the surface at a point 5 km West of the Isle of Man, stratification is uncommon on the West coast of the island (Kain, 1971) and it is unlikely that a large difference in nitrate concentration would occur in the top 10m in Bay Fine. Furthermore, light is likely to be limiting at a shallower depth in Manx waters than in Nova Scotia or Maine. Although Chapman and Craigie made no mention of light levels, Boden observed that 10% of the light entering the water column reached a depth of 15m in late July. Kain (1971) reported that no more than about 8% of the light entering the water column in Port Erin Bay in June 1968 reached 15m, with a mean value of about 4 - 5%. She further calculated that in summer the mean depth reached by an irradiance of 69 $\mu E\ m^{-2}\ s^{-1}$ (approximately equal to the saturating irradiance for mature fronds of Laminaria spp.) was between 0 and 6m below lowest astronomical tide (Kain, 1966). It is therefore reasonable to expect a shallower optimum depth in Manx waters.

Comparison of Figs. 49 and 50 shows that, even at 3 or 5m depth, production per plant in April seeded groups was considerably less than that from the December and February seeded plants at 2m depth.

5.3.2.3 SACCORHIZA

Table 12 shows that all strings seeded during November and December produced groups of plants, but also that none of these survived until the harvest in early September, the majority having

			MISSING GROUPS		
DATE & DEPTH (m)	SEEDING INTERVAL (cm)	NO. OF GROUPS HARVESTED	FAILED TO GROW	LOST MORE THAN 18 DAYS BEFORE HARVEST	LOST LESS THAN 18 DAYS BEFORE HARVEST
NOV	100	0	0	?	?
2m	50	0	0	?	?
	25	0	0	?	?
	10	0	0	?	?
	5	0	0	?	?
DEC	100	0	0	10	0
2m	50	0	0	10	0
FEB	100	0	10	0	0
2m	50	0	10	0	0
APR	100	rope lost	10	0	0
1m	50	May 20	10	0	0
APR	100	0	10	0	0
2m	50	1	9	0	0
	25	1	9	0	0
	10	2	8	0	0
	5	1	9	0	0
APR	100	4		?	?
			~9		
3m	50	1		?	?
APR	100	4	0	?	?
5m	50	5	0	?	?
APR	100	2	0	?	?
10m	50	3	0	?	?

Table 12 - The number of groups of <u>Saccorhiza</u> harvested from each set of 10 strings seeded in 1982-83 together with the causes of failure or loss of groups.

been removed by wave action when they were 1 - 2m in length. None of the strings seeded in February produced any plants at all, although the Alaria and Laminaria strings seeded on the same rope were successful. The spore suspension used for the February culture contained relatively few spores, so that there was less growth than usual on the strings, but this alone cannot explain the complete absence of plants.

Obviously nothing can be concluded about the effects of density or time of seeding upon growth in Saccorhiza.

5.3.2.3.1 Depth

It can be seen from Table 12 that, as with Laminaria, no plants appeared on the 1m deep April rope, again probably due in part to the rope floating at the surface for long periods. Only five out of fifty strings at 2m depth produced groups, while about half the strings at 3m and all of those at 5 and 10m produced groups, which is thought to be due to the denser growths of diatoms which were present at the shallower depths. Some of the 3m deep groups can be seen in Fig. 55.

There was no strong evidence from the numbers of groups produced that any significant protection from wave action was afforded by depth. However, Fig. 56, a comparison of dry weight and number of plants per group at the various depths, shows there to have been a slight increase in the number of plants from 2 to 5m, although the difference was not significant according to the Mann-Whitney test. It can also be seen that there was no evidence of increased survival of plants seeded at 10 (2)m. Production at 3 and 5m depth was about twice that at 10 (2)m, although again the difference was not significant. Most of the difference in production appears to be attributable to differences in numbers of plants. A plot of mean plant weights against plant numbers (Fig. 57) shows that there were insufficient numbers of groups to deduce whether there was any significant effect of depth upon plant size. Although the 5m deep plants had a lower mean plant weight than the others they also had higher plant numbers per group. It therefore seems unlikely that any great difference due to depth would have occurred.

5.3.3 PRODUCTION LEVELS

Maximum production levels obtained in the present work are summarised in Table 13. The largest groups grown were of a similar size in all three species (630 - 1020 g dry weight) but so many *Saccorhiza* groups were lost that the maximum production from any set of ten strings was very low - a mean of only 169g per string. The maximum production obtained from sets of ten *Alaria* and *Laminaria* strings was much higher at 655 and 476 g per string respectively, and if two of the *Laminaria* groups had not been lost, the latter figure might have been about 600 g/string.

The greatest production per metre was equivalent to nearly 5.4 kg/m by *Laminaria*, but this figure was extrapolated from only three groups spaced 5 cm apart. There is some evidence that the range of plant densities which developed in this species was not high enough to cause severe density effects. It is therefore possible that yields of up to 5 kg/m could regularly be obtained by seeding at densities of more than 300 plants per metre of rope.

The maximum production by Alaria was lower than for Laminaria at just over 1.1 kg/m. This is less than double the mean figure of 655g per string produced by one set of ten strings. There is evidence that plants seeded at very high densities at an appropriate time and depth could greatly improve upon this figure. Since Alaria is a smaller plant than Laminaria it should be feasible to use a much greater density of plants, perhaps up to around 1000 per metre.

SPECIES	DRY WEIGHT (g) PER STRING	MEAN OF 10 STRINGS	PER METRE
ALARIA	819.2 (1)	655.0 (2)	1,125.0 (3) (530 plants/m)
LAMINARIA	1020.8 (4)	476.1 (4) (2 groups lost)	5,390.0 (5) (307 plants/m)
SACCORHIZA	630.2 (6)	168.9 (7) (5 groups lost)	-

1 seeded Mar 26, 1982, aged 30 days aerated, 100cm spaced, 2m depth
2 seeded Mar 26, 1982, aged 30 days unaerated, 100cm spaced, 2m depth
3 seeded Nov 25, 1982, aged 37 days unaerated, 5cm spaced, 2m depth
4 seeded Feb 16, 1983, aged 34 days unaerated, 100cm spaced, 2m depth
5 seeded Nov 25, 1982, aged 37 days unaerated, 5cm spaced, 2m depth
6 seeded Apr 5, 1983, aged 46 days unaerated, 100cm spaced, 3m depth
7 seeded Apr 5, 1983, aged 46 days unaerated, 50cm spaced, 5m depth

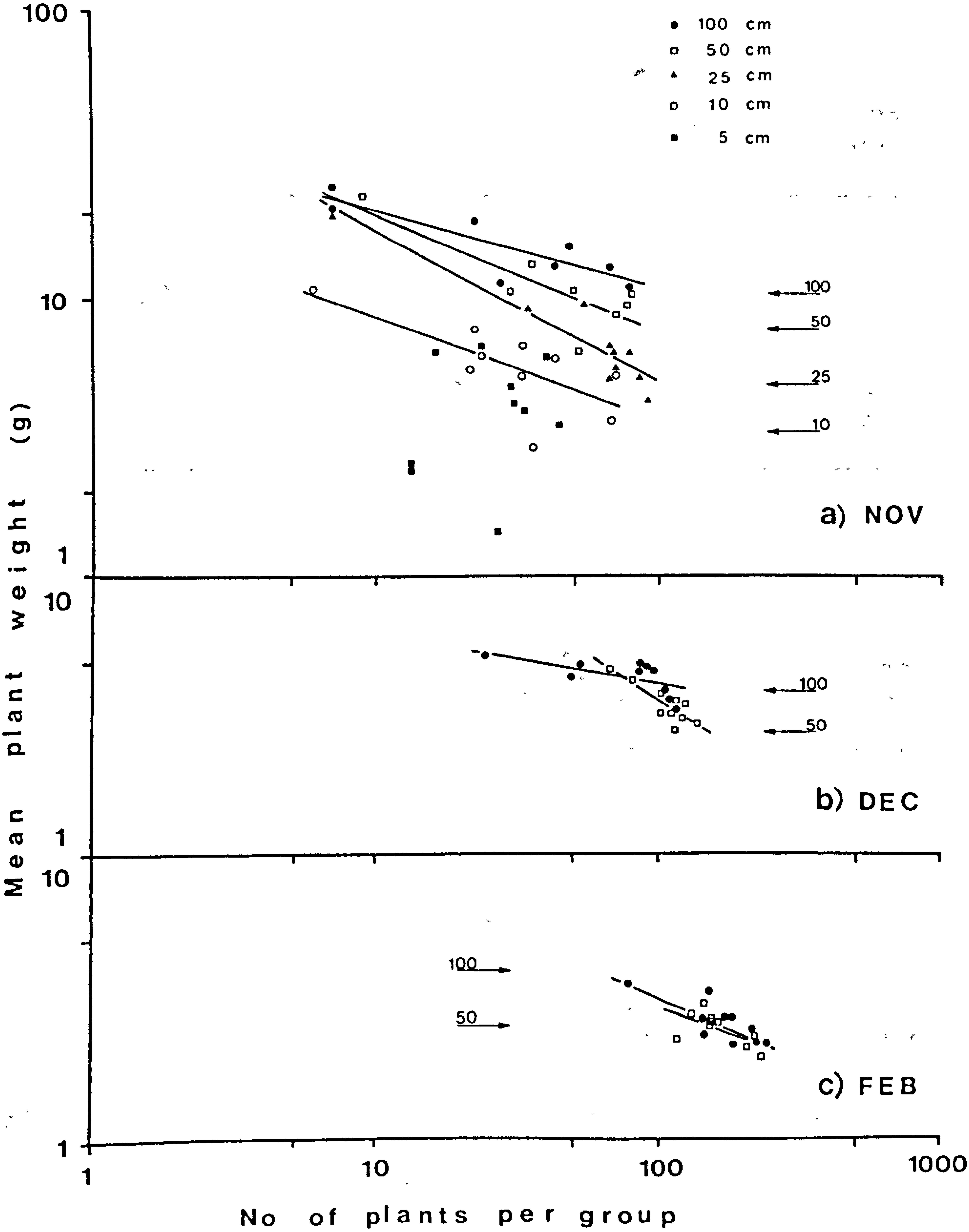
Table 13 - Maximum production levels attained by Alaria, Laminaria and Saccorhiza in terms of dry wt. per single string, mean dry wt. per string from sets of 10 strings and dry weight per metre of rope.

Fig. 39 - Mean dry weight per plant against no. of plants per groups for Alaria seeded in November at 5, 10, 25, 50 and 100 cm spacings and in December and February at 50 and 100 cm spacing, with fitted regression lines.

Comparison of regression coefficients (slopes) and elevations:

X - no difference at 5 % significance level.
✓ - difference at significance level indicated.

	regression	elevations
Nov. seeded:		
100 cm v 50 cm	X	X
100 cm v 25 cm	✓ 2%	✓ 0.1%
100 cm v 10 cm	X	✓ 0.1%
50 cm v 25 cm	X	✓ 0.5%
50 cm v 10 cm	X	✓ 0.1%
25 cm v 10 cm	X	✓ 0.1%
Dec. seeded:		
100 cm v 50 cm	✓ 2%	✓ 5%
Feb. seeded:		
100 cm v 50 cm	X	X



100 cm
50 cm
25 cm
10 cm
5 cm
a) NOV
b) DEC
c) FEB
100
50
25
10
Mean plant weight (g)
No of plants per group
1
10
100
1000

Fig. 39

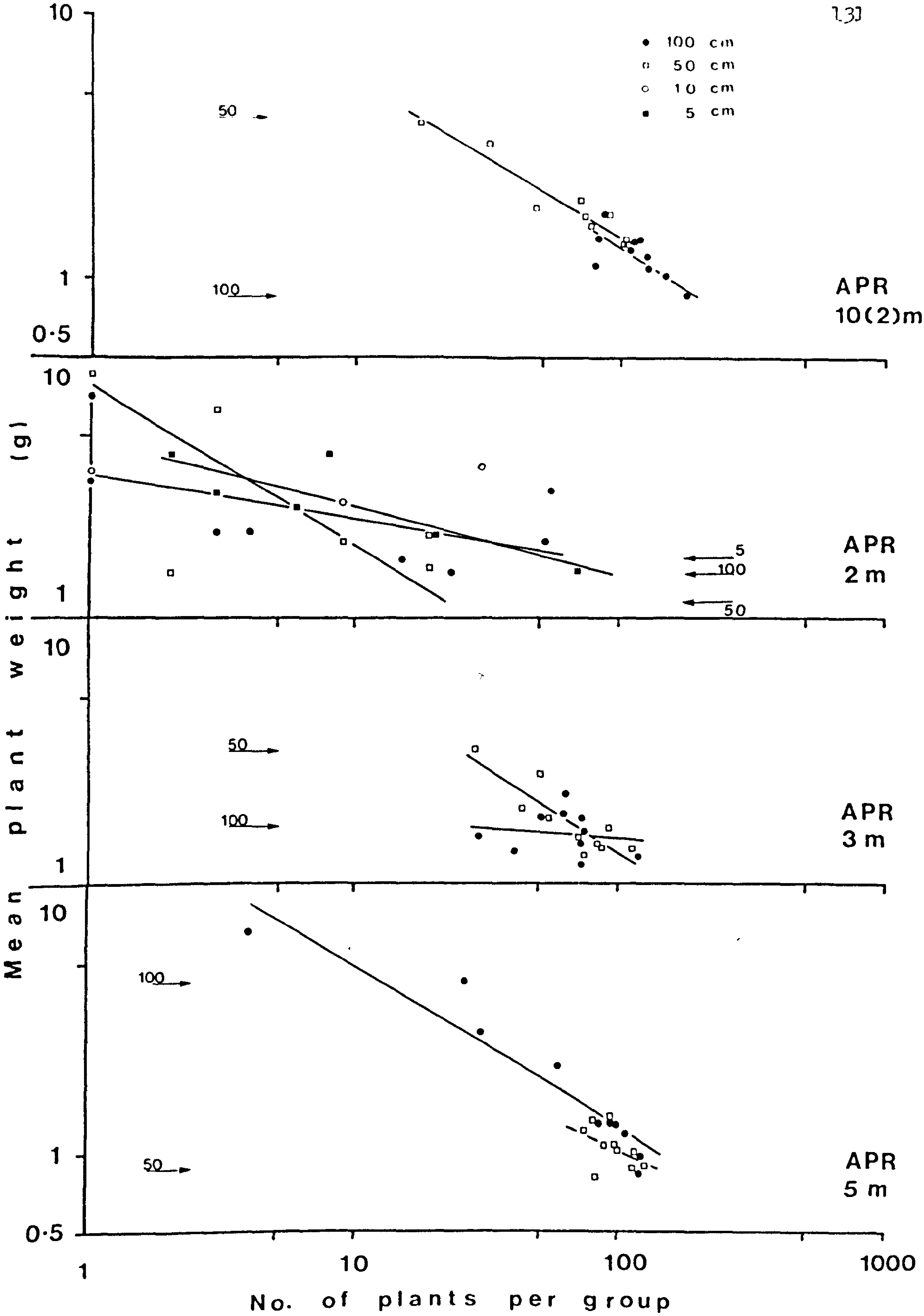


Fig. 40 - Mean dry weight per plant against no. of plants for groups of Alaria seeded at depths of 10 (2), 3 and 5 m at 50 and 100 cm spacings and at 2 m at 5, 10, 50 and 100 cm spacings in April, with fitted regression lines

Fig. 41 - Dry weight (top) and no. of plants (bottom) for groups of *Alaria* seeded at various spacings in November 1982. Stars represent mean values. N is indicated in parentheses above each seeding interval. Equivalent dry weight per metre of rope is also shown (top).

Mann Whitney tests to compare spacings:-

X - no significance difference at 5% level.

✓ - significant difference at level indicated.

weight:

5 cm	v	10 cm	✓ 5%
10 cm	v	25 cm	✓ 0.1%
25 cm	v	50 cm	X
50 cm	v	100 cm	X

nos:

5 cm	v	10 cm	X
5+10 cm	v	25+50+100 cm	✓ 1%
10 cm	v	25+50+100 cm	X

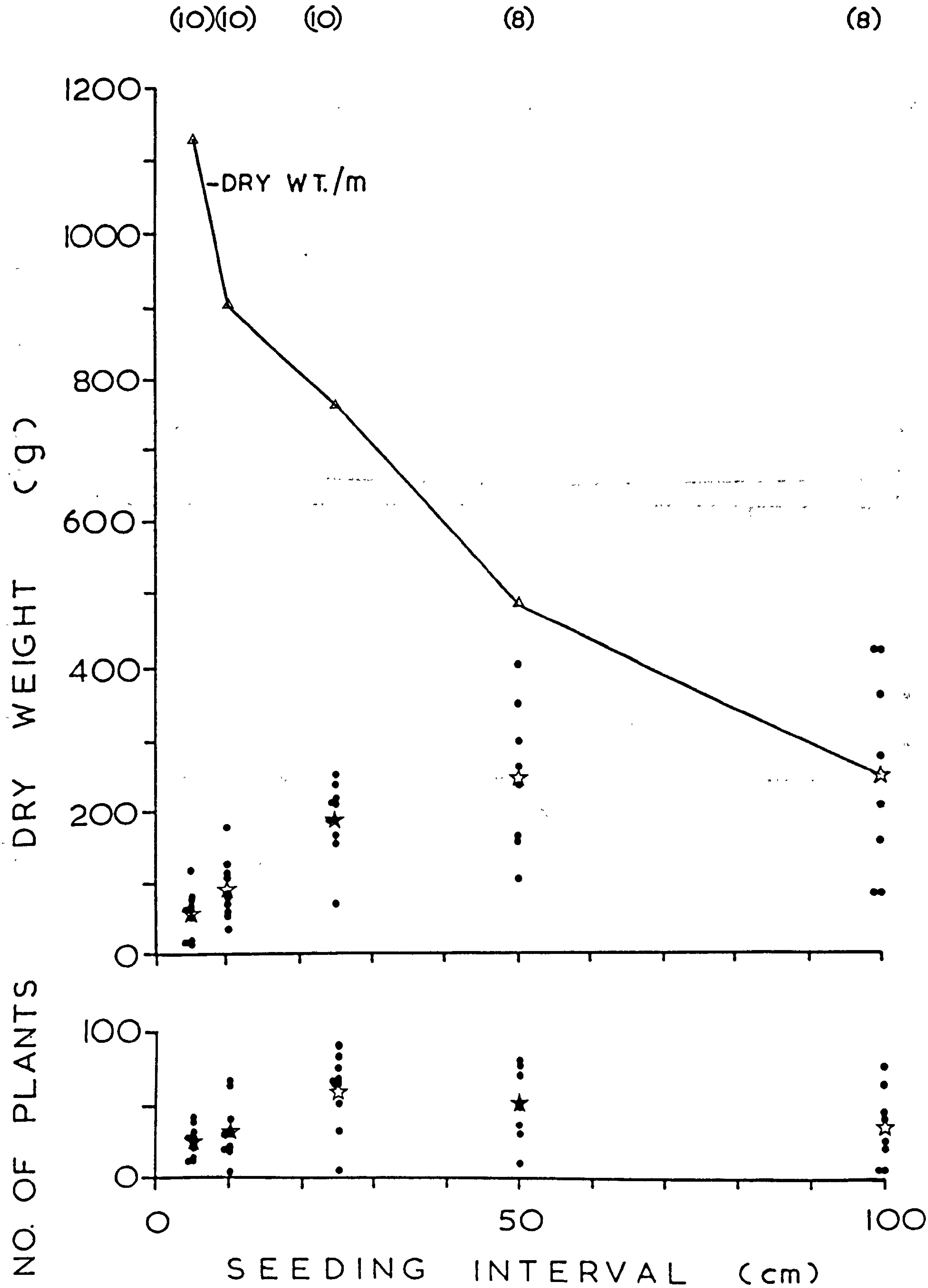

(10)(10)
(10)
(8)
(8)
1200
1000
800
600
400
200
0
-DRY WT./m
DRY WEIGHT (g)
100
0
NO. OF PLANTS
0
50
100
SEEDING INTERVAL (cm)

Fig. 41

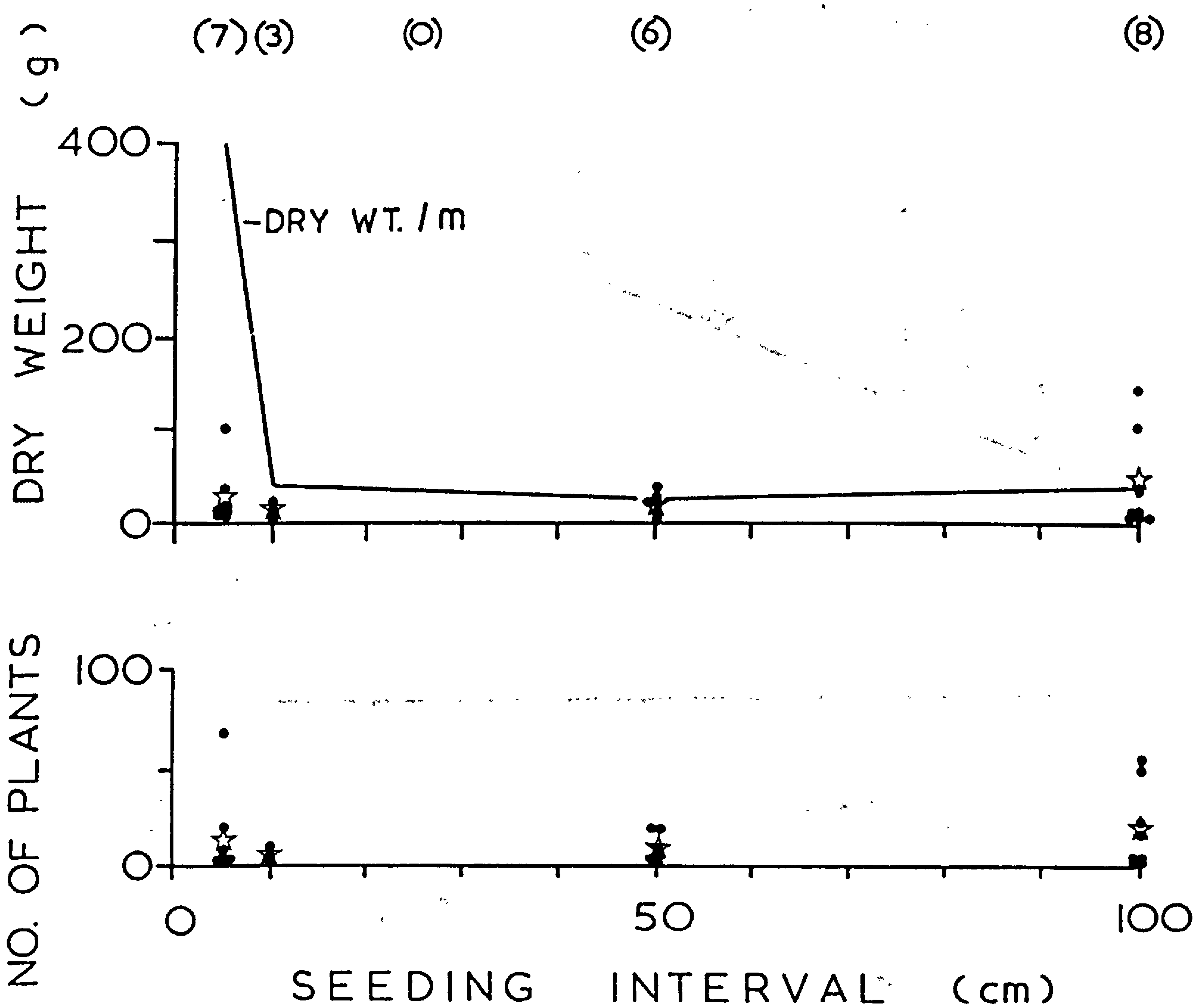


Fig. 42 - Dry weight (top) and no. of plants (bottom) for groups of <u>Alaria</u> seeded at various spacings in April 1983. Stars represent mean values. N is given in parentheses above each seeding interval. Equivalent dry weight per metre of rope is also shown (top).

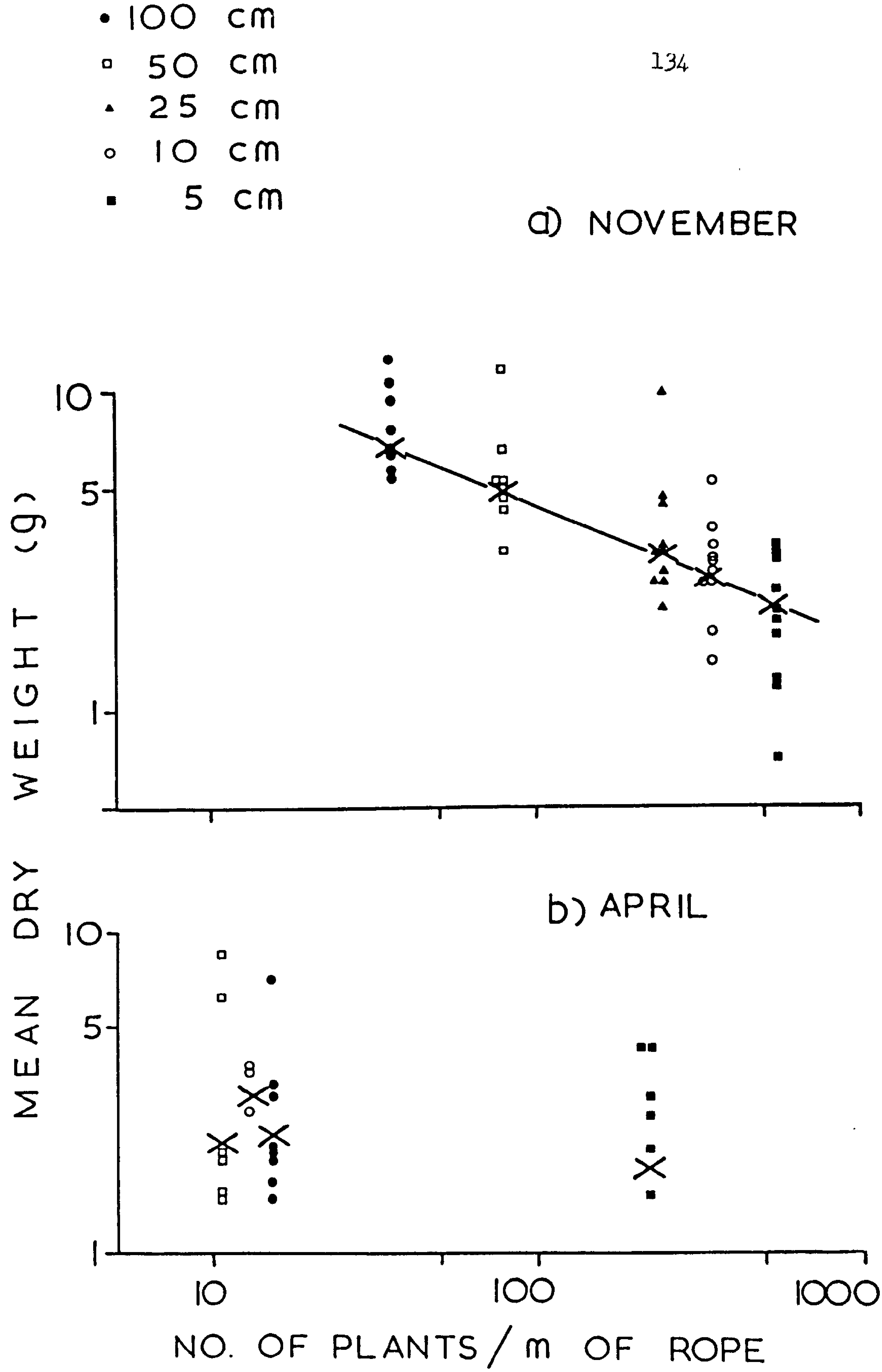


Fig. 43 - Mean dry weight per plant against mean no. of plants per metre of rope for groups of Alaria seeded at 5, 10, 25, 50 or 100cm intervals in November (top) and April (bottom). X = mean value for all the plants at each spacing. A regression line has been fitted to the 5 mean values in the November seeded plants.

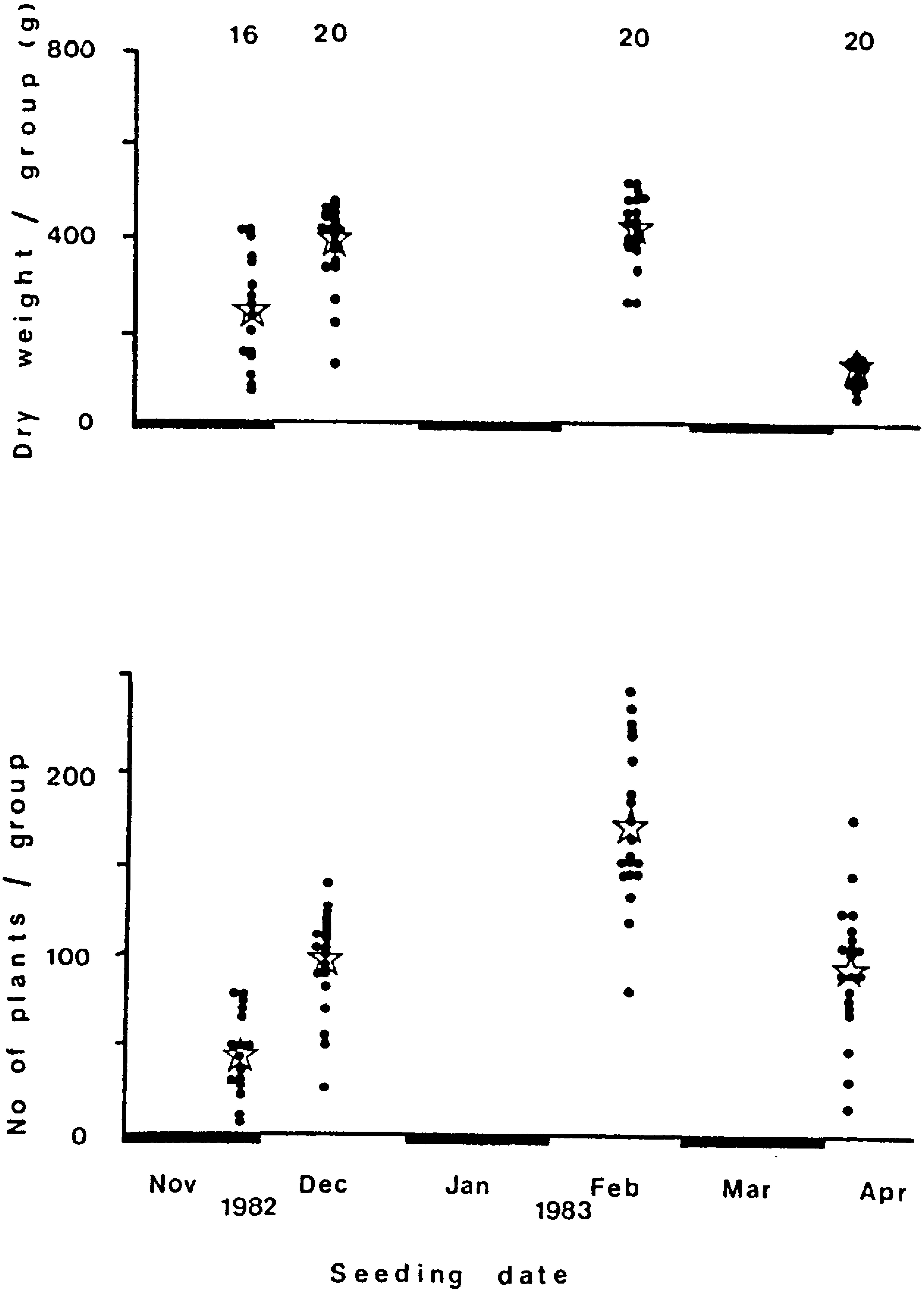
Fig. 44 - Dry weight (top) and no. of plants (bottom) for Alaria groups seeded in November, December, February (2 m depth) and April (10 (2) m depth) at 50 and 100 cm spacings. Stars indicate mean values. N is given above each point.

Mann Whitney test to compare months:

X - no difference at 5% level of significance.

✓ - difference at significance level indicated:

	Wts	Nos
Nov v Dec	✓ 1%	✓ 0.1%
Nov v Feb	✓ 0.1%	✓ 0.1%
Nov v Apr	✓ 0.1%	✓ 0.1%
Dec v Feb	X	✓ 0.1%
Dec v Apr	✓ 0.1%	X
Feb v Apr	✓ 0.1%	✓ 0.1%



Dry weight / group (g)
800
400
0
16
20
20
20
No of plants / group
200
100
0
Nov
1982
Dec
Jan
Feb
1983
Mar
Apr
Seeding date

Fig. 44

Fig. 45 - Mean plant weight against no. of plants for Alaria groups seeded in Nov, Dec, and Feb (2m deep) and April (10 (2) m deep) at 50 and 100 cm spacings, with fitted regression lines.

Comparison of regression coefficients (slopes) and elevations:

X - no difference at 5% significance level.

✓ - difference at significance level indicated:

	regression coefficients	elevations
Nov v Dec	X	X
Nov v Feb	X	✓ 0.1%
Nov v Apr	✓ 2%	✓ 0.1%
Dec v Feb	X	✓ 0.1%
Dec v Apr	✓ 0.5%	✓ 0.1%
Feb v Apr	✓ 5%	✓ 0.1%

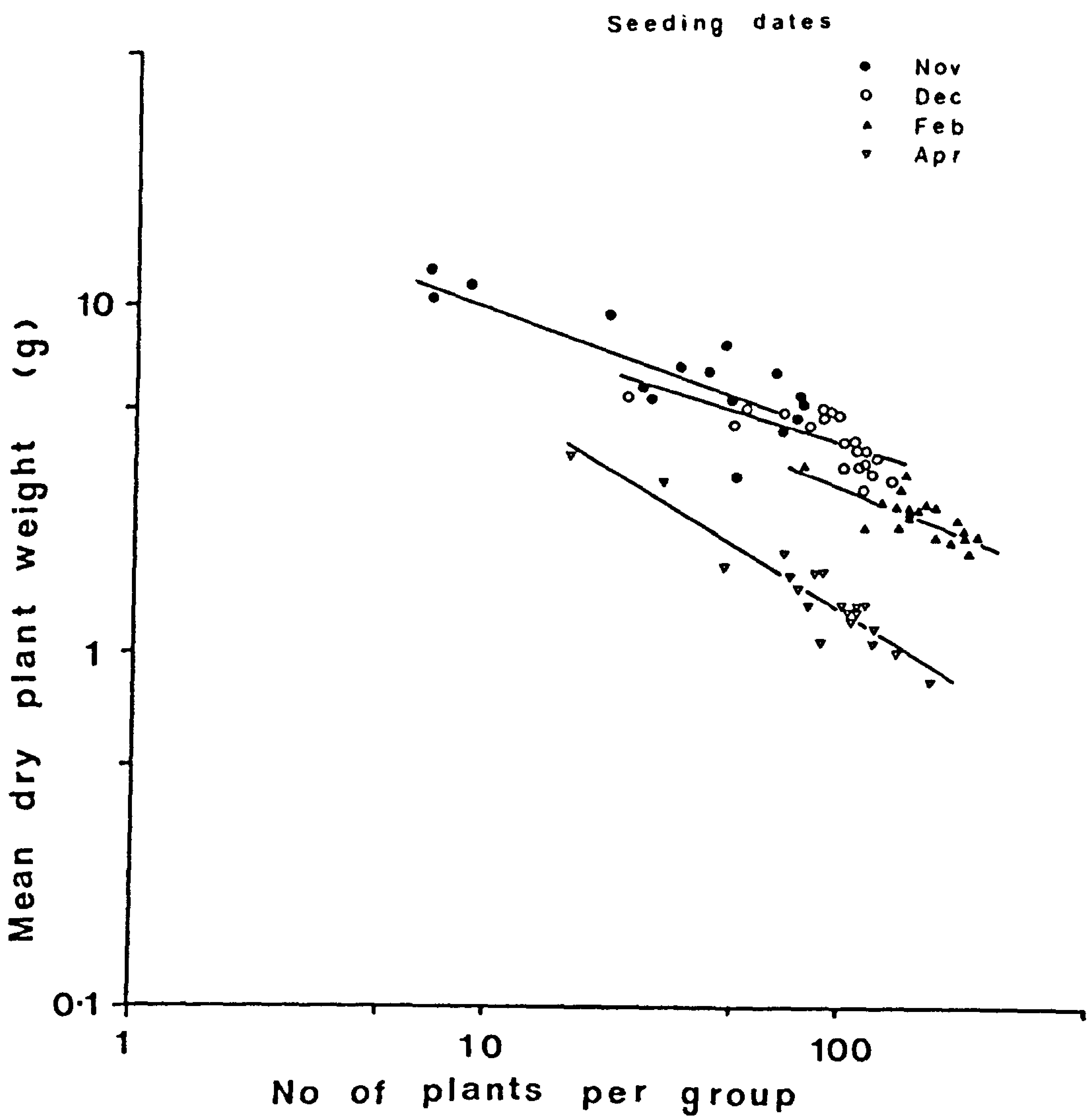

Seeding dates
Nov
Dec
Feb
Apr
Mean dry plant weight (g)
10
1
0·1
1
10
100
No of plants per group

Fig. 45

Fig. 46 - Dry weight (top) and no. of plants (bottom) in <u>Alaria</u> groups seeded at depths of 2, 3, 5 and 10 (2) m in April at 50 and 100 cm spacings. Stars indicate mean values. N is indicated in parentheses.

Mann Whitney tests to compare depths:

X - no difference at 5% significance level.

✓ - difference at significance level indicated.

	Wts	Nos
2 v 3m	✓ 0.1%	✓ 0.1%
2 v 5m	✓ 0.1%	✓ 0.1%
2 v 10 (2) m	✓ 0.1%	✓ 0.1%
3 v 5m	X	✓ 1%
3 v 10 (2) m	X	✓ 0.5%
5 v 10 (2) m	✓ 2%	X

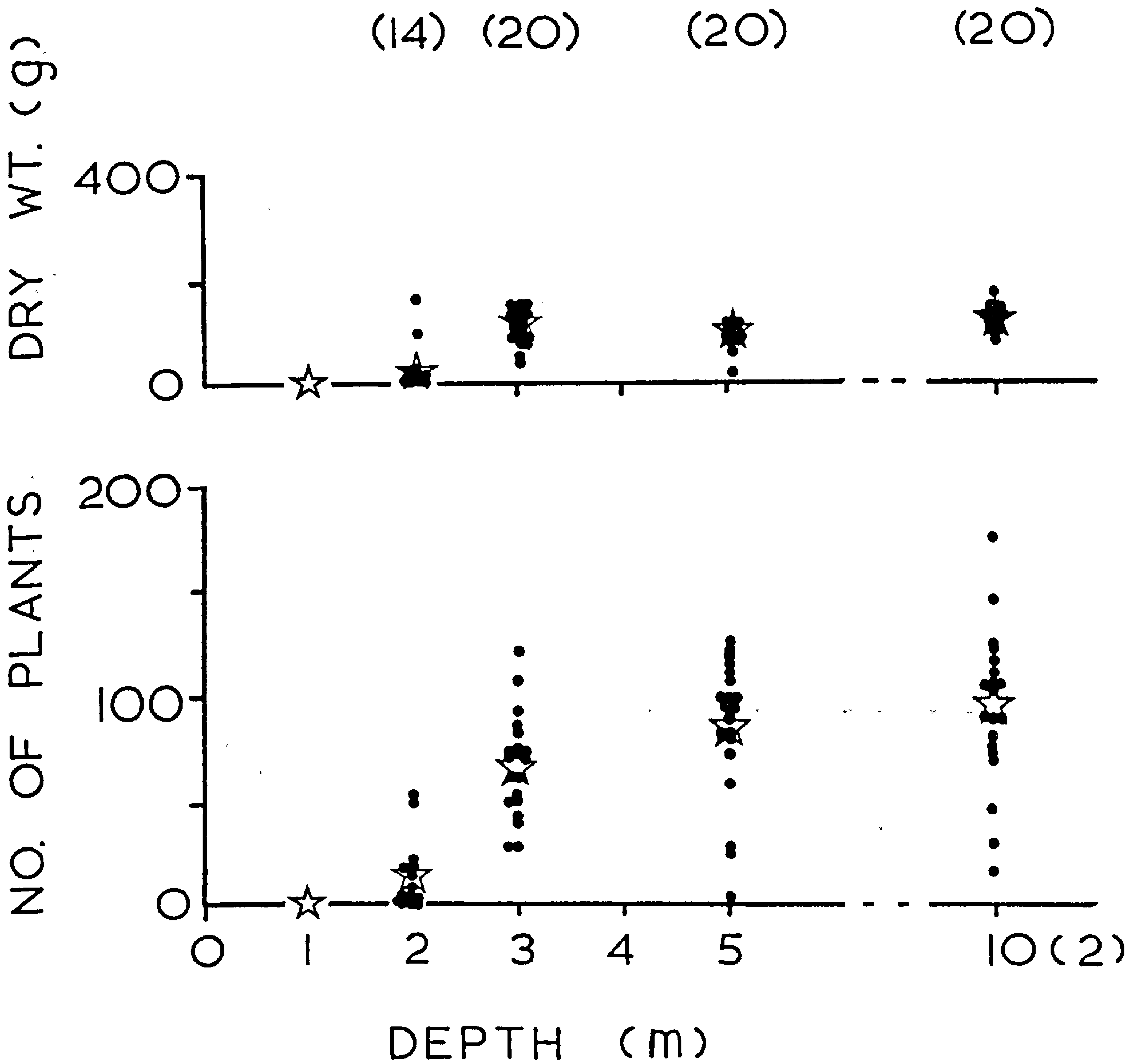

(14) (20) (20) (20)
DRY WT. (g)
400
0
NO. OF PLANTS
200
100
0
0 1 2 3 4 5 10(2)
DEPTH (m)

Fig. 46

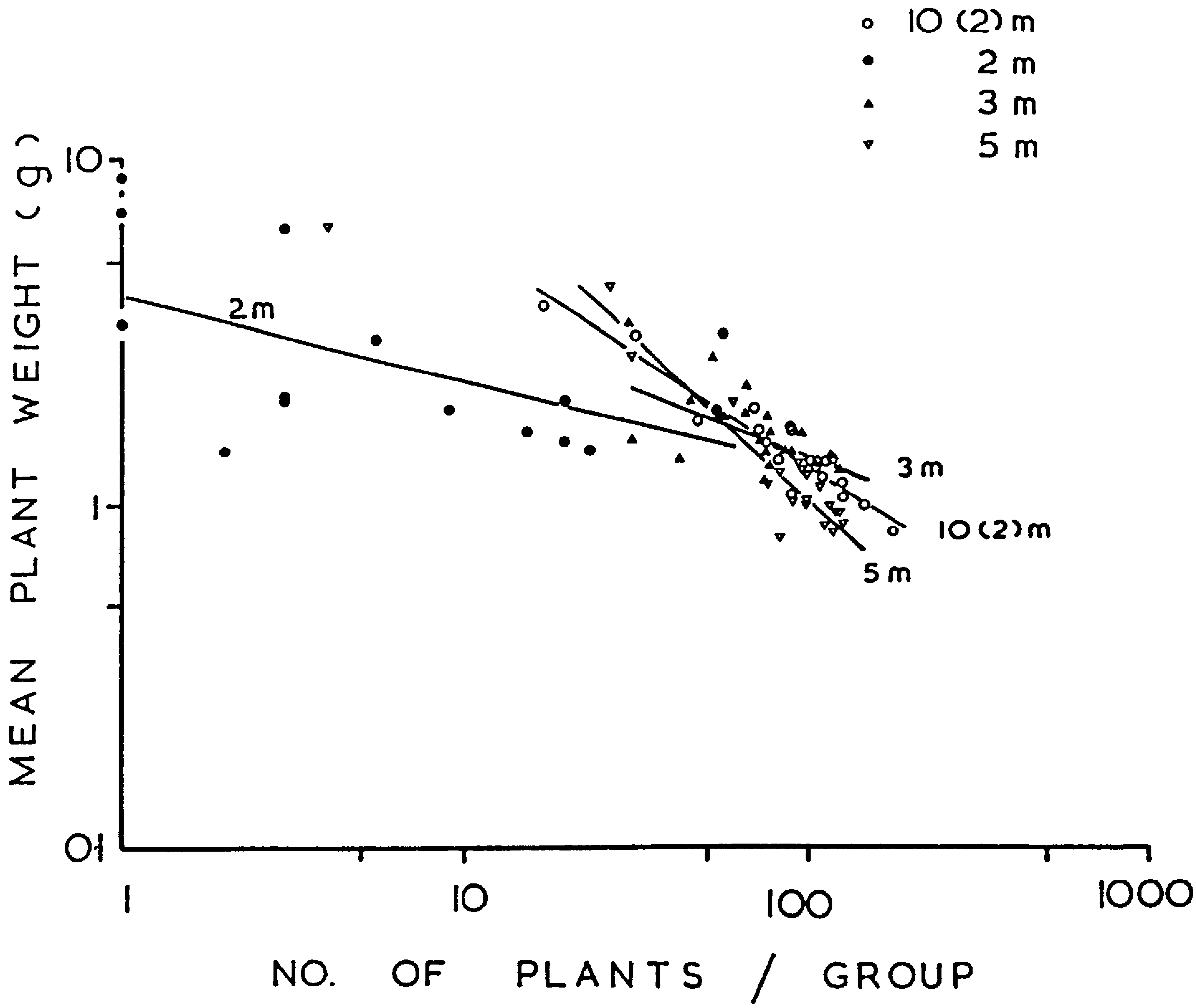


Fig. 47 - Mean dry weight per plant against number of plants per group for Alaria seeded at depths of 2, 3, 5 and 10 (2) m in April at 50 and 100 cm spacings, with fitted regression lines. The extreme left point from the 5m plants was omitted from the regression calculations.

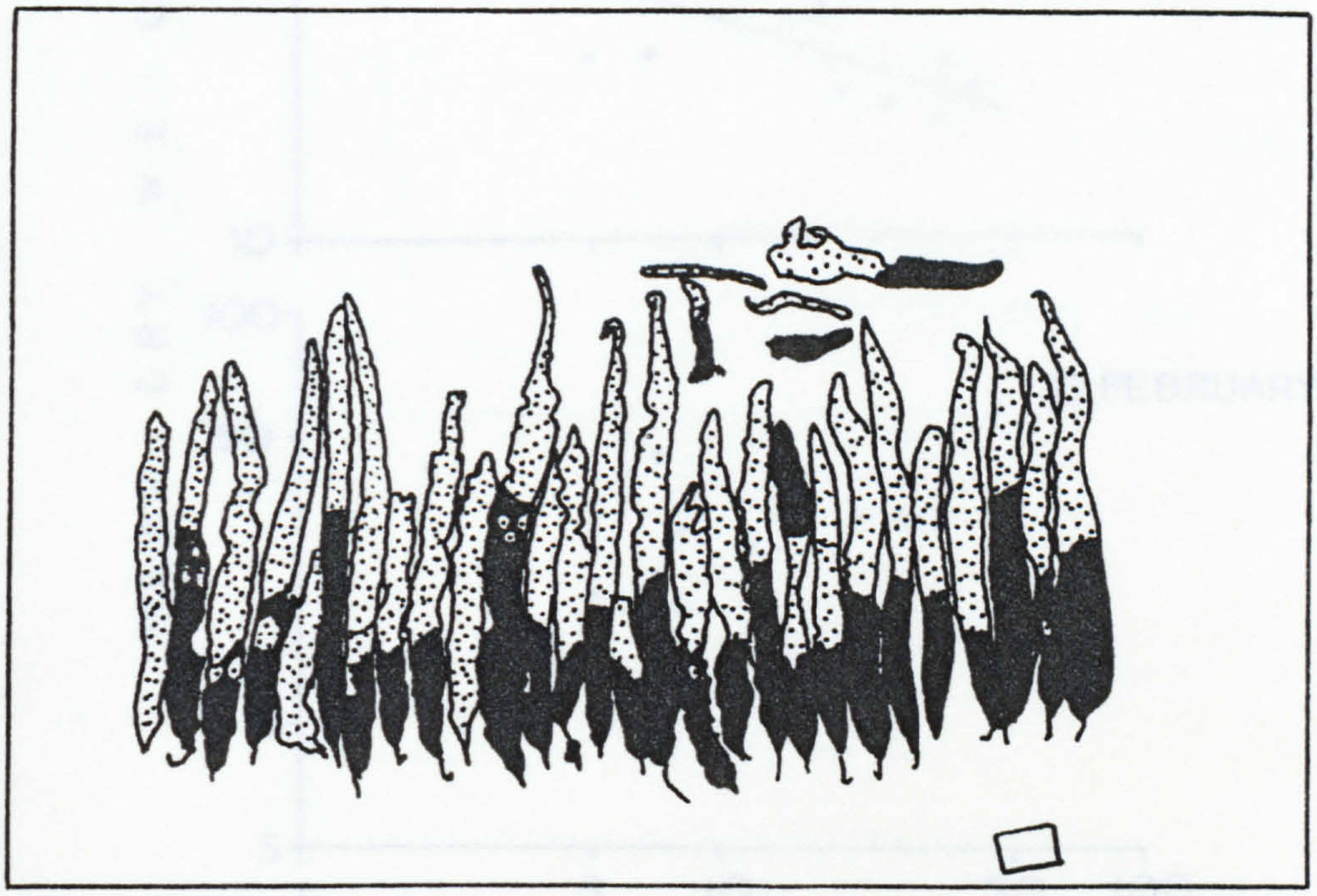


Fig. 48 - A Laminaria saccharina group seeded at 1m intervals from neighbouring groups at 2m depth in February, 1983, and harvested on September 7 1983. It contained 33 plants and weighed 1020g (dry weight). The plants were heavily colonised by the bryozoan Membranipora membranacea, shown more clearly in the diagram (stippled areas).

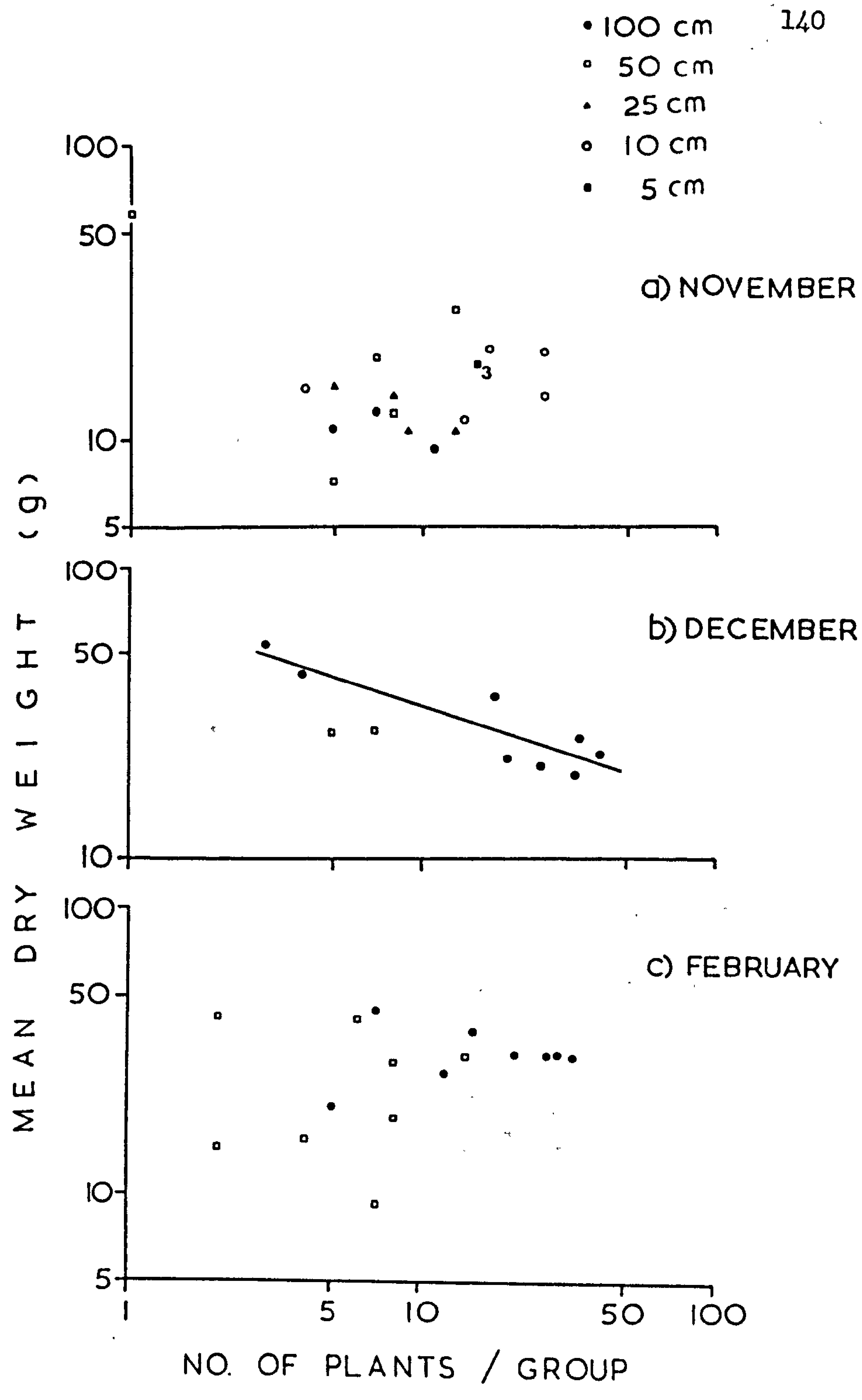


Fig. 49 - Mean dry weight per plant against number of plants for groups of Laminaria seeded in November at 5, 10, 25, 50 and 100 cm spacings and in December and February at 50 and 100 cm spacings.

■3 - mean of three 5 cm spaced groups which could not be separated.

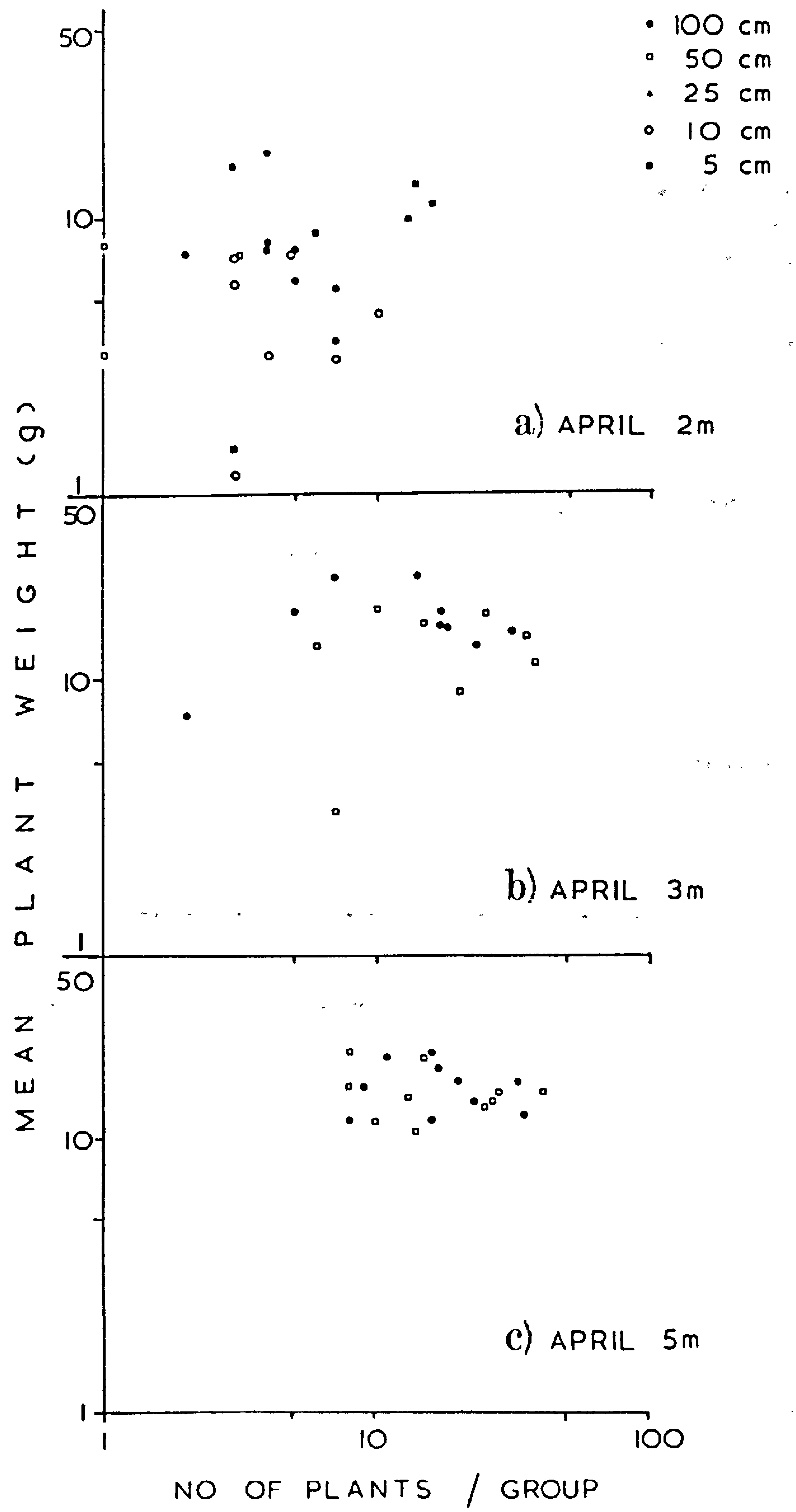


Fig. 50 - Mean dry weight per plant against number of plants for groups of Laminaria seeded in April at 2m at 5, 10, 25, 50 & 100 cm spacing (a) and 3m (b) and 5m (c) at 50 & 100 cm spacing.

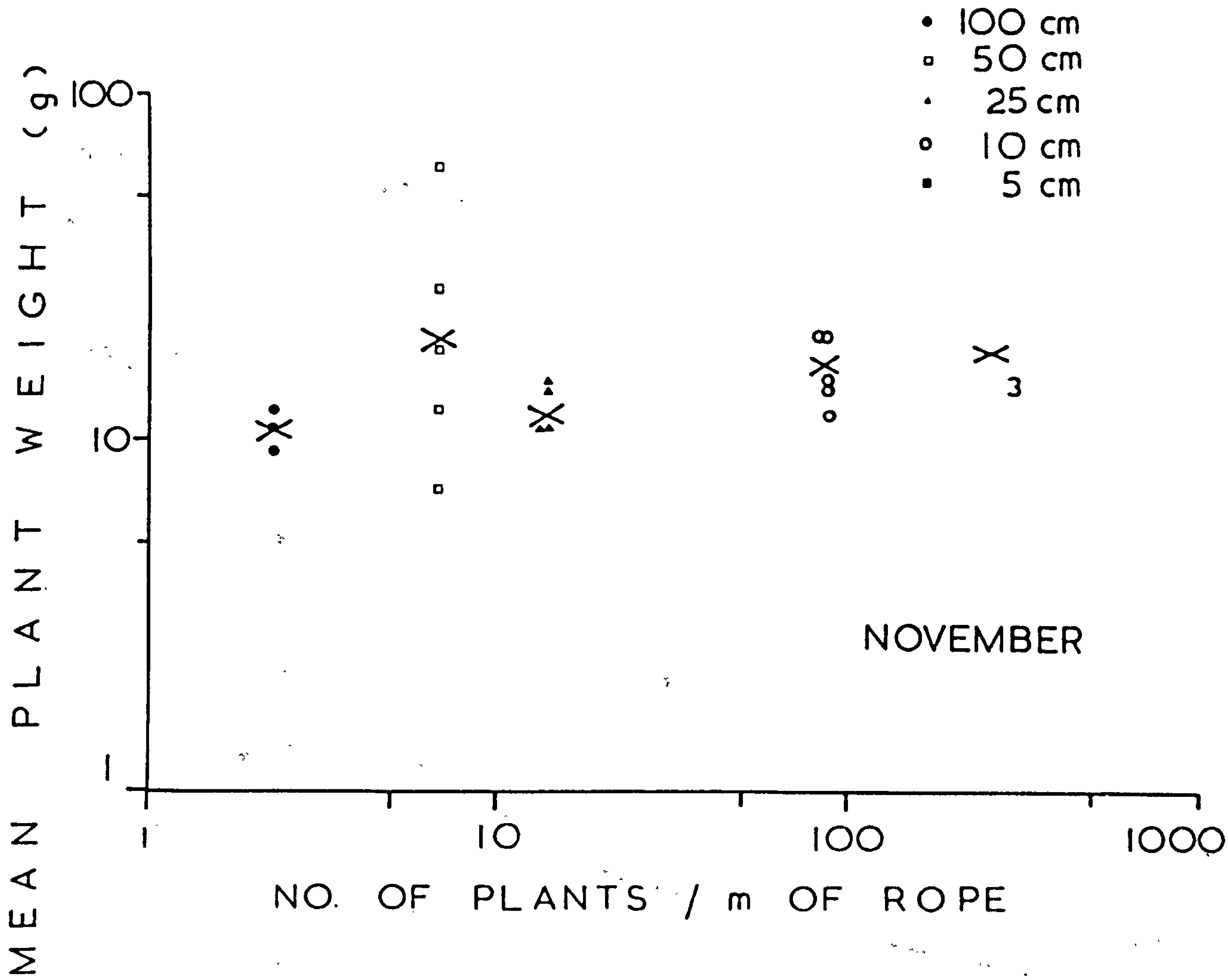


Fig. 51 - Mean dry weight per plant against mean number of plants per metre of rope for groups of Laminaria seeded at 5, 10, 25, 50 & 100 cm intervals in November

✕= mean value for all the plants at each spacing.

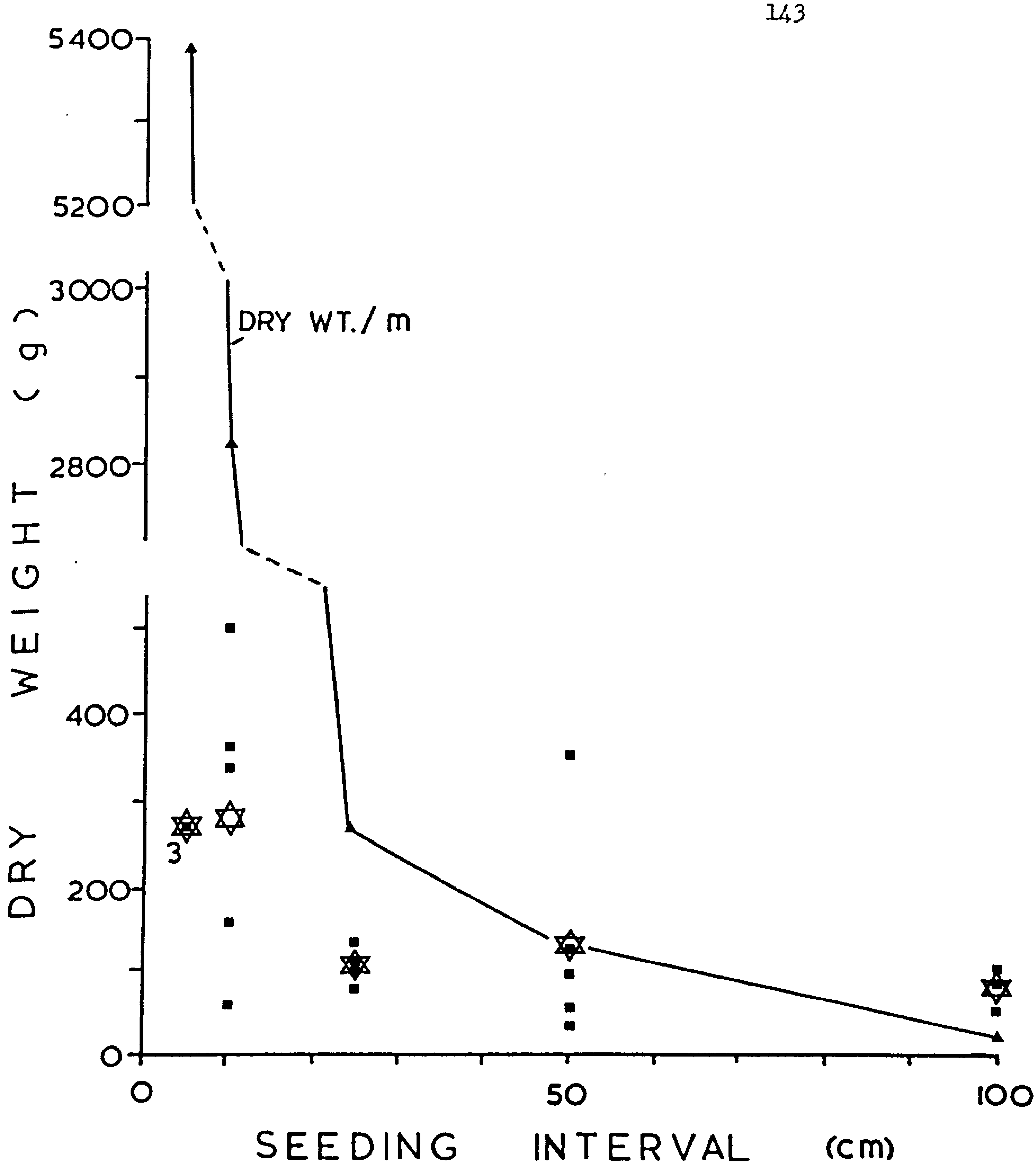


Fig. 52 - Dry weight against spacing interval for groups of Laminaria seeded in November. Stars represent mean values. Equivalent dry wt./m of rope is also given. At 50 & 100 cm spacing many groups were lost early in the season, and dry wt./m was calculated on the basis of those remaining at harvest. At other spacings missing groups were lost only days before harvest and dry wt./m was calculated on the basis of 10 groups at the original spacings.

✡ 3 = mean of 3 groups which could not be separated.

Fig. 53 - Dry weight (top) and number of plants (bottom) for groups of *Laminaria* seeded in November, December, February and April at 50 and 100 cm spacings at 2m depth. Stars represent mean values.

N is given in parentheses.

Mann - Whitney tests to compare months:

X - no difference at 5% level of significance

✓ - difference at significance level indicated:

	Wts	Nos
Nov v Dec	✓ 0.1%	X
Nov v Feb	✓ 5%	X
Nov v Apr	✓ 0.1%	✓ 5%
Dec v Feb	X	X
Dec v Apr	✓ 0.1%	✓ 1%
Feb v Apr	✓ 0.1%	✓ 0.5%

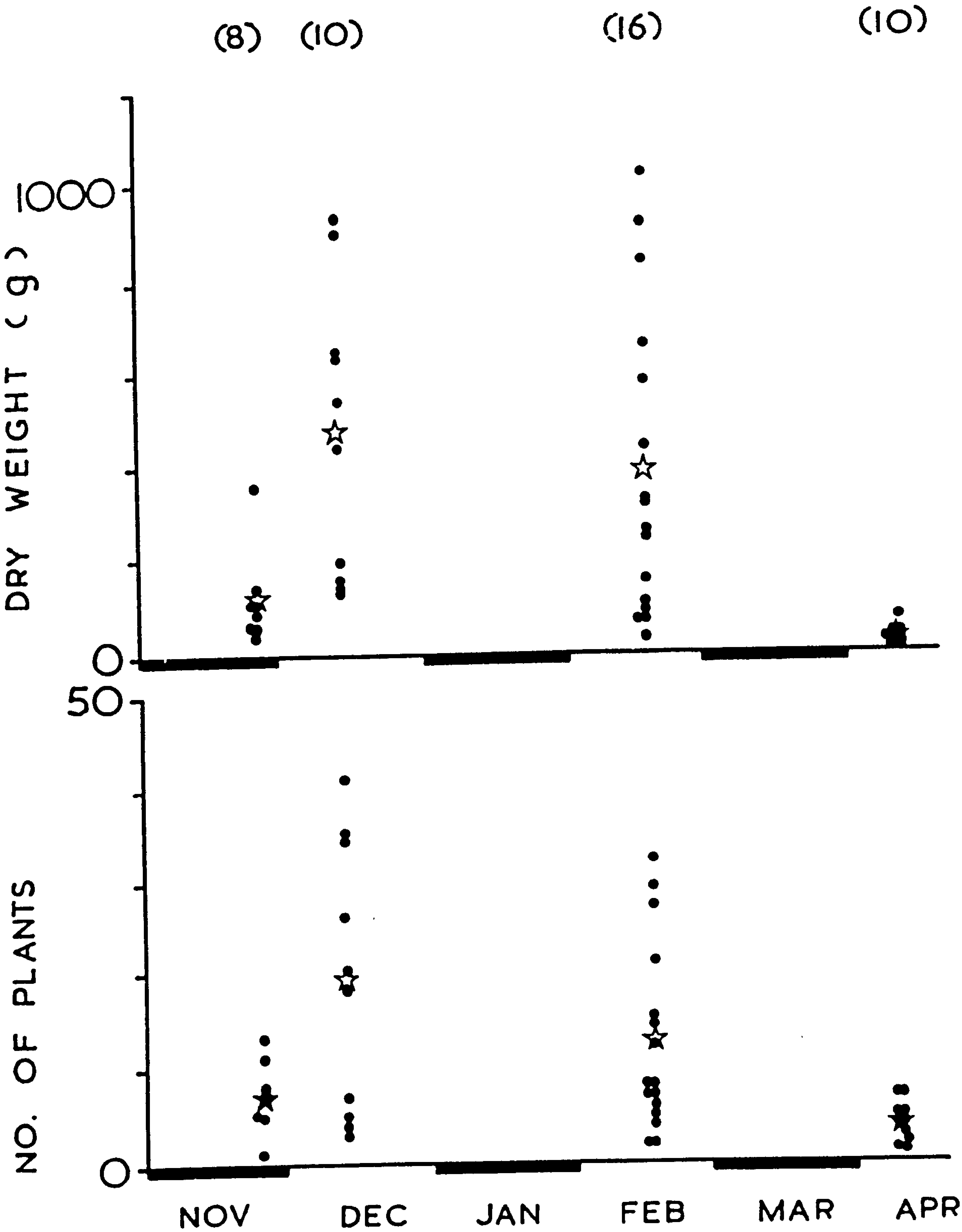

(8)
(10)
(16)
(10)
DRY WEIGHT (g)
1000
0
NO. OF PLANTS
50
0
NOV
DEC
JAN
FEB
MAR
APR

Fig. 53 -

Fig. 54 - Dry weight (top) and number of plants (bottom for groups of <u>Laminaria</u> seeded at various depths at 50 and 100 cm spacings in April. Stars represent mean values. N is given in parentheses.

Mann - Whitney tests to compare depths:

X - no difference at 5% level of significance

- difference at significance level indicated:

	Wts	Nos
2 v 3 m	0.1%	0.1%
2 v 5 m	0.1%	0.1%
3 v 5 m	X	X

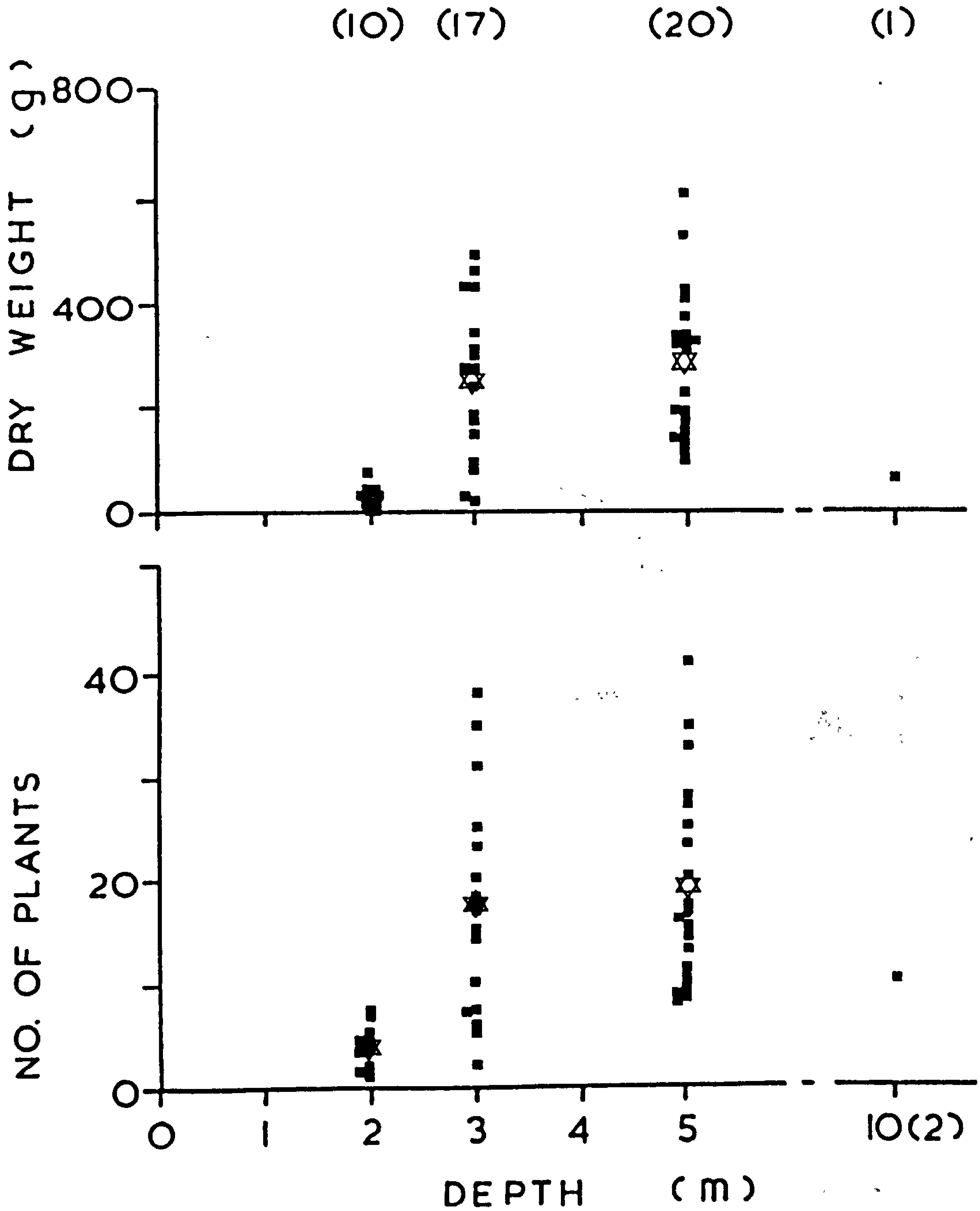

(10) (17) (20) (1)
DRY WEIGHT (g)
800
400
0
NO. OF PLANTS
40
20
0
0 1 2 3 4 5 10(2)
DEPTH (m)

Fig. 54 -

Fig. 55 - Saccorhiza polyschides groups seeded 1m apart at 3m depth on April 5 1983 being harvested on September 8, 1983. The group in the foreground weighed 630g dry weight, the other two about 200g.

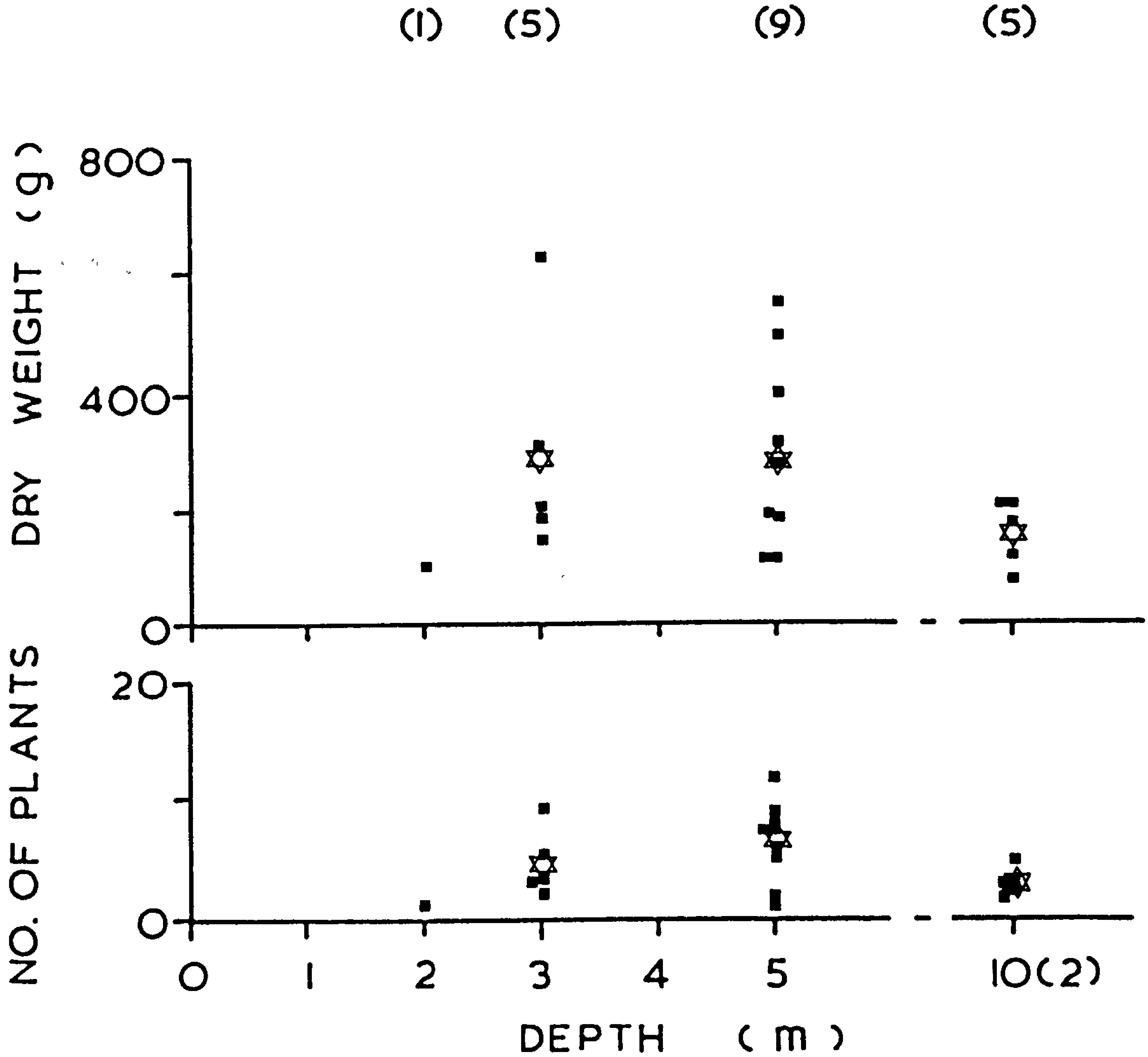


Fig. 56 - Dry weight (top) and number of plants (bottom) for groups of Saccorhiza seeded at various depths in April at 50 and 100 cm spacing. Stars represent mean values. N is given in parentheses. Mann- Whitney tests reveal no significant difference at 5% level between any pair of depths for both numbers and weight.

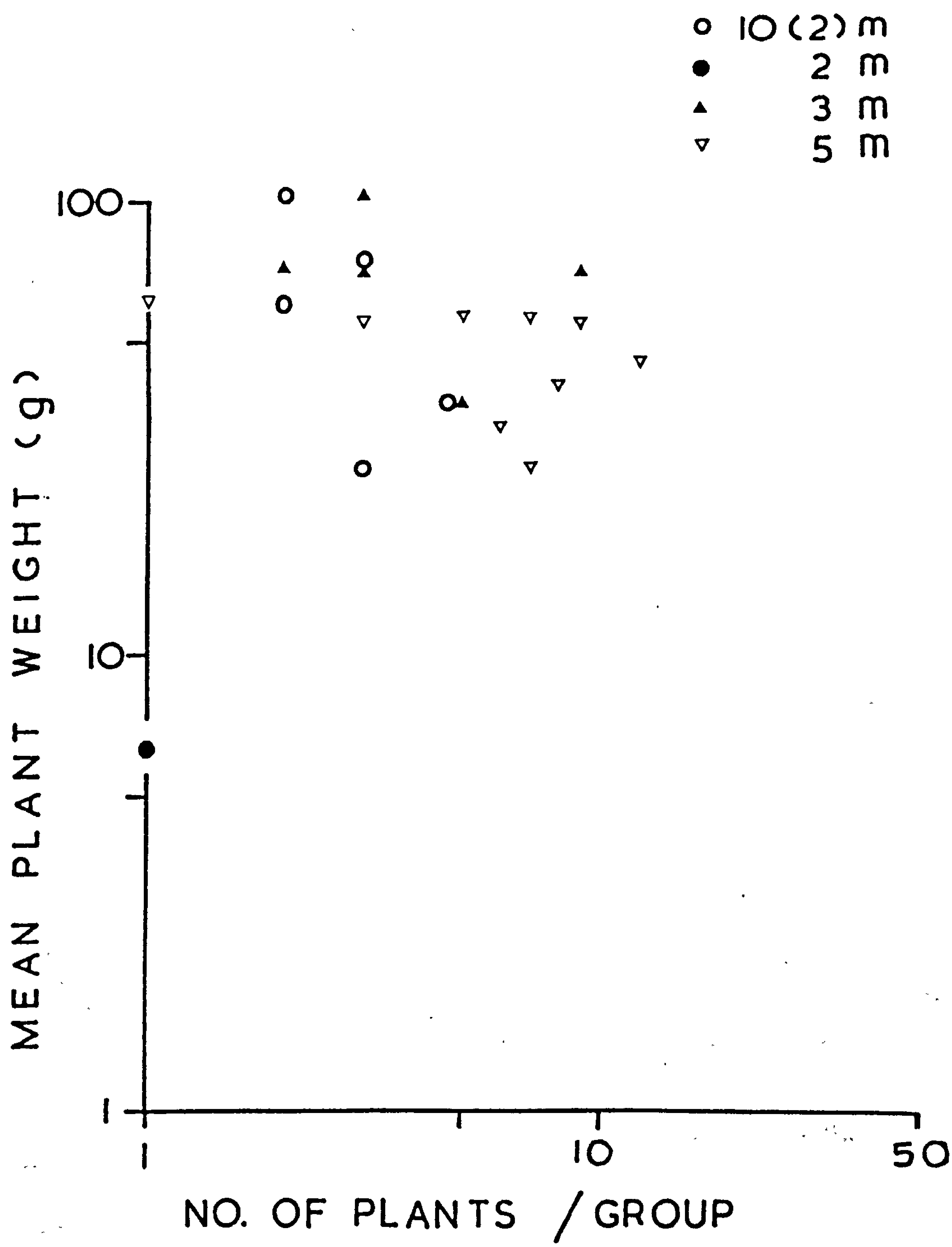


Fig. 57 – Mean dry weight per plant against number of plants for groups of Saccorhiza seeded in April at various depths at 50 and 100 cm spacings.

6. NATURAL COLONISATION

6.1 INTRODUCTION

In order for artificial seeding to be a worthwhile proposition it must be shown that it can greatly improve upon production by natural colonisation. Observations were therefore made upon production by naturally colonised plants on the structures. Since unseeded portions of horizontal rope were relatively scarce, many observations were made on the vertical ropes.

As well as the five or so dominant large brown algae, the ropes and algae themselves were often colonised by a wide variety of animals and plants. A list was made of the species found and a few observations made on some of them.

6.2 METHODS

Vertical ropes were removed from the water either when they were replaced because of damage or at the end of an experiment. The major colonisers were removed from each 1 metre section and the fresh weight of each species measured. The dry weight content of subsamples was calculated as described in section 3.3.1.3, and the dry weight of the colonising algae deduced from this.

The natural colonisation was analysed in detail on only one horizontal rope. This was done by removing the plants from four 2.5m sections of rope on each of several dates from June 1 to August 27 inclusive, so that variations in biomass with time could be observed . To reduce the effects of variations in colonisation along the length of the rope, the four sections cleared on each date were spread uniformly along the rope.

6.3 RESULTS

6.3.1 PRODUCTION BY MAJOR COLONISERS

Almost all ropes placed in the sea during November to March inclusive were quite heavily colonised by a number of large brown algae, while those placed in the sea during April were virtually bare. This can be explained by the fact that the majority of large brown algae spore mainly during autumn and winter. However, the horizontal rope seeded in February 1983 was not appreciably colonised, the reason for which is not known. Furthermore, a mooring rope placed in Port St. Mary outer harbour in mid April 1980 was very heavily colonised by *Saccorhiza*. Presumably either the sporing season was extended at Port St. Mary, which is a relatively sheltered area on the east coast of the island, or the rope was sufficiently close to a bed of *Saccorhiza* to be colonised by relatively small releases of spores.

Fig. 58 compares the colonisation on the mooring rope with that on six vertical ropes from Bay Fine in 1981 and 1981-82. The mooring rope, which is shown in Fig. 59, bore only one species, *Saccorhiza polyschides*. A biomass of 1.32 kg dry weight was found on the top metre of rope but production decreased rapidly with depth. According to the owner the same rope was heavily colonised by *Laminaria saccharina* with negligible amounts of other algae in 1979, but no record of production was made. In 1981 and 1982 it

Fig. 58 - Natural colonisation by large brown algae from a sheltered area (Port St. Mary Outer Harbour, 1980) and on 6 of the experimental ropes from Bay Fine in 1981 and 1982. The period for which each rope was in the water is given. "Extra" refers to debris which fell off the rope during transport or weighing.

The mooring rope can be seen in Fig. 59.

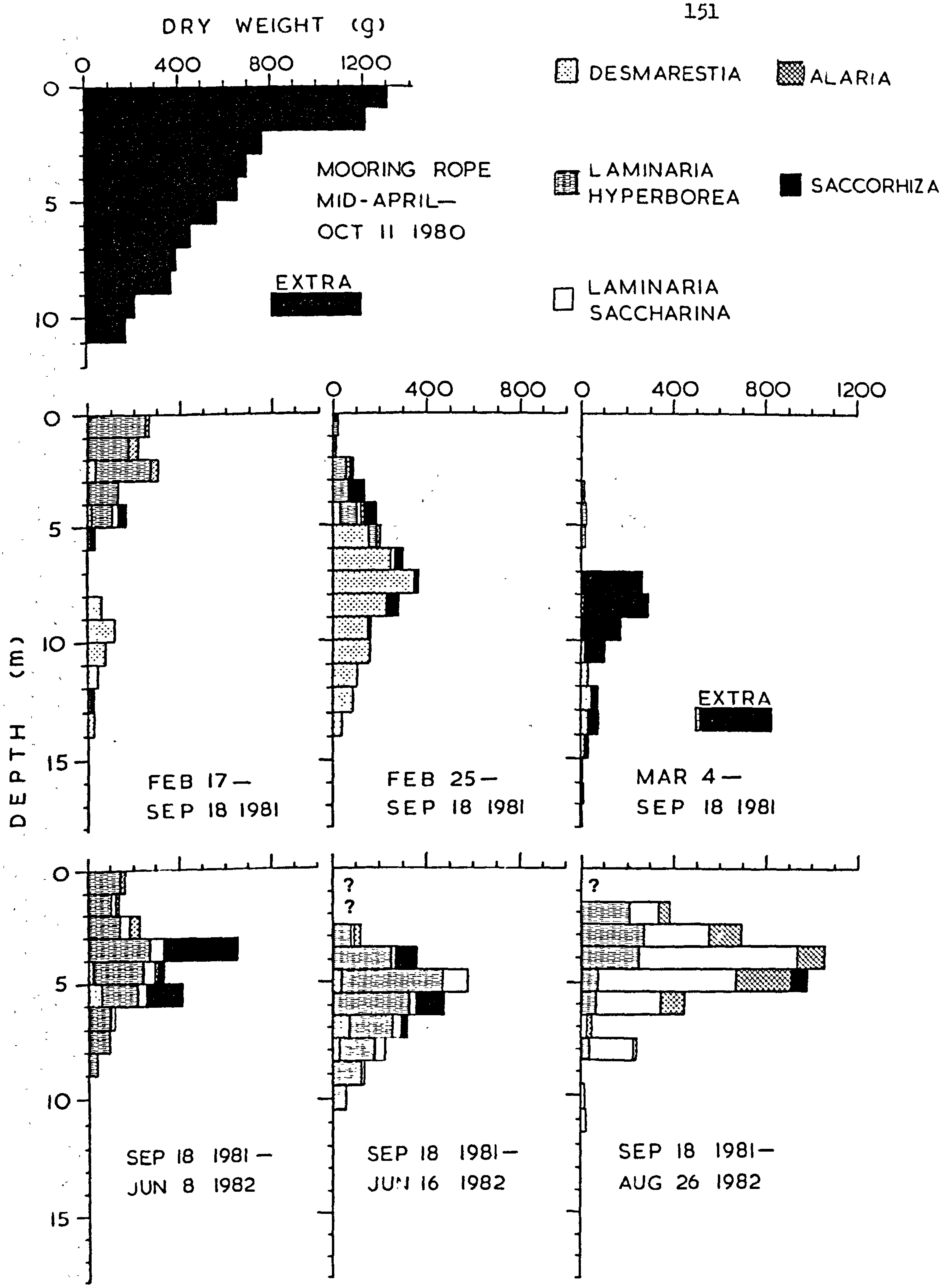

DRY WEIGHT (g)
0
400
800
1200
0
5
10
MOORING ROPE
MID-APRIL—
OCT 11 1980
EXTRA
DESMARESTIA
ALARIA
LAMINARIA HYPERBOREA
SACCORHIZA
LAMINARIA SACCHARINA
0
400
800
0
400
800
1200
0
5
10
15
DEPTH (m)
FEB 17—
SEP 18 1981
FEB 25—
SEP 18 1981
EXTRA
MAR 4—
SEP 18 1981
0
5
10
15
?
?
?
SEP 18 1981—
JUN 8 1982
SEP 18 1981—
JUN 16 1982
SEP 18 1981—
AUG 26 1982

Fig. 58 –

Fig. 59 - A mooring rope which was covered with <u>Saccorhiza polyschides</u> after having been in Port St. Mary Outer Harbour from mid-April until October 11, 1980.

bore no large brown algae at all, although there were large amounts of the red alga Ceramium in 1981. The colonisation on the vertical ropes in Bay Fine contrasted markedly with that on the mooring rope. Each rope bore several species, but there were large differences in the populations on different ropes even when they had been in the same area for very similar periods. The maximum biomass was never more than 0.96 kg dry weight/metre and occurred at a depth of 3-9m, with only one exception. L. hyperborea appeared to have a shallower depth distribution than Saccorhiza, L. saccharina or Desmerestia, and was the dominant large brown alga in terms of numbers. Over 250 small plants were often found on a single metre of rope.

Horizontal ropes set at a depth of 2m were frequently observed to be heavily colonised. Fig. 60 shows the production on 2.5m sections of a typical horizontal rope which was in the sea from November 1981. As with the other observed horizontal ropes, Saccorhiza was the dominant alga in terms of biomass. Production varied considerably from one part of the rope to another, but was generally higher than at 1-3m on the vertical ropes, with a maximum value of nearly 1.1 kg/m, and appeared to be higher in July than in early-mid June, despite the observation that growth in most of the large Saccorhiza plants had stopped by mid June. However, most of the Saccorhiza sampled in July had been heavily colonised by bryozoans, Enteromorpha, Ectocarpus and numerous other organisms, which were not removed during sampling. This, plus continued growth of small Saccorhiza plants and sampling error, may account for the increased biomass in July.

As on the vertical ropes, L. hyperborea was the most numerous

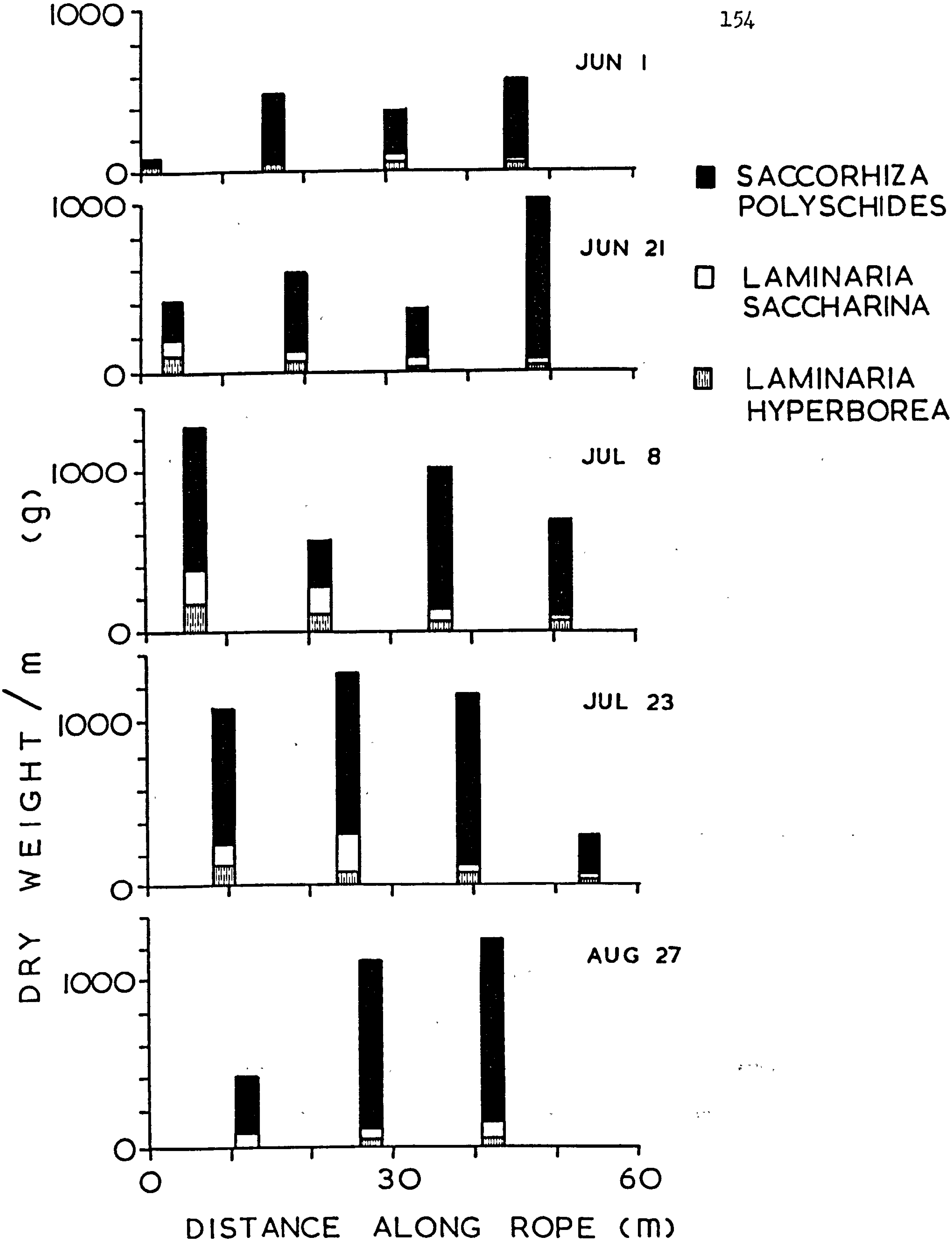


Fig. 60 – Natural colonisation on 2.5m sections of a horizontal rope which had been at 2m depth from Nov. 1981, sampled during 1982.

species, but the plants were usually very small.

The production at one end of the rope was low. That at the other end was not measured, but it was observed that production was usually very low at the ends of other horizontal ropes. It seems likely that the horizontal ropes rubbed against the vertical ropes during storms. This would dislodge young plants from both ropes and would at least partially explain the low production near the top of the vertical ropes. It is also possible that the movement of vertical ropes during wave action is more damaging to young plants than that of horizontal ropes. Vertical ropes suspended beneath buoys are often observed to 'snatch' quite violently even in a slight swell. This would explain why Saccorhiza, the most poorly attached species, was so dominant on horizontal ropes yet not on vertical ones except in sheltered conditions.

Variations in the relative amounts of different species on different ropes, or on different parts of the same rope, which were particularly noticeable on the verticals, may have been due to differences in the number of spores in different parts of the tidal stream. Amsler and Searles (1980) found large differences in the amounts of spores of various types of algae at different depths in a 20m water column, although they only distinguished between Chlorophyta, Phaeophyta, Bangiophycidae and Floridiophycidae.

6.3.2 MINOR COLONISERS

A full list of the animals and plants found on the ropes or associated algae, including the major algal colonisers mentioned previously, is given in Appendix 8.

Nomenclature followed that of Parke and Dixon (1976) for algae, Ryland (1969) for Bryozoa, and the Marine Biological Association (1957) for other animal phyla.

Many other species, though "minor" in terms of biomass, were extremely widely distributed on the ropes, or were present in very large numbers, and may have had a considerable influence on the cultivated plants. The possible effects of dense growths of diatoms in the spring have been mentioned. Bryozoans, particularly *Membranipora membranacea*, were very commonly found on both cultivated and naturally colonised algae, and are discussed in section 7. Amphipods, especially *Jassa falcata*, were extremely numerous in late summer, and tubes built from debris by *Jassa* were often found, particularly on the ends of large *Laminaria* plants and on *Desmarestia* during the summer. A single plant of *Desmarestia*, weighing 30g fresh weight, contained over 1200 amphipods of greater than 2mm in length. The majority of amphipods were easily removed from the cultivated algae prior to weighing. There were no obvious signs of grazing damage by amphipods or by other grazers such as *Gibbula*. Blue rayed limpets, *Patina pellucida*, commonly found on kelp in natural beds, were noticeably absent, the reason for which is not known.

The only fish noticed on the algae were tiny lumpsuckers, *Cyclopterus lumpus*, large numbers of which were observed on all *Laminaria saccharina* and *Alaria* from about May onwards. They reached about 4 cm in length by late summer.

A large number of small red algae colonised both the ropes and the older parts of the fronds of cultivated algae. However, one of the noticeable algal colonisers was a green, *Enteromorpha* intestinalis, which grew during the summer on relatively bare April seeded ropes. In 1982 the species grew exceptionally well, and lengths of over 2m were commonly observed. It is interesting to note that, in a study carried out at a wide range of depths at fourteen sites around the south end of the Isle of Man, Kain (1960) found no subtidal E. intestinalis. Other species found on the ropes but not recorded subtidally by Kain are E. compressa, * Desmarestia viridis, Gelidium latifolium, Cladophora spp. and young fucoids. This indicates that, as suspected, conditions on ropes suspended just below the surface of the sea are greatly different to those on the sea bottom below extreme low water of spring tides. Higher mean light intensities, increased exposure to wave action and currents and, perhaps initially, lack of competition for space are the ecological factors most likely to be responsible for these differences.

The number of algal species recorded was only 24 plus, much lower than the 88 plus recorded locally by Kain (1960), and the number of animals was very much lower than observed by Norton et al (1977) in the Laminaria forest at Lough Ine, Eire. Many species were doubtless overlooked, but nevertheless fewer species would be expected in view of the short time and small surface area usually available for colonisation, the ease with which some species were removed from the rope by wave action, and the fact that the ropes were always the same distance below the sea surface, which may have limited the number of larvae, spores etc. able to settle on the ropes.

* Desmarestia viridis was probably present, but misidentified (Kain pers. comm.).

7. WATER CONTENT, ORGANIC CONTENT AND STORAGE

7.1 INTRODUCTION

It was expected that the water content of the algae would vary both seasonally and between species as shown by Black (1948) and Haug and Jensen (1954). The effects of such variation upon apparent production were negated by measuring production in terms of dry weight. However, water content could have an important influence on the cost of transport per unit of organic material. Some analyses of the water content of the harvested algae were therefore carried out.

The organic content of the dry material was also expected to vary seasonally (Black 1948, Haug and Jensen 1954). Since this would be of importance not only in terms of transport costs but also in terms of the potential of the weed as an energy source, analysis of the total organic content of the weed was also carried out.

The large amounts of colonisation of the weed by both plants and animals have been mentioned previously (chapter 6). The larger algae, molluscs, amphipods, lumpsuckers etc. were easily removed prior to weighing, but some of the encrusting or well attached species including bryozoans and some hydroids were not removed. By far the most important of these was the bryozoan *Membranipora membranacea*, which was common on all three species, but was most noticeable on the *Laminaria*, the largest *Saccorhiza* plants, and those *Alaria* which were left unharvested for too long in 1982. Large amounts of the bryozoan *Electra pilosa* were also seen on the latter. In order to gauge the possible effects of Membranipora on the dry weight content and the organic content of the harvested weed, estimates of the amount of colonisation on Saccorhiza and Laminaria were made. Estimates of weight per unit area were relatively easy with Saccorhiza. This was not possible with Laminaria, but the proportion of the surface of Laminaria infested with Membranipora was estimated. The method used had to be extremely fast and simple to perform, because when the groups of plants were harvested they all had to be weighed and counted within a few hours, after which they began to decay, and there were no facilities for drying large numbers of individual plants for later analysis. The method chosen was very approximate, but involved only a few simple measurements on each plant.

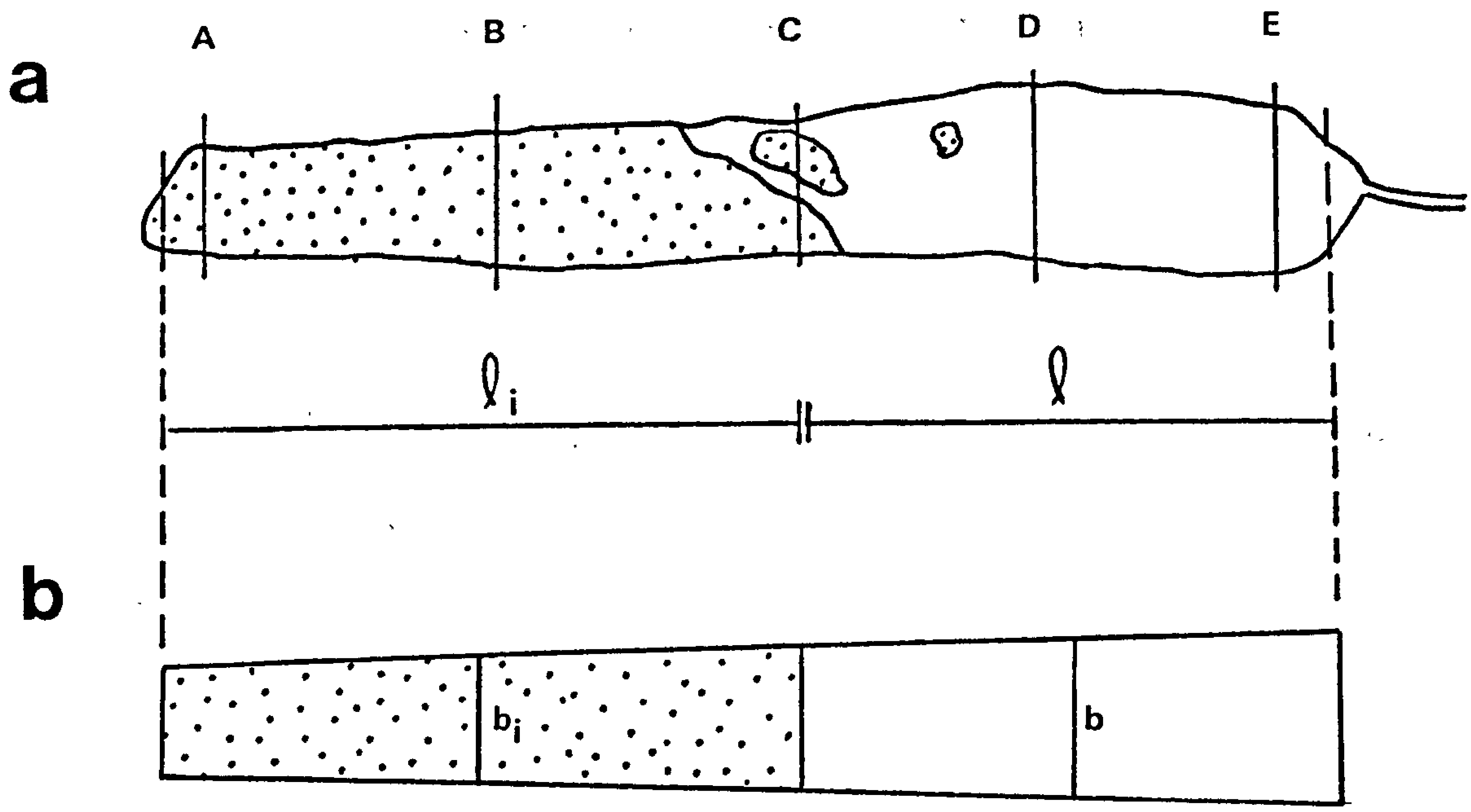
Previous reports on the dry weight and organic content of Membranipora have suggested widely varying values. Loppens (1920) reported that the dry weight was about 10% of the fresh weight, and the ash content about 44% of the dry content. Wing and Clendenning (1971) gave figures of about 14% for the dry weight content and 40.7 - 42.8% for the ash content. Hyman (1959) reported that the calcium carbonate content varied up to a maximum value of 70% of the dry weight. Schopf and Mannheim (1967) reported that the organic content constituted only 10.5% by weight of the polypide of Membranipora membranacea (quoted in Saudrey and Boffandeau, 1958). Measurements of the fresh weight and dry weight of Membranipora on the harvested algae in the present work were therefore carried out.

The seasonal nature of growth in the algae concerned necessitates some means of storage so that a methanation plant (or any other form of energy conversion) could be in use throughout the year. One possible method would be to dry the weed. Since high temperature drying is likely to be prohibitively expensive, some preliminary experiments were carried out in still air at 27-30°C, with relative humidities of 50 and 75%. Such conditions might be met by waste heat from power stations (Morley, pers. comm.). Experiments were carried out on both individual plants and groups. Morley (1983) carried out further experiments involving moving air.

It may be advantageous to store wet weed. A preliminary experiment was therefore carried out to see if ensilage under anaerobic conditions would be feasible. This method has been successfully used to store green algae over a period of several months (Croatto, pers. comm.). There was an initial fermentation by naturally occurring bacteria which released fatty acids. These inhibited any further bacterial activity. Methanation could be encouraged by neutralising the fatty acids with a mild alkali.

7.2 METHODS

To estimate the amount of bryozoan infestation on Laminaria, advantage was taken of the fact that colonisation tended to be 100% over the older tissue, but came to a more or less distinct stop at some point, as can be seen in Fig. 48. An imaginary straight line was drawn down the middle of the semi-colonised region (line c in Fig. 61a), and the lengths of the infested and uninfested parts measured (lengths l_i and l in Fig. 61a). The mean widths of the two portions (b_i and b in Fig. 61b) were calculated by measuring the width at three points on each (A – E in Fig. 61a). The areas of the infested and uninfested parts were then calculated, assuming each



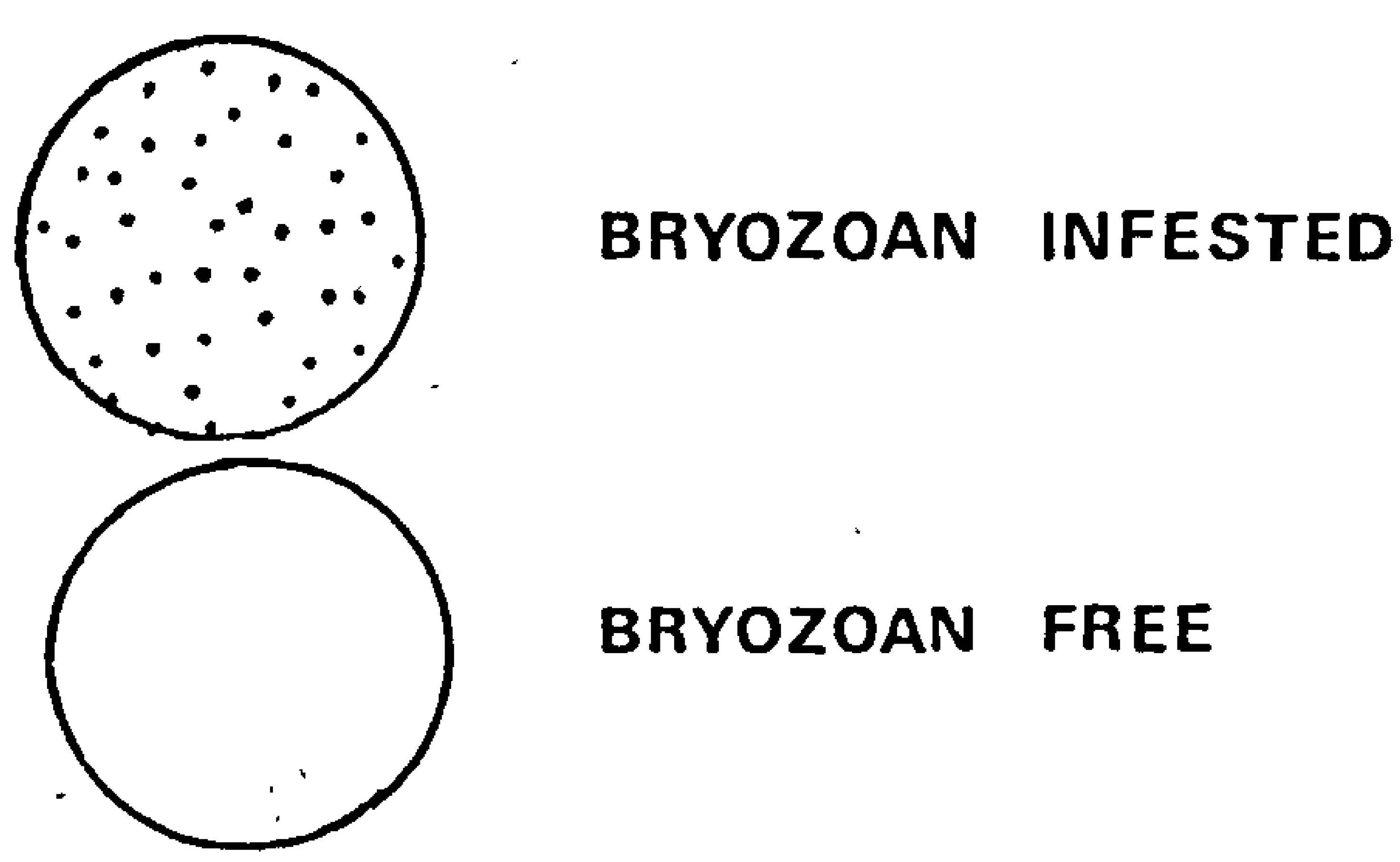


Fig. 61 - The method of estimating the percentage of the surface area of <u>Laminaria</u> fronds infested by the bryozoan <u>Membranipora membranacea</u>.

a) Length measurements (l_i and l) and breadth measurements (A–E) made on the frond.

b) The frond was assumed to be a simple quadrilateral shape consisting of infested and uninfested portions of length l_i and l, and mean breadth b_i and b respectively.

$$\text{percentage infestation} = \frac{b_i \times l_i}{(b_i \times l_i) + (b \times l)}$$

to be a quadrilateral, by multiplying b and l (or b_i and l_i). Percentage infestation in terms of surface area could then be calculated. The process was repeated ten times using randomly selected plants, ignoring those plants with a particularly irregular shape, or unusual distribution of bryozoans.

Investigations of the weight per unit area and the dry weight and ash content of bryozoans on the weed involved scraping clean small areas of the surface with a scalpel. This proved to be impossible with *Laminaria* because fresh samples gave off large amounts of exudate when scraped, and dried samples were too convoluted and brittle, so *Saccorhiza* was used. Fresh samples were scraped to determine the dry weight content of *Membranipora*, although it proved impossible to avoid scraping off some of the surface layers of the algae, and there appeared to be some exudate from the algae. Dry weight content of colonies which fell off the algae during transport was also determined for comparison.

Scraping the bryozoans off dried samples, although slower, was easy to do without removing the surface layers of the algae, and this method was used for determination of ash/organic content. Dry weight was determined by drying samples at 80-90°C for 48 hours. Organic content was calculated by ashing for five hours in a muffle furnace at 500°C.

In order to determine the dry weight content of the harvested groups of algae, holes were cut in the bottom of the plastic bags in which the plants were brought to the laboratory, and the groups allowed to drain for five minutes in 1982 and ten minutes in 1983. The plants were then vigorously shaken. The naturally colonised algae from the rope sampled during the summer of 1982 were allowed to stand for five minutes on a draining board and similarly shaken. After each group had been weighed and the number of plants counted, all the groups from each seeding date or depth were treated together, irrespective of spacing. In each case a subsample of 700 - 1000g fresh weight was accurately weighed before and after being dried at 80 - 90°C for 48 hours.

To determine the organic content, 20 - 30g of dry material from each subsample was ashed for five hours at 500°C.

Drying experiments were carried out by suspending the algae from strings tied around the holdfasts. Humidity was controlled manually by turning on and off a humidifier, and it varied by up to 15% from the mean. Temperature was automatically controlled and varied by ± 3°C from the mean.

The possibility of storing algae by ensilage was investigated by placing about 1 kg of fresh weed from a sample of known organic content in a sealed tube, which was left at 10°C. A small sealed hole was periodically opened to allow gas to escape. Three replicate tubes were used for each species. They were usually left for 24 or 32 weeks, after which the contents of the tubes were analysed. It was found that large quantities of liquid with a pH of about 4.0 - 4.5 had accumulated in the bottoms of the tubes. This liquid was evaporated to constant weight at 80°C and the residue ashed at 500°C for five hours to determine the organic content. The organic content of the solid component from the tubes was determined by drying and ashing as for the fresh weed.

Further tubes were set up containing Saccorhiza or Laminaria and opened after intervals of time ranging from 1 - 32 weeks, when the contents were examined, and the pH of the liquid portion measured.

7.3 RESULTS

7.3.1 MEMBRANIPORA INFESTATION

The percentage surface area of Laminaria infested by Membranipora is shown in Table 14. It can be seen that the amount on November and December seeded plants (61.3 and 62.6%) was significantly higher than on April seeded plants at 2 and 3m depths (39.5 and 48.7%) according to a t-test. This may have been because the plants had been present for a greater length of time, and there was therefore a greater chance of bryozoans settling and growing on them. However, Laminaria seeded at 5m depth in April had 54.6% cover, which was significantly more than on the 2m deep April seeded plants, and not significantly different from the November and December seeded ones. This could have been due to a reduction in the amount of movement caused by wave action at depth, so that those bryozoans which did attach to the algae were less likely to have been dislodged.

The cover of Membranipora on Saccorhiza was much more variable than on Laminaria. Some plants were completely covered, including the stipes and holdfasts. The majority had at least some portion of the frond infested but not the stipes or holdfasts. Others were completely uninfested, particularly the smaller plants. No attempt was made to estimate the mean percentage cover. The cover in terms of percentage of dry weight on heavily infested portions of large plants is shown in Table 15. It can be seen that from a)

DATE OF SEEDING		BRYOZOAN COVER - % S.A. (MEAN ± 1 S.D.)
NOV	2m	61.35 ± 12.56
DEC	2m	62.62 ± 8.55
FEB	2m	55.43 ± 16.11
APR	2m*	39.51 ± 20.41
	3m	48.66 ± 11.83
	5m	54.57 ± 11.56

b)

	NOV	DEC	FEB	APR 2m*	APR 3m	APR 5m
NOV	-					
DEC	X	-				
FEB	X	X	-			
APR 2m*	2%	2%	X†	-		
APR 3m	5%	2%	X	X	-	
APR 5m	X	X	X	5%	X	-

* - includes 10(2)m rope.

† - almost significant at 5% level.

X - no significant difference at 5% level.

Table 14 a) mean bryozoan cover expressed as percentage of surface area (± 1 S.D.) on L. saccharina in 1983. Only those plants spaced at 50 or 100 cm intervals were used.

b) results of t - tests to compare cover on L. saccharina seeded at different times/depths. Level of significance of differences are given.

BRYOZOAN CONTENT OF <u>SACCORHIZA</u>

SOURCE	(% DRY WT.).
7 PIECES OF FROND TOTAL 26.1 cm^2	44.4
2 PIECES OF STIPE 6.4g FRESH WT.	33.9
2 PIECES OF FROND TOTAL 28.15 cm^2	53.0
1 PIECE OF FROND 50g FRESH WT.	39.7

Table 15 - Infestation of Membranipora on Saccorhiza expressed as a percentage of dry weight.

39.7 - 53.0% of the fronds could be composed of bryozoans, while even quite large stipes could contain 34% bryozoan material. Since a high proportion of the larger plants were heavily colonised, it seems that an appreciable percentage of the biomass from a successful Saccorhiza cultivation system would actually be composed of bryozoans, unless the plants were harvested early in the summer.

From the infestation on the Saccorhiza fronds, it was calculated that the bryozoans weighed approximately 5.5 mg cm^{-2} (dry weight) on a single surface, i.e. 11 mg cm^{-2} on a frond if both sides are covered. This agrees roughly with a value of 7 mg cm^{-2} for one surface on Macrocystis (Wing and Clendenning 1971).

Assuming that the weight per unit area of Membranipora colonies on Laminaria is about the same as on Saccorhiza, it can be calculated that a typical large plant seeded in December or February (e.g. one of those shown in Figs. 16 or 48), weighing 41g dry weight and with a frond measuring 130 cm long by a mean width of 13 cm, with 63% of its surface area infested would have a total weight of bryozoans of 11.7g, about 29% of the total dry weight of the plant. Thus it seems likely that with any successful cultivation system producing large Laminaria plants, bryozoans would form a significant part of the crop.

The composition of bryozoans is shown in Table 16. It can be seen that there was a large discrepancy in water content between the sample scraped off the surface of the fresh weed and that from colonies which fell off the weed during transport. The scraped samples had a much higher water content, perhaps because of exudates from the algae produced when the surface layers were damaged. Assuming the value from the unscraped colonies to be more accurate,

CONTENTS OF MEMBRANIPORA

SOURCE	DRY CONTENT %	ASH CONTENT %
SCRAPED FROM SURFACE OF FRESH WEED	9.2	-
COLONIES WHICH FELL OFF FRESH WEED	17.1	40.2
SCRAPED FROM SURFACE OF DRIED WEED	-	42.9
"	-	42.0
"	-	43.4
"	-	43.75

Table 16 - Dry and organic content of *Membranipora* collected from *Sacchoriza* fronds.

it seems the dry content was about 17% of the fresh weight. It can also be seen from Table 16 that the organic content of bryozoans scraped from the surface of dried weed varied from 42.0 to 43.75%, while that from the free colonies was very slightly lower at about 40.2%. These values are somewhat lower than the 57.2 - 59.3% reported by Wing and Clendenning (1971). However, Hyman (1959) observed that calcium carbonate content increased with age up to a value of 70%. In the present work the bryozoans had not been present in any great quantity for more than about two months and might not therefore be expected to have reached a mean carbonate content of 70%.

7.3.2 DRY WEIGHT AND ORGANIC CONTENT OF ALGAE

Table 17 shows that the dry content varied considerably between species. *Saccorhiza* had the lowest value with 10.55 - 11.55% in 1983, agreeing with the figures gained by Black (1948) for *Saccorhiza* fronds. *Laminaria* in 1983 had values of 14.95 - 15.91%, only slightly higher than the peak of 14-15% found by Black (1948) in open sea plants, and slightly less than the peak of 17% he found for sheltered sea loch plants. It can also be seen from Table 17 that *Alaria* proved to have a similar dry weight content to that of *Laminaria*.

There was no evidence of any great difference in dry weight content between plants seeded at different times or depths.

The higher values for 1983 figures compared with 1982 are probably due to the longer length of time for which the groups were drained.

DRY WEIGHT (%)

DATE OF SEEDING	SPECIES AND YEAR					
	SACCORHIZA		LAMINARIA		ALARIA	
	1982	1983	1982	1983	1982	1983
NOV	-	-	-	15.04	-	14.22
DEC	-	-	-	15.43	-	15.63
FEB	-	-	-	15.91	-	13.61
APR 2m *	9.7	10.55	12.65	15.30	14.01	14.84
APR 3m	-	11.55	-	15.55	-	14.96
APR 5m	-	10.64	-	14.95	-	14.58

* includes 10(2)m rope in 1983

Table 17 - Dry weight content of harvested plants expressed as % of fresh weight.

Fig. 62 shows the variation in dry weight content of the Alaria groups sampled during 1982 (see section 4) and naturally colonised Saccorhiza and Laminaria during the same year. The Alaria plants were blotted dry individually, and therefore show a higher dry weight content than the other harvested Alaria groups, increasing from about 15% of dry weight in May to a maximum of almost 20% during June and July. The naturally colonised Laminaria reached a peak value of about 16% during August. This corresponds approximately with the observation of a broad peak in dry weight content of open sea Laminaria saccharina from June to September by Black (1948). Naturally colonised Saccorhiza reached a less pronounced peak during September of about 11%. Black (1948) showed no evidence of a seasonal trend in dry weight content of Saccorhiza, although he had rather few observations. Jensen et al (in prep.), in a more detailed study of a population of Saccorhiza from Port Erin Bay, also found no evidence of seasonal variation.

Since Membranipora had a dry weight content very similar to that of Alaria and Laminaria, the bryozoans can not have had any significant effect upon the percentage dry weight content of the harvested weed during the summer. However, the rise in dry weight content in Saccorhiza during July and August (Fig. 62) may have been due at least in part to the increasing amounts of Membranipora on the surface.

Table 18 shows that there was considerable variation in the organic content of harvested algae both between and within species. Saccorhiza had the lowest content, varying from 52 - 59.8%. This is within the range of 45-68% (fronds) and 53 - 68.5% (stipes) found by Black (1948), but slightly higher than the 45 - 55% found

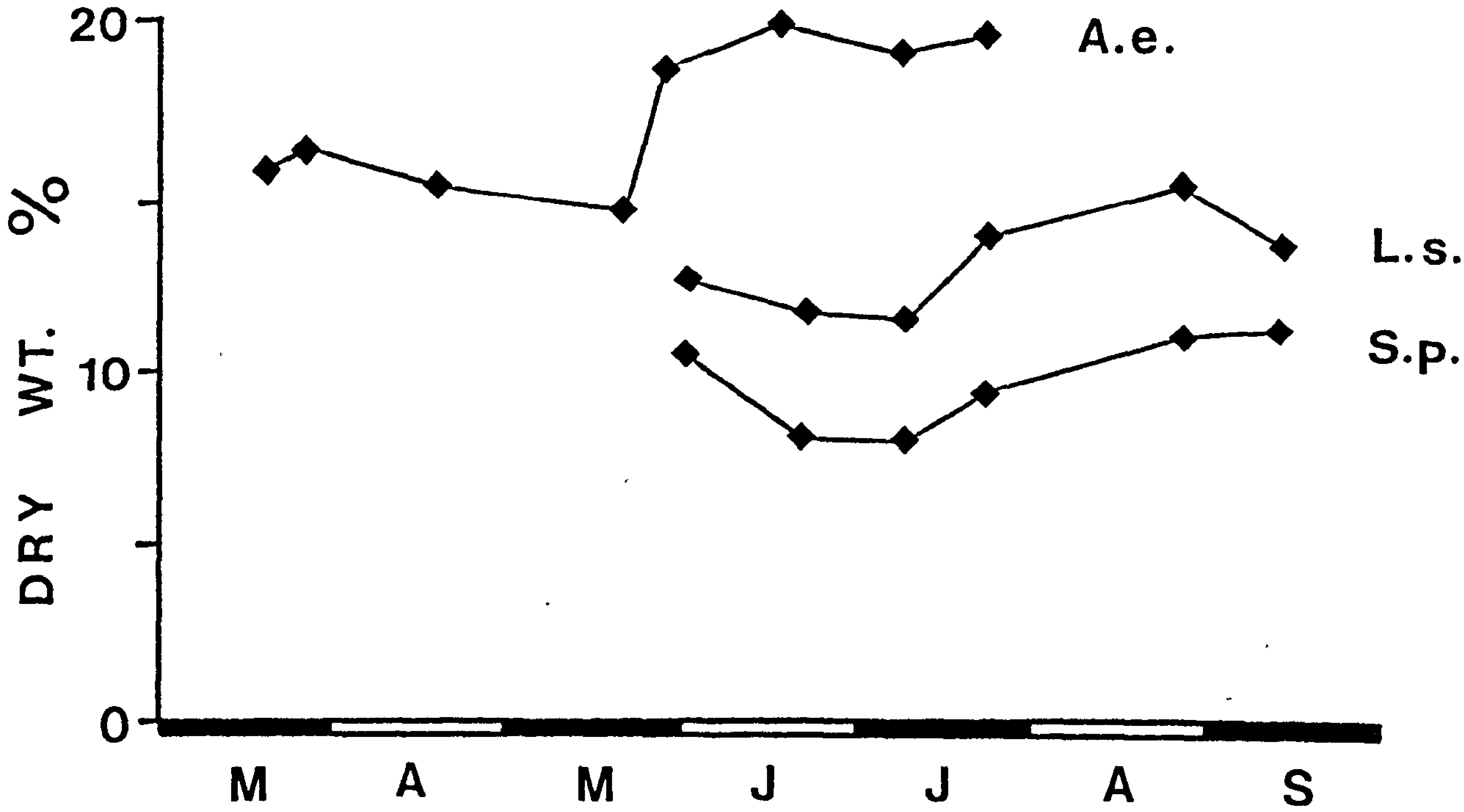


Fig. 62 - Seasonal variation in dry weight, expressed as percent of fresh weight, of Alaria (A.e.) from groups seeded in November 1982, and naturally colonised Laminaria (L.s.) and Saccorhiza (S.p.) from ropes placed in the sea in November 1982, observed during 1983.

ORGANIC CONTENT (%)

DATE OF SEEDING	SPECIES AND YEAR					
	SACCORHIZA		LAMINARIA		ALARIA	
	1982	1983	1982	1983	1982	1983
NOV	-	-	-	67.32	-	68.38
DEC	-	-	-	61.54	-	71.07
FEB	-	-	-	62.32	-	67.86
APR 2m *	55.60	59.76	61.44	65.31	64.80	74.10
APR 3m	-	57.09	-	62.58	-	74.74
APR 5m	-	51.97	-	59.08	-	72.90

* includes 10(2)m rope in 1983.

Table 18 - Organic content of harvested plants expressed as % of dry weight.

by Jensen et al (in prep.) in a natural population in Port Erin Bay. Table 18 shows that Laminaria had a higher organic content, with 59.1 - 67.3%. This is rather lower than the maximum value of 74-80% for fronds observed from June - November by Haug and Jensen (1954) or of 72-79% for fronds observed in May to October. It can further be seen from Table 18 that Alaria had the highest value with 64.8 - 74.7%, but again this was lower than Haug and Jensen's (1954) maximum value of 86% in September/October.

Since the Membranipora had a low organic content of about 43%, it would be expected that infestation might have had the effect of reducing the percentage organic content of all three species, and that this would have been least on Saccorhiza and greatest on Alaria. This is supported by the fact that harvested Laminaria and Alaria both had a lower organic content than previously reported, although that of Saccorhiza was not greatly different. As has already been shown, the colonisation on large Laminaria is likely to be quite considerable in terms of weight. However, the discrepancies in the Alaria figures are too great to be due solely to the bryozoan infestation, since there was relatively little apparent colonisation on the Alaria harvested in 1983. Differences in the genetic make-up of the plants or the environmental conditions under which they were grown may have accounted for some of the discrepancies.

Previous workers have shown that there is no obvious seasonal trend in organic content in Saccorhiza (Black 1948, Jensen et al in prep.), but that in Laminaria saccharina it increases during the summer to reach a maximum in late July/early August (Black 1948), or in September/October (Black 1948, Haug and Jensen 1954). In the same work, Haug and Jensen showed that the organic content of

Alaria increased rapidly from July to reach a maximum in September/October. However, it can be seen from Fig. 63 that in the present work the organic content of all three species decreased during the summer, most notably in *Alaria*, in which there was a rapid decrease between mid June and late July. It must be remembered that the previous workers studied populations of algae in which individuals may have arisen at different times, while the present work involved algae which all developed and grew at almost exactly the same time, in the case of *Alaria*, or in which the majority arose and grew at approximately the same time, in the case of the *Laminaria* and *Saccorhiza*. However, this in itself is unlikely to account for the differences in seasonal variation. It seems likely that much of the decrease in organic content was due to the increasing amounts of *Membranipora* colonising the algae. Although there was relatively little colonisation on most of the harvested *Alaria* in 1983, that shown in Fig. 63 which was cultivated in 1982, was allowed to remain on the ropes until about six weeks after it had reached its maximum standing crop, and consequently large *Membranipora* colonies developed on it. The organic content of about 65% in late July was rather lower than from the 1983 *Alaria*, and about the same as the rest of the 1982 *Alaria* (Table 18), which were also probably left on the rope too long, and were quite heavily colonised. It has already been shown that, later in the season, *Membranipora* infestation on *Laminaria* and *Saccorhiza* was often quite considerable, and it is reasonable to assume that it may have reduced the apparent percentage organic content of the weed.

Taking mean values for the dry weight and organic contents from the figures for 1983 in Tables 17 and 18, the organic contents as a

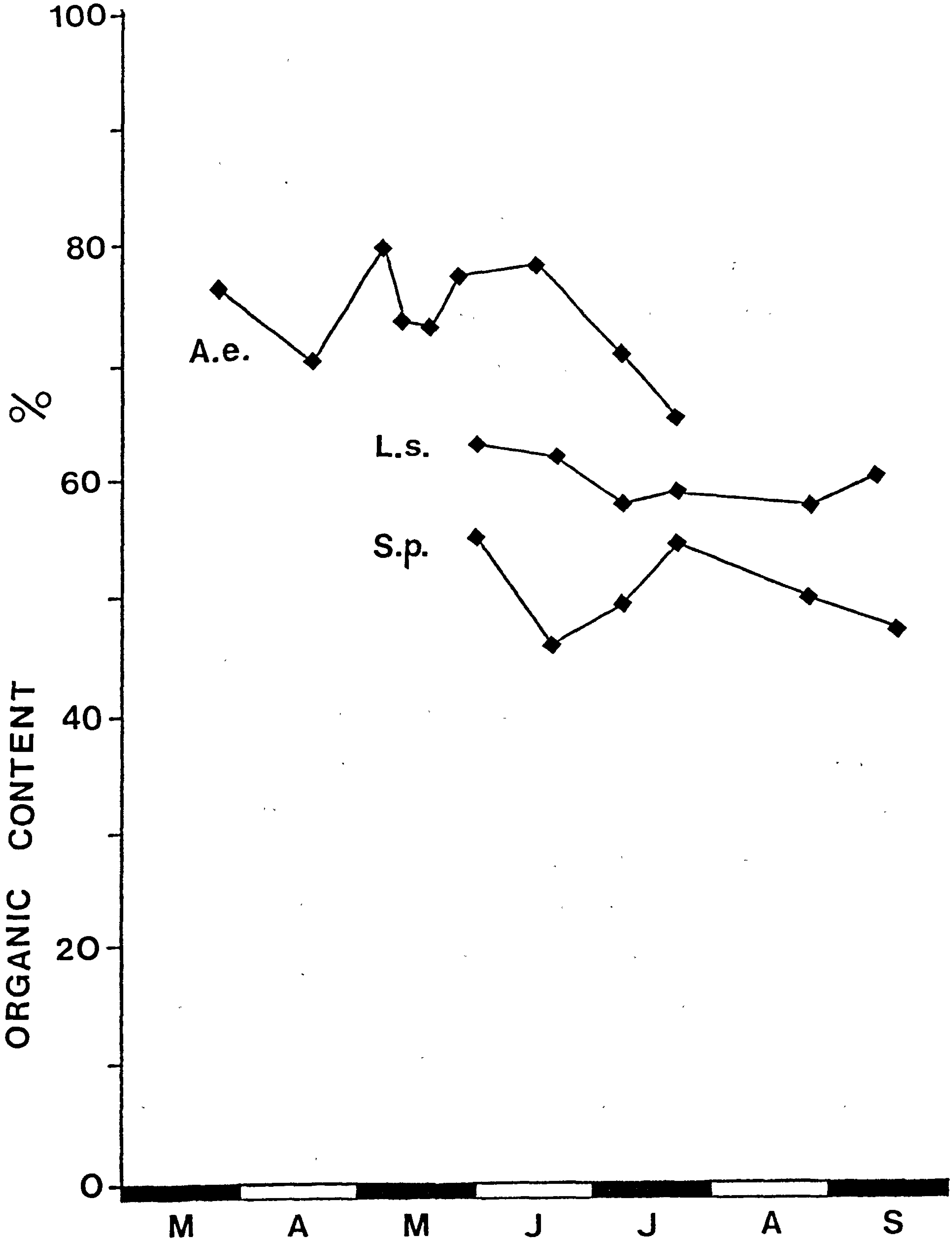


Fig. 63 - Seasonal variation in organic content, expressed as percentage of dry matter, of Alaria (A.e.) from groups seeded in November 1982, and naturally colonised Laminaria (L.s.) and Saccorhiza (S.p.) from ropes placed in the sea in November 1982.

percentage of fresh weight can be calculated as follows:

Saccorhiza	6.14%
Laminaria	9.70%
Alaria	10.44%

Thus, harvested Saccorhiza would contain less than two thirds of the organic content of the same weight of Alaria or Laminaria, and would consequently be a more expensive fuel crop to transport.

7.3.3 STORAGE

7.3.3.1 DRYING

Fig. 64 shows the weight of individual plants hung in still air at 29°C and 50% R.H., plotted against time. It can be seen that Laminaria plants weighing 140 and 170g dried out to within 1% of their original water content in less than 24 hours. Saccorhiza plants weighing 150 and 221g took just under 40 hours to dry out to the same degree, while larger Saccorhiza weighing 442 and 750g took 45-46 hours. No Alaria were available for this experiment.

Although individual plants can obviously be dried quite easily at low temperatures, such an approach would be extremely impractical with large quantities of algae. A further experiment was therefore performed to see how fast groups of plants of a similar size range to those grown in 1982 and 1983 would dry, as well as individual plants. Fig. 65 shows the percentage water loss after 113 hours at 27.5°C in a mean R.H. of 72%, plotted against fresh weight. It was intended that the R.H. be maintained at about 50% as previously, but this proved impossible with about 15 kg of weed drying in one small room. It can be seen that none of the plants lost more than

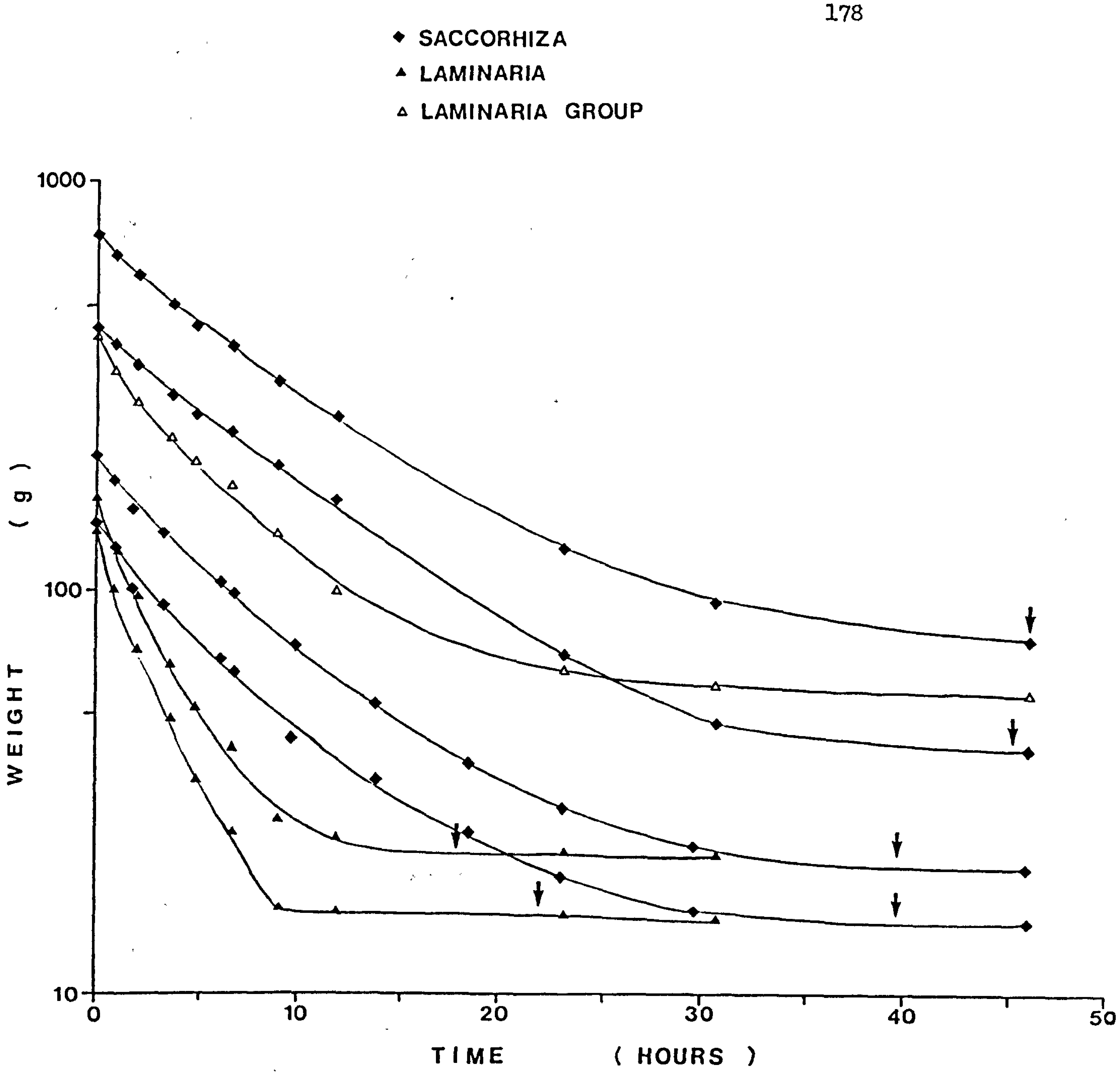


Fig. 64 - Changes in weight with time of groups of <u>Laminaria</u> plants and individual <u>Laminaria</u> and <u>Saccorhiza</u> suspended in still air at 29°C and 50% R.H.

↓ - time at which 99% of original water content was lost.

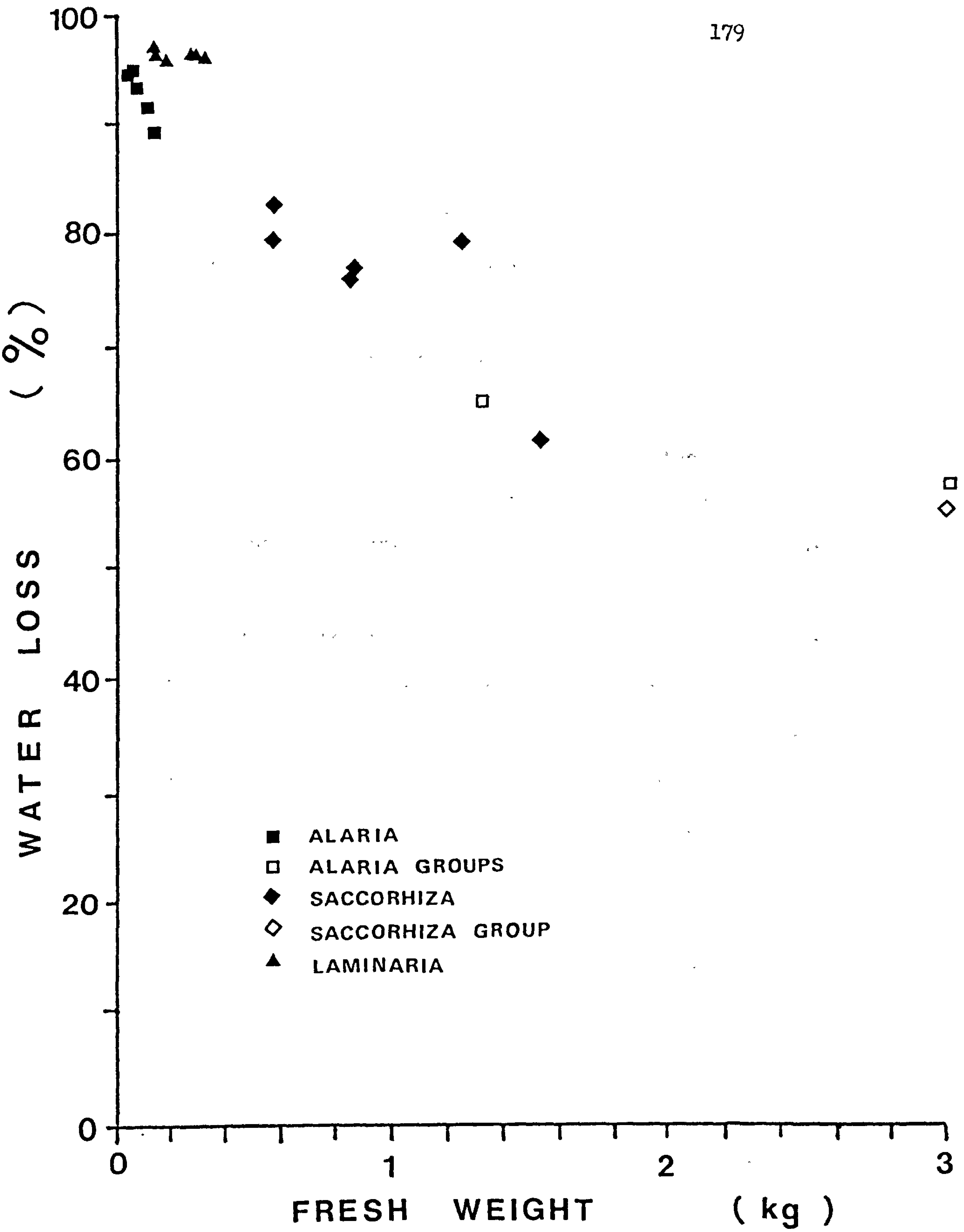


Fig. 65 - percentage water loss plotted against original fresh wt. for individual plants and groups of Laminaria, Alaria and Saccorhiza suspended for 113 hours in still air at a mean of 27.5°C in a mean R.H. of 72%.

97% of the original water content in 113 hours, even those whose initial weight was less than 200g. The Saccorhiza plants dried out particularly slowly, those weighing 600g losing only about 80% of their water content, and one weighing just over 1300g losing only 62%. This slow drying rate was probably due mainly to the high humidity, since the temperature was only 1.5°C lower than in the previous experiment.

Fig. 65 also shows that Alaria lost less water than larger Laminaria plants, even though Alaria has a much thinner blade. This was because the Alaria plants had numerous sporophylls which dried out only slowly.

There was no strong evidence that rates of water loss were lower from groups of plants than would be expected from individual plants of the same size. Nevertheless, the drying rates were so slow that in all cases the innermost plants in the group began to decay considerably, turning slimy in parts and often bearing growths of white fungus. Alaria groups weighing 1.35 and 3.0 kg lost only 65 and 57% of their water content respectively, while a Saccorhiza group weighing 3.0 kg lost only 55%. The Laminaria groups decayed so much that the fronds fell away from the stipes after less than 60 hours, at which point they still contained more than 50% of their initial water content.

In view of the large amounts of water remaining after 113 hours, it seems likely that even with an R.H. of 50% the innermost plants in a large group would have remained damp for a considerable length of time and started to decay, and therefore if low temperature drying was to be feasible, large groups would have to be split up into considerably smaller ones.

7.3.3.2 ENSILAGE

Examination of the contents of the sealed tubes opened after 1-32 weeks (Saccorhiza) or 4-32 weeks (Laminaria) revealed no observable difference in the state of the weed between the two extremes of time. There were no extensive fungal or bacterial growths. The weed was in all cases quite firm and not particularly slimy. It can be seen from Table 19 that the pH of the liquid fraction dropped only very slowly after the second week in the Saccorhiza filled tubes. There was a drop from 5.04 to 4.41 from 4-8 weeks with Laminaria, but the results are still in accordance with the expectation that most of the bacterial activity would be inhibited after the first few weeks of storage.

TIME (WEEKS)	SACCORHIZA	LAMINARIA
1	5.10	-
2	4.45	-
4	4.48	5.04
8/9	4.43	4.41
16	4.40	4.32
32	4.00	4.45

Table 19 - the pH of liquid drained from sealed tubes containing Saccorhiza or Laminaria after storage for various lengths of time.

Observation of the other sealed tubes stored for 24 or 32 weeks again revealed that the weed was quite firm, with no sign of bacterial or fungal growths except in two tubes where the liquid fraction had leaked out, in which there were light growths over the upper surface of the weed. It is assumed that air got into these tubes.

Table 20 shows that at least 82.5% of the organic material was retained in each case, with 100% retention in two of the *Alaria* filled tubes. A considerable amount of the organic material in the *Laminaria* and *Alaria* filled tubes was dissolved in the liquid, in concentrations ranging from 24.5 to 62.1 g/l. This liquid could probably be tapped off and used directly as a feedstock for methane generation. It has been shown that liquid runoff from ensiled grass is an excellent substrata for anaerobic digestion (Barry et al 1982).

Where losses of organic material have occurred during storage, some of this is likely to have been released as methane which could be tapped off during storage.

These results suggest that further investigation into the possibility of ensilage as a means of storage would be worthwhile.

		ALARIA			LAMINARIA			SACCORHIZA		
		1	2	3	1	2	3	1	2	3
INITIAL ORGANIC CONTENT (g)		131.7	126.6	103.4	71.9	67.2	132.2	40.90	39.0	67.2
LIQUID FRACTION	VOLUME (cc)	177	172	0 *	196	28 *	425	287	247	288
	pH	4.10	4.02	-	4.32	4.28	4.45	4.98	4.46	4.00
	organic content (g)	11.0	9.6	0	4.8	0.7	24.6	1.4	1.5	5.2
SOLID FRACTION	organic content (g)	122.1	119.0	87.0	54.5	58.8	89.4	32.9	30.9	59.5
TOTAL FINAL ORGANIC CONTENT (g)		133.1	128.6	87.0	59.3	59.5	114.0	34.3	32.4	64.7
(% INITIAL CONTENT)		(101.6)	(101.6)	(84.1)	(82.5)	(88.5)	(86.2)	(83.9)	(83.1)	(96.3)

* liquid leaked out

Table 20 - analysis of the contents of 3 sealed tubes packed with fresh <u>Alaria</u> <u>Laminaria</u> or <u>Saccorhiza</u> before and after storage for 24 weeks (tubes no. 1 & 2) or 32 weeks (tube no. 3).

8. GENERAL DISCUSSION

It has been shown that the described system of horizontal ropes suspended just below the sea surface is suitable for the cultivation of Laminariales even under quite rough conditions. Windspeeds of Force 8 on the Beaufort Scale (over 17 m s^{-1}) from the West and North-West, the directions to which Bay Fine is most exposed, were frequently encountered, especially during the winter. Occasional winds of Force 10 (over 25 m s^{-1}) were encountered. The major problems caused by the resulting strong wave action involved the structures themselves, including abrasion of the ropes on the thimbles and loosening of rust-weakened shackles, rather than the algae (with the exception of *Saccorhiza polyschides*). It is expected that these problems would be overcome relatively easily in the design of permanent, large scale structures.

Alaria and *L. saccharina* both proved to be suitable for cultivation by seeding in early winter at a depth of 2m, because they were not easily removed by wave action.

Druehl has successfully cultivated *Laminaria groenlandica* (Druehl 1981 a,b) and *L. saccharina* (Druehl 1982) in moderately exposed conditions in British Columbia, using an artificial substratum and seeding technique similar to that used here. Although losses due to storms were only slight, many young plants were removed from the ropes by drifting material, mainly *Macrocystis* and *Nereocystis* (Druehl 1981a).

An experimental *Macrocystis* farm in California suffered heavy losses due to waves in hurricane force winds (31-45 m s^{-1}) (Leone, 1980). The actual cause of loss was thought to be abrasion of the plants against the structure. The losses may have been worsened by the fact that the structures used were not very compliant, consisting of six stiff radiating arms 15m in length, between which were strung the ropes to which the plants were attached.

Loss of plants due to wave action appears to be of little importance in China and Japan, where compliant structures similar to those used in this work are often employed. The amount of wave action experienced in the cultivation areas is unclear, although it is thought that considerable wave action might occur in some areas in China (Kain, pers. comm.) and Funano (1980) reported that areas of strong wave action were required for production of artifical forests of L. japonica in less than 3m of water in Japan.

In the present work, losses of plants due to wave action seemed to be mainly confined to the very small sporophytes present on the strings when they were first placed in the sea, and to the larger plants and groups. Sacchoriza plants of more than about 1m in length, and, occasionally, large Laminaria groups were entirely removed. Saccorhiza plants were often lost even when the holdfasts were attached directly to the rope, and it seems unlikely that the species could be reliably cultivated in exposed areas, but the mooring rope found in Port St. Mary outer harbour in 1980 bore up to 1300g dry weight of Saccorhiza per metre of rope, suggesting that cultivation in, for example, sheltered sea lochs may be feasible. Estuaries and lagoons such as those employed for mussel cultivation in Spain may also be suitable. Lapointe et al (1981) reported an annual productivity by Saccorhiza of 1350g dry weight/m^2 on mussel rafts in Northern Spain, while John (1968) reported a net annual organic (ash-free) production of up to 3882 g/m^2 in shallow water in the channels of Playa de Lago, North West Spain.

The majority of sheltered areas in North-East Atlantic waters are in the Scottish lochs and Norwegian fjords. Unfortunately, utilization of many of these areas for algal mariculture would be in competition with traditional fisheries, salmon, scallop and mussel farms, inshore shipping and naval bases. The total area available would therefore be relatively small in comparison with the area needed to make a significant impact on European energy production. Moreover, lack of water movement is often prevalent in such areas and is likely to result in very heavy infestations of epiphytes (Druehl 1980), and possibly slower nutrient uptake, in which water movement has been shown to be an important factor (Conover, 1968, Schumacher and Whitford, 1965).

Although seeding at a depth of 5m in April improved the survival rate of the plants, over half of the groups were still lost, and production was quite low. Seeding during the winter at 5m depth might improve production by surviving plants, but would almost certainly result in even greater losses, so that seeding at depth is probably not a viable solution to the problem.

Saccorhiza has further disadvantages as an energy crop. The fresh weed contains only about two-thirds of the dry matter content of Laminaria and Alaria, and a smaller fraction of this is organic. This means that a greater fresh weight of Saccorhiza than of the other two species would need to be cultivated to give an equivalent amount of organic material, and that transport costs may be significantly higher. The possibility of squeezing most of the water out of freshly harvested weed on board the harvesting boat by some form of press has been suggested (Morley, pers. comm.). This would greatly reduce transport costs, but it is not known how feasible it would be, nor how much organic material would be lost in the process.

Although Laminaria also suffered considerable losses, it seems likely that these could be greatly reduced, since the plant has a quite strongly attached holdfast. Most of the losses were of groups attached only to the string, which had either snapped or slipped through the holdfasts. This could be remedied by encouraging at least some of the plants in the groups to attach to the horizontal rope, for example by passing the string through the rope several times, or by wrapping it around the rope several times and tying it. Care would be needed to ensure that the young plants were not dislodged from the string in the process.

Apart from losses of plants, among the major limitations to production were the cessation of growth in Alaria in June/July, and possibly the slow growth of Laminaria and Saccorhiza during the summer. The reason for the cessation of growth in Alaria is not known. Sundene (1962) demonstrated a significant reduction in growth rate at 17°C compared to 14°C, and suggested that the 16°C isotherm in summer may limit the southern distribution of Alaria. However, temperature may not have limited growth in the present experiments since weekly mean surface temperatures are rarely more than about 12°C in June and rarely more than 14°C until August (Slinn, unpublished). Buggeln (1974) showed that trimmed laboratory grown Alaria plants in running sea water in Newfoundland were nitrate or phosphate limited in the spring, but untrimmed plants in the wild apparently had sufficient reserves to last at least two months, by which time other factors such as temperature may have become limiting. In 1983, the nitrate content of surface water 5 km offshore from Bay Fine fell to about 1 μM by mid April and remained between 0.5 and 2.9 μM during June and July (Slinn, unpublished). It is important to note that those plants in the centre of large groups probably had very little exchange of water during periods of calm weather, even when strong currents were running and that this would considerably reduce the nutrient uptake rate. The extensive cover of bryozoans on some of the plants may also have severely reduced nutrient uptake. Although nitrogenous excretion by the animals may have countered this to some extent, the net effect of bryozoan infestation is likely to have been a reduction in nitrate uptake. Nitrate limitation may therefore have played a part in the lack of growth in Alaria during the summer.

It is also possible that low nitrate levels were responsible for the slow growth of Laminaria and Saccorhiza during the summer. Nitrate limitation has been demonstrated in L. longicruris in summer in Nova Scotia (Chapman and Craigie, 1977, 1978), and, although not demonstrated in any Laminariales in North East Atlantic waters, has been suggested for deep water L. hyperborea in summer in Scotland (Kain 1977). As with Alaria, the large number of plants in some groups of Laminaria may have greatly reduced water movement and nutrient uptake rates during calm weather, and bryozoans on both Laminaria and Saccorhiza may have further inhibited nutrient uptake.

Lack of nitrogen is a problem in the cultivation of L. japonica in many areas of the Yellow Sea, and artificial fertilization has been carried out for many years. Early methods included the use of porous earthenware bottles containing sodium or ammonium nitrate (Tseng et al, 1955a). Later plastic bags with holes in, containing ammonium nitrate, were suspended in the water adjacent to the plants (Tseng, 1981b). Dipping the algae into an ammonium nitrate solution was found to be suitable for small plants (Cheng, 1969). Most fertilization is now carried out by spraying a 5-10 ‰ solution of ammonium sulphate into the water. The large size of the cultivation areas means that the fertilizer stays in the area for "quite some time" (Tseng 1981b). Wu et al (1959)(in Chinese, quoted by Cheng 1969) reported that fertilization could be suspended 1½ - 2 months before harvesting without affecting the nutritional value of the weed, although it is not clear if growth continued at a high rate. In all cases the increased production was sufficient to make artificial fertilization economically viable. Tseng (1981b) reported that, at a production level of 15 dry tons/hectare, the cost of fertilization was only 8% of the value of the crop.

Off California, experimental fertilization of natural beds of Macrocystis with ammonium sulphate was carried out from crop dusting helicopters (North et al, 1981), and on an experimental farm water upwelled from a depth of 450m was used as a fertilizer, being retained in the area by a large flexible curtain (Gerard and North 1981, Leone 1980). Both systems led to increased production, but economic viability has not been proven.

The significance of nitrate limitation with respect to organic production is unclear, since many species are known to accumulate the storage products mannitol and laminaran during the summer, including L. saccharina (Haug and Jensen, 1954, Black 1948) and A. esculenta (Haug and Jensen 1954), but not Saccorhiza (Jensen et al, in prep.). Unless the plants erode rapidly, as occurs with Alaria, the absolute organic content of each plant should continue to increase, in which case economic viability of nitrate fertilization would be extremely unlikely. However, there was no evidence of any accumulation of organic material in the present work, since the organic content expressed as a percentage of dry matter decreased during the summer in all three species on the experimental ropes. This may have been due to the increasing amounts of bryozoans in the case of Laminaria, but nevertheless it seems unlikely that there was any large scale storage of organic material. This suggests that a low photosynthetic rate was the limiting factor, and therefore that artificial fertilization would not increase organic production.

Production by all three species was probably affected by the heavy growths of fouling organisms. The effects of the diatom growths in spring have been mentioned several times. Similar inhibition of the microscopic stages of plants by many fouling algae, including diatoms, was encountered during autumn seeding in China, but was overcome by seeding with laboratory grown cultures containing sporelings up to 2 cm in length (Tseng 1981b, Tseng et al 1955b). The present work suggests that in the Irish Sea the problem can easily be overcome by seeding before the spring.

The extensive colonies of Membranipora membranacea which grew on many of the plants were a problem. It was noticed that the presence of the bryozoans made the frond more brittle. It is not known if this resulted in significant losses, although Dixon et al (1981) reported severe blade loss in Macrocystis plants infested with *Membranipora*.

The effects of encrusting organisms on photosynthesis and growth in Laminariales have not been well documented. Wing and Clendenning (1971) reported that the full photosynthetic capacity of *Macrocystis* was retained under heavy *Membranipora* encrustation, but that 50% higher light intensities were required for photosynthesis and growth. It is therefore possible that, at a depth of 2m or more, heavily encrusted algae, particularly those growing in dense groups, might be light limited a great deal of the time, particularly at the beginning and end of the day. The possibility that encrustation might lead to or worsen nitrate limitation has been mentioned.

It was noticed that natural populations of algae very close to the cultivation site had very little bryozoan encrustation. Hasegawa (1978) observed similarly that *Membranipora serrilanella* was a problem on cultivated *Laminaria* in Japan, but never seemed to have seriously affected natural stands. Bernstein and Jung (1979) reported that *Membranipora* is never abundant in the middle of large *Macrocystis* beds. The abundance of bryozoans may be linked to the amount of abrasion of the plants against other surfaces, in which case the abrasion of naturally occurring plants against rock surfaces could be a major factor in reducing infestation. The increased shelter from wave action with depth of the cultivated plants would explain why there was increased infestation with depth on the April seeded *Laminaria* because of the reduced abrasion of the plants on each other.

Prevention or discouragement of such infestation is likely to be extremely difficult. In Japan, harvesting is carried out before the infestation becomes too widespread, although severe encrustation occurs if harvesting is delayed (Hasegawa, 1978). In Alaria, the onset of heavy encrustation more or less coincided with the maximum biomass in any case, but Saccorhiza and Laminaria continued to increase in biomass even after infestation had become severe. It is possible that infestation could be reduced in extremely densely grown algae, both by a reduction in settlement of the larvae on the innermost plants, and by abrasion of plants against each other, but there are nevertheless almost certain to be considerable amounts of bryozoans on any cultivated algae. Fortunately it is likely that methanation of the algae would be unaffected by the bryozoans, and that some of the organic content of the latter would be fermented (Colleran, pers. comm.).

It has been shown that production levels in excess of 1.1 dry kg/m (Alaria) and 1.4 dry kg/m (Laminaria) are attainable, and there was strong evidence that increases in plant density could result in considerably higher production levels, especially with Laminaria. Comparison with production levels attained by natural populations is difficult, since 1m of rope can not be assumed to be equivalent to 1 m^2 of natural substrata but it was shown that production by the cultivated plants could exceed the maximum attained by plants naturally colonising the ropes.

In view of the lack of experience of cultivation in local waters, and the undoubted scope for improvement, the figures also compare well with those of other workers. Druehl (1982) reported a level of 8 kg fresh weight (about 1.2 kg dry weight) per metre of rope after seven months using groups of L. saccharina spaced at 30 cm intervals grown at 2m depth in Barkley Sound, British

Columbia. A value of 20 kg fresh weight/m was obtained using L. groenlandica, but this took eighteen months to achieve.

Production by the Chinese and Japanese is almost always reported as fresh or dry weight/plant, usually without specifying the number of plants per metre of rope, or as tonnes/unit area, without specifying the amount of rope involved. Both the Chinese and Japanese use low plant densities because the size and quality of individual plants is of paramount importance when they are to be used as a source of food. However, figures from Hasegawa (1971) suggest that with only 10 - 15 L. japonica plants per metre, the Japanese achieved a production level of 1.2 - 1.9 dry kg/m in nine months. Tseng et al (1957) reported that ten L. japonica plants grown on a 30 cm length of rope attained a total weight of 1.98 dry kg after less than nine months in the sea. Although the latter cannot be realistically translated into production per metre of rope, both sets of figures serve to emphasise that production levels well in excess of 2 kg/m of rope should be possible using densely seeded Laminaria.

It was independently concluded from the present work that production might be greatly increased by using plant densities greater than those used with both Alaria and Laminaria. This is despite the fact that mean plant size was shown to decrease with increasing plant density.

It might be possible to increase the density of plants by seeding the strings even closer together or by using longer lengths of string, but the former would be difficult to implement, and both might lead to heavy losses of young plants because of increased abrasion. Furthermore, longer strings might exacerbate the problem of groups not being attached directly to the rope. The best method would be to increase the number of plants on each string. This might be achieved with Laminaria by culturing the plants for some time in red light at 15°C, which would allow vegetative growth of the gametophytes without allowing them to become fertile, since fertility occurs only after exposure to a certain number of blue quanta (Luning and Dring, 1972, 1975). A few weeks before the strings are to be placed in the sea, the plants could be exposed to blue light, allowing them to become fertile before seeding. Druehl (1981b) successfully used this system to delay development of Laminaria groenlandica, so that seed strings could be put in the sea nine months later than normally. The delayed plants were cloned by fragmenting individual male and female gametophytes and combining the fragments. In June 1981 the plants in groups grown from delayed plants seeded in October 1980 were only slightly smaller than those from "normal" seed seeded nine months earlier. However, the numbers of plants in the groups were not reported.

By growing the plants in a light/dark cycle, the female gametophytes could be encouraged to release their eggs at the same time, which may result in a higher percentage fertilization (Luning 1981). It is not known if this system would work with Alaria esculenta, although Druehl and Boal (1981) demonstrated that at 10°C blue light is required for gametogenesis in A. marginata. Other methods of increasing plant density would be to find a sufficiently cheap string with a larger surface area for the attachment of plants, and to increase the number of spores added. These methods could, of course, be used in conjunction with the above light regime.

There was strong evidence that November/December seeding could result in greater production than February seeding with Alaria. This could not be demonstrated with L. saccharina, but the species was shown to be capable of reaching a length of 19.5 cm between November and February. The earliest seeding experiments carried out were in November, because it is difficult to obtain sporing algae of the three species concerned before September/October. However, the system of growth in red light described earlier, if carried out under a low intensity, could be used to delay development to such an extent that "seed" could be made available for about September. Nitrate levels begin to rise in Manx waters in September and the water temperature is favourable at a mean of about 13.8°C (Slinn, in prep.), so September seeding should enable the plants to reach a good size before the start of the rapid-growth period in spring. It is possible that a layer of diatoms would develop on the ropes at this time, but this is likely to be less dense and shorter lived than the spring growth, due to falling light levels.

The results of the November and December seeding experiments at a depth of 2m suggest that few losses should occur due to wave action, particularly if the groups are encouraged to attach to the horizontal rope, and that 2m is therefore a suitable depth for early seeding.

An alternative possibility is that September seeded plants could provide a second crop, harvested during the winter, at which time the main crop could be seeded. This would probably increase costs, since this "catch" crop is unlikely to provide a large amount of biomass, but would help to lessen the need for large-scale storage of algae.

The extensive work carried out on the cultivation of Laminaria by the Chinese suggests that further increases in production might be possible. By using inbreeding and selection, they developed a strain of L. japonica with longer, broader and heavier blades, called Haiquing No. 1 (Fang et al 1963). Later, other strains were bred including Haiquing No. 2, with a longer, narrower frond, shorter stipe, and maturing earlier than No. 1, and Haiquing No. 3, similar to No. 1 except for a shorter, thicker frond (Fang et al 1965, 1966). Further strains with high production and high iodine content are now being cultivated (IOG and QMF 1976).

Wu et al (1981) showed that removing the distal ⅓ of the plants when they had reached 3 metres in length resulted in an increase in production of 12 - 15%. There is no reason why such removed material could not be used for methane production, but it is unlikely that tip cutting could be performed economically in Europe.

The possibility of nitrogenous fertilization has been mentioned previously.

Apart from having a high productivity and being easy to cultivate in rough conditions, any candidate for an energy crop must be a good substrate for methanation. Saccorhiza again seems to have a disadvantage compared to Laminaria and Alaria because of its lower organic content. However, the potential for methanation may be further influenced by the chemical make up of the algae. Chynoweth et al (1978) reported that the most digestible fractions of Macrocystis pyrifera were mannitol and alginate, while the least digestible were protein and cellulose. According to Jensen et al (in prep.) the mannitol plus alginate content of Saccorhiza collected from Port Erin Bay in August was about 54% of the organic content. Values of 51 - 52% for Laminaria and 65% for Alaria were calculated from the work of Haug and Jensen (1954) in Norway. Figures from Black (1948) who worked in Scotland, indicate a higher value of 60 - 63% for Saccorhiza and a lower value of 44 - 46% for Laminaria, both calculated for August.

These figures suggest that Saccorhiza may not be so unsuitable for methanation as suggested by total organic content. However, Chynoweth et al (1978) have suggested that recycling of unfermented fractions after appropriate treatment may be feasible, and Troiano et al (1976) have shown that alkaline pretreatment can increase considerably the efficiency of methanation, although this may be expensive. Furthermore, Chynoweth et al did not comment on the possible methanation of laminaran, presumably because the laminaran content of their M. pyrifera sample was less than 2% of the organic content (Klass and Ghosh 1977), but the laminaran content of 45 kg of fresh weed was reported to have been reduced from 31.5g to 4.5g during fermentation (Chynoweth et al, 1978). This suggests that it may be a good substrate for methanation. The laminaran content of Saccorhiza is negligible (Black 1948, Jensen et al, in prep.), but Laminaria and Alaria may contain laminaran levels of 25% and 5% of organic content in August and June respectively (calculated from Haug and Jensen 1954).

At present it cannot be said which species is the best substrate for methanation, but all three are likely to be suitable. Troiano et al (1976) achieved an organic conversion efficiency of 55 - 60% with freshly harvested L. saccharina, and Asinari et al (1981) achieved an efficiency of 72% with dried L. saccharina.

The present work has shown that large groups of Laminaria and Alaria hung in still air at 27°C at 75% R.H. began to rot before they dried, but Morley (1983) reported that with an air temperature of 20°C at an R.H. of 50% and an air-speed of 1.7 m s^{-1} individual algae could be dried in about two hours. Thus it is likely that small groups of algae could be efficiently air dried at low temperatures.

The present work has also shown that ensilage may be a suitable alternative method of storage for future methanation.

Although this work was carried out with a view to the algae being used as an energy source, there are other potential uses, for example as a source of alginate and mannitol, two important chemicals extracted from brown seaweeds. L. digitata and L. hyperborea have recently been the major sources of alginate in Europe (Indegaard and Jensen, 1982). It is possible that both could be cultivated using the system described here, although they are both relatively slow growing (Kain 1969) and L. hyperborea might be prone to removal by wave action in the surface layers because of its relatively stiff stipe. It may be better to utilise Alaria and L. saccharina which both contain alginate and mannitol (Haug and Jensen, 1954, Black 1948).

As a product of cultivation, alginate would have the advantage that it commands a much higher price than methane, but there has been a drop in demand in recent years (Boalch 1981). However, if cultivated algae were to be a source of good quality alginate at competitive prices, this may prove not to be a serious problem. Recent improvements in extraction of alginates and mannitol from kelp (Mateus et al, 1977) and in recovery of mannitol from seawater in which kelp has been stored (Yu et al 1981) should help to reduce costs, and it may be possible to develop strains of algae with increased alginate contents. Although Chapman and Doyle (1978) concluded that the genetic heritability of alginate content of L. longicruris was negligible, they did not rule out the possibility of increased yields by genetic inbreeding and selection.

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ADDENDUM

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Appendix 1 - Alaria esculenta 1982

Number of plants, fresh weight, dry weight and dry weight per plant grown from each seeding string in 1982. Strings were placed in the sea in batches of 10, and were unaerated except where stated otherwise. Equivalent aerated and non-aerated cultures were counted together for calculation of mean values.

i) Culture set up on February 10

a) Seeded on February 17, aged 7 days
Harvested on July 2
Dry weight = 13.2% of fresh weight

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
	35	316	41.7	1.19	aerated
	60	420	55.4	0.92	aerated
	47	235	31.0	0.66	aerated
	104	1009	133.2	1.28	aerated
	106	439	57.9	0.55	aerated
	70	519	68.5	0.98	aerated
	36	249	32.9	0.91	aerated
	46	123	16.2	0.35	aerated
	89	486	64.2	0.72	aerated
	78	492	64.9	0.83	aerated
	95	1128	149.0	1.57	
	80	582	76.8	0.96	
	122	685	90.4	0.74	
	75	420	55.4	0.74	
	83	944	124.6	1.50	
	93	592	78.1	0.84	
	160	920	121.4	0.76	
	87	819	108.1	1.24	
	110	815	107.6	0.98	
	65	553	73.0	1.12	
$\bar{x}$	82		77.5		

b) Seeded on March 1, aged 19 days

Harvested on July 2

Dry weight = 13.2% of fresh weight

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)
17	346	45.7	2.69
55	1095	144.5	2.63
47	793	104.7	2.23
63	873	115.2	1.83
20	327	43.2	2.16
63	711	93.9	1.49
41	815	107.6	2.62
24	570	75.2	3.13
42	672	88.7	2.11
59	877	115.8	1.96
$\bar{x}$ 43.1		93.5	

c) Seeded on April 22, aged 71 days

Harvested on July 27

Dry weight = 13.2% of fresh weight

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)
66	225	29.7	0.45
49	264	34.8	0.71
64	373	49.2	0.77
65	430	56.8	0.87
93	450	59.4	0.64
80	670	88.4	1.11
66	265	35.0	0.53
51	195	25.7	0.50
72	485	64.0	0.89
71	310	40.9	0.58
$\bar{x}$ 67.7		48.4	

Appendix 1 continued

ii) Culture set up on February 24

a) Seeded on March 26, aged 30 days
Harvested on August 13
Dry weight = 14.84% of fresh weight

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
31	600	89.0	2.87	aerated
144	4180	620.3	4.31	aerated
141	3080	457.1	3.24	aerated
109	3100	460.0	4.22	aerated
162	3970	589.1	3.64	aerated
163	2910	431.8	2.65	aerated
127	4220	626.2	4.93	aerated
117	3820	566.9	4.85	aerated
170	4310	639.6	3.76	aerated
92	4724	701.0	7.62	aerated
160	4570	678.2	4.24	
177	4810	713.8	4.03	
225	5520	819.2	3.64	
174	4540	673.7	3.87	
157	5080	753.9	4.80	
146	3950	586.2	4.01	
178	4510	669.3	3.76	
115	3870	574.3	4.99	
103	4280	635.2	6.17	
86	3010	446.7	5.19	
$\bar{x}$ 138.8		586.6		

Appendix 1 continued

b) Seeded on April 22, aged 57 days

Harvested on July 27

Dry weight = 13.2% of fresh weight

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
	175	1795	236.9	1.35	aerated
	83	1362	179.8	2.17	aerated
	95	1615	213.2	2.24	aerated
	159	1190	157.1	0.99	aerated
	120	760	100.3	0.84	aerated
	170	1405	185.5	1.09	aerated
	184	1550	204.6	1.11	aerated
	110	1410	186.1	1.69	aerated
	109	1260	166.3	1.53	aerated
	168	2000	264.0	1.57	aerated
	132	965	127.4	0.97	
	73	909	120.0	1.64	
	39	705	93.1	2.39	
	46	564	74.4	1.62	
	107	1140	150.5	1.41	
	132	588	77.6	0.59	
	66	786	103.8	1.57	
	43	300	39.6	0.92	
	138	1005	132.7	0.96	
	106	930	122.8	1.16	
$\bar{x}$	112.75		146.8		

iii) Culture set up on March 17

a) Seeded on March 26, aged 9 days

Harvested on August 13

Dry weight = 14.84 % of fresh weight

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
	71	1435	212.9	3.00	aerated
	29	640	95.0	3.28	
	135	2130	316.1	2.34	
	21	240	35.6	1.70	
	45	810	120.2	2.67	
	36	870	129.1	3.59	
	34	560	83.1	2.44	
	29	420	62.3	2.15	
	6	90	13.4	2.23	
	12	160	23.7	1.98	
$\bar{x}$	41.8		109.1		

b) Seeded on April 22, aged 36 days

Harvested on July 27

Dry weight = 13.2% of fresh weight

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
	52	540	71.3	1.37	aerated
	28	190	25.1	0.90	
	28	229	30.2	1.08	
	77	530	70.0	0.91	
	35	275	36.3	1.04	
	24	142	18.7	0.78	
	39	215	28.4	0.73	
	58	560	73.9	1.27	
	31	320	42.2	1.36	
	113	566	74.7	0.66	
$\bar{x}$	48.5		47.1		

Appendix 2 - Laminaria saccharina 1982

Number of plants, fresh weight, dry weight and dry weight per plant grown from 10 aerated and 10 unaerated seeding strings in 1982.

Culture set up on February 24

Seeded on March 19, aged 23 days

Harvested on August 13

Dry weight = 12.29% of dry weight

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
	69	5500	676.0	9.80	aerated
	36	3268	401.6	11.16	aerated
	64	6490	797.6	12.46	aerated
	45	4570	561.7	12.48	aerated
	97	6650	817.3	8.43	aerated
	69	5220	641.5	9.30	aerated
	56	5020	617.0	11.02	aerated
	2	105	12.90	6.45	aerated
	-	-	-	-	aerated
	-	-	-	-	aerated
	15	1770	217.5	14.50	
	1	58	7.1	7.13	
	1	120	14.8	14.75	
	3	205	25.2	8.40	
	9	810	99.5	11.06	
	7	1380	169.6	24.23	
	7	700	86.0	12.29	
	8	1100	135.2	16.90	
	2	220	27.0	13.52	
	-	-	-	-	
$\bar{x}$	28.9		312.2		

Appendix 3 - Saccorhiza polyschides 1982

Number of plants, fresh weight, dry weight and dry weight per plant for groups grown from each seeding string in 1982. Strings were placed in the sea at 2m depth in batches of 10 and were unaerated except where stated otherwise. Equivalent aerated and unaerated cultures were counted together for calculation of mean values and groups which were lost or failed to grow were ignored.

i) Culture set up on February 10

a) Seeded on March 19, aged 37 days
Harvested on August 13
Dry weight = 10.53% of fresh weight

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)
	2	1010	106.4	53.18
	7	2620	275.9	39.41
	4	3550	373.8	93.45
	1	710	74.8	74.76
	2	1330	140.0	70.02
	4	1760	185.3	46.33
	-	-	-	-
	-	-	-	-
	-	-	-	-
	-	-	-	-
$\bar{x}$	3.33		192.7	

Appendix 3 continued

b) Seeded on April 22, aged 71 days

Harvested on July 22

Dry weight = 8.87% of fresh weight

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)
13	515	45.7	3.51
16	1165	103.3	6.46
11	1050	93.1	8.47
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
$\bar{x}$ 13.3		80.7	

ii) Culture set up on February 24

a) Seeded on March 19, aged 23 days

Harvested on August 13

Dry weight = 10.53% of wet weight

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)
4	3620	381.2	95.3
1	1220	128.5	128.5
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
$\bar{x}$ 2.5		254.8	

aerated

Appendix 3 continued

b) Seeded on March 26, aged 30 days

Harvested on August 13

Dry weight = 10.53% of wet weight

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
2	1960	206.4	103.19	aerated
11	5030	529.7	48.15	
5	2010	211.7	42.33	
2	1810	190.6	95.30	
6	880	92.7	15.44	
4	2260	238.0	59.49	
-	-	-	-	
-	-	-	-	
-	-	-	-	
-	-	-	-	
$\bar{x}$ 5		244.8		

c) Seeded on April 22, aged 57 days

Harvested on July 27

Dry weight = 8.87% of wet weight

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
13	350	13.0	2.39	aerated
5	145	12.9	2.57	
6	420	37.2	6.21	
3	310	27.5	9.17	
8	514	45.6	5.70	
14	885	78.5	5.61	
16	995	88.3	5.52	
10	415	36.8	3.68	
22	649	57.6	2.62	
-	-	-	-	
$\bar{x}$ 10.8		44.2		

Appendix 3 continued

iii) Culture set up on March 17

Seeded on April 22, aged 36 days

Harvested on July 27

Dry weight = 8.87% of wet weight

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	
	8	204	18.1	2.26	aerated
	17	1110	98.5	5.79	
	22	1030	91.4	4.15	
	27	1715	152.1	5.63	
	34	2290	203.1	5.97	
	12	720	63.9	5.32	
	-	-	-	-	
	-	-	-	-	
	-	-	-	-	
	-	-	-	-	
$\bar{x}$	20		104.5		

Appendix 4

The lengths of the longest single plants in groups of Alaria, Laminaria and Saccorhiza seeded in November 1982, December 1982, February 1983 and April 1983 at 2m depth (10(2)m in April) at 50 and 100cm spacings, measured during the growth period. Shortened plants which were obviously damaged, e.g. by ropes tangling, rather than simply eroded, are marked * .

a) Alaria

i) November seeded

50 cm spacing

Date	Length (cm)									
Apr 21	-	-	105	110	156	153	150	114	58	60
Apr 28	-	-	128	123	179	176	174	134	78	78
May 5	-	-	135	144	190	191	189	156	87	89
May 16	-	-	150	177	214	213	210	175	106	103
May 23	-	-	173	187	212	217	225	189	123	116
May 31	-	-	180	219	225	218	240	214	135	132
Jun 7	-	-	175	210	221	223	215	206	151	-

100 cm spacing

Date	Length (cm)									
Apr 21	94	117	108	87	111	133	145	88	84	92
Apr 28	110	149	124	108	133	155	164	114	96	111
May 6	120	170	148	122	153	173	178	132	98	128
May 16	148	209	179	136	180	202	178	160	151	153
May 23	159	215	207	151	199	213	196	166	177	178
May 31	168	235	-	-	212	222	199	188	115	201
Jun 7	162	216	-	-	216	190	203	178	137	191

Appendix 4(a) continued

ii) December seeded

50 cm spacing

Date	Length (cm)									
Apr 28	187	185	200	173	206	196	191	205	163	141
May 5	193	192	206	179	214	205	195	201	171	157
May 16	214	195	223	199	230	238	224	233	190	195
May 23	202	207	218	199	247	251	203	240	185	212
May 31	190	200	235	197	242	250	203	225	194	205

100 cm spacing

Date	Length (cm)									
Apr 15	99	117	143	168	159	178	152	121	125	96
Apr 28	116	148	164	191	184	189	179	147	158	118
May 5	129	158	174	197	202	192	181	152	166	111
May 16	160	187	191	220	223	212	198	172	186	142
May 23	174	195	208	230	224	214	194	186	193	149
May 5	190	201	208	206	229	218	214	188	203	160
Jun 7	214	199	209	184	231	221	204	198	192	149

Appendix 4(a) continued

iii) February seeded

50 cm spacing

Date	Length (cm)									
Apr 21	119	103	91	120	121	120	115	106	105	113
Apr 28	156	144	144	171	165	176	151	160	151	172
May 5	171	180	191	208	197	229	177	192	162	189
May 16	220	221	254	236	241	282	223	261	243	160
May 23	278	270	303	270	272	295	243	281	275	286
May 31	257	256	323	294	291	310	251	292	314	307
Jun 7	265	247	312	296	283	289	256	282	315	312

100 cm spacing

Date	Length (cm)									
Apr 21	110	117	127	132	141	121	123	104	108	100
Apr 28	161	173	183	192	189	166	182	149	153	133
May 5	206	218	222	196	218	204	209	180	165	156
May 16	292	250	289	262	288	261	259	224	211	223
May 23	317	273	326	294	294	265	284	252	234	240
May 31	354	280	341	315	288	270	301	270	252	263
Jun 7	380	275	336	295	253	262	224	269	265	249

Appendix 4(a) continued

(iv) April seeded

50 cm spacing

Date	Length (cm)									
Jun 16	103	98	109	131	124	106	103	128	100	103
Jul 1	130	117	136	169	155	129	127	167	137	117
Jul 8	128	131	133	168	176	128	132	172	144	125
Jul 18	121	137	171	134	136	159	164	136	123	141

100 cm spacing

Date	Length (cm)									
Jun 16	139	115	112	120	140	136	120	92	110	87
Jul 1	151	145	144	138	173	157	144	135	123	114
Jul 8	155	141	154	145	169	155	130	144	127	127
Jul 18	124	121	154	131	145	155	140	140	141	145

Appendix 4 continued

b) Laminaria

i) November seeded

50 cm spacing

Date	Length (cm)									
Apr 21	78	78	89	83	39*	15*	-	-	-	-
Apr 29	92	91	99	98	46	34	-	-	-	10
May 11	107	108	101	117	61	57	-	-	-	33
May 24	142	132	110	136	85	66	-	-	-	48
Jun 3	162	152	129	48*	99	85	-	-	-	59
Jun 16	-	174	152	63	123	96	-	-	-	82
Jun 24	-	183	165	75	140	107	-	-	-	86
Jul 7	-	199	170	109	154	126	-	-	-	93
Jul 27	-	210	199	125	172	143	-	-	-	105
Aug 4	-	212	195	161	101*	157	-	-	-	109
Aug 17	-	-	-	163	162	174	-	-	-	-
Aug 25	-	-	-	172	179	-	-	-	-	128

100 cm spacing

Date	Length (cm)									
Apr 21	110	93	87	78	91	89	67	-	-	63
Apr 29	108	119	102	100	102	102	84	-	-	77
May 11	133	140	114	134	118	114	107	-	-	95
May 24	170	161	142	149	159	165	128	-	-	109
Jun 3	186	123	140	189	139	59*	137	-	-	80
Jun 16	-	78*	146	-	144	71	-	-	-	95
Jun 24	-	87	154	-	152	75	-	-	-	-
Jul 7	-	99	168	-	176	98	-	-	-	-
Jul 21	-	104	183	-	-	108	-	-	-	-
Aug 4	-	115	186	-	-	121	-	-	-	-
Aug 17	-	121	141	-	198	-	-	-	-	-
Aug 25	-	193	125	-	144	-	-	-	-	-

Appendix 4(b) continued

ii) December seeded

50 cm spacing

Date	Length (cm)									
Apr 29	95	77	67	43	56	67	96	112	111	104
May 11	135	111	95	58	85	91	123	139	139	137
May 24	150	136	120	73	102	118	141	157	164	170
Jun 3	172	155	142	91	104	140	180	-	189	201
Jun 16	136	104	166	122	132	99	220	-	111	232
Jun 24	152	104	193	131	155	106	235	-	103	245
Jul 7	161	125	-	140	171	118	243	-	-	275
Jul 21	178	135	-	143	202	-	263	-	-	285
Aug 8	193	155	-	142	221	-	234	-	-	248
Aug 17	196	174	-	154	231	-	244	-	-	246
Aug 25	-	177	-	164	242	-	235	-	-	253

100 cm spacing

Date	Length (cm)									
Apr 15	72	75	83	73	55	47	24	60	68	77
Apr 29	103	113	101	90	97	72	36	89	99	106
May 11	132	135	121	115	123	91	53	104	120	124
May 24	156	165	143	149	145	108	71	128	139	151
Jun 3	186	195	164	169	170	127	87	149	162	165
Jun 16	210	213	190	193	198	-	104	166	152	-
Jun 24	217	224	197	204	207	-	118	177	-	-
Jul 7	241	195	222	226	228	-	135	198	-	-
Jul 21	263	224	231	224	254	132	146	203	-	-
Aug 8	245	241	258	220	257	149	165	222	-	-
Aug 17	252	255	238	221	235	162	175	224	-	-
Aug 25	250	249	238	234	250	165	185	241	-	-

Appendix 4(b) continued

iii) February seeded

50 cm spacing

Date	Length (cm)									
Apr 21	22	24	25	29	28	21	27	25	20	0
May 5	48	47	48	49	61	47	48	45	44	14
May 18	74	71	70	70	89	79	71	70	68	32
Jun 3	118	103	109	101	125	115	109	92	84	60
Jun 16	136	122	131	130	137	198	-	116	132	79
Jul 1	148	143	156	153	180	180	-	139	111	93
Jul 9	166	171	174	167	196	191	-	153	183	101
Jul 18	190	176	196	183	205	193	-	174	200	109
Aug 4	209	195	230	205	232	226	-	189	190	110
Aug 16	216	205	243	203	233	224	-	113	203	132
Aug 23	221	214	254	208	226	236	-	203	216	148

100 cm spacing

Date	Length (cm)									
Apr 21	0	-	36	34	29	38	33	38	35	-
May 5	18	-	59	55	49	59	61	58	62	-
May 18	37		83	78	70	69	81	78	79	-
Jun 3	60	56	114	103	94	103	120	115	113	-
Jun 16	-	70	134	133	101	107	155	146	132	-
Jul 1	-	88	140	138	114	117	175	164	164	-
Jul 9	-	94	151	145	120	126	183	172	173	-
Jul 18	-	101	165	164	140	134	185	172	195	-
Aug 4	-	115	192	185	166	136	214	175	216	-
Aug 16	-	63*	206	199	149	139	225	183	227	-
Aug 23	-	76	226	211	159	144	236	185	237	-

Appendix 4(b) continued

iv) April seeded

50 cm spacing

Date	Length (cm)									
Jul 8	69	60	80	72	65	70	69	70	60	59
Jul 18	70	76	81	84	83	75	61*	72*	61*	56*
Aug 4	80	90	95	92	94	92	75	90	81	73
Aug 16	102	110	112	119	96	106	97	99	82	83
Aug 23	105	120	117	132	103	106	100	106	98	89

100 cm spacing

Date	Length (cm)								
Jul 8	49	83	78	78	92	81	64	61	76
Jul 18	65	96	86	92	100	95	72	72	80
Aug 4	82	114	97	101	122	111	80	83	98
Aug 16	92	119	117	116	146	117	83	88	117
Aug 23	92	131	118	118	145	135	87	95	125

Appendix 4 continued

c) Saccorhiza

i) November seeded

50 cm spacing

Date	Length (cm)									
Apr 21	-	74	94	77	-	-	61	-	161	152
Apr 29	-	86	148	110	-	-	78	-	209	181
Apr 11	-	-	-	116	-	-	168	-	147	272

100 cm spacing

Date	Length (cm)									
Apr 21	-	-	209	164	139	152	113	168	154	103
Apr 29	-	-	252	210	167	183	144	189	186	136
May 11	-	-	-	244	278	243	224	229	-	-

ii) December seeded

50 cm spacing

Date	Length (cm)									
Apr 29	108	102	133	104	129	130	136	111	136	193
Apr 11	133	158	163	163	206	203	226	171	214	160
May 24	203	225	197	240	295	-	303	225	298	233
Jun 8	-	-	280	-	298	-	-	48*	220	255

100 cm spacing

Date	Length (cm)									
Apr 15	64	53	42	36	59	52	65	39	50	48
Apr 29	124	107	78	86	126	113	124	73	106	100
May 11	149	185	122	119	196	174	199	120	155	103
May 24	204	249	180	160	259	-	266	169	235	170
Jul 3	230	-	222	-	-	-	-	190	257	218

Appendix 4(c) continued

iii) April seeded

50 cm spacing

Date				Length (cm)						
Jul 8	116	103	-	126	98	73	89	99	47	59
Jul 18	115	113	-	160	117	86	112	121	62	87
Aug 4	166	122	-	149	139	125	124	-	95	128

100 cm spacing

Date				Length (cm)						
Jul 8	129	-	155	112	102	143	140	152	156	135
Jul 18	168	-	170	138	132	173	160	178	160	162
Aug 4	137	-	-	152	124	181	-	187	160	152

Appendix 5 - Alaria esculenta 1983

Number of plants, fresh weight, dry weight, dry weight per plant and, where measured, length of longest plant for each group harvested in 1983. Strings were placed in the sea in batches of 10.

i) Seeded on November 25 at 2m depth

Harvested on June 9

Dry weight = 14.22% of fresh weight

a) Spaced at 100cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	47	2525	359.1	7.64	189
	77	2940	418.1	5.43	194
	42	1935	275.2	6.55	188
	65	2930	416.6	6.41	204
	7	517	73.5	10.50	152
	22	1455	206.9	9.40	164
	27	1085	154.3	5.71	157
	7	615	87.5	12.49	110
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	36.75		248.9		

Appendix 5 continued

b) Spaced at 50cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	75	2445	347.7	4.64	207
	49	1820	258.8	5.28	191
	69	2100	298.6	4.33	219
	78	2820	401.0	5.14	195
	51	1130	160.7	3.15	206
	35	1640	233.2	6.66	168
	9	730	103.8	11.53	151
	29	1080	153.6	5.30	205
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	49.4		244.7		

c) Spaced at 25cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	77	1680	238.9	3.10	186
	69	1310	186.3	2.70	185
	66	1530	217.6	3.30	205
	7	480	68.3	9.80	162
	90	1325	188.4	2.09	187
	53	1770	251.7	4.75	220
	34	1078	153.3	4.51	173
	66	1165	165.7	2.51	189
	67	1470	209.0	3.12	197
	84	1480	210.5	2.51	185
$\bar{x}$	61.3		189.0		

Appendix 5 continued

d) Spaced at 10cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
32	750	106.6	3.33	179
69	1248	177.5	2.57	176
32	573	81.5	2.55	169
23	489	69.5	3.02	171
35	352	50.1	1.43	136
6	228	32.4	5.40	130
22	590	83.9	3.81	192
66	818	116.3	1.76	183
42	872	124.0	2.95	176
21	401	57.0	2.72	151
$\bar{x}$ 34.8		89.9		

e) Spaced at 5cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
16	353	50.2	3.14	135
30	437	62.1	2.07	157
39	823	117.0	3.00	172
43	521	74.1	1.72	194
29	488	69.4	2.39	161
33	446	63.4	1.92	159
13	110	15.6	1.20	114
26	129	18.3	0.71	106
13	114	16.2	1.25	135
23	540	76.8	3.34	151
$\bar{x}$ 26.5		56.3		

Appendix 5 continued

ii) Seeded on December 13 at 2m depth

Harvested on June 1 (50cm) and June 8 (100cm)

Dry weight = 15.63% of fresh weight

a) Spaced at 100cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	89	2712	423.9	4.76	191
	111	2672	417.6	3.76	171
	99	3040	475.2	4.80	215
	54	1734	271.0	5.02	184
	118	2635	411.9	3.49	189
	50	1445	225.9	4.52	194
	89	2880	450.1	5.06	224
	94	3000	468.9	4.99	185
	25	865	135.2	5.41	143
	108	2790	436.1	4.04	195
$\bar{x}$	83.7		371.6		

b) Spaced at 50cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	103	2635	411.9	4.00	181
	127	2942	459.8	3.62	183
	124	2555	399.3	3.22	186
	82	2372	370.7	4.52	195
	118	2865	447.8	3.79	208
	103	2233	349.0	3.39	209
	116	2170	339.2	2.92	203
	69	2163	338.1	4.90	182
	113	2450	382.9	3.39	220
	140	2775	433.7	3.10	195
$\bar{x}$	109.5		393.2		

Appendix 5 continued

iii) Seeded on February 16 at 2m depth

Harvested on June 8

Dry weight = 13.61% of fresh weight

a) Spaced at 100cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
79	1970	268.1	3.39	301
146	2450	333.4	2.28	254
188	2900	394.7	2.10	290
242	3780	514.5	2.13	265
225	3530	480.4	2.14	245
175	3350	455.9	2.61	225
145	2750	374.3	2.58	240
185	3540	481.8	2.60	260
152	3560	484.5	3.19	380
218	3800	517.2	2.37	275
$\bar{x}$ 175.5		430.5		

b) Spaced at 50cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
154	2790	379.7	2.47	215
221	3670	499.5	2.26	285
232	3250	442.3	1.91	280
155	2955	402.2	2.59	285
132	2580	351.1	2.66	319
148	3160	430.1	2.91	276
153	2860	389.2	2.54	260
166	3100	421.9	2.54	278
207	3160	430.1	2.08	255
119	1945	264.7	2.22	242
$\bar{x}$ 168.7		401.1		

Appendix 5 continued

iv) Seeded on April 5 at 2m depth

Harvested on July 20

Dry weight = 15.76% of fresh weight

a) Spaced at 100 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
55	1065	167.8	3.05	-
15	156	24.6	1.64	-
23	214	33.7	1.47	-
1	21	3.31	3.31	-
3	53	8.4	2.09	-
52	635	100.1	1.92	-
1	45	7.1	7.10	-
3	40	6.3	2.10	-
-	-	-	-	-
-	-	-	-	-
$\bar{x}$ 19.1		43.9		

b) Spaced at 50cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
19	247	38.9	2.05	-
19	184	29.0	1.53	-
9	110	17.3	1.93	-
2	18.5	2.9	1.46	-
1	59	8.7	8.70	-
3	120	18.9	6.30	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
$\bar{x}$ 8.8		19.3		

Appendix 5 continued

c) Spaced at 10cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	3	73	11.5	3.80	-
	1	23	3.6	3.62	-
	9	155	24.4	2.71	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	4.3		13.2		

d) Spaced at 5cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)	
	6	99	15.6	2.60	-	
	69	654	103.1	1.49	-	
end group ⟶X	3	60	9.5	3.15	-	X
	8	81	12.8	4.26	-	
	20	259	40.8	2.04	-	
	3	57	9.0	3.00	-	
	2	54	8.5	4.26	-	
	-	-	-	-	-	
	-	-	-	-	-	
	-	-	-	-	-	
$\bar{x}$	15.9		28.5			

Appendix 5 continued

v) Seeded on April 5 at 10m depth (raised to 2m after 6 weeks)

Harvested on July 18

Dry weight = 14.31% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	125	938	134.2	1.07	-
	145	1028	147.1	1.01	-
	124	1034	148.0	1.19	-
	117	1131	161.8	1.38	-
	89	674	96.4	1.08	-
	106	917	131.2	1.24	-
	81	774	110.8	1.37	-
	176	1028	147.1	0.84	-
	89	1052	150.5	1.69	-
	110	1035	148.1	1.35	-
$\bar{x}$	116.2		137.5		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	104	966	138.2	1.33	-
	102	971	139.0	1.36	-
	69	925	132.4	1.92	-
	47	585	83.7	1.78	-
	72	839	120.1	1.67	-
	17	440	63.0	3.70	-
	104	959	137.2	1.32	-
	76	817	116.9	1.54	-
	31	672	96.2	3.10	-
	89	1058	151.4	1.70	-
$\bar{x}$	71.1		117.8		

Appendix 5 continued

vi) Seeded on April 5 at 3m depth

Harvested on July 18

Dry weight = 14.96% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	74	899	134.5	1.82	-
	63	797	119.2	1.89	-
	120	1038	155.3	1.29	-
	41	376	56.2	1.37	-
	73	704	105.3	1.44	-
	75	817	122.2	1.63	-
	52	644	96.3	1.85	-
	30	312	46.7	1.56	-
	73	582	87.1	1.19	-
	64	961	143.8	2.25	-
$\bar{x}$	66.5		106.7		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	84	819	122.5	1.46	-
	51	920	137.6	2.70	-
	112	1037	155.1	1.39	-
	29	642	96.0	3.31	-
	75	658	98.4	1.31	-
	71	739	110.6	1.56	-
	55	677	101.3	1.84	-
	44	557	87.8	2.00	-
	86	834	124.8	1.45	-
	93	1040	155.6	1.67	-
$\bar{x}$	70.0		119.0		

Appendix 5 continued

vii) Seeded on April 5 at 5m depth

Harvested on July 18

Dry weight = 14.58% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	119	678	98.9	0.83	-
	4	175	25.5	6.38	-
	30	561	81.8	2.73	-
	82	720	105.0	1.28	-
	107	854	124.5	1.16	-
	59	821	119.7	2.03	-
	98	838	122.2	1.25	-
	95	839	122.3	1.29	-
	121	804	117.2	0.97	-
	26	757	110.4	4.25	-
$\bar{x}$	74.1		102.75		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	82	449	65.5	0.80	-
	114	778	113.4	1.00	-
	126	769	112.1	0.89	-
	98	707	103.1	1.05	-
	111	660	96.2	0.87	-
	98	683	99.6	1.02	-
	94	864	126.0	1.34	-
	81	719	104.8	1.29	-
	74	603	87.9	1.19	-
	89	637	92.9	1.04	-
$\bar{x}$	96.7		100.15		

Appendix 6 - Laminaria saccharina 1983

Number of plants, fresh weight, dry weight, dry weight per plant and, where measured, length of longest plant for each group harvested in 1983. Strings were placed in the sea in batches of 10. Missing values were ignored for calculation of means.

i) Seeded on Novr. 25 at 2m depth

Harvested on September 7

Dry weight = 15.04% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	7	564	84.8	12.12	-
	11	682	102.6	9.32	-
	5	359	54.0	10.80	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	7.7		80.48		

Appendix 6 continued

b) Spaced at 50 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
5	235	35.4	7.07	-
7	856	128.7	18.39	-
13	2341	352.1	27.08	-
1	390	58.7	58.70	-
8	641	96.4	12.05	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
$\bar{x}$ 6.80		134.3		

c) Spaced at 25 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
9	627	94.3	10.48	-
5	494	74.3	14.86	-
13	907	136.4	10.49	-
8	735	110.5	13.82	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
$\bar{x}$ 8.75		103.9		

Appendix 6 continued

d) Spaced at 10 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	26	3316	498.7	19.18	-
	26	2384	358.6	13.79	-
	17	2242	337.2	19.84	-
	14	1061	159.6	11.40	-
	4	386	58.1	14.51	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	17.4		282.4		

e) Spaced at 5 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
*	46	5376	808.6	17.58	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	15.33		269.5		

* 3 Groups which could not be separated because the holdfasts had fused together.

Appendix 6 continued

ii) Seeded on December 13 at 2m depth

Harvested on September 7

Dry weight = 15.43% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. / plant (g)	Length (cm)
	41	6029	930.3	22.69	-
	34	4210	649.6	19.11	-
	20	2836	437.6	21.88	-
	35	5832	899.9	25.71	-
	26	3468	535.1	20.58	-
	18	4141	639.0	35.50	-
	3	1008	155.5	51.84	-
	4	826	127.5	42.48	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	22.6		546.8		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. / plant (g)	Length (cm)
	7	1246	192.3	27.47	-
	5	876	135.2	27.03	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	6		163.75		

Appendix 6 continued

iii) Seeded on February 16 at 2m depth

Harvested on September 7

Dry weight = 15.91% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	29	5749	914.7	31.54	-
	33	6416	1020.8	30.90	-
	27	5282	840.4	31.12	-
	21	4166	662.8	31.56	-
	7	1987	316.1	45.16	-
	12	2032	323.3	26.94	-
	5	642	102.1	20.43	-
	15	3650	580.7	38.71	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	18.5		595.1		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	14	2748	437.2	31.23	-
	6	1604	255.2	42.53	-
	8	948	150.8	18.85	-
	8	1496	238.0	29.75	-
	2	543	86.4	43.20	-
	4	401	63.8	15.95	-
	7	416	66.2	9.46	-
	2	187	29.8	14.88	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	6.4		165.9		

Appendix 6 continued

iv) Seeded on April 5 at 2m depth

Harvested on September 8

Dry weight = 15.30% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	4	215	32.9	8.22	70
	7	163	24.9	3.56	74
	2	99	15.1	7.57	61.5
	7	252	38.6	5.51	89
	5	194	29.7	5.94	80.5
	4	455	69.6	17.40	103
	5	252	38.6	7.71	91
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	4.9		35.6		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	1	52	8.0	7.96	37
	1	21	3.2	3.21	65
	3	144	22.0	7.34	95
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	1.7		11.1		

Appendix 6 continued

c) Spaced at 10 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
10	295	45.13	4.51	85
3	114	17.40	5.81	82.5
3	141	21.57	7.19	26
4	84	12.85	3.21	60
7	141	21.57	3.08	72.5
5	250	38.25	7.65	80
3	24	3.70	1.22	45
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
$\bar{x}$ 5.0		22.92		

d) Spaced at 5 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
6	350	53.55	8.92	113
4	205	31.36	7.84	97
3	307	47.00	15.66	92
14	1202	183.90	13.14	124
16	1161	177.60	11.10	123
3	29	4.44	1.48	53
13	834	127.60	9.82	104
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
$\bar{x}$ 8.43		89.35		

Appendix 6 continued

v) Seeded on April 5 at 10m depth (raised to 2m after 6 weeks)

Harvested on September 7

Dry weight = 15.30% of fresh weight

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
10	412.7	62.0	6.20	95.5
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

Appendix 6 continued

vi) Seeded on April 5 at 3m depth

Harvested on September 8

Dry weight = 15.55% of fresh weight

a) Spaced at 100 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
2	94	14.6	7.31	71
17	1921	298.7	17.57	126
17	1693	263.3	15.49	131
7	917	142.6	20.37	116
14	2164	336.5	24.04	134.5
18	1738	270.3	15.01	149
5	562	87.4	17.48	111
23	1953	303.7	13.20	121
31	2963	460.7	14.86	142
-	-	-	-	-
$\bar{x}$ 14.9		242.0		

b) Spaced at 50 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
20	1145	178.0	8.90	116.5
38	2797	434.9	11.45	164.5
25	2793	434.3	17.37	153
35	3212	499.5	14.27	153
15	1544	240.1	16.01	132
6	510	79.3	13.22	123.5
7	147	22.9	3.27	96
10	1171	182.1	18.21	127.5
-	-	-	-	-
-	-	-	-	-
$\bar{x}$ 19.5		258.9		

Appendix 6 continued

vii) Seeded on April 5 at 5m depth

Harvested on September 8

Dry weight = 14.95% of fresh weight

a) Spaced at 100 cm intervals

	No. of plant	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	20	2160	322.9	16.15	154
	8	625	93.4	11.68	132.5
	35	2837	424.1	12.12	140
	17	2066	308.9	18.17	123
	11	1488	222.5	20.22	168
	33	3553	531.2	16.10	155
	16	2235	334.1	20.88	155.5
	9	926	138.4	15.38	126.5
	16	1251	187.0	11.69	121
	23	2120	316.9	13.78	149
$\bar{x}$	18.8		287.9		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	28	2744	410.2	14.65	132
	8	837	125.1	15.64	138
	41	4088	611.2	14.91	159
	25	2181	326.1	13.04	133
	13	1228	183.6	14.12	126
	8	1137	170.0	21.25	151
	10	770	115.1	11.51	131
	27	2486	371.7	13.77	136
	14	977	146.1	10.44	123
	15	2006	298.9	19.93	160
$\bar{x}$	18.9		275.8		

Appendix 7 - Saccorhiza polyschides 1983

Number of plants, fresh weight, dry weight, dry weight per plant and, where measured, length of longest plant for each group harvested in 1983. Strings were placed in the sea in batches of 10. Missing values were ignored for calculation of means.

i) Seeded on April 5 at 2m depth

Harvested on September 8

Dry weight = 10.34% of fresh weight

a) Spaced at 50 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
1	61	6.3	6.3	77.5
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

b) Spaced at 25 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
1	1081	111.8	111.8	126
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

Appendix 7 continued

ii) Seeded on April 5 at 10 m depth (raised to 2 m after 6 weeks)
Harvested on September 8
Dry weight = 10.64% of fresh weight

a) Spaced at 100cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	2	1136	120.9	60.44	109.5
	3	2031	216.1	73.03	141
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	2.5		168.5		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	2	2043	217.4	108.69	107.5
	5	1728	183.9	36.77	205.5
	3	746	79.4	26.46	104
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	3.3		160.2		

Appendix 7 continued

c) Spaced at 10 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
1	364	37.6	37.6	118.5
1	480	49.6	49.6	124
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

d) Spaced at 5 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
1	591	61.1	61.1	156
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

Appendix 7 continued

iii) Seeded on April 5 at 3 m depth

Harvested on September 8

Dry weight = 11.55% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	5	1618	186.9	37.38	111
	9	5456	630.2	70.02	156
	2	1246	143.9	71.96	126
	3	1804	208.4	69.47	133
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	4.75		292.3		

b) Spaced at 50 cm intervals

No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
3	2761	318.9	106.3	115.5
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

Appendix 7 continued

iv) Seeded on April 5 at 5 m depth

Harvested on September 8

Dry weight = 10.64% of fresh weight

a) Spaced at 100 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	7	3713	395.1	56.44	122.5
	1	597	63.5	63.52	100
	5	2661	283.1	56.63	109
	7	1730	184.1	26.30	82
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	5		231.4		

b) Spaced at 50 cm intervals

	No. of plants	Fresh wt. (g)	Dry wt. (g)	Dry wt. /plant (g)	Length (cm)
	12	5196	552.9	46.07	204
	9	4658	495.6	55.07	206
	6	1860	197.9	32.98	199
	2	1081	115.0	57.50	108
	8	3080	327.7	40.96	99
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
$\bar{x}$	7.4				

APPENDIX 8

Abundance and general observations on fauna and flora associated with the horizontal ropes in Bay Fine. Many of the species were growing on the cultivated algae, rather than directly on the rope.

ANIMALS

Pisces

Cyclopterus lumpus	v. common, up to 5 per plant, on Alaria and Laminaria late spring - early summer. To 4cm by late summer.

No other fish were ever seen by divers or during weighing of the weed.

Mollusca

Gastropoda

Prosobranchs:

Lacuna vincta	v. common, on all three species especially Laminaria.
Gibbula cinereria	occasionaly, on all three species especially Saccorhiza.

Opisthobranchs

Polycera quadrilineata	v. common, on all three species.
Facelina auriculata	occasional, on all three species.
Dendronotus frondosus	occasional, distribution unknown.

3 unidentified spp, one similar to Eolis pistulata/E.glaucoides
one similar to Limacea claviger.
one dorid.

App. 8 cont.

Bivalvia

Chlamys opercularis	v. common, mainly on *Laminaria*. Occasionally on rope.
Modiolus modiolus	common, mainly in holdfasts at *Laminaria* to 1.5cm by end of summer. Occasionally on rope.

Crustacea

Decapoda

Leander serratus	common, distribution unknown.

Amphipoda

Jassa falcata	v. common, on all three species, especially *Laminaria* and *Saccorhiza*, also *Desmerestia.*
Amphithoe rubricata	common, distribution as above.
1 unidentified sp., similar	to *Nototropis*, occasional.
Caprella fretensis	common, associated with red algae on plants and rope.
Caprella acanthifera	occasional, distribution as *C. fretensis*.

Isopoda

Idotea baltica	common, distibution unknown.

Pycnogonida

Endeis spinosa	occasional, distribution unknown.

Cirripedia

Balanus balanoides	occasional, on rope.

App. 8 cont.

	Polychaetes
Nereis pelagica	common, in holdfasts of all three species.
Hymothoe impar	occasional, ina holdfasts of all three species.
1 other unidentified errant polychaete.	
	Echinoderma
	Echinoidea
Psammechinus miliaris	common, to 0.75cm on Laminaria.
	Crinoidea
Antedon bifida	occasional, in holdfasts of all three species.
	Tunicata
Ascidia conchilega	common, in holdfasts of all three species.
	Hydrozoa
Syncoryne eximia	v. common, on all three species but mainly old Laminaria. Common on rope.
Sertularella polyzonias	common, on old Laminaria and on rope.
	Bryozoa
Membranipora membranacea	v. common on all three species.
Electra pilosa	v. common on Alaria in 1982, none in 1983.

App. 8 cont.

PLANTS

Chlorophycae

Enteromorpha compressa	occasional, on ends of all three species.
Enteromorpha intestinalis	occasional, on all three species. common on rope, to 3m length in early summer.
Ulva lactuca	occasional, on rope.
Cladophora spp	common, on all three plants and rope.

Rhodophycae

Ceramium rubrum	common, on all three species and rope in late summer.
Ceramium sp	common distribution as above.
Porphyra umbilicalis	common, distribution as above.
Palmaria palmata	occasional, distribution as above.
Antithamnion plumula	occasional, distribution as above.
Gelidium latifolium	occasional, distribution as above.
Phycodris rubens	occasional, distribution as above.
Plocamium cartilagineum	occasional, distribution as above.
Polysiphonia urceolata	common, on all three species.
Polysiphonia elongata	common, on all three species.

Phaeophycae

Saccorhiza polyschides	v. common, on ropes.
Laminaria saccharina	v. common, on ropes.
Alaria esculenta	v. common, on ropes.
Desmarestia aculeata	common, on ropes.
Desmarestia viridis	v. common, on ends of all three species in early summer.
Scytosiphon lomentaria	occasional, on ropes.
Dictyota dichotoma	occasional, on ropes.
Ectocarpus spp	common, on all three spp and ropes.

App. 8 cont.

Pilayella spp	occasional, on all three species.
Young fucoids	occasional, on ropes, to 3cm.

Diatomaceae

Unidentified filamentous diatoms - everywhere, densest on surface ropes in spring.