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Preliminary studies on the utilization of the resources of spat mussels, *Mytilus edulis* L., occurring in Morecambe Bay, England

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I INTRODUCTION

Morecambe Bay, an exposed locality on the eastern shores of the Irish Sea, has long been noted for regular and heavy mussel spatfalls but poor survival. Since 1968, settlement, growth and survival in this area have been studied with a view to stimulating large-scale but rational exploitation of the stocks of both spat and seed mussels. The first year's work was reported by Dare (1969). The present paper first summarizes the main findings of the three-year ecological study and then describes work in progress on possible methods of utilizing the spat.

II MUSSEL RESOURCES AND ECOLOGY

From 1968 to 1971, an annual cycle of dense intertidal spatfall, rapid growth and almost complete destruction of settlements occurred in the bay. Each settlement was short-lived so that few mussels survived beyond their second year to reach marketable size (55 mm). These findings broadly confirm the earlier reports of fishery officers, and the observed pattern of events is considered typical of the present ecological régime in the bay.

Spat (mostly plantigrades of the secondary settlement stage, see Bayne 1964) occur plentifully in the waters of the bay throughout the year, being especially abundant in May-July after the main spawning, and scarcest in early spring and late summer (Figure 1). Intertidal settlement is not correlated directly with spat availability in the sea, but is controlled by a naturally re-occurring sequence of physical and biological events on the mussel-bearing grounds. The major crop-producing spatfalls occur in winter and early spring (December-April) after the hard stony grounds have largely been denuded of the previous year's mussels by storms and tidal scour, and when spat are not particularly plentiful. The winter spatfall secures itself in the interstices of the compact stony and shell gravel substrates, and accumulates over several months to reach densities often of 100 000-200 000 spat per m^2. The spat, of mean length 1.0-1.5 mm, lie dormant until April when shell growth starts. In May, a phase of expansion, during which spat are actively mobile, precedes a summer period of rapid growth.

By the time spring-spawned spat, including primary settlement stages, are abundant in the water (May-July) most suitable substrates are already covered by dense populations of fast-growing winter seed. Few spat settle or survive on these established seed beds. Consequently, summer spatfalls intertidally are of minor importance, and possibly most spat then settle sublittorally. Autumn spat do not form intertidal settlements either, due to lack of suitable ground or, in any case, to the destructive action of storms.

At the end of summer some beds are carpeted with 20-30 mm seed at densities of 50-100 tons per acre (1 ton per acre = 2 500 kg per hectare). The largest, and most exposed ground - "South America" near Barrow-in-Furness - may then hold 2 000-4 000 tons ($2\text{-}4 \times 10^6$ kg) of dredgeable seed, most of which is doomed to destruction and dispersion by autumn storms. The annual seed crop from this particular ground can be harvested by conventional dredges, for relaying elsewhere, but the gathering season is restricted to about 2 months by the onset of bad weather. Less exposed, but smaller, beds in the bay, e.g. at Heysham, retain much seed through the first autumn but are too rocky and uneven for dredging.

The logistics of extracting large quantities of seed mussels in such a short period and transporting them long distances across open sea (75 miles - 120 km - to the nearest culture grounds in North Wales) pose formidable problems. A less laborious, and biologically more attractive, approach is to utilize not the seed but the plentiful and ever-present spat supply to stock fisheries - and even to introduce hanging culture to distant estuaries where spatfalls are deficient and conditions are unfavourable for bottom culture. The first year's results from a feasibility study of these prospects are presented below.

III CAPTURE AND TREATMENT OF SPAT

The field studies indicate that it should be possible to catch spat throughout the year by adapting techniques to seasonal changes in spat behaviour and occurrence. From April to September 1970, and again since February 1971, methods have been tested to harvest both "settled" ground spat and planktonic spat. In 1970, collecting materials were exposed near the mean low-water mark of spring tides (MLWMST) on the "South America" ground for periods of two or four weeks. During 1971, experiments are being conducted at a higher and less remote site not far below the low-water mark of neap tides, where monitoring records (Figure 1) suggest that sufficient spat are still available.

(i) Ground spat During January-May these crawl and resettle in large numbers on ropes staked flat over stony, spatted grounds. This method cannot be used after May, due to ropes soon being buried by mud and silt accreted by the then rapidly developing mussel bed. For the 1970 work 2 cm diameter coir ropes, 2-4 m long, were used, but 1 cm diameter polypropylene rope is also effective. Short cross-sticks were inserted at 30 cm intervals to prevent the growing crops from sliding off the ropes.

(ii) Planktonic spat During May-July enormous numbers of spring-spawned spat were caught on collectors of rubberized fibrous material ("hairlok", see Dare 1969) set 0.5 to 1 m above the ground. Monitoring data (Figure 1) indicate that such collectors should catch spat in all months. In 1970, hairlok was deployed either in strips bound spirally around coir ropes slung horizontally off the bottom, or as large (180 x 60 x $2\frac{1}{2}$ cm) vertical sheets supported in timber and netting frames. Sheets were later cut into 5 cm wide strips and spiralled loosely around coir ropes fitted with cross-sticks just before immersion in the sea. Coir ropes by themselves caught relatively small numbers of planktonic spat.

Some typical catch rates are given in Table 1, derived from spat extracted from sample lengths of different materials. Observations later suggested that the higher catch rates resulted in overcrowding and reduced growth on ropes (see below).

Ropes were taken 200 miles by road to the Menai Straits, North Wales, where they were suspended vertically with their tops 2 m beneath the sea surface. This site was chosen because of its sheltered deep waters, good salinity, proximity to the Conway laboratory and to a mussel industry, and because of earlier work at Conway on mussel growth rates (Davies 1969).

In transit, spat-laden materials were placed between wet sacks for up to 20 hours in summer without obvious adverse effects. It was soon realized that collectors stored under seawater circulation, even overnight, should be laid horizontally to prevent spat swarming upwards and producing very uneven distributions. Vertical movements, even of 30-50 mm mussels, sometimes occurred long after immersion in the sea, but these were relatively minor.

IV GROWTH IN HANGING CULTURE

Certain ropes were sampled every one to two months for growth studies. Detailed measurement of survival and yield was, however, precluded by damage and losses caused (a) by coir ropes and hairlok starting to disintegrate after 6-9 months, and (b) by shell stunting at the lower ends of ropes due to adjacent mussel masses brushing together in the turbulent waters. Sampling was restricted, therefore, to the upper region of ropes. There were no predation or fouling problems in 1970, but light barnacle and algal settlements occurred in spring 1971.

(1) Shell length (Figure 2)

Mean growth rates on two of the four pairs of ropes set out in May 1970 (curves A and B) are compared with those of contemporary 1970 spat populations at MLWNST in Morecambe Bay (curves C and D). Growth on all ropes was much faster than that of the original "South America" stock (D), but only on plain coir ground ropes (A, and another pair not shown) did growth match or exceed that (C) on the low shore at Heysham. Growth on hairlok-entwined ropes (B and others not shown) was slower than at Heysham. After one year the 1-2 mm spat had attained mean lengths ranging from 32 mm (some hairlok populations) to 46 mm (on plain coir). Fastest-growing individual mussels grew to 58 mm after six months and 68 mm after one year. These observations are in accord with the growth of caged sublittoral spat in the Menai Straits, where Davies (1969) reported the mean length after one year to be 42 mm. Faster mean growth rates, to 49-61 mm in the first year, occur among natural settlements on ropes in Linnhe Mhuirich, Scotland (Mason 1968).

Most of our rope populations were clearly overcrowded, with the mussel clusters up to 20-25 cm in diameter after only four months. It is likely that faster growth would be achieved by less dense initial settlements, or by thinning out the crop within the first few months.

(2) Condition

Measurements of dry meat and shells (Figure 3) showed that the transplanted mussels contained less flesh during their first year than did mussels of the same age and size growing on the exposed Morecambe Bay shore at Heysham, where feeding conditions appear to be especially good. As expected, however, shells were thinner and smoother in the rope population. Direct comparison with growth at the "South America" ground was not possible because few mussels survived there to 40 mm. The occasional data available, however, clearly showed that growth and condition were always poorer than at Heysham.

Dry Condition Indices - i.e. (dry meat weight ÷ dry shell weight) x 100 - of the experimental rope mussels are compared with data from Heysham and from navigation buoy populations in Table 2. Due largely to their thinner shells the meat yield per unit weight of rope mussels is likely to exceed that of Morecambe Bay shore mussels, and to compare favourably with that of buoy chain populations.

V DISCUSSION

These first results are on the whole encouraging. It has been demonstrated that large quantities of spat can readily be caught during at least six months of the year, and transported 200 miles by road to produce viable rope cultures. Indeed, Morecambe Bay might well supply spat to culture sites up to 400 miles (or 24 hours travelling time) away. However, the most efficient types and arrangements of collector and culture materials remain to be perfected.

Growth of the first trial stocks was poorer than expected, except on the less densely stocked bare coir ropes, and it is evident that controlling population density - perhaps by the method of Bøhle (1970) - to attain better growth and optimum yield is of vital importance. The most suitable size and time for harvesting remain to be determined. From the data of Davies (1969), rope mussels in the Menai Straits will probably take 16-18 months to reach acceptable minimum size (50-55 mm) for the British markets. In France, however, mussels are usually marketed at only 40-50 mm (Mason 1971). Table 3 shows that on our best ropes the majority of mussels had attained this size after only one year under (probably) suboptimal conditions. Density control should improve this growth rate.

The advantages of harvesting at a smaller size, and being able to restock with spat for much of the year from a reliable source, could go a long way to making hanging culture in Britain economically, as well as biologically, feasible.

VI SUMMARY

Ecological studies of the large mussel resources in Morecambe Bay during 1968-71 demonstrated the existence of an annual cycle of heavy intertidal spatfalls and rapid growth followed by massive mortality from storms and tidal scour during the first autumn and winter after settlement. Several thousand tons of 20-30 mm seed mussels become available

for dredging towards the end of each summer, but harvesting is restricted by the onset of autumnal gales and by the long sea crossing to the nearest relaying grounds.

An alternative method of exploitation is to utilize the spat stage. Spat are plentiful in Morecambe Bay waters throughout the year, being especially abundant in May-July (after the spring spawning peak) and scarcest in early spring and late summer. Large quantities of spat can be obtained, both from the plankton and after settling on stony substrates, by adapting collecting techniques to observed seasonal changes in occurrence and behaviour.

Coir ropes and fibrous rubberized material ("hairlok") were used to demonstrate successfully that spat-laden collectors can be taken by road for more than 200 miles to establish viable hanging cultures in more sheltered waters. Thus, expansion into quite distant areas where natural spatfalls are deficient and conditions unfavourable for bottom culture might be possible. The need to control stock density on culture materials, to obtain optimum growth and yield, is especially vital due to the high catch rates of spat collectors in Morecambe Bay.

Harvesting rope crops at a smaller size for export, together with the major advantage of a reliable large source of spat for much of each year, suggests that Morecambe Bay's spat potential could help significantly to introduce an economical method of hanging culture to Britain and to open up new areas for mussel production.

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Table 1 Numbers of spat caught by various collectors exposed near MLWMST in Morecambe Bay

Collector		Exposure period		Spat caught		State of crop after 6 months
Type	Setting	Weeks	Dates	No. per metre	Mean length (mm)	
Coir rope	on ground	4	29 Jan-28 Feb 1971	15 000	1.4	-
" "	" "	4	29 Mar-27 Apr 1971	28 000	2.1	-
" "	off ground	4	24 June-22 July 1970	6 000	1.7	Good set
" "	" "	8	22 July-18 Sept 1970	4 000	1.8	Sparse, not viable
Coir and hairlok	off ground	2	7-21 May 1970	49 000	1.9	Very dense set
" " "	" "	4	22 May-24 June 1970	19 000	3.4	Heavily set

(N.B. One sheet of hairlok, 180 x 60 x 2.5 cm, caught an estimated 550 000 spat during two weeks in mid-May 1970 and 180 000 during four weeks from late May 1970)

Table 2 Dry Condition Indices of transplanted Morecambe Bay mussels growing on ropes in the Menai Straits, compared with populations on shore and navigation buoys in these areas

(Dry Condition Index $= \frac{\text{dry weight of meat}}{\text{dry weight of shell}} \times 100$)

Mean length (mm)	MORECAMBE BAY					NAVIGATION BUOYS		
	Rope transplants		Heysham, MLWMST, 1969-71			Morecambe Bay	Menai Straits	
	Nov 1970	Apr 1971	Nov 1970	Annual max. (Sept-Oct)	Min. (June)	Dec.1969	June 1970	Oct 1970
40	16.0	12.1	12.5	17.4	10.5	18.4	19.6	15.9
45	18.1	13.5	11.3	18.2	10.0	18.3	18.6	18.9
50	17.2	14.8	11.3	15.7	8.3	22.3	18.1	21.5
55	-	16.1	11.3	16.6	6.7	23.6	17.6	-
60	-	-	-	-	7.1	26.0	16.0	-

Table 3 The proportions of transplanted Morecambe Bay spat exceeding certain sizes after one year's growth on ropes in the Menai Straits

Rope		Population mean length (mm)	Percentage of population exceeding:			
Type	Code no.		40 mm	45 mm	50 mm	55 mm
Coir, plain	5	47.0	82.9	67.2	38.8	11.8
" "	7	38.6	41.4	23.5	6.8	0
" "	8	42.6	63.7	43.1	17.1	3.4
	Averages	42.7	62.7	44.6	20.9	5.1
Coir and hairlok	1	39.2	43.5	18.4	5.9	0
" " "	3	36.9	34.5	19.3	3.8	1.1
" " "	9	39.1	51.9	25.5	7.3	2.4
" " "	10	32.2	15.3	3.9	0.6	0
	Averages	36.9	36.3	16.8	4.4	0.9

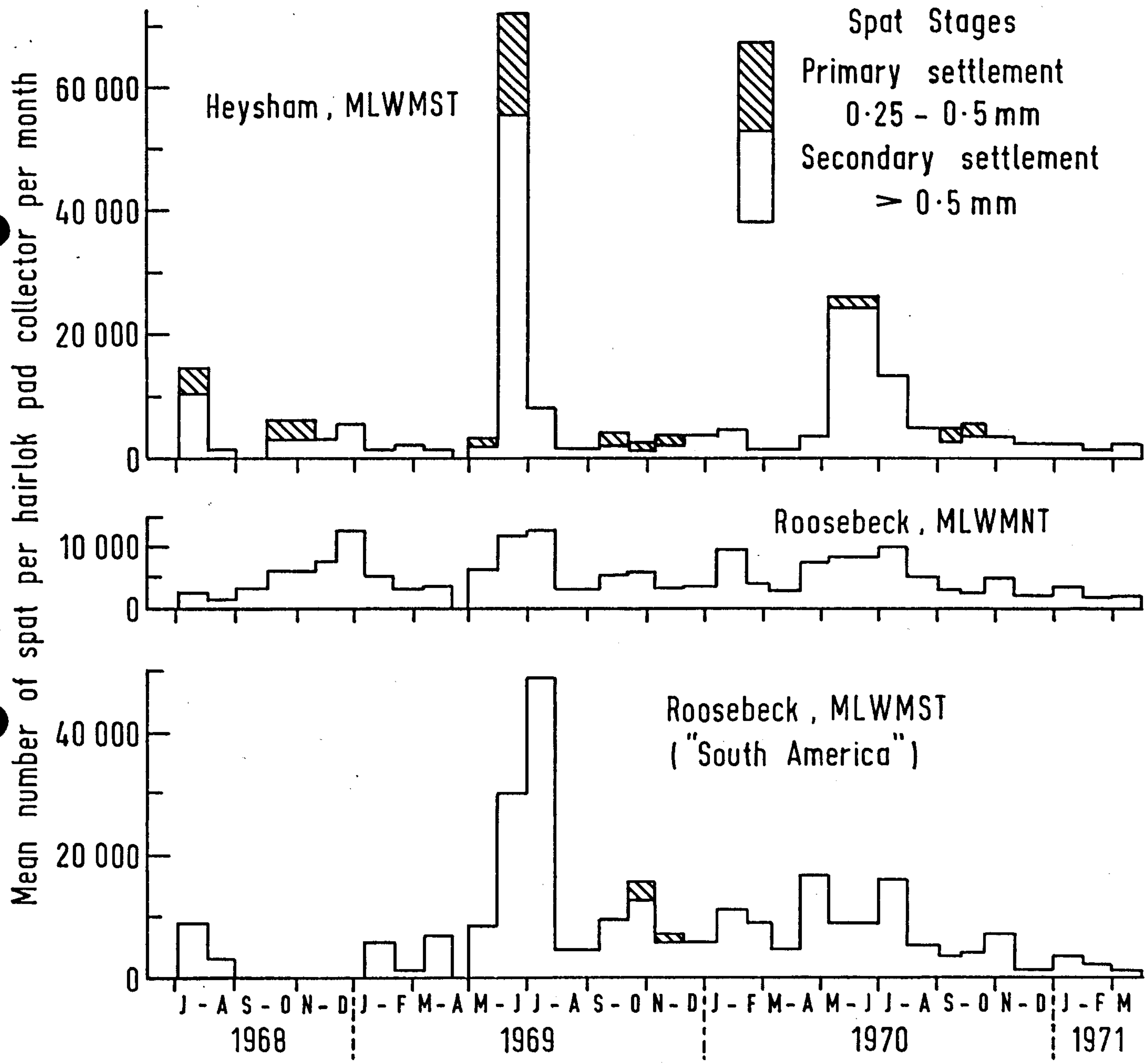

Figure 1 Seasonal variations in the abundance of available spat in the sea at three stations in Morecambe Bay, 1968-71.
(MLWMST and MLWMNT = mean low-water mark of spring tides and neap tides respectively.)

There are five periods in which no observations could be made: at Heysham, in September 1968 and April 1969; at Roosebeck, in April 1969; at "South America", in September 1968-January 1969 and April 1969.

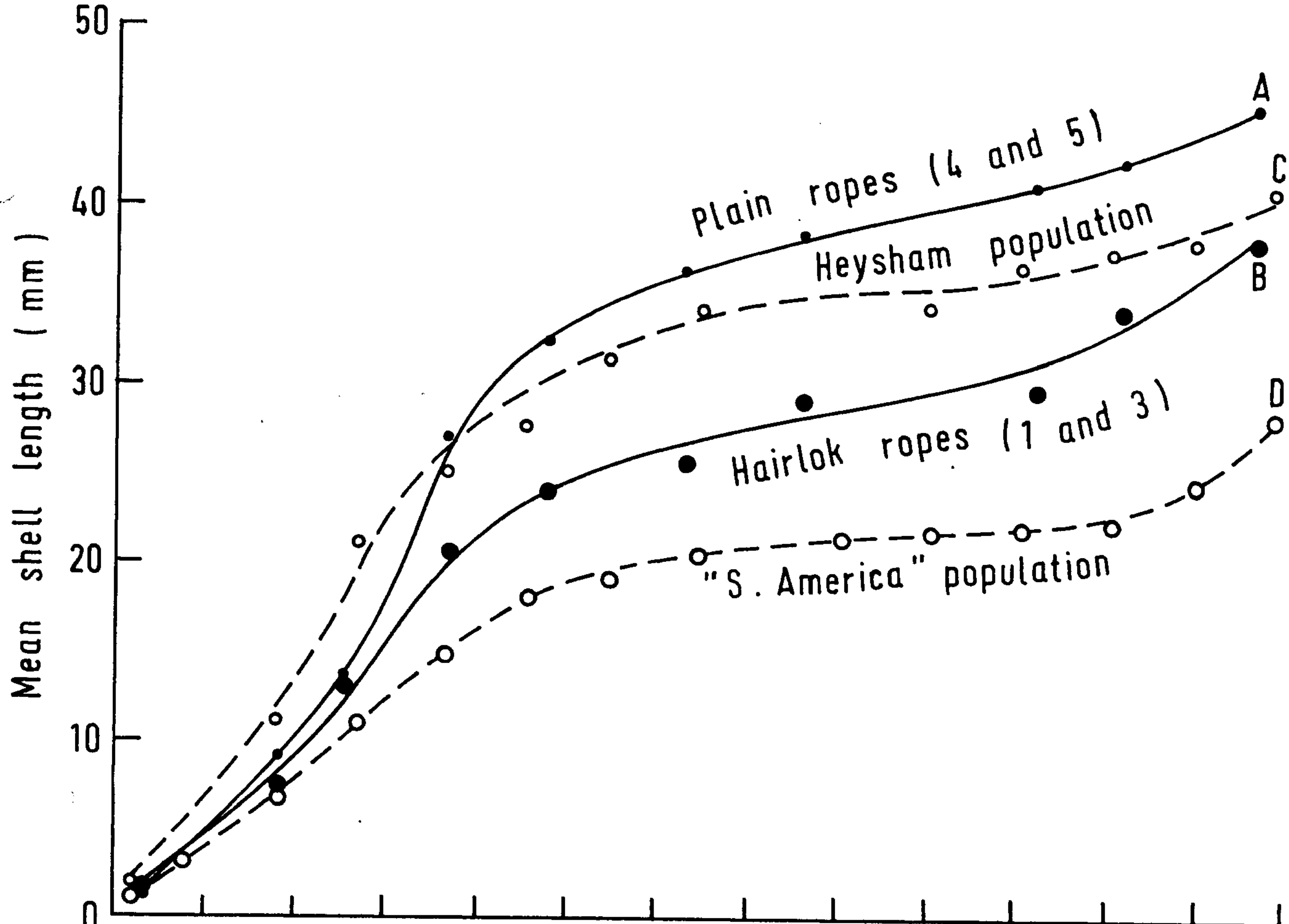

Figure 2 Shell growth of 1970 Morecambe Bay spat populations in situ (at mean low-water mark of spring tides) compared with that of contemporary spat taken from the bay and suspended on coir ropes in the Menai Straits. (Transplanted rope populations are indicated by continuous lines and filled circles, natural ground populations by broken lines and open circles.)

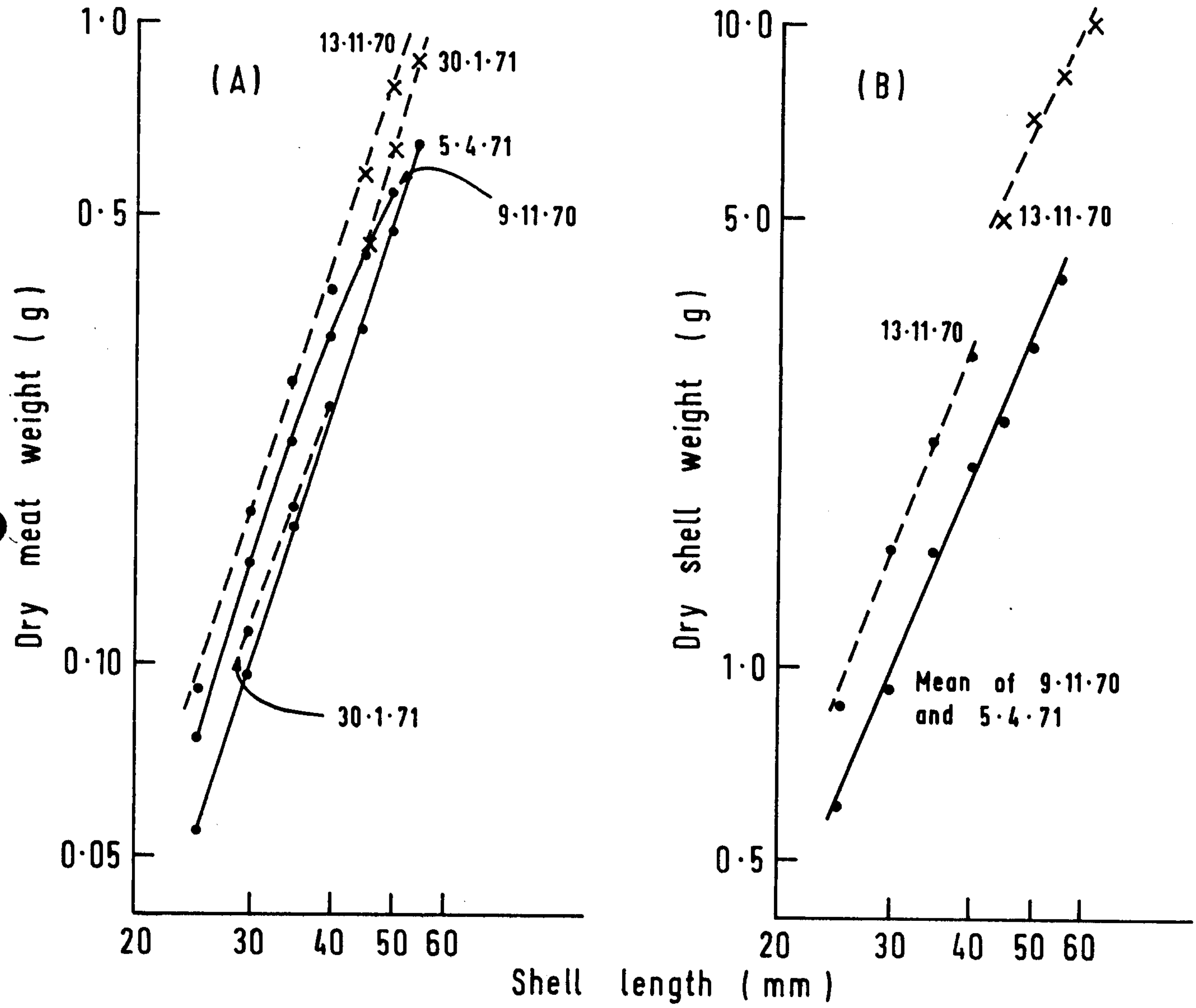

Figure 3 Dry meat weight (A) and shell weight (B) of 1st year (1970) Morecambe Bay seed, at mean low-water mark of spring tides, Heysham (broken lines) and transplanted as spat to ropes in Menai Straits (full lines). Heysham mussels older than 1st year are denoted by crosses.