AN ECOLOGICAL INVESTIGATION OF THE INTERTIDAL BENTHIC INVERTEBRATES OF THE DEE ESTUARY

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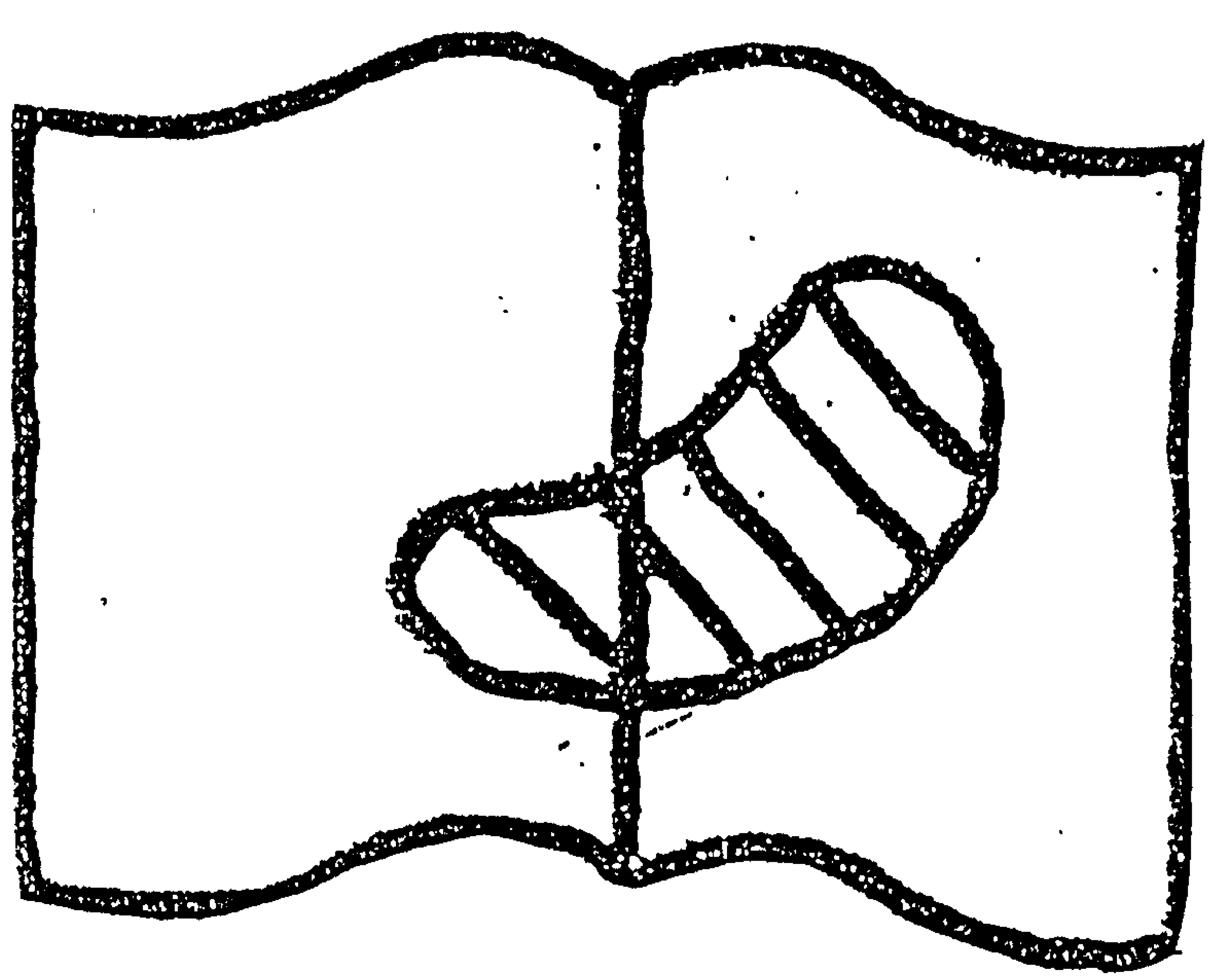

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R. M. Gillham

ABSTRACT

The aim of the thesis was the investigation of the intertidal macroinvertebrate distributions of the Dee Estuary and the factors controlling their distributions.

The work consisted of a series of extensive systematic grid surveys over the Estuary in the Spring and Autumn covering a period from 1971-76, backed up with more intensive stratified random sampling in selected representative areas of the Estuary.

The environmental factors investigated included salinity, temperature, particle size, percentage loss on ignition, tidal height but as the work progressed two other factors were found to be of great importance, these were the degree of protection from wave action and the effect of predation.

Five consistent biological communities were defined for each of the surveys by objective numerical analysis techniques (Normal Association Analysis) and it was found possible to relate each of these communities to a unique set of physical/chemical factors.

The data obtained in the initial stages of the study revealed the possibility of a balance in the relationship between the invertebrates and their predators which included other invertebrates, estuarine fish and birds.

Analysis of the predation rate on _Macoma balthica_ data revealed a mathematical relationship and an apparent minimum feeding density by the predators.

The hypothesis was tested further by a variety of techniques including experiments with netted exclosures constructed on the Estuary and all the available evidence from the study substantiated the hypothesis.

1 INTRODUCTION

1.1 The Study

The Dee Estuary is situated on the northernmost part of the boundary between England and Wales. It drains in a north-westerly direction into Liverpool Bay, 5 kilometres west of the Mersey Estuary. The upper part of the Estuary is a tidal canal 15 kilometres in length from Flint to Chester, the lower Estuary is 17.6 kilometres long gradually broadening to 8 kilometres in width at the mouth. Its total area is approximately 125 square kilometers of which 65% is intertidal mud and sand (Map 1). For the purposes of this study the Estuary does not include the canalized portion from Flint to Chester. The outer limits of the study were defined by a line joined from Point of Air (SJ 121853) to Red Rocks (SJ 203885).

The Dee in common with other major estuaries in the British Isles is under very considerable pressure from man's activities at the present time. Three new major developments could have dramatic effects on the biology of the Estuary and these are :

(1) proposals for a large urban complex with a population of ¼ million centred on the Welsh side of the Estuary.

(2) Industrial development is steadily increasing and there are proposals for a nucleur or conventional power station of 2500 megawatts near Flint.

(3) The Dee is proposed as an area for a barrage scheme combining a road crossing and multipurpose reservoirs, such a scheme would provide 300 million gallons of fresh water per day.

To place these new developments in perspective and in particular the impact a possible barrage scheme would have on the

Estuary I have included at the end of the introduction a short historical account of the history of the Dee Estuary. With these considerable threats to the Estuary it was felt that there was an urgent need to assess the ecology especially since the last invertebrate survey of the Estuary was in 1949 (Stopford 1951) and the Estuary is of international importance as a feeding ground for large numbers of migratory waders and wildfowl supporting over 10% of the British wader population and 2% of the wildfowl population.

The basic aim of this thesis was to investigate the distribution of the intertidal benthic macroinvertebrates in the Dee Estuary and attempt to define the main environmental factors affecting these distributions.

The Dee Estuary falls within the definition of an Estuary in that it is a semi-enclosed coastal body of water having a free connection with the open sea and within which seawater is measurably diluted with freshwater run off (Pritchard 1955).

The term benthic intertidal invertebrate is defined as those invertebrates found between high and low tide marks, either permanently living on or within soft sediments or temporary invertebrates trapped by the tide but more normally found within the water column.

The definition of the term macroinvertebrate is subjective. Many early surveys of estuarine faunas were restricted to those animals retained by a 1 mm mesh sieve (Beanland 1940; Holme 1949; Stopford 1951; Raymont 1955). Smidt (1951), like Beanland (1940), made the distinction between macroinvertebrate and microfauna on the basis of a 1 mm mesh sieve. This definition has remained and Green (1968) stated in his book "that it is possible to place whole groups of estuarine animals into one or other of these two categories so that a systematic account does not become too disjointed". Other workers investigating the interstitial fauna defined a further group, the meiofauna (Mare 1942) and this distinguished invertebrates which could pass through a 0.5 mm mesh sieve but which were retained by a 0.05 mm mesh sieve. Many recent macroinvertebrate studies have reflected this distinction from the meiofauna by adopting a 0.05 mm sieve. The division is supported by the differing nature of the general sampling and processing techniques required (McIntyre 1971). Further it has been found that a 0.5 mm mesh retains the young stages of certain typical macroinvertebrate types such as Hydrobia ulvae (McGrorty 1973). Eltrincham (1974) further defined the macroinvertebrates as those species which moved or occupied spaces by displacing or swallowing benthic sediments. The definition can best be described therefore as one of convenience imposed artificially by man, and the definition of many macroinvertebrate species, particularly annelids, becomes determined by the length and intensity of sieving at either mesh size.

The imposition of this man-made division also automatically means that the study of macroinvertebrates is concerned principally with adult stages and ignores the larval or small stages which may be released into the water column or be found on the surface of the sediment. Therefore this is essentially a study of the distribution of the adult stage of the life cycle.

Investigations of the macroinvertebrates on estuaries has a long history dating from the work of Allen and Todd (1900, 1902) on the Salcombe and Exe estuaries. Over the years many of the British estuaries have been studied, e.g. the Tamar by Percival (1929); the Tees by Alexander, Southgate and Bassindale (1935);

the Dovey by Beanland (1940); the Aberdeenshire Dee by Milne (1940); the Exe by Holme (1949); the Towy by Howells (1964); the Ribble by Popham (1966); Morecambe Bay by Anderson (1972); the Severn by Boyden and Little (1973). Benthic invertebrates have been investigated on the Dee Estuary by Stopford (1951) and Perkins (1956).

In addition to these general surveys on estuaries several works have been published of a more autecological nature so that many of the typical estuarine species have been studied in relation to a variety of environmental factors, e.g. Corophium volutator (Hart 1930; Watkin 1941), Cardium edule (Cerastoderma edule) (Kreger 1940; Hancock and Uquhart 1965); Crangon vulgaris (Lloyd and Yonge 1947); Nereis diversicolor (Dales 1951); Carcinus maenas (Naylor 1962; Crothers 1968); Nephthys sp. (Clarke, Alder and McIntyre 1962); H.ulvae (Newell 1964); Macoma balthica (Chambers and Milne 1975b; Caddy 1967); Scrobicularia plana (Hughes 1970a). Many of these works emphasised the difficulties the physical environment represented to the macroinvertebrates, a dynamic environment determined partly by marine, freshwater and atmospheric components.

Fluctuations in populations of intertidal estuarine macroinvertebrates have been recorded over many years (Coe 1956) and since many of these species are of economic importance the fluctuations became particularly noticeable. On the Dee Cerastoderma edule was severely affected by the cold temperatures of 1962/63 (Crisp 1964), as a result a commercial fishery disappeared. In any investigation of estuarine macroinvertebrates therefore some account has to be taken of their natural fluctuations. This could be overcome in two ways :

(1) Extend the period of study over as many years as possible;

(2) investigate the community level rather than the individual species.

The latter approach would appear to be particularly valuable in an estuary. Although the concept of greater homoeostasis at the community level has been recognised for many years (Odum 1963). Objective investigation of communities has only become feasible with the development of techniques for the handling of large numbers of calculations required in the numerical analysis. With these developments have evolved several statistical methods of identification of the communities. No long-term estuarine investigation could be found which tested the community concept. The advantage of an investigation of the population at the community level was the possibility of defining objectively distinct habitats with common environmental parameters. Central therefore to the identification of factors controlling the distribution of the intertidal macroinvertebrates of the Dee was the identification initially of consistent communities.

The choice of important environmental variables affecting the population of macroinvertebrates on the Dee had initially to be decided by the synthesis of critical factors built up over the years by previous estuarine researchers. Unfortunately limitations had to be imposed by the ability of myself to carry large numbers of samples and the problems of physical chemical analysis.

Environmental factors investigated were divided into -

(1) physical/chemical, which included salinity, particle size composition of the sediments, percentage loss on ignition of the sediments, height on the shore,

temperature, and selected heavy metals.

(2) biological, which included waders, wildfowl and fish. By good fortune, running concurrently with the first years of the project, a detailed monthly count of numbers of birds on the Estuary was undertaken. In the latter three years a more detailed ornithological study took place by Buxton (1978) as part of the Dee Estuary Barrage Feasibility Study. In the final year of the study this was supplemented by estimates of seasonal variation in numbers of Platichthys flesus L. (flounder) by a postgraduate student colleague at Salford University, N Parsons.

The sampling programme took the form of a series of twice yearly extensive grid surveys established over the Estuary (Map 2) in which the macroinvertebrates and physical/chemical environmental factors were sampled, and backed up with more intensive sampling in selected areas. The extensive surveys were undertaken in the Autumn and Spring. In the Autumn the invertebrates could be expected to be near their maximum numbers after the Summer recruitment and the Spring surveys were carried out to note any subsequent changes in populations. More intensive sampling took place at three selected areas, these were along a transect from the saltmarsh to the main channel at Gayton (Map 3) and two supplementary one year studies at Thurstaston and Mostyn (Map 4 & 5)

From an appraisal of the information derived from the early surveys and transect data a more detailed investigation took place on M.balthica. The population dynamics of this species suggested a tentative hypothesis that there was some form of density dependent mechanism influencing the numbers of M.balthica subsequent to its settlement. From the various lines of investigation which included experimental nets the strength of this hypothesis was examined. This part of the investigation was basically looking at the structure of the system. I had hoped.to investigate the energetics of the system but this functional part has now been undertaken by a postgraduate student colleague, Mrs H Moreira, using my stored material. This will provide important information on the relative productivity of the communities of macroinvertebrates outlined in this present investigation.

1.2 History of the Dee Estuary

During pre-glacial times there was an extensive plain probably covered periodically by the sea extending from North Wales to the Pennines, these were the Triassic deposits.
Later extensive faulting took place within the region, this has not been accurately dated but was possibly Tertiary or Cretaceous (Shackleton 1953). During the faulting on the Dee older Carboniferous rocks became exposed on the Flintshire shore. The presence of this faulting at first sight indicates the Estuary originating as a rift valley. Gresswell (1964) disputed this since the present Estuary does not follow the line of the faults, which are on average 40° out from the present line of the coast.

Early authorities differed as to whether a major river system flowed into the Irish Sea through the Dee, some felt that the Dee joined up with the Severn and flowed south to the Bristol Channel. Wills (1912) was of the opinion that the upper tributaries of the Severn joined with the Dee and flowed north, the course presumably guided by the faulting, so that the actual course of this major river would not have been the same as the present Dee.

The Pleistocene (glacial) period had a profound effect on the present Dee Estuary, there were a number of retreats of the ice sheet, possibly four. Apart from the erosion of 'U' shaped valleys, with freezing and melting of the icecaps, there were also large changes in the relative heights of the coastline and the land itself could rise and fall.

The topography of the Estuary is unusual with its rectangular shape and parallel sides, quite unlike the shape of a normal fluvial valley with marine incursion. Reade (1873); Lomas

(1904); Wills (1912) & Gresswell (1964) believed that the origin of the Dee and nearby Mersey Estuaries to be glacial. The early authorities had to make use of the results from only a few bore holes in their hypotheses which indicated the present rock base in the two estuaries of the Dee and Mersey to be about 18 metres below aluvium. But later borings, particularly in the upper regions of the two estuaries, indicated the rock to be much deeper, in fact over 83 metres in some cases, e.g. near Connah's Quay. Gresswell (1964) came to the conclusion that there had been direct ice gouging creating an irregular base.

During the first phase glaciation Würm I and perhaps in the older glaciations, valley glaciers of eastern Scotland and the Lake District became Piedmont in the Irish Sea and south-west Lancashire. Moving southwards driven by the thicker and higher ice to the north it came up against the mountains of North Wales. Much of the ice escaped over Anglesey and the Lleyn Peninsula to the west but there was also a lowland route at the south-eastern corner of the basin in the region of the present day Dee, Mersey and Alt Ditton rivers. As the glaciers moved inland they gouged deeper into the rock. Gresswell (1964) could find no term for the features and described them as 'iceways'. The Dee was the most westerly and the largest. Howell (1973) modified Gresswell's (1964) hypothesis by indicating that the irregular solid rock base was not caused by the direct action of ice. By using all the available bore hole data he considered that the pattern of erosion was more fluvial in origin and was created by meltwaters flowing beneath the glaciers.

After the retreat of the glaciers much of the area became covered by glacial drift material attaining a considerable thickness in places. Then followed deposition of boulder clay and fluvio glacial sands and gravels. On the Dee all the bore holes sunk have encountered considerable thicknesses of these sands and gravels at places up to 50 metres in thickness and the greater part of the Estuary is now floored with these fluvio glacial sediments. These deposits pass upwards into the recent sediments comprising sands, silts and muds deposited in the Estuary by the sea and river.

The first reliable historic records of the Estuary comes with the Romans. Chester during the Roman occupation was an important port, second in importance to London, at the head of a deep sheltered estuary. During the succeeding centuries the Estuary probably remained relatively stable and in balance with the tidal regime but during the Norman period, although still navigating the Estuary to Chester, local merchants were complaining that the wier, which was built in the 11th Century to drive the flour mills for the town, was interfering with the sedimentation. The effect of the wier was to reduce the tidal influence above Chester since only large Spring tides could effectively top the wier and this would have the effect of reducing the amount of scour in the Estuary. Silting became so severe that by 1449 it became necessary to establish an outport 8 kilometres downstream at Shotwick (Map 6). The following series of historical maps taken from original prints have been redrawn by myself on present day Ordanance Survey maps using the original line of sight landmarks. Unfortunately silting continued so that by 1689 the outport had been moved a further 8 kilometres downstream to Parkgate. During all of this period the River Dee tended to follow the English northern side of the Estuary and extensive saltmarsh was restricted to the Welsh shore (Map 7).

Several attempts were made to improve the navigation but with little success. In 1732 there were proposals to improve the navigation by the construction of a completely new cut, a canalized section of the river cut through solidified marshy ground on the southern side of the Estuary (Map 8) and extended from Chester to Connah's Quay a distance of nearly 13 kilometres. It was 24 metres wide by 2.5 metres deep. Over the years the embankment of the canal was extended into the Estuary with the object of making the channel in the Estuary more stable and to try and confine it to the Welsh side. However, this was not particularly successful, even in the 1930s with the embankment extending down the Estuary to Flint, the main channel meandered to the English shore.

The immediate consequences of the diversion of the River into the new cut, finally constructed in 1737, was the rapid build up of sediment in the sheltered water on the northern side and this rapidly became colonized by saltmarsh vegetation. Areas of saltmarsh away from prevailing gails proved easy to reclaim by the construction of embankments and the areas reclaimed formed excellent agricultural land (Map 9). The net effect was that reclamation encouraged more deposition of sediment, then advance of saltmarsh followed by further reclamation and the process continued (Maps 10, 11 and 12). In addition to the reclamations on the northern shore, other reclamations had been taking place on the Welsh side of the Estuary mainly associated with the advance of the railways in the 1850s and in the latter years of the Century industrial development was a contributory factor, e.g. Mostyn Dock and Point of Air Colliery.

Up until the 1930s a notable feature displayed in Table 1 and Fig. 1 was the progressive relative decrease in the proportion of saltmarsh within the Estuary down to 5.7% in 1932. However, since 1931 the position has changed dramatically, apparently

Date	Reclamation		Saltmarsh			Banks			Channels		
	Area	⊕	Area	⊕	+	Area	⊕	+	Area	⊕	+
1684			36.68	19.7		104.36	55.9		45.6	24.4	
1732	2.52	1.4	34.16	18.3	18.6	104.36	44.9	56.7	45.6	24.4	24.8
1749	3.4	1.8	36.2	19.4	19.8	107.96	57.8	58.9	39.08	20.9	21.33
1800	31.68	17.0	18.48	9.9	11.9	97.8	52.4	63.1	38.68	20.7	25.0
1849	38.96	20.9	12.44	6.7	8.4	106.44	57.0	72.1	28.8	15.4	19.5
1910	49.12	26.3	10.84	5.8	7.9	89.16	47.8	64.8	37.52	20.1	27.3
1932	53.88	28.9	7.6	4.1	5.7	82.8	44.4	62.4	42.36	22.7	31.9
1956	55.28	29.6	13.64	7.3	10.38	89.96	48.2	68.5	27.76	14.9	21.13
1971	56.16	30.1	21.72	11.6	16.7	84.56	45.3	64.8	24.2	13.0	18.6
1976	56.2	30.1	23.44	12.6	18.0	82.80	44.4	63.5	24.2	12.97	18.6
Future	110.32	59.1	?			?			?		

Table 1. Progressive change in areas of the Estuary since 1684 in Km^2.
⊕ Percentage of 1984 Total Area (186.64 km2).
\+ Percentage of Estuary excluding reclamations.

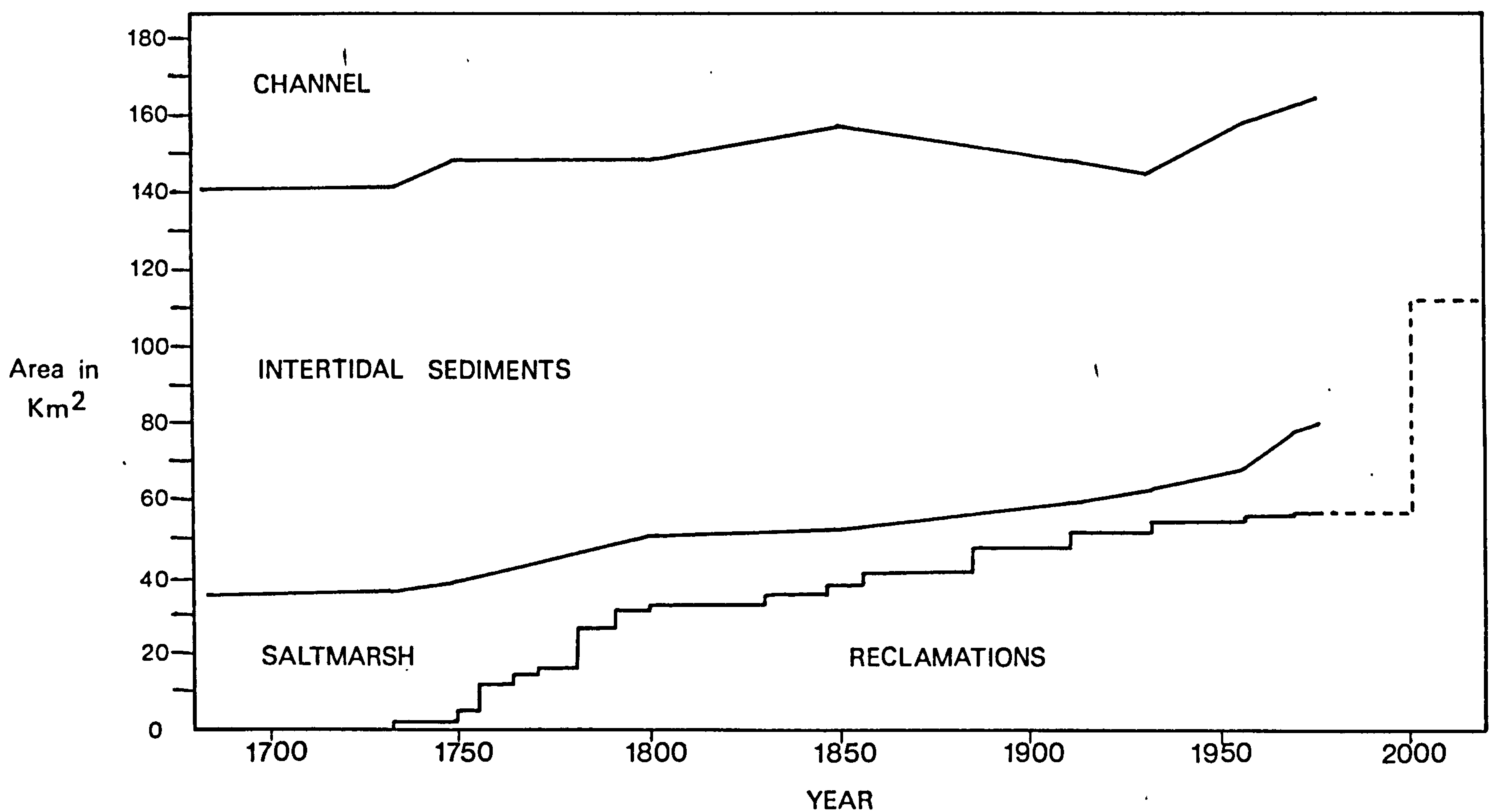

Figure 1. Progressive change in the area of the main component parts of the Estuary since 1684.

(------ Proposed barrage).

associated with the artificial introduction to the Estuary of the vigorous grass Spartina anglica (Hubbard). This plant was first introduced on the Dee in 1928 (Massey 1937) this failed but further plantings were made in 1929. The next record was in 1945 when McMillan (1945) found two plants between Gayton and Parkgate and at Point Point of Air. There were then several records of its rapid spread on the Estuary and S.anglica has now taken over as a primary colonizer of the substrate. In 1956 (Map 13) saltmarsh had increased and accounted for 10% of the open Estuary. By 1971 (Map 14) it was 16.7% and in 1976 (Map 15) it was 18%. The present situation is now approaching the percentage found in the 1684 situation (bearing in mind cartographic problems) but the indications are that stability with the environment has not yet been established.

Examination of surveys taken in 1888 and 1965 enabled the Hydraulics Research Station (HRS 1973) to estimate the accretion to be $100 \times 10^6 m^3$. Theoretical considerations suggested that the rate of annual accretion was $1 \times 10^6 m^3$. Five possible reasons can be given as explanations for the accretion witnessed in the Dee :

(1) The Estuary represents an embayment of the Irish Sea acting as a trap for material which is moved eastward along the North Wales coast by longshore drift around the Bay. The quantities of material involved and the examination of the particles of the sediment revealed a mainly marine origin (H.R.S. 1973).

(2) The tidal flow within the Estuary exacerbates the situation. Throughout the Estuary the ebb runs for a longer period of time and therefore more slowly than the flood (Fig.2). At Spring tides the ebb runs for 9 hours at Connah's Quay and the flood for only 2½ hours, at Hilbre Island the figures are 7 hours and 4½ respectively. Average Spring tide maximum velocity of 1.2m /sec

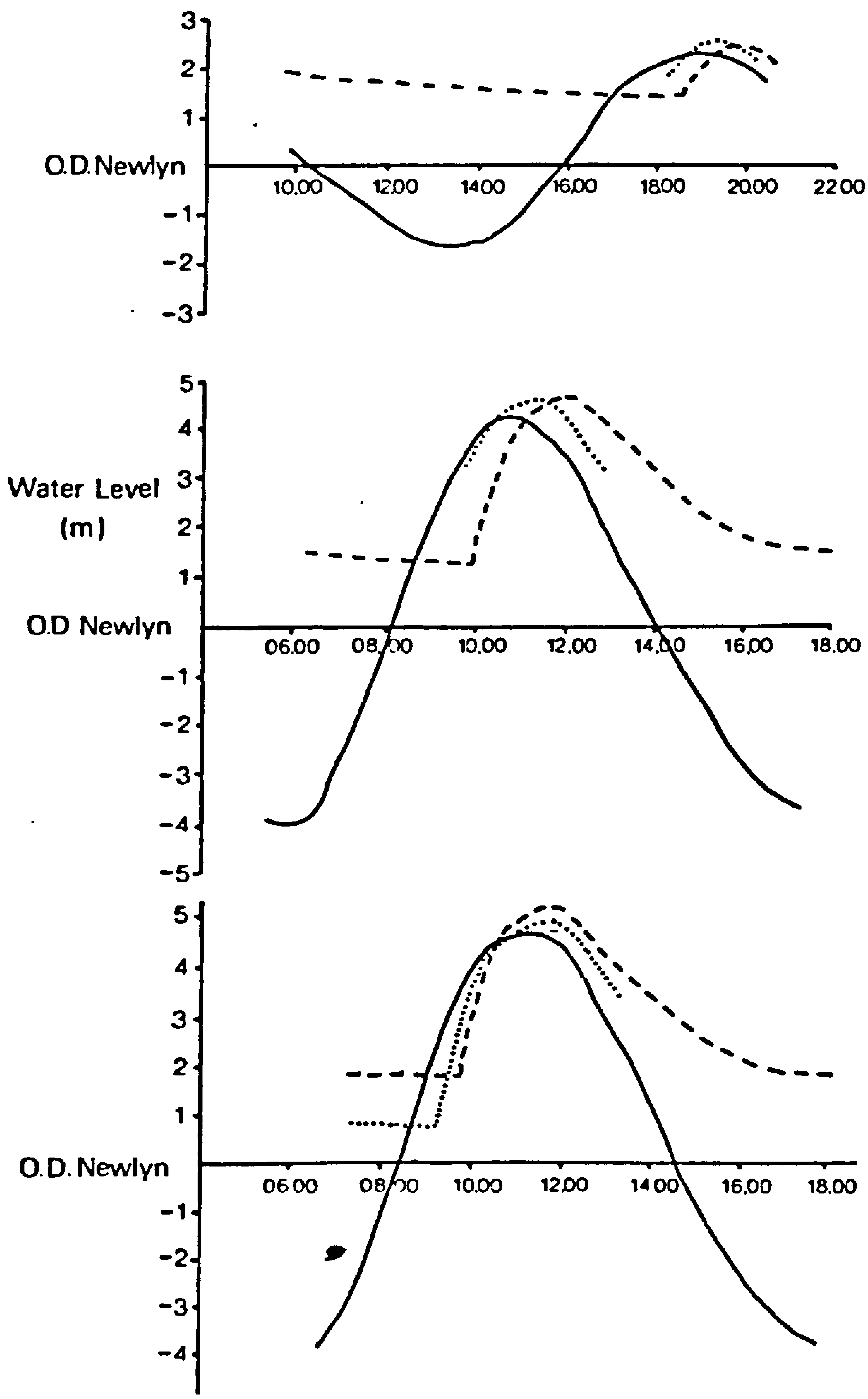

Figure 2. Simultaneous observation of (a) mean neap tide 1-2-66, (b) mean spring tide 25-10-65 and (c) high spring tide 6-4-66 at ——— Mostyn, ... Flint and - - - - Connah's Quay.

for the ebb compared with 2.4m/sec for the flood tide means that material brought in would be dropped because the slower ebb current could carry less sediment. The actual shape of the Estuary widening towards the sea itself reduces the scouring effects of the tides. The reclamation schemes outlined in the Upper Estuary have all in turn reduced the tidal scour.

(3) Control schemes for the prevention of floods and river regulations in the Dee River system also tend to limit the amount of land drainage water which might add force to the ebb current.

(4) The training wall over the years has been extended until it now lies above Flint and this now effectively encourages the main channel to meander to the Welsh side of the Estuary where strong man-made sea defences prevent erosion on the Welsh shore but allow accretion to occur at an increased rate on the northern shore.

(5) The position of saltmarsh in the process as a contributor to the initial sedimentation is difficult to assess. Certainly accretion occurs within the saltmarsh (Jenson 1949) and water movement must be interfered with by S.anglica, but S.anglica is established after sedimentation has occurred and the relevant critical tidal height and degree of protection has been reached. The critical height has been defined by Ranwell (1964) at approximately +3.3 m Ordnance Datum (O.D.). Possibly the main influence of the saltmarsh is that these areas are generally considered as wastelands by the general public and apparently the engineers! and are considered to be potential reclamation areas, but reclamation in these saltmarsh areas further reduces the tidal volume and contributes to the inbalance within the dynamics of the

Estuary. Even at the present time major new developments have been proposed (Map 16) which will totally cover the existing saltmarshes and these could have even more dramatic effects than the reclamations which have already been outlined. An indication of the change can be obtained from Fig 1. The saltmarsh cliffs witnessed at Flint and Bagillt although in a natural estuary indicate a balance developing with the tidal velocity in that estuary, in the Dee the training wall keeps the channel to the southern shore. In most places there are concrete sea defences but in the other areas saltmarsh cliffs have developed. In Map 15 the natural loss denotes the removal by the tide as opposed to hand picking of S.anglica by man which occurs in the Outer Estuary in an attempt to control its spread.

Therefore it can be seen that man has had a profound effect on the Dee Estuary with approximately 30% of the Estuary of 1684 having been reclaimed. Any further reclamation however small or large should be very carefully considered with a long term perspective.

2 METHODS

2.1 Biological

2.1.1. Sampling techniques

The Estuary of the Dee covers an area of 125 km^2. At the start of the study an important period of familiarization had to occur. The Estuary is particularly treacherous and more so for a single-handed undertaking. This unfortunately meant that at times the sampling method was dictated by the limitations imposed by the environment.

During this period of general familiarization a pilot qualitative survey was carried out in various regions of the Estuary. Sampling of the invertebrates using a quadrat soon left much to be desired and it quickly became obvious that an efficient method of taking samples and sieving the animals from the sediment would be necessary.

(a) Corer (Fig 3)

Although the area of a corer can be important statistically, practical considerations played a large part in the decision to use 100 cm^2. Large cores presented problems of obtaining a clean cut at the base of the corer and extraction from the substrate, small cores presented greater interference by damage to the invertebrates and the core sample became more difficult to extract. Several recent surveys have made use of corers, Buscemi (1966); McLusky (1968a); Anderson (1972); Boyden and Little (1973); Kay and Knights (1975) and apparently they reached similar conclusions the majority selecting 100 cm^2.

The simplest method of operation proved to be the most efficient. The corer was pushed to the required depth then knocked sideways sharply, this cleanly broke the core sample free of the

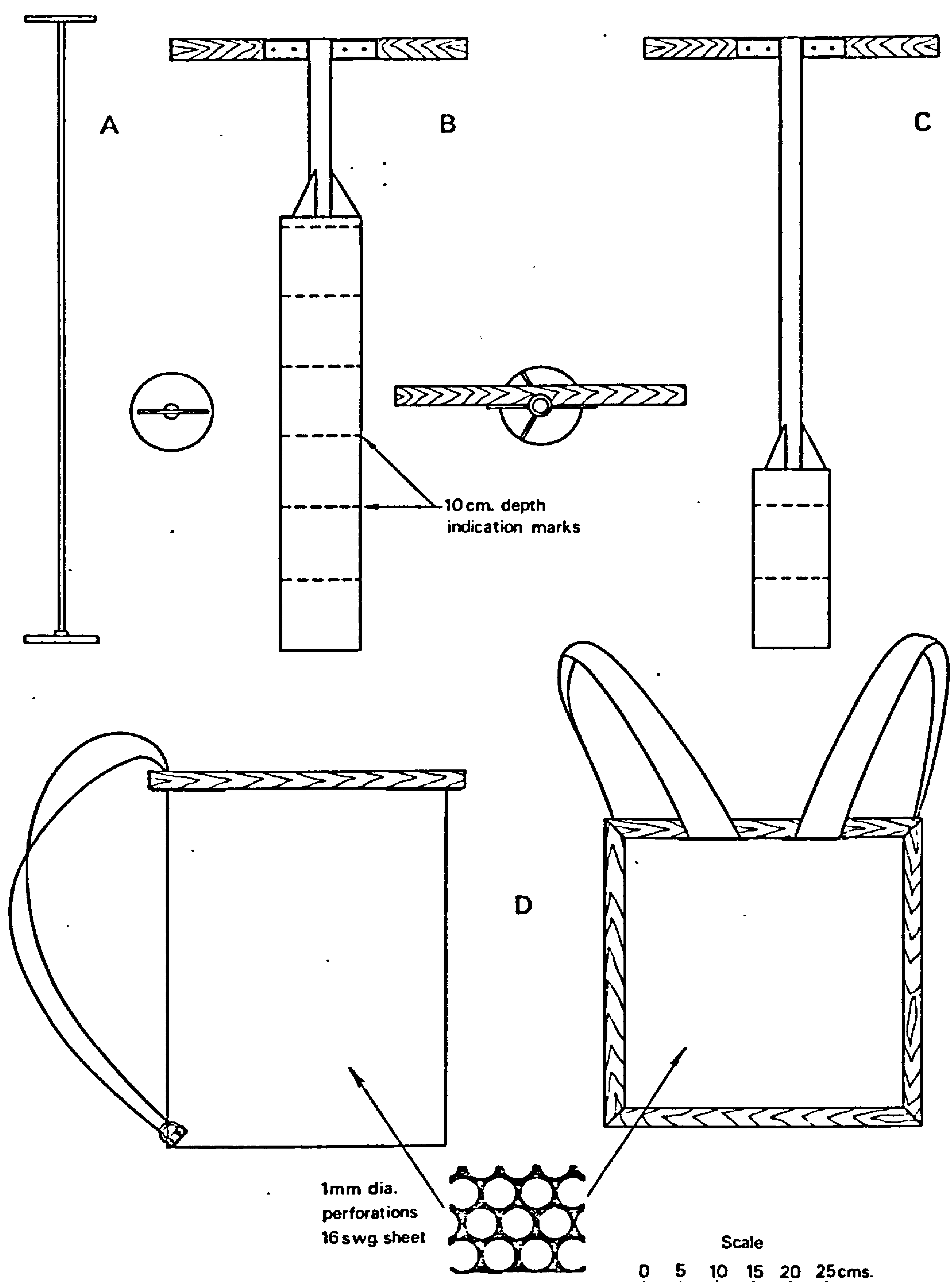

Figure 3. Construction of Corer and Sieve. (A - core plunger; B - deep corer; C - survey corer; D - sieve, side and plan view).

sediment which was then lifted in a horizontal position into the sieve and given a sharp jolt usually the sample sliding out freely. In early models a piston arrangement was also tried but this proved inefficient. Finally a quick check was made to note if any invertebrates remained.

(b) Sieve (Fig. 3)

The importance of the sieve aperature size has been stated in the introduction. However the size of mesh greatly influenced the speed of sieving and an early decision was taken to adopt the 1 mm aperature size. Construction was of 16 gauge perforated mild steel, welded and brazed at the seams. The structure was made rigid with a wood square at the upper lip which also doubled as a convenient handle. For transport there were heavy canvas straps. Holes were round and of 1 mm diameter, these were preferred since unlike square holes the size of the aperature was not affected by the orientation of some of the invertebrates, e.g. bivalves. Also it was found that round holes did not become clogged by Annelids to the same extent as intertwined mesh and the removal of invertebrates was easier and more efficient. In operation the square construction of the sieve permitted gentle agitation of the water and substrate by a simple twisting and up/down motion. To decrease sieving time this was occasionally supplemented by gently breaking the larger pieces by hand. For transport on the back the corer fitted into the sieve together with buckets and samples.

The construction of the sieve was determined largely by practical considerations. In use it was found that a bucket type sieve with a mesh only at the base gave a tendency for the sieve to clog. Holme (1964) found this problem could be solved by having a side window of finer gauge or by having the bottom of the sieve curved into an arc of almost a semi-circle. The present sieve was a development of this idea. In use perforations on the sides of the sieve proved as important as the base in allowing escape of excess water and a proportion of the sediment, this considerably reduced the sieving time. Like the corer the sieve had the disadvantage of mild steel construction involving oiling at the end of each session.

(c) Core depth

Previous work (Vader 1964; Holme 1949; Hughes 1970) on depth distribution of macroinvertebrates indicated that a very deep core would have to be employed if all the fauna was to be sampled. A compromise had to be made and 20 cm was selected. Notable species which presented problems were -

(1) Nereis diversicolor was found to move vertically in the substrate (Vader 1964) apparently controlled by the tide and water table. On the Dee specimens have been recorded at 30 cm depth. The time of sampling, therefore, could be critical in estimating numbers of this species and as far as possible sampling followed the ebb tide, which also conveniently meant there was abundant water for sieving.

(2) Mya arenaria was found to occur at various depths in proportion to its size. Generally either only spat, small individuals or a portion of the massive siphon were sampled.

(3) Arenicola marina was generally found at depths below the core limits in this study but its presence was made obvious by the typical A.marina casts. However the non occurrence of casts could not be taken as a sign A.marina was absent as quiescent periods have been recorded for this species (Newell 1948; Wells 1953).

The depth adopted by other recent surveys was 15 cm (Kay & Knights 1976; Eagle et al 1974), 10 cm (Anderson 1972; Boyden and Little 1973).

(d) Sampling intensity

The pilot surveys indicated that the sampling would have to be at two levels of intensity depending on whether it involved extensive surveys covering the whole Estuary for elucidation of community structure and relation to environmental factors or more intensive sampling on a monthly basis in which more reliable estimates of variation in invertebrate density throughout the year would be required. The choice of numerical analysis technique would have a large bearing on the ultimate way in which the extensive survey would be carried out either a systematic sampling of the Estuary on a regular grid or taking random samples.

Following statistical advice Association Analysis (AA) (Williams and Lambert 1959) was selected for community structure analysis. This meant selection of systematic sampling on a regular grid. The grid was selected at random by basing it on Ordnance Survey grid coordinates.

The extensive grid samples were taken on a predetermined regular grid over the intertidal regions, every 350 metres across and 700 metres along the Estuary (Map 2). At each site 5 x 100 cm^2 replicate cores were taken from an area 1 m^2. Two main problems arose : Melgraves (sand waves) (Humby & Dunn 1975) usually with deep water pools. By adhering strictly to the compass bearings to avoid selection meant some samples had to be lost. Similarly, some sample sites lay near or actually in a drainage channel. In most cases these could be left and returned to later when the water level had dropped sufficiently to make a sampling possible. This technique was greatly helped by the hovercraft allowing quick return visits.

The number of sampling sites ranged from 96 sites in Spring 1975 to 275 in Autumn 1971. Ideally, for the methods of analysis used later, it was preferable to aim for approximately 200 sample sites. These can be seen in Maps 17 - 24.

Sampling was carried out in the Autumn and Spring. In practice due to difficulties this was not possible over the six years of the study but priority was given to the Spring surveys for reasons which will be seen later. The aim was to keep the sampling period in the surveys as short as possible to prevent problems of change in the invertebrate densities, e.g. migration. In early surveys carried out on foot the period was approximately seven weeks. Later surveys using the vehicles cut this time down to 2-3 weeks.

At <u>Gayton</u> nine sample stations were selected down the shore and these were based on the extensive survey grid to complement it and provide economy of effort. Distance between sites was 350 metres (Map 3). The stations were numbered from the upper shore down 1, 8, 15, 22, 29, 36, 43, 50 and 57. At each site five random replicate 400 cm^2 cores were taken, from a $25m^2$ area using random orthogonal coordinates. Sampling was as near monthly as possible.

At <u>Thurstaston</u> (Map 4) there were three sample sites and sites 1 and 3 were based on the extensive grid, the middle site was off line to take in a bird observation hectare. Five random replicate 200 cm^2 cores were taken from a $25m^2$ area by random orthogonal coordinates. Sampling took place approximately every 2 - 3 months.

At Mostyn (Map 5) there were two sites, site 1 was based on the extensive grid, site 2 was 20 metres distant. Five replicate random 200 cm^2 cores were sampled and this took place approximately every 2 - 3 months.

(e) Statistics

The requirements of the AA was a reliable estimation of the species found at each sample site. Several workers have investigated the problem by recording the cumulative increase in numbers of species taken in successive replicate samples. Holme (1953); Jones (1956); Longhurst (1959a); Ellis (1960); Ursin (1960). Similar cumulative curves were found on the Dee (Fig. 4). This specimen indicates the rate of increase in species when 50 samples were taken at site 33-18, .01m^2 replicates from a 50m^2 area by random orthogonal coordinates in Autumn (30-9-73). The proportion of species was high even in the first core sample then increased in the next few samples quickly reaching a plateau. Holmes (1953) pointed out that the cumulative curve would not reach an asymtote until every part of the ground had been taken because there are always rare species. On this graph the recruitment rate after 7 cores was very slow with the addition of only one species in the next 43. Ursin (1960) discussed in detail the use of cumulative curves and pointed out that much was left to chance, using the previous method theoretically if one replicate contained all the species represented in the sample the curve would have no slope at all. He proposed the use of semi-cumulative curves. The number of species in one core is calculated by computing the mean of the number of species in single cores, the mean of the number of species in two cores is calculated by taking the cores two by two and so on. By this method he obtained more consistent and smooth curves. The results of this method are shown in Fig. 5 using the same sampling data at site 33-18. Both these curves indicated that the 500 cm^2 used in the extensive surveys was adequate for a qualitative assessment of the invertebrate fauna in the area, 80% of the species being present. To sample the other 20% would have required a ten-fold increase in sampling effort. These findings are an example relating to one site during the Autumn sampling period but examples are also presented (Fig. 6) of the cumulative curve during the Spring (7-3-75) sampling period at sites 33-19, 33-18 and 33-14. Similar curves were produced supporting the adequacy of the selected sampling size. Here quadrupling of the sampling effort would have increased the species list by approximately 8% at site 33-19, by 10% at site 33-18 and 30% at site 33-14. The requirements of the quantitative intensive sampling and the quantitative aspect of the extensive sampling was for a reliable estimate of the density, this partly depends on the dispersion of the fauna, but a preliminary estimate can be calculated by plotting the mean of the number of individuals in increasing numbers of samples. Examples have been presented of four of the more common species Eteone longa, H.ulvae, M.balthica and N.diversicolor both in the Autumn (Figs. 7 - 10) and Spring surveys (Fig. 11) at site 33-18, using the previous sample data.

The intensive sampling required random samples. Only when this occurs can an estimate of the mean be given which includes an estimate of the precision of the mean (Greig Smith 1957). Unfortunately the pattern of distribution which is a fundamental characteristic of any population, has an important effect on the precision which can be obtained. Organisms can be distributed in three basic alternative patterns. Random, even or aggregated, or a combination of these types depending on the scale of

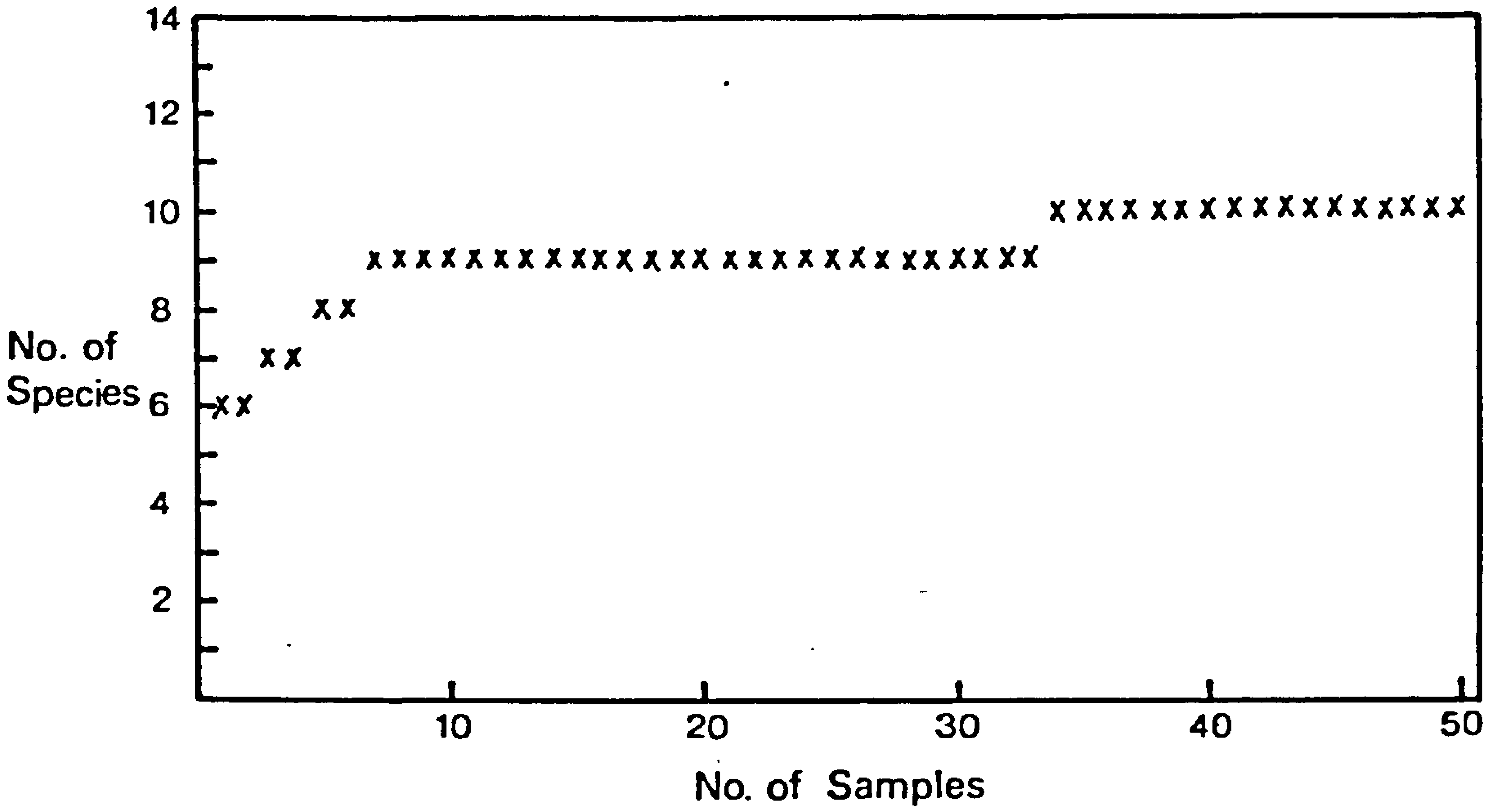

Figure 4. Cumulative curve of species taken in successive samples at Station 22 on the Gayton transect in Autumn. (Sample unit - .01 m^2 cores 20 cms deep).

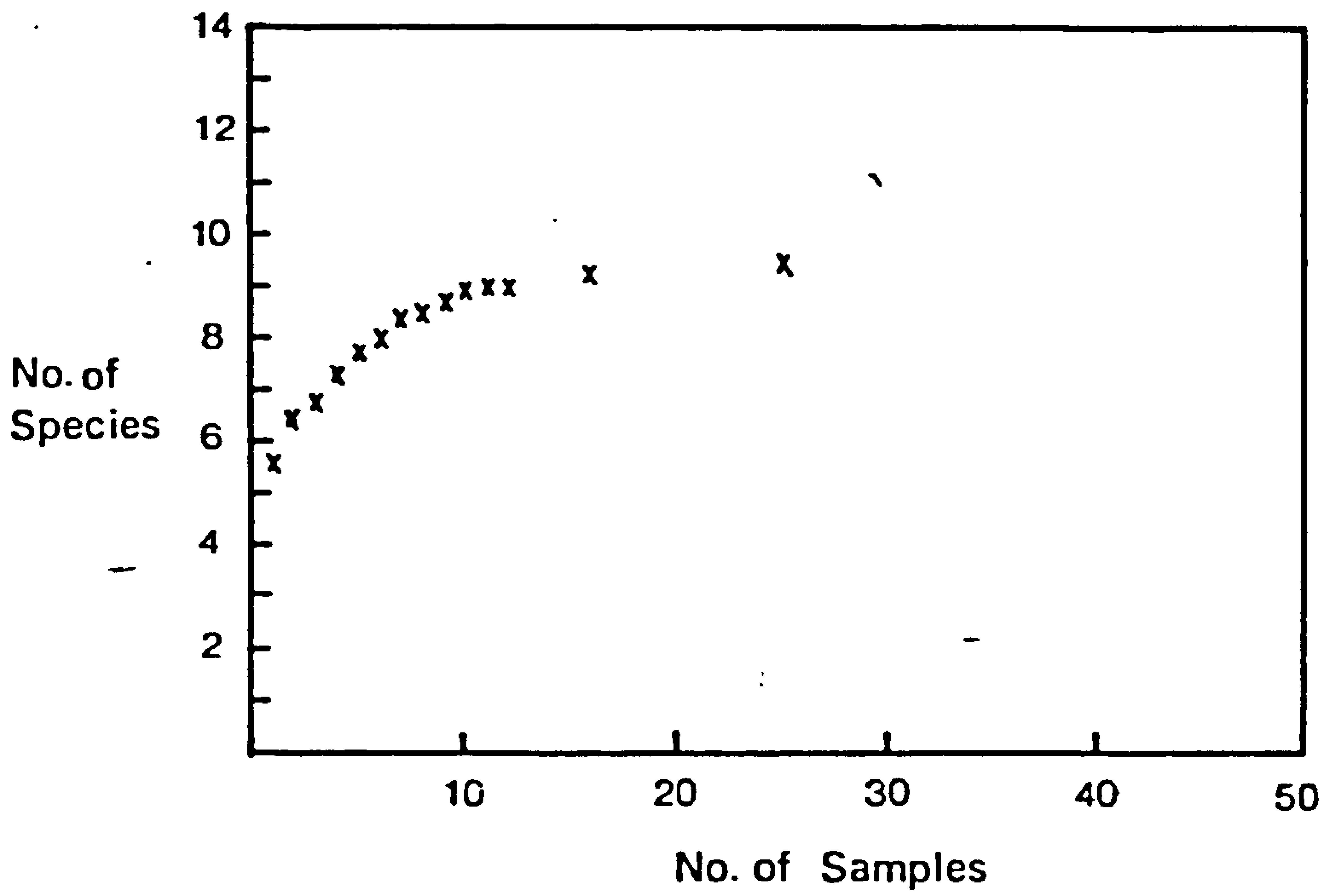

Figure 5. Species/area cumulative curve using means of number of species against increasing numbers of samples. (Sample unit - .01 m^2 cores 20 cms deep).

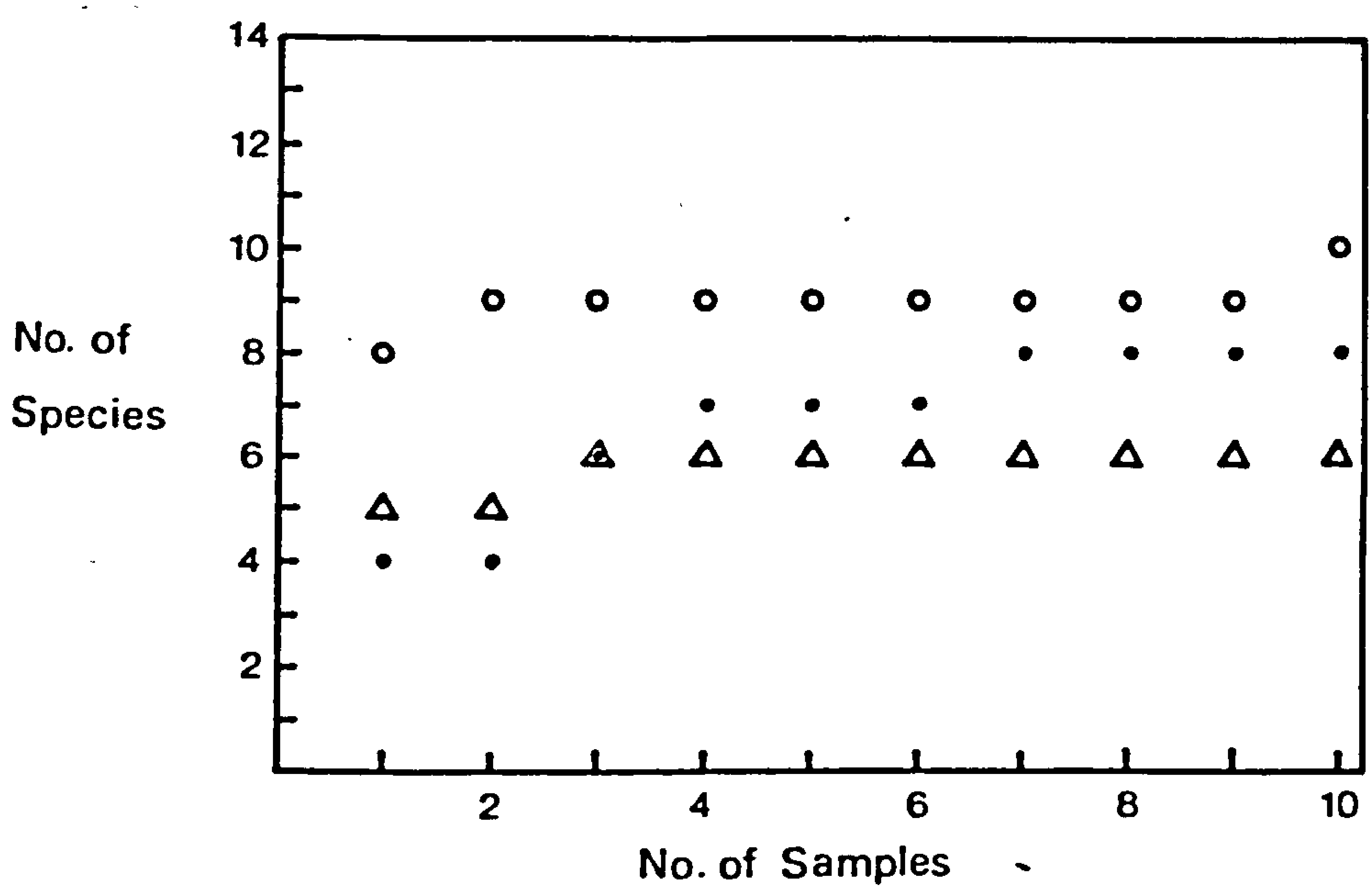

Figure 6. Cumulative curves of species taken in successive samples at three Stations on the Gayton Transect in Spring. (.02m^2 replicate cores 20 cm deep from 25m^2 area by random orthogonal coordinates).

Δ = Station 15 (33-19)
o = Station 22 (33-18)
• = Station 50 (33-14)

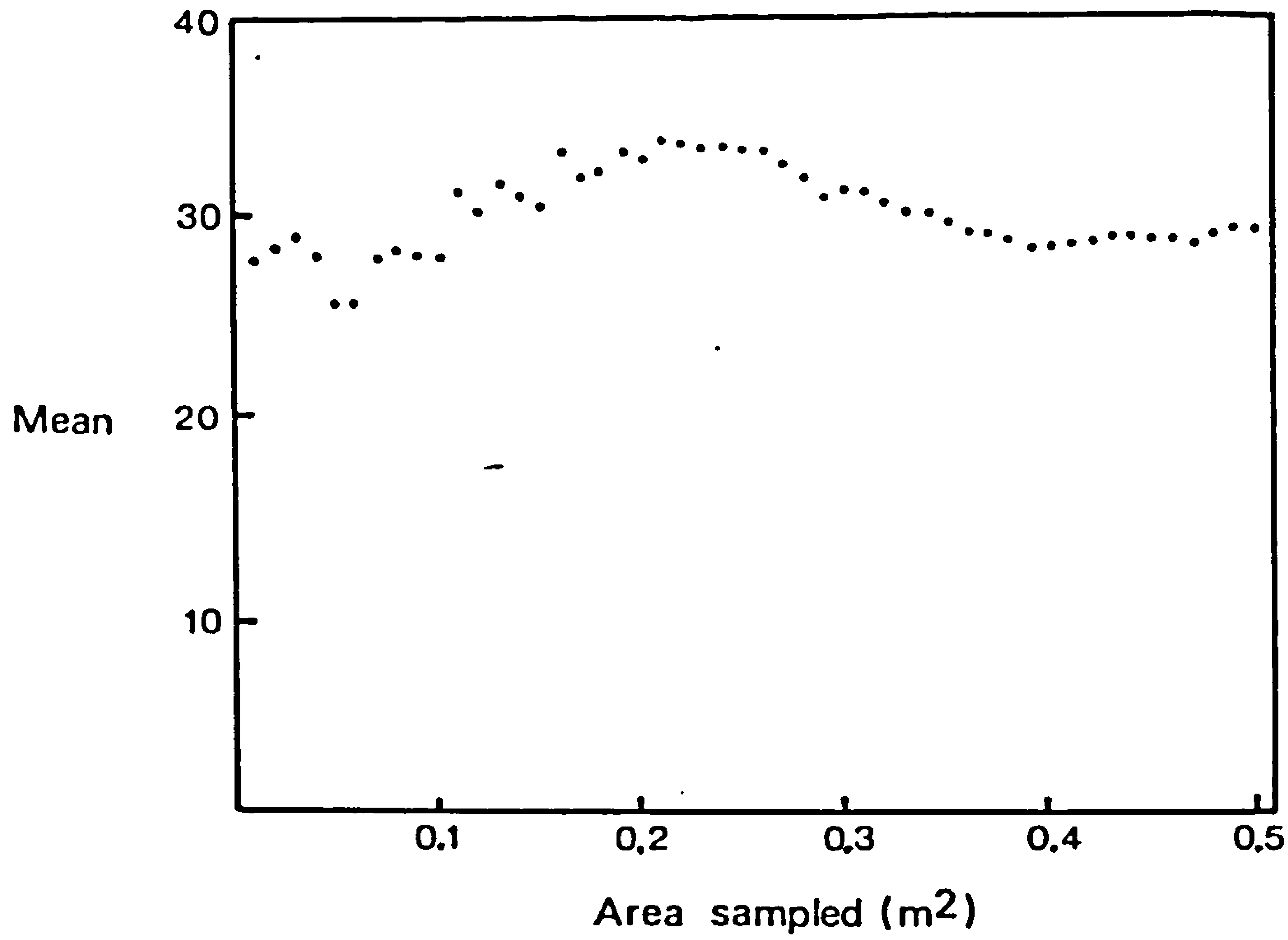

Figure 7. Plot of mean numbers of Eteone longa against increasing numbers of samples at Station 22 on the Gayton transect in Autumn. (Sample unit - .01 m^2 cores 20 cms deep).

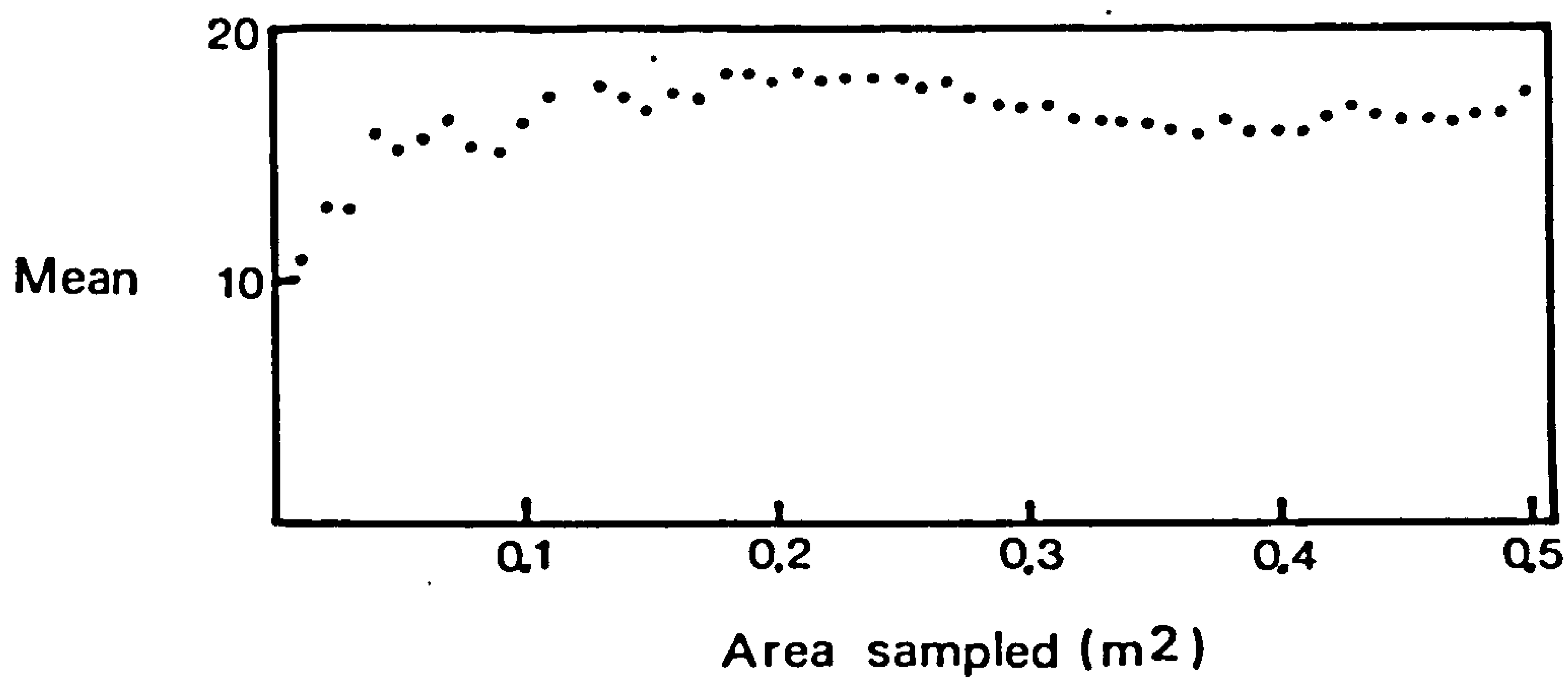

Figure 8. Plot of mean numbers of Hydrobia ulvae against increasing numbers of samples at Station 22 on the Gayton transect in Autumn. (Sample unit - .01 m^2 cores 20 cms deep).

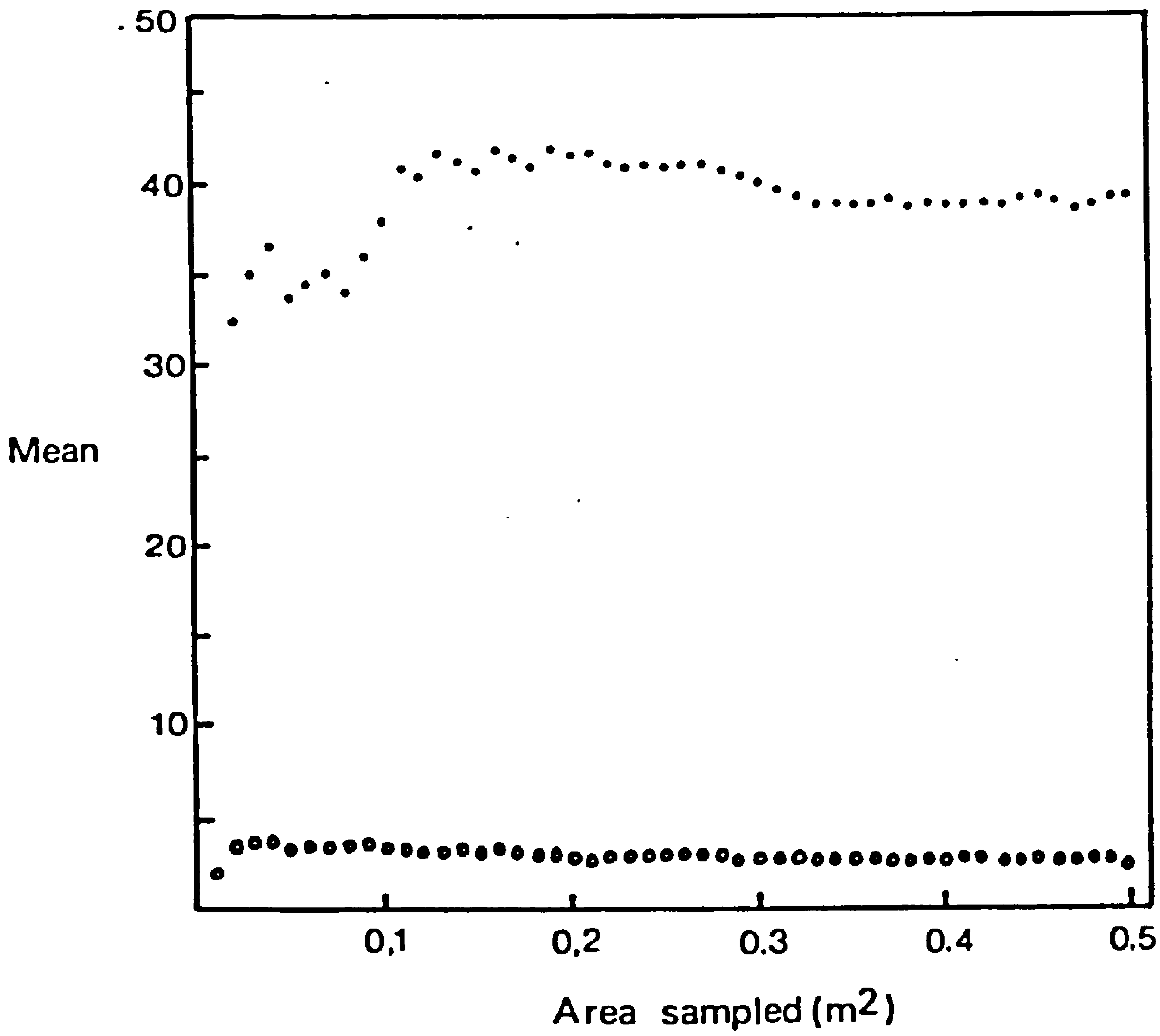

Figure 9. Plot of mean numbers of Macoma balthica against increasing number of samples at Station 22 on the Gayton transect in Autumn. (Sample unit - .01 m^2 cores 20 cms deep).

• = Macoma balthica 10 mm and less in length.
o = Macoma balthica more than 10 mm in length

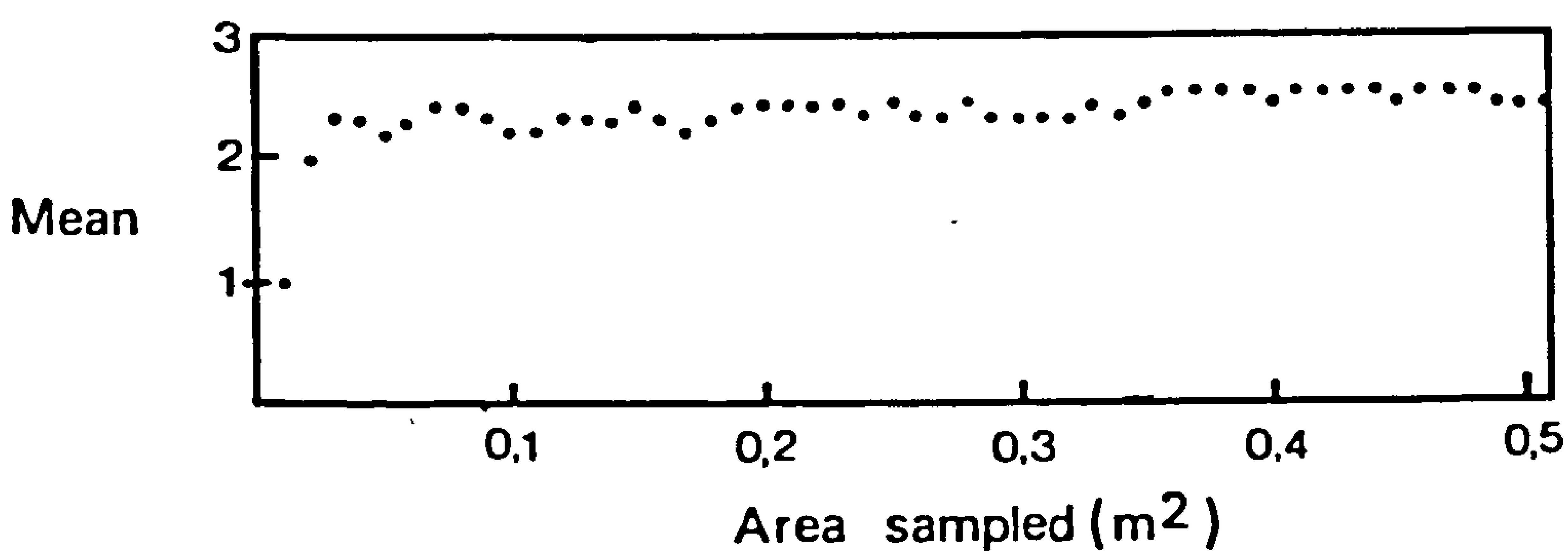

Figure 10. Plot of mean number of Nereis diversicolor against increasing number of samples at Station 22 on the Gayton transect in Autumn. (Sample unit - .01 m^2 cores 20 cms deep).

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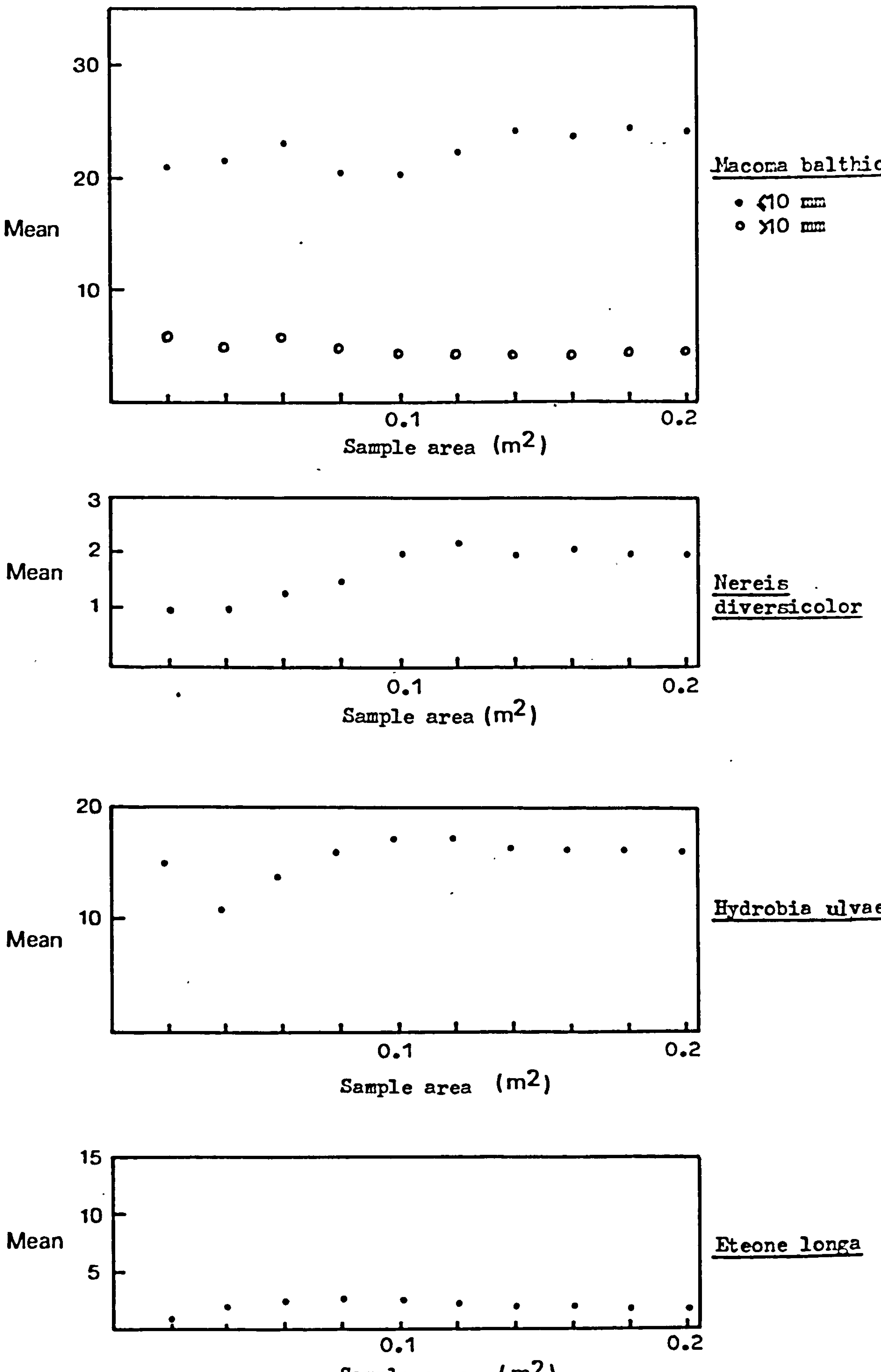


Figure 11. Plot of mean number of four species against increasing number of samples at Station 22 on the Gayton transect in Spring. (Sample unit - .02 m2 cores 20 cms deep).

investigation.

Random in which the probability of an individual occurring at any one location is the same as the probability of it occurring at any other location.

Even distribution occurs when the individuals are so distributed that all are equidistant from their nearest neighbour.

Aggregated distribution occurs when the individual at a given location is apparently dependant upon the position of other individuals.

In the study of distribution patterns a common procedure has been to make the assumption of random distribution and test departure from the Poisson series, using a variance statistic. In this study the closeness to a Poisson type distribution has been assessed by the Coefficient of Dispersion (C.D.) as first used by Salt and Hollick (1946) and later used in the benthic investigations of Holme (1950); Clarke and Milne (1955); Ursin (1960); Jones (1961). The coefficient

$$\frac{\sum (x - \bar{x})^2}{\bar{x}\,(n - 1)}$$

is based on the fact that the variance is equal to the mean in the Poisson distribution. Therefore the coefficient is equal to unity in a randomly dispersed population, to more than 1 if there is a tendancy to aggregation and to less than 1 if the distribution is more even than random. The limits denoting significant aggregation or evenness were calculated by using the formula

$$1 \pm 2\sqrt{\frac{2n}{(n - 1)^2}}$$

Examples of Coefficient of Dispersion values for six common macroinvertebrates throughout the period 1975-76 have been presented in Tables 2 - 9. Use of five as the basic sampling replicate made

Date	Station 15	Station 22	Station 29	Station 36
7- 3-75	4.76 *	0.56	0.48	1.09
16- 4-75	0.89	-	-	0.38
15- 5-75	3.36 *	0.78	0.71	2.32
17- 6-75	0.67	0.63	3.09 *	0.53
18- 7-75	2.43	0.75	8.90 *	1.38
21- 8-75	3.42 *	0.67	13.29 *	5.93 *
26-10-75	1.29	0.43	7.78 *	2.24
30-11-75	0.70	6.18 *	3.25 *	0.9
28- 1-76	2.58	1.44	0.64	-
27- 3-76	1.76	0.06	1.76	0.44
6- 5-76	0.33	0.29	0.67	0.43
19- 6-76	0.35	0.37	0.03	1.22
4- 8-76	2.63 *	4.0 *	2.07	0.1
4-10-76	2.76 *	1.24	1.29	0.17
31-12-76	1.95	0.02	3.0	0.28
27- 2-77	-	4.91 *	2.27	0.53

Table 2. Coefficient of dispersion values for Nereis diversicolor at four Stations on the Gayton transect. * - value showing significant aggregation.

Date	Station 15	Station 22	Station 29	Station 36
7- 3-75	420.91 *	2.71 *	58.35 *	16.19 *
16- 4-75	10.67 *	-	-	19.06 *
15- 5-75	6.45 *	-	164.71 *	54.65 *
17- 6-75	325.29 *	28.57 *	98.65 *	18.18 *
18- 7-75	439.39 *	97.92 *	466.67 *	171.43 *
21- 8-75	-	75.83 *	163.39 *	9.25 *
26-10-75	69.23 *	62.8 *	524.31 *	14.07 *
30-11-75	23.59 *	6.36 *	170.91 *	21.04 *
28- 1-76	25.18 *	6.67 *	0.67	-
27- 3-76	122.96 *	33.35 *	19.30 *	-
6- 5-76	163.50 *	66.66 *	4.0 *	0.59
19- 6-76	15.0 *	0.33	220.61 *	0.75
4- 8-76	3.70 *	26.67 *	66.56 *	100.31 *
4-10-76	93.17 *	55.35 *	0.17	4.19 *
31-12-76	0.14	14.0 *	192.50 *	15.40 *
27- 2-77	-	866.51 *	141.88 *	2.67

Table 3. Coefficient of dispersion values for Pygospio elegans at four Stations on the Gayton transect.
* - value showing significant aggregation.

Date	Station 15	Station 22	Station 29	Station 36
7- 3-75	-	1.0	-	0.5
16- 4-75	1.05	-	-	5.71 *
15- 5-75	-	1.81	3.94 *	0.96
17- 6-75	2.0	1.0	0.75	0.5
18- 7-75	4.4 *	20.65 *	1.48	0.13
21- 8-75	0.80	3.12 *	1.13	1.35
26-10-75	0.22	5.04 *	6.36 *	2.02
30-11-75	0.5	1.38	1.5	1.64
28- 1-76	2.86	14.73 *	1.0	-
27- 3-76	-	7.82 *	1.67	-
6- 5-76	-	-	-	-
19- 6-76	-	1.0	3.5 *	-
4- 8-76	0.75	0.55	2.61 *	-
4-10-76	0.69	0.75	1.0	-
31-12-76	-	0.5	1.8	-
27- 2-77	-	1.0	-	-

Table 4. Coefficient of dispersion values for <u>Scrobicularia plana</u> at four Stations on the Gayton transect. * - value showing significant aggregation.

Date	Station 15	Station 22	Station 29	Station 36
7- 3-75	13.91 *	2.21 *	1.2	1.17
16- 4-75	3.3 *	-	-	1.38
15- 5-75	0.81	0.96	1.67	2.01
16- 6-75	2.57	124.03 *	695.6 *	15.88 *
18- 7-75	47.62 *	47.81 *	98.1 *	40.44 *
21- 8-75	10.68 *	72.78 *	55.53 *	1.05
26-10-75	5.33 *	24.3 *	166.99 *	4.88 *
30-11-75	6.94 *	12.47 *	8.23 *	9.5 *
28- 1-76	16.28 *	6.45 *	3.20 *	-
27- 3-76	3.65 *	22.33 *	7.97 *	0.71
6- 5-76	2.96 *	0.53	1.68	4.38 *
19- 6-76	0.43	27.66 *	5.29 *	0.36
4- 8-76	13.26 *	13.12 *	17.23 *	0.25
4-10-76	80.52 *	1.84	3.58 *	0.54
31-12-76	17.62 *	3.64 *	9.33 *	0.17
27- 2-77	-	15.83 *	0.34	0.88

Table 5. Coefficient of dispersion values for <u>Macoma balthica</u> at four Stations on the Gayton transect.
* - value showing significant aggregation.

Date	Station 15	Station 22	Station 29	Station 36
3- 3-75	12.29 *	2.22 *	0.93	2.4 *
16- 4-75	2.58 *	-	-	0.59
15- 5-75	0.08	0.67	1.12	3.21 *
17- 6-75	5.81 *	135.14 *	741.7 *	17.34 *
18- 7-75	82.42 *	50.59 *	101.1 *	45.59 *
21- 8-75	8.25 *	71.84 *	58.36 *	1.23
26-10-75	6.94 *	20.29 *	166.53 *	8.19 *
30-11-75	7.44 *	15.91 *	8.55 *	1.24
28- 1-76	17.5 *	4.66 *	2.54	-
27- 3-76	4.13 *	22.02 *	6.26 *	0.36
6- 5-76	2.5	0.06	0.85	3.21 *
19- 6-76	0.23	28.94 *	4.7 *	0.64
4- 8-76	14.24 *	11.03 *	20.73 *	0.59
4-10-76	76.31 *	2.97 *	4.23 *	0.49
31-12-76	22.70 *	3.54 *	15.38 *	0.70
27- 2-77	-	17.57 *	0.32	1.49

Table 6. Coefficient of dispersion value for <u>Macoma balthica</u> 10 mm and less in length at four Stations on the Gayton transect. * - value showing significant aggregation.

Date	Station 15	Station 22	Station 29	Station 36
7- 3-75	2.75 *	0.83	2.12 *	2.4
16- 4-75	1.83	-	-	1.71
15- 5-75	0.89	1.13	1.41	0.6
17- 6-75	0.74	0.67	1.42	2.15
18- 7-75	12.16 *	0.72	0.56	1.31
21- 8-75	2.55	3.16 *	1.8	0.66
26-10-76	1.06	4.53 *	6.27 *	0.79
30-11-75	0.5	0.59	2.16	1.26
28- 1-76	2.0	2.95 *	1.02	-
27- 3-76	0.68	2.6	2.05	0.88
6- 5-76	1.2	1.4	3.98 *	1.64
19- 6-76	1.55	0.5	1.68	0.04
4- 8-76	1.48	3.02 *	0.85	0.72
4-10-76	4.5 *	0.33	2.36	2.4
31-12-76	0.06	0.23	6.2 *	1.41
27- 2-77	-	0.47	1.01	1.44

Table 7. Coefficient of dispersion values for <u>Macoma balthica</u> more than 10 mm in length at four Stations on the Gayton transect. * - value showing significant aggregation.

Date	Station 15	Station 22	Station 29	Station 36
7- 3-75	1.52	1.58	1.47	1.64
16- 4-75	3.96 *	-	-	2.04
15- 5-75	0.5	7.40 *	7.31 *	1.0
17- 6-75	3.56 *	116.13 *	17.49 *	0.58
18- 7-75	49.69 *	17.73 *	3.59 *	0.2
21- 9-75	15.07 *	13.53 *	26.95 *	1.0
26-10-75	11.42 *	2.45	2.31	0.75
30-11-75	12.74 *	25.34 *	0.5	-
28- 1-76	11.56 *	41.05 *	1.48	-
27- 3-76	1.87	2.5	0.09	-
6- 5-76	6.30 *	11.96 *	3.71 *	0.66
19- 6-76	2.33	2.29	2.07	0.88
4- 8-76	6.25 *	13.47 *	76.0 *	9.81 *
4-10-76	5.48 *	0.21	0.76	3.91 *
31-12-76	23.27 *	2.45	0.83	0.78
27- 2-77	-	8.80 *	-	1.89

Table 8. Coefficient of dispersion values for Hydrobia ulvae at four Stations on the Gayton transect. * - value showing significant aggregation.

Date	Station 15	Station 22	Station 29	Station 36
7- 3-75	-	2.0	2.06 *	1.0
16- 4-75	0.89	-	-	0.75
15- 5-75	2.0	0.90	0.94	0.75
17- 6-75	1.0	3.97 *	2.0	1.0
18- 7-75	0.74	1.5	2.81	0.75
21- 8-75	0.57	17.42 *	36.97 *	2.37
26-10-75	0.70	291.57 *	166.35 *	0.67
30-11-75	11.23 *	115.83 *	266.53 *	-
28- 1-76	98.81 *	10.91 *	2.86	-
27- 3-76	11.35 *	3.09 *	0.67	2.0
6- 5-76	1.55	2.0	1.0	1.0
19- 6-76	1.0	1.0	0.5	-
4- 8-76	26.46 *	3.40 *	0.94	2.48
4-10-76	66.45 *	17.84 *	61.22 *	4.71 *
31-12-76	6.86 *	47.89 *	2.98 *	11.87 *
27- 2-77	-	25.13 *	3.72 *	1.0

Table 9. Coefficient of dispersion values for Corophium sp. at four Stations on the Gayton transect. * - value showing significant aggregation.

the data unsuitable for estimating even distributions.

When dealing with populations which are non random an important consideration becomes the size of the sample replicate. Different size samples will be influenced by the inherent pattern of the aggregation and the problem has been outlined by Greig-Smith (1957). When estimating density of individuals per unit area these will be more accurate when based on samples of small variance. Greig-Smith (1952) indicated that sampling of an aggregated distribution gives a graph of variance against sampling block size having a pronounced peak, which occurs at a sample size corresponding to the mean area of the clumps. The existence and recognition of the peak therefore makes it possible to decrease the variance around the mean either by increasing or by decreasing the sample size depending on the actual position in relation to the peak. An example of the effect of the size of the sample on the variance (the C.D. value in this case) is given in Fig. 12. The results indicated the pronounced peak in three of the species, i.e. Pygospio elegans, E.longa and H.ulvae corresponding to a block size of 0.1 m^2 indicating that sampling size should be either above or below this value. Given knowledge of the dispersion it is then possible to set limits to the accuracy of the mean. Since statistical probabilities assume normal distribution of data, the data is then normalized by transformation. For random distributed populations a square root transformation is appropriate but for aggregated populations a log transformation has been found satisfactory (Barnes 1952; McIntyre 1971).

(f) Sample site location

The sample sites on the grid surveys were located by compass bearing. The bearings of known easily visible reference (Table 10, Map 25) were predetermined from large scale

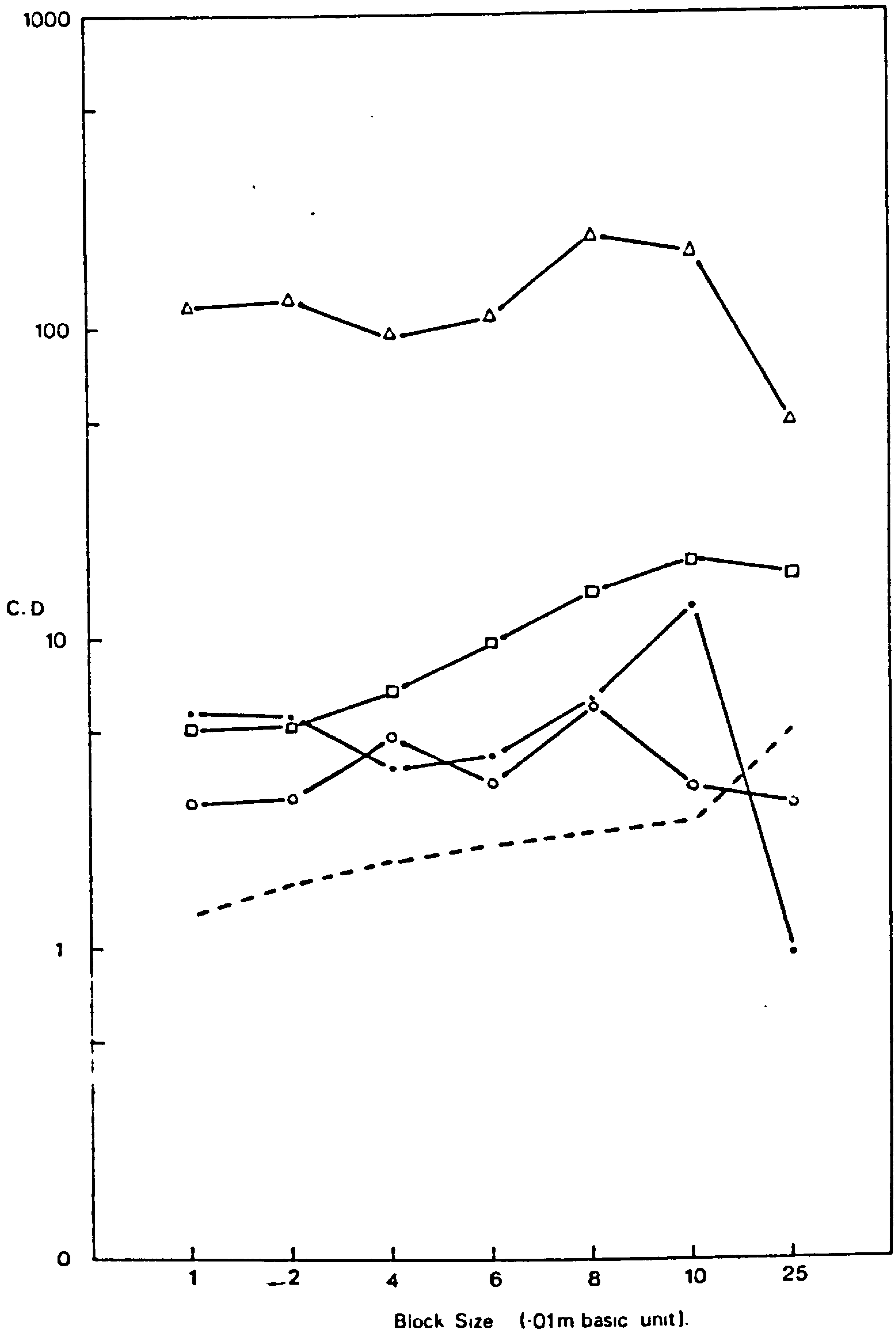


Figure 12. Plots of Coefficient of Dispersion (C.D.) values at various sampling block sizes. Limits of aggregation shown by the dashed line using 50 x .01 m^2 samples at Station 22 on 30-9-73.

Δ = Pygospio elegans

□ = Eteone longa

• = Hydrobia ulvae

o = Macoma balthica

Map Reference	Compass Bearing Point	O.S. Grid Reference
1	Navigation Mast, Hilbre Island	SJ 184880
2	Observation Post, Red Rocks, Hoylake	SJ 203885
3	Slipway to shore, Red Rocks, Hoylake	SJ 203883
4	Little Eye	SJ 199867
5	North edge of Marine Lake or Slipway, West Kirby (depending on site)	SJ 210868
6	South edge of Marine Lake, West Kirby (depending on site)	SJ 211859
7	Observation Tower, West Kirby Sailing Club	SJ 216859
8	Navigation Column, West Kirby	SJ 223866
9	'Gable End', Shore Road, Caldy	SJ 221851
10	Top of zig-zag footpath on the shore, Caldy	SJ 222848
11	'Aunt Sally's Cottage', Thurstaston	SJ 236835
12	Observation Tower, Dee Sailing Club, Heswall	SJ 253815
13	Clock Tower, Royal Liverpool Childrens Hospital, Heswall	SJ 267819
14	Gayton Cottage, Gayton	SJ 266800
15	Bell Tower, Mostyn House School, Parkgate	SJ 280779
16	Bell Tower, Neston Parish Church, Neston	SJ 292774
17	Harp Inn, Little Neston	SJ 290761
18	'Cosy Light' Navigation light at end of training wall, Flint	SJ 258736
19	Chimney, Paper Works, Oakenholt	SJ 262715
20	'Donjon', Flint Castle, Flint	SJ 247733
21	Boiler house chimney (tallest), Courtaulds Rayon Factory, Flint	SJ 244734
22	Railway Footbridge, Bagillt	SJ 222754
23	Highest point of Slag Reduction Co. Tip, Bagillt	SJ 217761
24	No. 1 Boiler house chimney, Courtaulds Rayon Factory, Greenfield	SJ 202772
25	Red corrugated iron hut, Llannerchymor Dock	SJ 177796
26	Mostyn Warehouse, Industrial Estate, Mostyn	SJ 159807
27	Centre door of No. 5 transit shed (bonded) warehouse Mostyn Dock	SJ 155812
28	Railway Footbridge, Ffynnongroew	SJ 141820
29	East lift winding gear, Point of Air Colliery, Ffynnongroew	SJ 128837
30	Point of Air Lighthouse, Talacre	SJ 121853

Table 10. Positions of compass reference points used in the surveys (see Map 25).

Ordnance Survey maps of $2\frac{1}{2}$" and 6" scale and placed on individual record cards carried in the field. To increase accuracy the bearing line from the sample site to the reference points was kept as short as possible and the angle between two of the bearings as close to 90° as would permit. A minimum of three bearings at each site enabled triangulations to increase the accuracy further. Corrections were made for magnetic deviation appropriate for the year. The method although accurate was tedious especially as the corer and sieve and any metal objects had to be removed before each site bearing was taken.

The Gayton sampling sites were initially located by compass bearings. The sites were then marked by thin bamboo stakes. Between each site further stakes were positioned every 50 metres. These were mainly for safety in conditions of low visibility and the short winter days and they also provided quick references if a particular stake was lost along the line, an army type marching stick was most useful in this respect. Provided the stakes were sunk deeply, except for some of the lower sites near the main channel, many remained for a considerable time. By using thin bamboo stakes scour round the base was minimised and little interference was caused to the local trammel net fishermen, the net either easily bending or pulling over the stake or breaking it with little net damage. No visible evidence of vandalism was encountered probably due to the 30 minute walk across dense S.anglica to the first sample site.

Initial location of the Thurstaston and Mostyn sample sites was by compass bearings. Subsequent location was by a combination of stakes, these were not a success due to easy access from the shore for vandals or anchored polypropalene twine free to float.

(g) Transport

On an estuary covering 125 km^2 it became clear after the first grid survey that I would need another means, other than walking, to cover the large distances involved quickly and efficiently. A variety of methods were used and I have outlined some of the advantages and disadvantages of each.

Vehicles must now, however, be considered as pieces of necessary apparatus in estuarine benthic studies. Much of the efficiency of these studies depending on rapid sampling.

Walking proved by far the most reliable and convenient and it caused little disturbance to invertebrates or birds. Within the limitations of the compass it was also unaffected by weather but over the large distances involved it was slow and there was a load limit particularly of soil samples. Access was also a problem in some areas, e.g. deep channels or difficult substrate conditions, including S.anglica saltmarsh up to two miles wide, thick mud or thixotropic sand.

Boats and inflatables were used at various times in combination with the other methods. They were most used in the Outer Estuary to survey the isolated sandbanks. The inflatables were particularly useful as safety boats. During the Spring 1972 survey a small two-man fibreglass body All Terrain Vehicle (Amphicat) was used. Good points included the improved speed when compared to walking, high payload, economy, independence of weather conditions and little damage to the environment either to the birds or the invertebrates. Although classed as amphibious, its use had to be limited to the low water period, motion in water was very slow and unstable and drainage channels had to empty before access could be gained. Due to the low ground clearance in soft sediments even on the large tyres the vehicle 'bellied'. Perhaps the greatest disadvantage lay in their unreliability and the need for constant expensive and time consuming maintenance. In 1973 the University University accepted a small prototype two-man Hovercraft to be field field tested on the Dee Estuary (Appendix 1). This was later followed by a purchase in Autumn 1973. The advantages over other vehicles after improvements were immediately apparent. Very rapid journey times between sampling sites were possible, enabling the whole Estuary to be sampled in 2-3 weeks as opposed to the former 4-7 weeks. Access to the Estuary was no problem, channels, even the main channel, could be crossed with ease and the saltmarsh, although an obstacle to a hovercraft in itself could be easily bypassed, the increased distance being covered quickly. Sampling could now follow the ebb tide, with the advantages of abundant water for sieving and alleviating the problem of vertical invertebrate migration in the sediment. Very soft sediments were little problem, the large surface area when idle spreading the load. There was little obvious disturbance to the invertebrates and although noise was a problem to the waders and wildfowl noticeably more disturbance was caused when I presented the human silhouette. Two big advantages were the relatively high payload (the craft was designed for two people but only myself used it during sampling) and the built in safety factor in that construction was based on an inflatable.

The craft, however, was not perfect. Weather, particularly high winds, caused problems and other physical limitations in its use include - large waves, saltmarsh, deep-sided gutters and melgraves. However, most of these could be avoided, the speed of the vehicle nullifying the increased distance covered. The most serious defect of the craft lay in the engineering. Initially, particularly on the prototype but also on the purchased craft, several design problems had to be overcome. Breakdowns in the field were few but this would not have been the case if time had not been allocated in regular maintenance. By the end of the study the craft was considered well developed and engendering some confidence in its ability bearing in mind its inherent weaknesses, the concept of the craft was ideal for estuarine study but the point must be stressed that I had to spend a considerable number of man hours in maintenance.

2.1.2 Analysis

(a) Sorting and enumeration

The invertebrates, after sieving on the Estuary, were carefully placed in plastic bags, labelled with insulation tape and returned to the laboratory as quickly as possible to prevent possible predation. The material was placed in deep freeze until analysis could proceed at the end of the survey. When analysing material there was the need for rapid defrosting to preserve the texture, particularly of the Annelids.

The invertebrates were examined in large white enamel dishes. Macroinvertebrates were identified, enumerated and recorded on standard record sheets. Counting of the large numbers involved meant that it was not possible to identify every animal to specific level,* rare species were preserved separately for later identification. In later analytical methods some species were responsible for only the finer divisions, so time spent identifying individual species, e.g. *Bathyporeia* sp. was not economical. Numbers were converted to /m2 and the data punched onto paper tape. A flow chart has been presented in Appendix 2 - 5). A particular problem was presented with *P.elegans*. At certain times of the year dense 'carpets' were present and on these occasions sub-sampling had to

* For convenience later species lists refer collectively to genera and species.

be adopted. It was also impossible to examine every P.elegans tube for habitation and I had to make an informed estimate from the numbers involved. The P.elegans results should therefore be treated with less precision.

(b) Statistical analysis

Association Analysis was chosen as being the most appropriate numerical technique and is particularly useful for interpreting data from regular grid surveys and for the production of distribution maps. The method used was that of Williams and Lambert (1959). Analysis took place at the Institute of Terrestrial Ecology, Merlewood Research Station, on a DEC-PDP8/I computer, with 16K of core and disc/dec-tape back up storage facilities. Initial processing and handling of the data was in a mixture of FORTRAN and BASIC languages using the TS-8 system. The AA was carried out with programmes written in FORTRAN II and using the OS-8 software system.

2.2 Environmental factors

2.2.1 Physical/Chemical

(a) Sampling

Samples of the sediment were obtained by corer at each of the invertebrate grid survey sites, and placed in plastic bags and labelled. For the early surveys samples were placed in a refrigerator and analysed almost immediately, samples from later surveys were deepfrozen. Soil samples were taken on all the extensive surveys and all the intensive surveys except the last six months. Samples were taken at two depths 0-2.5 cm and 17.5-20 cm. The principle reason for selecting 17.5-20 cm was to sample interstitial salinity. From other work (Reid 1930; Smith 1956; Capstick 1957) at this depth salinity fluctuations were less variable.

(b) Analysis

(i) Salinity

Salinity of the interstitial water was determined, after separation from the sediment in a Buchner funnel, by standard methods of titration with silver nitrate.

(ii). Particle size

In early surveys a dry sieve method was attempted, this presented problems particularly with the smaller size fractions. In later work a wet method was used. A weighed quantity (100 gms) of oven dried sediment was passed through a column of sieves under a cascade of running water. The fractions were removed from the sieves, dried at 105°C for 24 hours and reweighed. The quantity of silt and clay was determined by loss. The results were placed on standard record sheets and percentage composition of the fractions determined. Cumulative percentage frequency curves were constructed (examples in Appendix 6) and from these I calculated the median phi and mean phi values (Folk & Ward 1957). The distributions were unimodal, so I have used the median phi measure for further analysis.

(iii) Percentage loss on ignition

A weighed quantity of approximately 10 gms of soil was dried for 24 hours at 105°C. After reweighing, this was then placed in a muffle oven for four hours at 550°C. The value of percentage loss on ignition was then expressed as the percentage weight loss before and after treatment in the oven. The method described, as noted by Ball (1964), could only be used as an estimate of the organic matter and organic carbon. The main disadvantage of the method is that in addition to the weight loss from the destruction of organic matter further weight loss occurred due to loss of CO_2 from carbonates in the soil. There is also loss of elemental carbon and loss of water from clay minerals.

The main loss of carbon dioxide from carbonates occurred at high temperatures and therefore this error was likely to be substantially reduced in the relatively low temperature procedure employed. In the upper sediment sample benthic algae was also included in the breakdown. Evidence of seasonal change was not investigated but in some surveys thick mats of Enteromorpha and filamentous algae were present giving very high percentage loss on ignition. These were restricted to the upper shore. Another factor possibly affecting the results was the presence of the active coal mine at Point of Air with the dumping of tip waste onto the shore at Mostyn Bank.

(iv) Elevation

For the calculation of tidal heights use has been made of the detailed aerial survey made available by Binnie & Partners for 1971. A summary of the data available has been presented in Map 26 with the main Spring and neap tide levels indicated. Although subsequent surveys were planned problems developed so that for the biological interpretation the 1971 data has had to be employed in all the analyses. Some change in bank formation has occurred but the general physiographic pattern has been maintained. Any conclusions drawn from relationships between height and community distributions have to become considered within wider error considerations. The main reference levels are :

		Height in relation to Ordnance Datum, Newlyn
Mean high water spring tides	(MHWS)	4.37 m
Mean high water neap tides	(MHWN)	2.47 m
Mean tide level	(MT)	0.27 m
Mean low water neap tides	(MLWN)	-2.03 m
Mean low water spring tides	(MLWS)	-3.93 m

The percentage cover and exposure values have been calculated from the Liverpool tide curves and presented in Figs. 13 and 14.

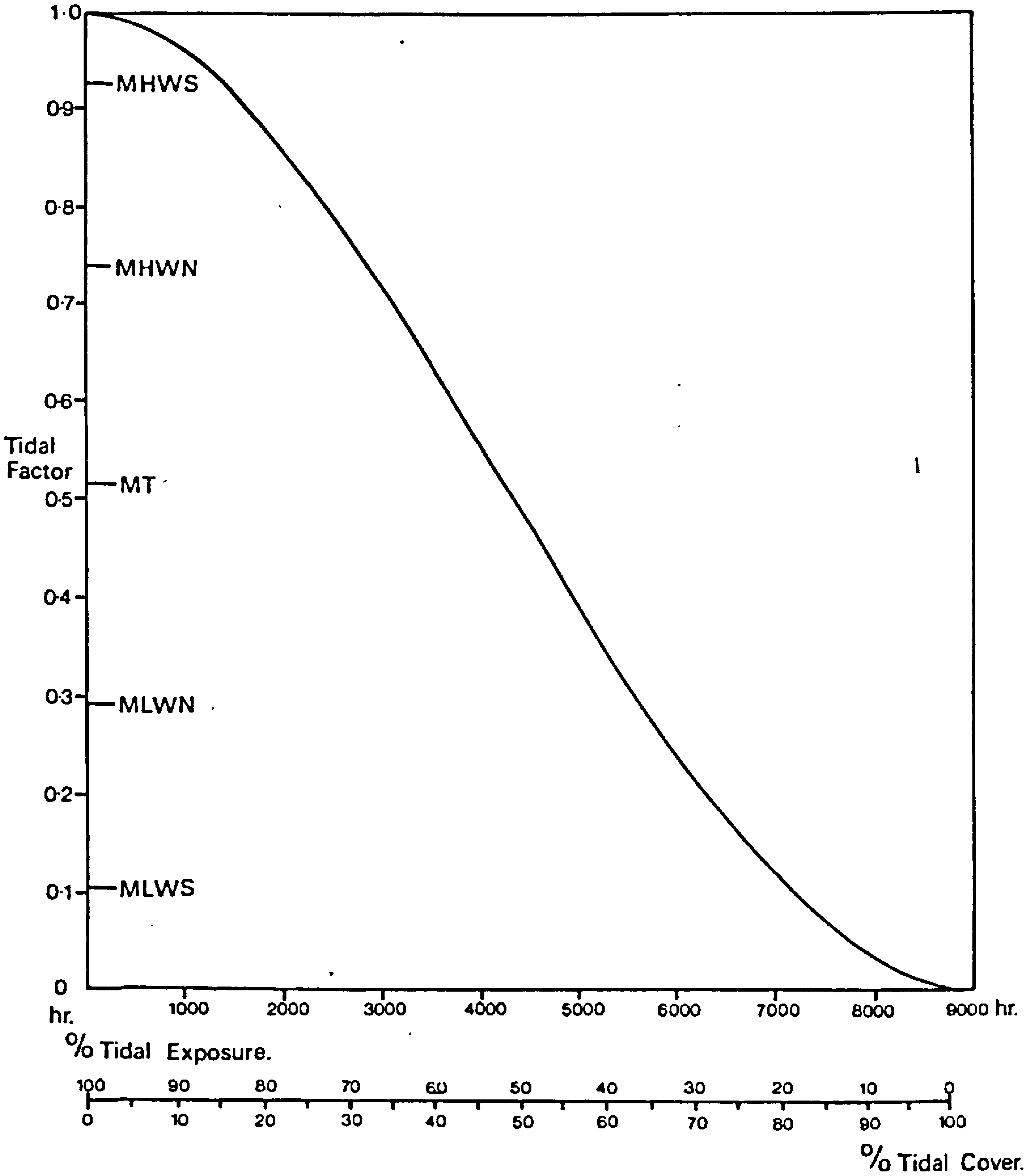


Figure 13. Hours of total annual tidal cover and exposure at Hilbre Island in relation to height on the shore. (Based on Liverpool Tide Table predictions).

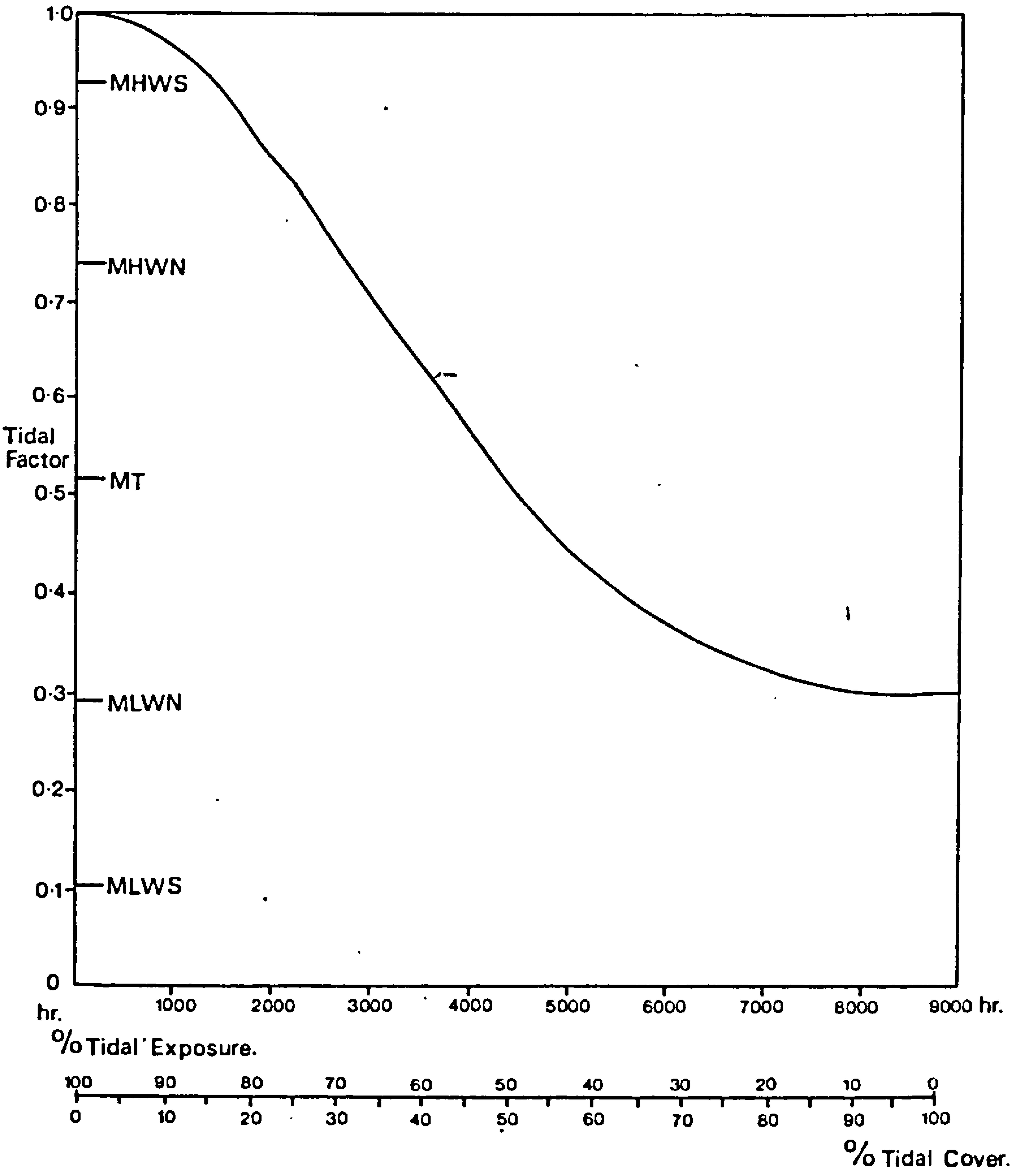


Figure 14. Hours of total annual tidal cover and exposure, main Dee channel at the base of the Gayton transect. (Based on Liverpool Tide Table predictions).

These graphs were prepared using the methods by Dalby (1970) and making similar mathematical assumptions in their preparation, e.g. The tide interval between successive high tides was assumed to be constant: the tide curve was estimated to be constant throughout the spring neap cycle and a line has been drawn midway between the extremes shown on the Liverpool tide curves: No allowance could be made for meteorological variations. The tide curve of the Dee becomes modified as the Estuary is ascended. (Fig. 2). The ebb flow being of longer duration than the flood. This has been taken into consideration in the preparation of Fig. 14 using available tide curve data (H.R.S. 1967). The figure represents the tide cover exposure value at the base of the Gayton transect. Fig. 15 was constructed to indicate the relation between the number of coverings by the tide related to the height on the shore.

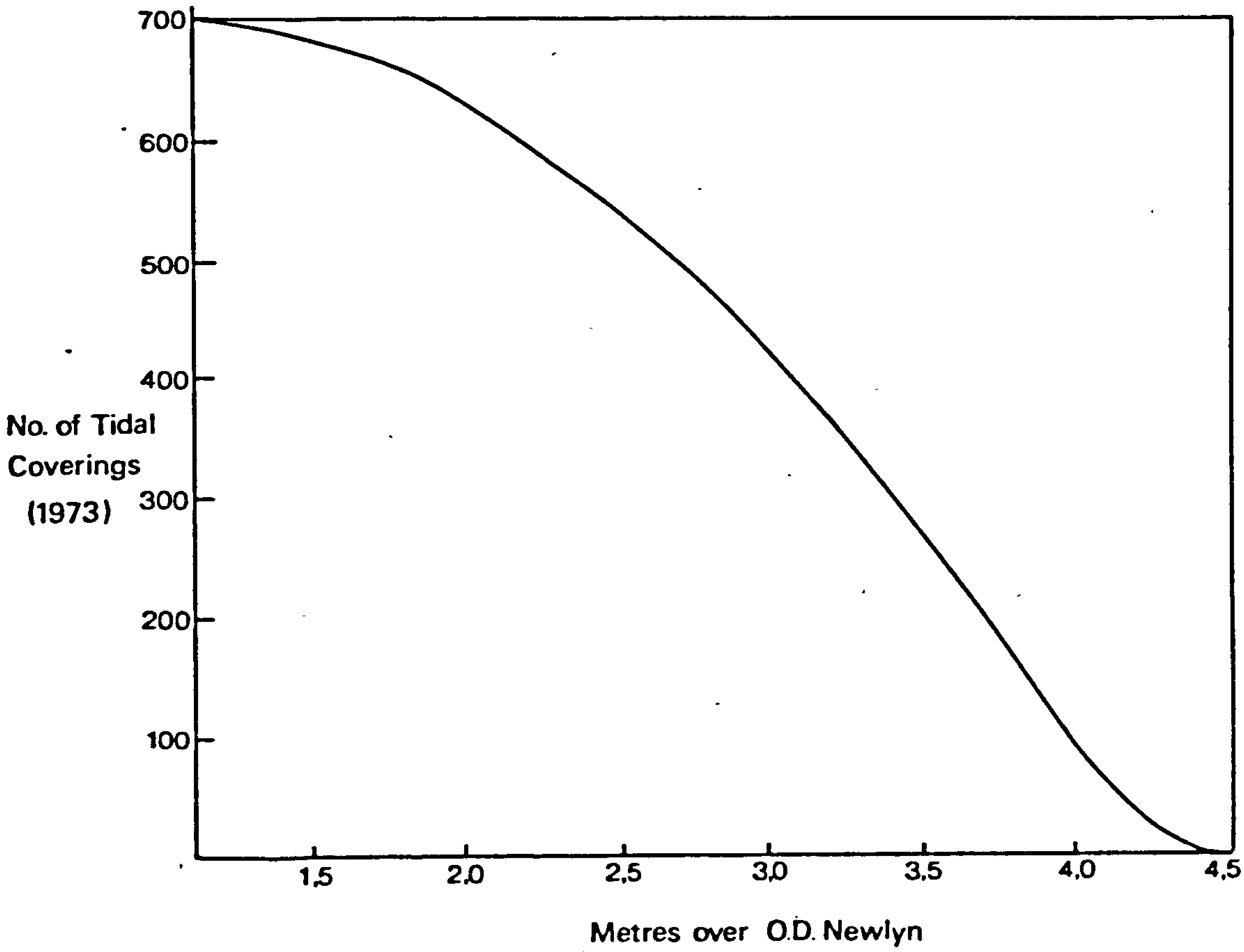


Figure 15. Number of actual tidal coverings in relation to height. (Based on Liverpool Tide Table predictions).

3 RESULTS

3.1 Extensive surveys

3.1.1 Environmental factors

(a) Physical/Chemical

(i) Salinity

The results of the salinity analyses are presented graphically in Maps. 27 - 30 for Autumn 1971 and Spring 1974. The results were complex with much spatial variation. However, general trends were present, the outer estuary had salinities near or occasionally above that of seawater, particularly in regions high on the shore, probably representing evaporation of the interstitial waters of the sediments. In the middle regions of the Estuary salinities were generally between 26‰ to 31‰. The higher values occurring high on the shore (Newell 1964; Popham 1966). In the Inner Estuary, although there were high values near the saltmarsh, there was a rapid fall in salinity in the channel near Flint. Salinities ranged overall from 39‰ high on the shore in the Outer Estuary to approximately 14‰ in the Inner Estuary.

(ii) Particle size

The distributions of the various particle size fractions have been presented graphically in Maps 31 - 50. Although some variation was present, there was a generally close agreement between the 0-2.5 cm and 17.5-20 cm distributions. The variation perhaps reflecting the dynamic nature of the environment with the constant redistribution of sediments. Within the Estuary there was a predominance of fine sand (125 - 250µ) and very fine sand (63 - 125µ). Coarse sand (>500µ) in small quantities tended to be restricted to the outer exposed Estuary and in particular on the outer exposed sides of the sandbanks where the effects of wave action from Liverpool Bay was most pronounced. Medium sand (250-500µ) again in small quantities was also restricted to the the outer exposed areas. The areas adjacent to the main channels were fine sand (125 - 250µ). The composition of the 'melgraves' also consisted of this fine sand fraction. The very fine sand in the Estuary was found in more protected areas either away from the effects of wave action at the entrance to the Estuary in the lee of the main sandbanks or the upper shore. The silt and clay fraction (<63µ) in small quantities was restricted to even more protected areas away from the main channels, high on the shore or in the lee of sandbanks. Although no direct experiments were carried out to relate the water velocity to sediment type, clearly the results indicate an interaction between two water velocity regimes. The ebb and flow of the tide and the drainage of the River Dee system, superimposed upon by the effects of wave action from Liverpool Bay. Clearly the shape, height and position of the outer sandbanks at the entrance to the Estuary can have a critical bearing upon the distribution of sediments within the Estuary.

The results of the various soil fractions have been summarised by the estimation of the median phi value and the distribution of medium phi at 0-2.5 cm depth in Spring 1974 and 1976 have been presented graphically in Maps 51 and 52.

(iii) Percentage loss on ignition

The distribution of percentage loss on ignition has been presented graphically in Maps 53 - 57. The relationship to the silt and clay distribution was very evident with the higher percentage loss on ignition values in well protected areas high on the shore. Variations between Autumn and Spring surveys were not pronounced. Maximum values attained 14% in Autumn 1971 on the edge of the saltmarsh at Heswall, but over much of the central parts of the Estuary adjacent to the main channel values were less than 2%. The values at 17.5-20 cm, although lower than those on the surface, had similar distributions.

(b) Predation

(i) Waders

The seasonal distribution of five important waders and wildfowl on the Estuary are presented graphically in Figs. 16 & 17)* The striking feature was the almost complete absence of birds in Summer. At this period the birds are breeding in northern latitudes. The various peaks in the wader graphs reflect the passage migration through the Estuary in combination with the resident winter population.

(ii) Fish

The distribution of monthly variation in numbers of adult P.flesus caught in a fixed net at a position approximately midway between Stations 22 and 29 on the Gayton transect has been presented in Fig. 18 (N. Parsons pers. comm.). The figures represent the results from one year but are thought to indicate a reasonable estimate of the annual variation in popultion. Marked increases in numbers occurred in May/June 1977 and this was followed by a gradual but later increased reduction in numbers in November/December 1977, down to insignificant numbers in January.

* These graphs were constructed from data kingly provided by R A Eades, Organiser for the Dee Estuary monthly wader counts and G A Williams, Organiser for the Dee Estuary monthly wildfowl counts.

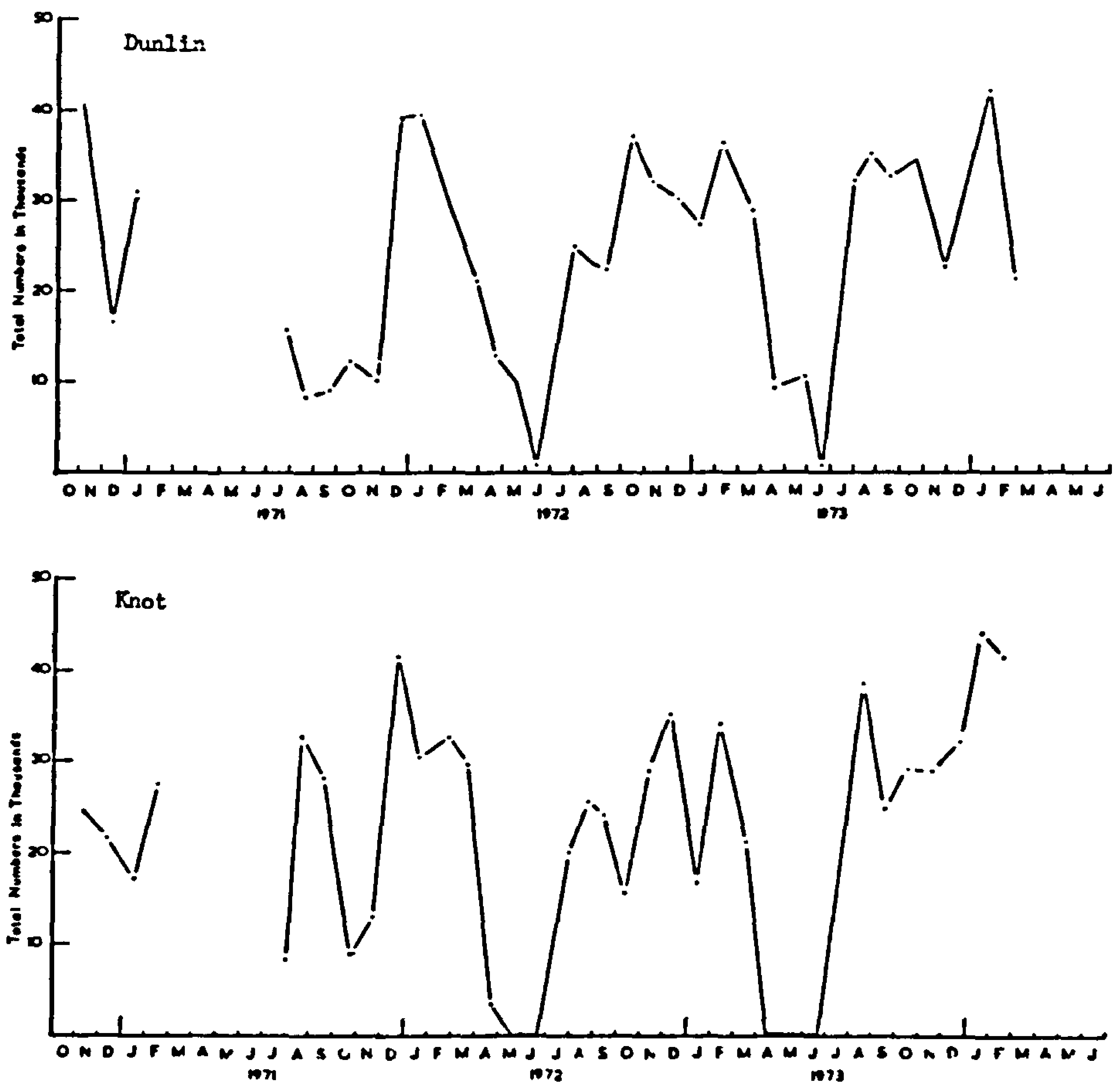


Figure 16. Seasonal variation in counts of waders in the Estuary 1971-73.

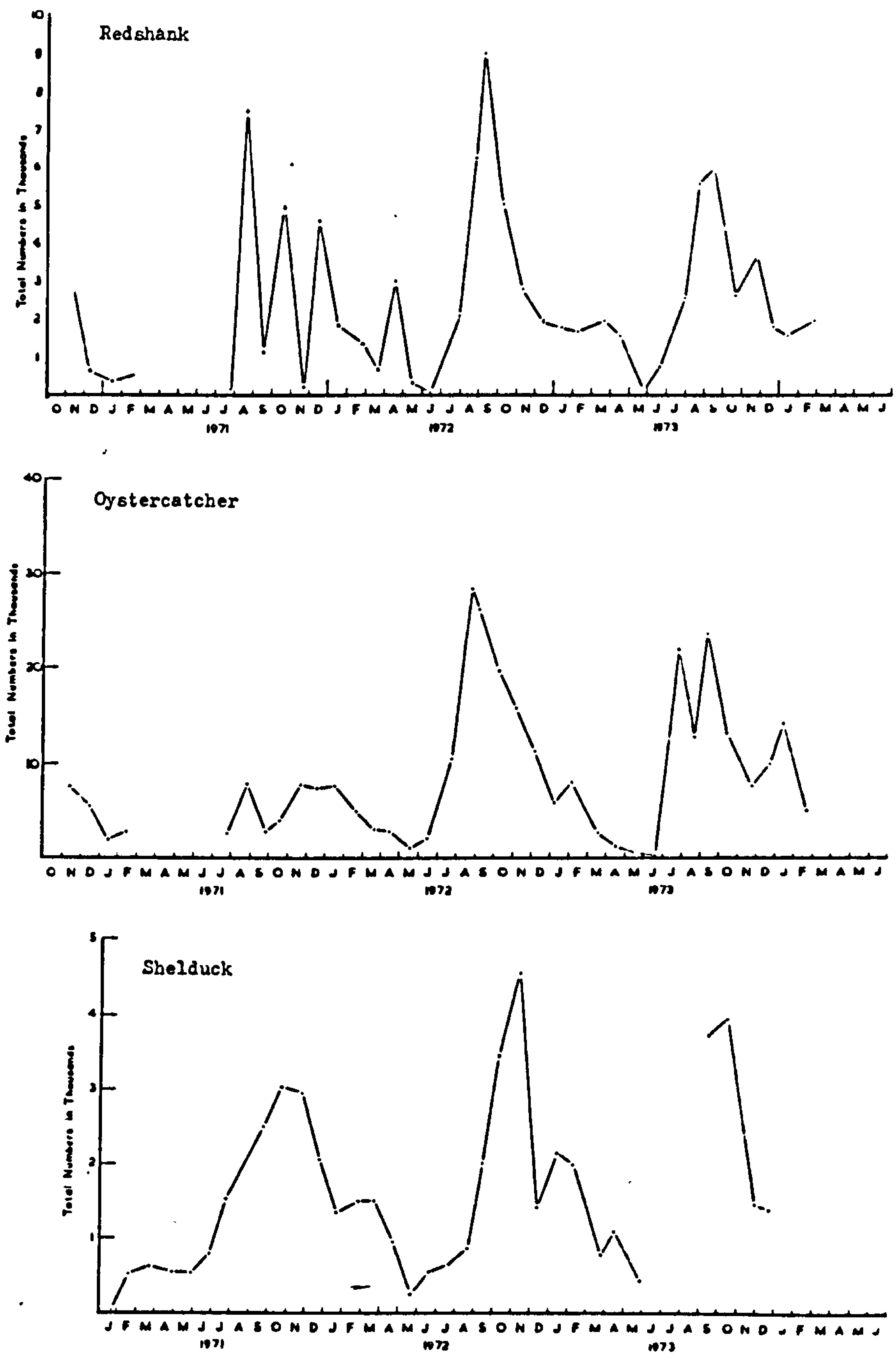


Figure 17. Seasonal variation in counts of waders & wildfowl in the Estuary 1971-73.

Figure 18. Monthly variation in numbers of Platichthys flesus caught in a fixed net positioned approximately midway between Stations 22 and 29 on the Gayton transect.

3.1.2 Macroinvertebrates

The central aim of the extensive surveys was to establish objectively macroinvertebrate communities and to relate these communities to their environmental factors, at the same time noting the degree of variability between seasons and years. To help in the interpretation of the numerical analysis of the community groups the basic raw data has been presented in the form of distribution maps for each of the species (Maps 58-243). With the material available it was possible to relate each of the species to its physical chemical environment for comparison with other autecological studies but this was not the central aim of the study, although it will be possible to do this for individual species later. However, the density distributions provided additional information on the population dynamics of each species over the whole Estuary and were of value as contributory evidence for the density dependant mechanism to be outlined later. To provide a summary of the quantitative data for each species and to complement the distribution maps, tables have been constructed (Tables 11 - 36) which divide up the sites at which the species were present into frequency groups depending on the number of individuals $/m^2$ occurring at that site. For comparative purposes the Autumn and Spring series of surveys have been distinguished. The seasonal percentage loss figures presented refer to the period between sampling surveys, i.e. Autumn and Spring. They are, therefore, only indications of loss between these two seasons not the loss between recruitment periods and will therefore tend to be underestimates of the actual annual loss. Also due to reduced sampling of the Estuary in Spring 1975 this survey has been ommitted in calculating the mean Spring values.

In the following results certain species occurred in only low abundance, maps and tables however have been presented but comment has been restricted to the more abundant species. The surveys were undertaken in the Autumn and Spring with the object of noting changes caused by predators over the winter. Direct evidence of known predation on the Dee has been provided from the ornithological studies of N. Buxton and the fish studies by N. Parsons. Where possible this has been supplemented by evidence from other sources.

(a) Nereis diversicolor (Maps 64-71, Table 12)

This polychaete annelid was found growing to approximately 10 cm. Depth of the polychaete in the substrate was variable depending on a number of factors including size, depth of water table and temperature (Linke 1939). On the Dee large specimens were found up to 30 cm in the substrate on a neap tide at the edge of the saltmarsh on the Gayton transect but they were in general above 20 cm depth. Following the receding of the tide they were particularly near the surface.

The distribution was concentrated on the Middle and Inner Estuary. The polychaete was found in a variety of finer substrates and tended to lie near the MHWN tide line, with the exception of areas protected from wave action, but very few were recorded below the MT line. Densities of N.diversicolor were higher in the Autumn compared to the Spring. In the Spring there was an average loss in the total population of 47% but in contrast to most other species there was a slight rise in areas covered (8%). Total numbers recorded in the Autumn as well as being higher were more variable, e.g. 71% less in Autumn 1976 compared to Autumn 1971. Autumn 1976 represented a relatively 'poor' year with

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	1 200 200	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	3 120 40	2 30 15	- - -
Total	No. of sites No. in sites Mean/m2	4 320 80	2 30 15	- - -
Maximum density/m2		200	20	-

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	2 40 20	1 33 33	- - -	4 100 25	1 20 20
Total	No. of sites No. in sites Mean/m2	2 40 20	1 33 33	- -	4 100 25	1 20 20
Maximum density/m2		20	33	-	40	20

Table 11. *Phyllodoce* sp. - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	12 19320 1610	2 2660 1330	1 1620 1620
100-1,000	No. of sites No. in sites Mean/m2	56 20925 374	47 15625 332	35 10055 287
10-100	No. of sites No. in sites Mean/m2	40 1440 36	35 1425 41	27 1025 38
Total	No. of sites No. in sites Mean/m2	108 41685 386	84 19710 235	63 12700 202
Maximum density/m2		2660	1540	1620

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	1 1160 1160	- - -	2 2140 1070
100-1,000	No. of sites No. in sites Mean/m2	57 16400 288	32 8549 267	39 8425 216	33 10085 306	37 7367 199
10-100	No. of sites No. in sites Mean/m2	51 2050 40	60 2494 42	43 1900 44	34 1675 49	48 1869 39
Total	No. of sites No. in sites Mean/m2	108 18450 171	92 11043 120	83 11485 138	67 11760 176	87 11375 131
Maximum density/m2		840	717	1160	860	1120

Table 12. *Nereis diversicolor* - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

an increase in numbers of only 10% from the previous Spring and the lowest recorded area present (63 sites). The Spring surveys in contrast were much less variable especially in 1973 and 1974. Overall decrease in numbers during the winter was 74% in 1971/72 and 42% in 1975/76 with a much larger percentage loss in the 'good' year of 1971/72. Dales (1951) found comparable losses over the winter on the Thames. As possible explanations of the loss, other workers have indicated N.diversicolor to be a prey of other invertebrates, e.g. C.maenas (Blegvad 1914), Lloyd and Yonge (1947) found large N.diversicolor being predated by C.vulgaris on the Severn Estuary. It has also been recorded as a prey of fish, e.g. P.flesus (Summers 1974) and Pleuronectes platessa (Williams, Perkins and Hinde 1965). Observation on the Dee (N. Parsons pers. comm.) confirmed it to be a common prey of P.flesus. It was also a common bird prey and was taken on the Dee by several species and also on other estuaries (Goss-Custard 1969, Prater 1972).

(b) Nephthys sp. (Maps 72-79, Table 13)

This genus of polychaete annelids grew up to 6 cm on the Dee. The polychaete does not have a permanent burrow and it was found 10 - 20 cm below the surface by Holme (1949) and Thamdrup (1939). Although they do not burrow deeper in the winter (Linke 1939) vertical migration occurs on the tidal cycle (Vader 1964). Nephthys sp. were found in the Outer and Middle Estuary and the overall seasonal pattern did not change substantially. Although occurring in a range of sediments Nephthys sp. was more often found in coarse sediments and this was in agreement with other observations by Clarke, Alder and McIntyre (1962); Wolff (1971). The polychaetes range on the shore was from approximately MT to low water. In three of the surveys Nephthys sp. were

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	45 6780 151	23 4020 175	8 800 100
10-100	No. of sites No. in sites Mean/m2	69 2720 39	62 2520 41	49 1909 39
Total	No. of sites No. in sites Mean/m2	114 9500 83	85 6540 77	57 2709 48
Maximum density/m2		300	440	150

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	28 3920 140	28 4450 159	3 340 113	2 220 110	10 1320 132
10-100	No. of sites No. in sites Mean/m2	52 2210 43	48 2023 42	24 980 41	21 759 36	64 2549 40
Total	No. of sites No. in sites Mean/m2	80 6130 77	76 6473 85	27 1320 49	23 979 43	74 3869 52
Maximum density/m2		340	433	120	120	180

Table 13. *Nephthys* sp. - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

recorded near the main water channel in the Inner Estuary but only in low densities. The frequency distributions (Table 13) are presented only as an indication of the numbers involved on the surveys, sampling was curtained in the sand regions of the Estuary hence Nephthys sp. populations are not fully represented. However, reasonable coverage of the Estuary was made in Autumn 1971, Autumn 1975, Spring 1972, Spring 1973 and Spring 1976 and the distributions indicated that Nephthys sp. was an animal of the large sandbanks. Bearing in mind the limitations of the surveys, in Autumn 1971, perhaps the best coverage, total numbers attained 9,500 with an average density of $83/m^2$ by the following Spring this had dropped by 35%. Nephthys sp. was not recorded as an important bird or fish prey species on the Dee and references in the literature are rare.

(c) Eteone longa (Maps 80-87, Table 14)

E. longa is a polychaete annelid growing to approximately 6 cm on the Dee. There were marked changes in the extent of the distribution between the Autumn and Spring surveys. Tidal height was probably particularly important in this species, maximum densities were concentrated on the MHWN tide line. Both in the Autumn and Spring a variety of sediment types were inhabited except the very fine. Salinity was not apparently a limit to its Inner Estuary distribution, many specimens being recorded in this area in the Autumn series. In the Spring series the distributions became much protracted and no E.longa were found in the Inner Estuary. Total numbers in the Autumn surveys were considerably higher than the Spring with a mean loss of 92% over the winter. The total numbers in the Autumn ranged from 15,550 - 66,020 . Loss over the specific winters of 1971/72

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	4 8050 2013	19 45720 2406	3 3908 1303
100-1,000	No. of sites No. in sites Mean/m2	47 13460 286	54 18800 348	38 9817 258
10-100	No. of sites No. in sites Mean/m2	69 2660 39	38 1500 39	44 1825 41
Total	No. of sites No. in sites Mean/m2	120 24170 201	111 66020 595	85 15550 183
Maximum density/m2		2860	6700	1575

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	5 903 181	- - -	- -	1 100 100
10-100	No. of sites No. in sites Mean/m2	12 300 25	20 491 25	14 404 29	19 615 32	18 560 31
Total	No. of sites No. in sites Mean/m2	12 300 25	25 1394 56	14 404 29	19 615 32	19 660 35
Maximum density/m2		40	217	60	80	100

Table 14. Eteone longa - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

and 1975/76 was 98.7% and 99% respectively. The cause of this dramatic reduction was not known but being a small polychaete and not unlike N.diversicolor from a distance ornithological predation investigations could possibly class it as a Nereid. No specific references could be found to the polychaete as a prey species and it was not identified on the Dee as such by either the ornithological or fish studies.

(d) Scoloplos armiger (Maps 88-95, Table 15)

This polychaete Annelid rarely exceeded 5 cm on the Dee. It has been quoted at a number of depths but is generally near but not at the surface, Vader (1964) also reported vertical migration takes place in the sediment. The distribution of the polychaete on the Dee was limited, only being found in the Outer Estuary in particular restricted to Mostyn and West Kirby Banks. S.armiger was found in a variety of substrate but mainly between MT and MHWN. There was only a small seasonal variation in distribution. Its absence from the Middle and Inner Estuary indicated salinity could be a limiting factor. This lack of penetration into the Estuary was also noted by Spooner & Moore (1940). Numbers were generally higher in the Autumn surveys, with a 23% mean loss over the winter. Over the 1971/72 winter there was a 44% loss and over the 1975/76 winter a 21% loss. Blegvad (1930, 1932) listed S.armiger as an excellent fish food and Bulycheva (1948) listed it as an important food of P.flesus. It was no , however, registered an an important prey item in either the bird or fish observations on the Dee.

(e) Nerine cirratulus (Maps 96-103, Table 16)

This polychaete Annelid grew to approximately 5 cm on the Dee Estuary. The polychaete was found in the Outer, Middle

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	1 800 800	4 700 175	2 400 200
10-100	No. of sites No. in sites Mean/m2	11 280 25	4 160 40	2 100 50
Total	No. of sites No. in sites Mean/m2	12 1080 90	8 860 108	4 500 125
Maximum density/m2		800	280	300

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	1 460 460	4 550 138	2 300 150	4 740 185	2 420 210
10-100	No. of sites No. in sites Mean/m2	4 140 35	6 184 31	4 200 50	6 300 50	3 260 87
Total	No. of sites No. in sites Mean/m2	5 600 120	10 734 73	6 500 83	10 1040 104	5 680 136
Maximum density/m2		460	183	180	360	280

Table 15. Scoloplos armiger - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	1 1000 1000	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	17 3960 233	16 5740 359	4 525 131
10-100	No. of sites No. in sites Mean/m2	48 1700 35	21 620 30	21 800 38
Total	No. of sites No. in sites Mean/m2	66 6660 101	37 6360 172	25 1325 53
Maximum density/m2		1000	880	150

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	1 1780 1780
100-1,000	No. of sites No. in sites Mean/m2	7 2400 343	3 733 244	2 280 140	2 240 120	9 1720 191
10-100	No. of sites No. in sites Mean/m2	27 880 33	27 876 32	7 320 46	7 300 43	16 660 41
Total	No. of sites No. in sites Mean/m2	34 3280 96	30 1609 54	9 600 67	9 540 60	26 4160 160
Maximum density/m2		820	433	160	140	1780

Table 16. Nerine cirratulus - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

and Inner Estuary but the maximum densities were limited to the Outer Estuary. N.cirratulus was recorded in a variety of the coarser sediments and field observations indicated that it occurred most frequently in rapid draining sediments adjacent to main channels. The polychaete was recorded at practically all tidal heights and on a number of occasions was recorded in the Inner Estuary near the main Dee channel indicating a tolerance of a lowered salinity. Like S.armiger this species only occurred in small numbers and it was not recorded as a prey for either birds or fish on the Dee.

(f) Pygospio elegans (Maps 104-111, Table 17)

P.elegans is a tube dwelling polychaete annelid growing to a length of approximately 1-1.5 cm on the Dee Estuary. The species was recorded in the Outer, Middle and Inner Estuary in a range of sediments with the exception of -

very coarse sand, probably due to disturbance by wave action, and

very fine sediments, probably due to difficulties in tube construction (Clay 1967).

Maximum densities were therefore recorded in regions of intermediate exposure to wave action. Although recorded at a variety of tidal heights P.elegans was found approximately either side of MHWN. P.elegans occurrence in high densities in the Inner Estuary indicated low salinity tolerance and Refers (1933) found it in salinities of 5-6‰. Evidence of the polychaetes susceptability to wave action was supported by observations of large continuous mats of the vertical tubes being present at certain times of the year usually early summer but these mats, as the Autumn progressed became fragmented and erosion holes developed. Later in the winter gales the surface usually became uniform and apparently devoid of

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
100,000-1,000,000	No. of sites No. in sites Mean/m2	6 1632400 272067	- - -	- - -
10,000-100,000	No. of sites No. in sites Mean/m2	22 568200 25827	12 50400 42000	5 86655 17331
1,000-10,000	No. of sites No. in sites Mean/m2	36 116440 3234	24 95200 3967	14 41170 2941
100-1,000	No. of sites No. in sites Mean/m2	26 11440 440	17 5400 318	33 10025 304
10-100	No. of sites No. in sites Mean/m2	35 1510 43	7 360 51	9 453 50
Total	No. of sites No. in sites Mean/m2	125 2329990 18640	60 151360 2523	61 138303 2267
Maximum density/m2		660000	80000	30000

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
100,000-1,000,000	No. of sites No. in sites Mean/m2	- - -	3 457424 152474	- - -	- - -	- - -
10,000-100,000	No. of sites No. in sites Mean/m2	4 70000 17500	24 951268 39636	5 102840 20568	18 459600 25533	3 56000 18667
1,000-10,000	No. of sites No. in sites Mean/m2	19 67400 3547	28 111914 3997	16 71180 4449	17 70200 4129	13 51200 3938
100-1,000	No. of sites No. in sites Mean/m2	13 6240 480	17 6514 383	28 9815 351	23 8410 366	17 6320 372
10-100	No. of sites No. in sites Mean/m2	5 190 38	13 689 53	8 520 65	8 340 43	15 580 39
Total	No. of sites No. in sites Mean/m2	41 143830 3508	85 1527809 17974	57 184355 3234	66 538550 8160	48 114100 2377
Maximum density/m2		32000	209375	32000	60000	24000

Table 17. *Pygospio elegans* - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

P.elegans, however, close examination usually revealed a residual population. There was evidence of much annual and seasonal variation in total numbers of P.elegans on the surveys with the possibility of a two year cycle (see transect data). Total numbers were an average 45% higher in the Autumn surveys compared with the Spring, a figure due mainly to the very high total in Autumn 1971, this was seventeen times higher than the total for Autumn 1976. Similar high variability was seen in the Spring surveys with the highest in Spring 1973 being fourteen times higher than Spring 1976. The Spring 1973 total was eleven times higher than Autumn 1976. In the consecutive years of 1971/72 and 1975/76 there was a 93% loss and 24% loss respectively. The results are difficult to interpret but recruitment outside the more normal summer period may have contributed to the Spring increase, e.g. eggs and larvae have been recorded at various times of the year, Winter and Spring (Leschke 1903; Thorson 1946; Marine Biological Association 1957), February to August (Hannerz 1956) and June to August (Soderstrom 1920; Thorson 1946). The loss in numbers as previously noted could have been due to storms but although the losses were abrupt on occasions usually the decline in numbers was slower than the increase, indicating possible predation.

Its importance as a prey species is not widely given in the literature but Hannerz (1956) listed it as a prey of Nephthys sp. Linke (1939) found it in the gut of A.marina. In my laboratory it has been observed to be actively searched for and preyed upon by C.vulgaris and also by C.maenas. Bulycheva (1948) lists it among the food of P.platessa. On the Dee it was taken in large quantities by P.flesus and the ornithological investigations indicated that possibly Shelduck (Tadorna tadorna L.) could be taking the polychaete but this may have been incidental to finding other prey, e.g. M.balthica.

(g) Arenicola marina (Maps 112-118, Table 18)

This polychaete annelid grew to a length of approximately 15 cm on the Dee although few were found and recorded. The distribution of casts was restricted to the Outer and Middle Estuary, particularly to mud/sand deposits where the water table remained high throughout low water. Casts were not observed in the Inner Estuary. A.marina was not recorded on the Dee as a prey from either the fish or bird observations, however, its limited distribution did not correspond with the main bird and fish observation areas. Bulycheva (1948) records the polychaete being taken by P.flesus and P.platessa. Orton (1925) ascribed the variation in tail length in Morecambe Bay as being due to bird predation.

(h) Cerastoderma edule (Maps 129-135, Table 22)

This lamellibranch grew to a length of approximately 30 mm and burrows in the substrate to a depth of approximately 4 cm. The species was found in a number of sediment types from fine to coarse sand. The population in coarse sand was present near low water on Middle Salisbury Bank in Spring 1976 but they were not registered on the distribution maps, being between the sample sites. The maximum densities occurred in fine sediments around the MT level, but this was modified by protection from wave action, e.g. West Kirby. Penetration of the species into less saline waters of the Inner Estuary was more marked in the Autumn surveys but its absence in the Spring surveys in the Inner Estuary was possibly not necessarily linked with salinity. Other factors may have been responsible, e.g. predation. C.edule appears historically to have

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
Total	No. of sites No. in sites Mean/m2	16 - -	20 - -	19 - -
Maximum density/m2		-	-	-

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
Total	No. of sites No. in sites Mean/m2	20 - -	7 - -	9 - -	3 - -	15 - -
Maximum density/m2		-	-	-	-	-

Table 18. Arenicola marina - Frequency of sampling sites with casts for Autumn and Spring surveys.

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	1 20 20	- - -	- - -
Total	No. of sites No. in sites Mean/m2	1 20 20	- - -	- - -
Maximum density/m2		20	-	-

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	1 20 20
Total	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	1 20 20
Maximum density/m2		-	-	-	-	20

Table 19. Pectinaria koreni - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	3 820 273	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	2 120 60	2 60 30	2 40 20
Total	No. of sites No. in sites Mean/m2	5 940 188	2 60 30	2 40 20
Maximum density/m2		300	40	20

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	1 20 20
Total	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	1 20 20
Maximum density/m2		-	-	-	-	20

Table 20. Lanice conchilega - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	1 4700 4700	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	2 60 30	7 180 26	- - -
Total	No. of sites No. in sites Mean/m2	2 60 30	8 4880 610	- - -
Maximum density/m2		40	4700	-

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	1 20 20	1 20 40
Total	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	1 20 20	1 40 40
Maximum density/m2		-	-	-	20	40

Table 21. Mytilus edulis - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	3 5380 1793	1 1425 1425
100-1,000	No. of sites No. in sites Mean/m2	- - -	18 4740 263	19 4075 214
10-100	No. of sites No. in sites Mean/m2	11 320 29	40 1202 30	41 1706 42
Total	No. of sites No. in sites Mean/m2	11 320 29	61 11322 186	61 7206 118
Maximum density/m2		60	3240	1425

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	2 2580 1290
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	4 500 125
10-100	No. of sites No. in sites Mean/m2	1 20 20	1 17 17	- - -	2 40 20	21 620 30
Total	No. of sites No. in sites Mean/m2	1 20 20	1 17 17	- - -	2 40 20	27 3700 137
Maximum density/m2		20	17	-	20	1480

Table 22. Cerastoderma edule - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

been particularly susceptible to low temperatures. The previously commercially exploited beds in the Dee were destroyed by the frosts of 1962-63 (Crisp 1964). A similar destruction occurred in the area in 1904-5 (Scott 1910). Kreger (1940) also noted low temperature was particularly detrimental to the planktonic larvae. The results of the present surveys revealed the return of C.edule, in high densities, to the Estuary in 1975 but in the previous Autumn 1971 survey there was an indication of a smaller settlement, here the loss over the winter (bearing in mind the low numbers involved) was 93%. The low Spring numbers were repeated for the next four years but following the relatively good settlement in Autumn 1975 the loss in total numbers over the winter was 67.3%, unlike M.balthica (see later) the maximum densities recorded at two sites after the winter had remained. Total numbers recorded the following year (Autumn 1976) were less but growth of the Autumn 1975 settlement had been rapid and the majority were approximately 16 mm individuals. Kristensen (1957) found in the Wadden Sea that a previous year class could have a marked effect on the survival of subsequent settlement and this apparently occurred on the Dee in the maximum density areas of the adults. In other less dense areas the settlement was relatively unaffected. A number of other factors affect the survival of C.edule, e.g. Smidt (1951) recorded rapidly silting ground as detrimental, they can also be eroded out of the sediment (Stopford 1951). A number of invertebrates have been found to predate C.edule, e.g. Mytilus edulis injested the reproduction products and young (Kreger 1940), C.maenas (Bouxin 1937) and N.diversicolor (Linke 1939). C.edule was predated by P.flesus on the Dee (N. Parsons pers. comm.) and fish predation has also been recorded by Williams et al (1965); Hancock and Urquhart

(1965). There are references to a variety of birds predating C.edule including duck, rooks, gulls (Scott 1910) and particularly Oystercatcher (Haematopus ostralegus L.) Dare (1966). On the Dee it was found that H.ostralegus did not predate greatly the 1975 settlement. This is in agreement with other work by Hancock and Uquhart (1965); Drinnan (1957) who noted that H.ostralegus concentrated their predation on two year old cockles on the Bury Inlets. Commercial fishing had not taken place on the Dee since the 1962-63 winter but gathering started in Autumn 1976 particularly off West Kirby.

(i) Tellina tenuis (maps 136-143, Table 23)

T.tenuis is a medium size lamellibranch growing to approximately 2.5 cm. It was found 5-12.5 cm below the surface (Teeble 1966) and there was evidence of vertical migration according to the tide (Yonge 1953). The animal was limited to the Outer Estuary in the medium sand sediments at a variety of tidal heights, although present in every survey, numbers were low. The lamellibranch was not observed on the Dee to be a food of either fish or birds but I have observed it to be predated by gulls by 'puddling' on Middle Salisbury Bank.

(j) Scrobicularia plana (Maps 144-151, Table 24)

This lamellibranch ranged in size from approximately 1 mm at settlement to approximately 5 cm in length. Its depth in the sediment varied according to size but none were found greater than 20 cm deep (Hughes 1970a). The surveys revealed a distribution confined to the finer sediments, and maximum densities were recorded in sheltered areas. Its range on the shore extended from MHWS to MLWS but the maximum densities were between MHWN and MT. Although low salinity was a possible cause of the low densities in

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	15 500 33	5 100 20	6 150 25
Total	No. of sites No. in sites Mean/m2	15 500 33	5 100 20	6 150 25
Maximum density/m2		60	20	25

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	1 220 220	- - -	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	2 40 20	9 219 24	2 60 30	2 40 20	8 280 35
Total	No. of sites No. in sites Mean/m2	3 260 67	9 219 24	2 60 30	2 40 20	8 280 35
Maximum density/m2		220	67	40	20	80

Table 23. *Tellina tenuis* - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	2 3240 1620	6 7758 1293	5 7290 1458
100-1,000	No. of sites No. in sites Mean/m2	10 1200 120	24 5592 233	14 3150 225
10-100	No. of sites No. in sites Mean/m2	18 594 33	18 630 35	20 640 32
Total	No. of sites No. in sites Mean/m2	30 5034 168	48 13995 291	39 11087 284
Maximum density/m2		1800	1860	2325

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	1 1000 1000	2 2017 1008	1 1080 1080	1 1440 1440	- - -
100-1,000	No. of sites No. in sites Mean/m2	4 1760 440	8 2516 315	12 4716 393	4 980 245	15 5940 396
10-100	No. of sites No. in sites Mean/m2	14 448 32	20 734 37	13 416 32	16 688 43	12 440 37
Total	No. of sites No. in sites Mean/m2	19 3208 169	30 5267 176	26 6213 239	21 3107 148	27 6380 236
Maximum density/m2		1000	1000	1080	1440	940

Table 24. Scrobicularia plana - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

the Inner Estuary S.plana has been recorded in waters with a salinity of 10% in the Baltic (Jaekal 1951). Green (1957) noted salinities as low as 2‰ on the Gwendreath Estuary. Smidt (1951) considered particle size as the decisive factor in the distribution of S.plana. Although the animal is susceptible to very cold conditions with heavy mortalities recorded in the cold winter of 1962-63 (Crisp 1964), during the mild conditions of the study there was no obvious evidence of low temperature mortality. In the surveys high densities and wide distribution were found in the Autumn series but with greater variability, e.g. total number varied between $5034/m^2$ in Autumn 1971 and $13,995/m^2$ in Autumn 1975, also the area covered varied between 30 sites in Autumn 1971 and 48 sites in Autumn 1975. This contrasted with the Spring surveys where variability was less. Population differences between the successive surveys of 1971/72 and 1975/76 recorded a 36% and 54.4% loss over the winter, with a corresponding loss in area of 36% and 43.8%. S.plana was recorded as a prey species by the bird and fish investigations. Small individuals have been observed in the gut of N.diversicolor (Linke 1939).

(k) Macoma balthica (Maps 152-159, Table 25)

This lamellibranch mollusc grew to approximately 26 mm and was found depending on size to a depth of approximately 10 cm. Prater (1972) found in the substrate of Morecambe Bay that 90% of M.balthica were within the top 4 cm when not in adverse conditions. Similar results were recorded by Caddy (1966) on the Thames where 87.4% were in the top 4.5 cm of the sediment. M.balthica was widely distributed in a range of substrates from coarse to very fine but maximum densities were in areas with a high percentage of very fine sand. It was found at a large range of tidal heights but

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	10 139340 13934	12 158412 13201	2 22625 11313
1,000-10,000	No. of sites No. in sites Mean/m2	75 271360 3618	74 276760 3740	51 112873 2213
100-1,000	No. of sites No. in sites Mean/m2	80 30110 376	61 25498 418	91 37428 411
10-100	No. of sites No. in sites Mean/m2	48 1940 40	18 700 39	23 1092 47
Total	No. of sites No. in sites Mean/m2	213 442750 2079	165 461370 2796	167 174018 1042
Maximum density/m2		18580	20400	10550

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	18 22310 1239	21 29434 1402	30 47432 1581	17 25758 1515	40 59720 1493
100-1,000	No. of sites No. in sites Mean/m2	119 53834 452	96 37753 393	69 36335 527	62 31800 513	114 49134 431
10-100	No. of sites No. in sites Mean/m2	46 1820 40	33 1337 40	9 280 31	8 250 31	29 1298 45
Total	No. of sites No. in sites Mean/m2	183 77964 426	150 68524 457	108 84047 778	87 57808 664	183 110152 602
Maximum density/m2		2140	2533	2740	2580	3280

Table 25. Macoma balthica - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

maximum densities were near the MHWN tide line. This was modified in the wave protected areas where the highest densities were below MT, e.g. West Kirby and Dawpool Banks, this indicated that substrate type was having a greater effect on distribution than tidal height. The lamellibranch was well represented in the Inner Estuary indicating a tolerance of low salinities. Highest temperatures recorded on the Dee do not appear lethal to M.balthica (see transect data) and to counteract adverse temperatures M.balthica can burrow to avoid the extremes (Vader 1964). At no time during the study did low temperatures apparently have an effect on the survival of M.balthica (Kennedy and Mihursky 1971). Seasonally the populations of M.balthica were higher in the Autumn compared to the Spring and over the study period there was a mean loss in numbers of 76% between Autumn and Spring. In the Autumn series the total numbers involved were variable with high density 'peaks' corresponding to optimum settlement areas. In the Autumn series densities of 20,400/m^2 were recorded and there was an average of 8 sites over 10,000/m^2 and 67 sites over 1,000/m^2, but in the following five Spring surveys the variability was much less, both between years and in the frequencies recorded, e.g. the high density peaks were removed and no sites were in the frequency category above 10,000/m^2 and there was a mean of only 27 sites over 1,000/m^2. The net loss in total numbers was 82.4% for winter 1971/72 and 76.1% for the 1975/76 winter. As a possible explanation (see transect data) a number of animals are known to feed on M.balthica and often there is a size category involved, e.g. C.maenas has been observed in the laboratory to predate M.balthica, particularly the newly settled spat (see transect data). Records exist of the lamellibranch being predated by several fish species, e.g. P.flesus (Summers 1974);

Hancock and Urquhart 1965). On the Dee it formed a common prey of P.flesus. M.balthica is also eaten by several bird species, e.g. H.ostralegus (Dare 1966; Heppleston 1971), Redshank (Tringa totanus L.) Goss-Custard (1969), Knot (Calidris canutus L.) Prater (1972). On the Dee it formed an important part of the diet of several species. It was observed that different species were feeding on a size range of M.balthica, e.g. on the Dee spatfall corresponded with the presence of young P.flesus and these predated the young M.balthica. Elsewhere T.totanus preferentially selected the largest M.balthica on the Ythan (Goss-Custard 1969) and Prater (1972) noted some degree of selection by C.canutus for the medium sized M.balthica (6-14.9 mm). With this differential predation in mind and relating it also to size frequency investigations (Figs. 61 & 62) the M.balthica population was further divided into individuals above and below 10 mm in length.

(1) Macoma balthica <10 mm (Maps 160-166, Table 26)

Following summer recruitment numbers of small M.balthica were higher in the Autumn than the following Spring. During the study there was a mean loss of 76% in total numbers over the winter. High density peaks were evident in the Autumn, however, Autumn 1976 was a poor settlement, overall numbers were 64% less than in Autumn 1975. The Spring series of surveys were much less variable with the exception of an occasional site in the 10^3 - 10^4 frequency group, the majority of densities were in the 10^2 - 10^3 group. Even then the higher densities were only marginally over $1,000/m^2$. Over the study this steady reduction of peak densities to more uniform densities over the whole Estuary was one of the pointers to there possibly being a density dependant mechanism controlling the post-spatfall numbers of M.balthica

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	10 127644 12764	1 12050 12050
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	61 235141 3855	38 93594 2463
100-1,000	No. of sites No. in sites Mean/m2	- - -	60 25055 418	92 33323 362
10-100	No. of sites No. in sites Mean/m2	- - -	24 900 38	32 1450 45
Total	No. of sites No. in sites Mean/m2	- - -	155 388740 2508	163 140417 861
Maximum density/m2		-	19620	12050

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	7 9940 1420	4 5034 1259	19 26744 1486	8 11900 1488	17 24762 1457
100-1,000	No. of sites No. in sites Mean/m2	124 50020 403	101 37199 368	78 38298 491	68 29573 435	121 52324 432
10-100	No. of sites No. in sites Mean/m2	49 1880 38	40 1700 43	11 340 31	12 400 33	38 1638 43
Total	No. of sites No. in sites Mean/m2	180 61840 344	145 43933 303	108 65382 605	88 41873 476	176 78725 447
Maximum density/m2		1740	1334	2580	2340	2560

Table 26. Macoma balthica ≤10 mm - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

(Gillham 1974, 1976) and possibly other species in the Estuary.

(m) *Macoma balthica* >10 mm (Maps 167-173, Table 27)

The frequency of *M.balthica* for the Autumn series were higher on average than the following Spring series with a mean of 38.3% loss over the Winter. The Autumn totals were more variable than the Spring. In this larger size group *M.balthica* losses were greater at the margin of the distributions in contrast to the small size *M.balthica* where the greatest loss was in the areas of maximum density.

(n) *Hydrobia ulvae* (Maps 182-189; Table 29)

H.ulvae is a gastropod mollusc growing to approximately 5-6 mm on the Dee. The animal exhibited a tidal rhythm inhabiting the surface or near surface of the substrate at low water, but on tidal inundation had the ability to enter and float in the water column (Newell 1962; Linke 1939; Smidt 1951). Distribution on the Dee even with this migratory ability was remarkably consistent but it was noted that generally the higher and more protected sediments were occupied well away from the main channels. Sediments in which *H.ulvae* was recorded ranged from sand to mud, its presence on the coarser sediments being in the Outer Estuary. The distribution was centred on the MHWN extending from MT to near MHWS. Very few *H.ulvae* were recorded in the Inner Estuary but the area in which they occurred was well up the shore near the saltmarsh agreeing in general with the observations of Newell (1964); Popham (1966). Higher salinities were found high on the shore in the Inner Estuary. Newell (1964) found only small populations of *H.ulvae* below 2.8‰ but this critical limit was a much lower salinity than on the Dee where *H.ulvae* ended its distribution, but he also discovered *H.ulvae* adapted to the salinities prevailing

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites	-	-	-
	No. in sites	-	-	-
	Mean/m2	-	-	-
1,000-10,000	No. of sites	-	9	2
	No. in sites	-	13140	2460
	Mean/m2	-	1460	1230
100-1,000	No. of sites	-	96	81
	No. in sites	-	35170	22929
	Mean/m2	-	366	283
10-100	No. of sites	-	43	63
	No. in sites	-	1912	2721
	Mean/m2	-	44	43
Total	No. of sites	-	148	146
	No. in sites	-	50222	28110
	Mean/m2	-	339	193
Maximum density/m2		-	2200	1460

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites	-	-	-	-	-
	No. in sites			-	-	-
	Mean/m2	-	-	-	-	-
1,000-10,000	No. of sites	-	1	2	-	6
	No. in sites	-	1250	2355	-	6925
	Mean/m2	-	1250	1178	-	1154
100-1,000	No. of sites	72	67	56	60	95
	No. in sites	15440	19109	13329	17116	28667
	Mean/m2	214	285	238	285	302
10-100	No. of sites	62	62	35	24	45
	No. in sites	2750	2778	2040	830	1994
	Mean/m2	44	45	58	35	44
Total	No. of sites	134	130	93	84	146
	No. in sites	18190	23137	17724	17946	37586
	Mean/m2	136	178	190	214	257
Maximum density/m2		700	1250	1280	800	1575

Table 27. *Macoma balthica* >10 mm - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	3 460 153	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	18 620 34	9 190 21	4 175 44
Total	No. of sites No. in sites Mean/m2	21 1080 51	9 190 21	4 175 44
Maximum density/m2		240	40	75

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	6 800 133	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	2 40 20	23 908 39	2 100 50	5 140 28	2 80 40
Total	No. of sites No. in sites Mean/m2	2 40 20	29 1708 59	2 100 50	5 140 28	2 80 40
Maximum density/m2		20	183	80	40	40

Table 28. Mya arenaria - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites	1	2	-
	No. in sites	47600	22180	-
	Mean/m2	47600	11090	-
1,000-10,000	No. of sites	22	21	38
	No. in sites	61740	50935	102172
	Mean/m2	2806	2425	2689
100-1,000	No. of sites	38	35	54
	No. in sites	14440	14265	20945
	Mean/m2	380	408	388
10-100	No. of sites	31	23	26
	No. in sites	1240	1055	1107
	Mean/m2	40	46	43
Total	No. of sites	92	81	118
	No. in sites	125020	88435	124224
	Mean/m2	1359	1092	1053
Maximum density/m2		47600	11680	9750

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites	-	-	-	-	-
	No. in sites	-	-	-	-	-
	Mean/m2	-	-	-	-	-
1,000-10,000	No. of sites	5	1	5	4	13
	No. in sites	10000	1300	8800	7300	24860
	Mean/m2	2000	1300	1760	1825	1912
100-1,000	No. of sites	40	37	33	33	48
	No. in sites	14450	12372	9829	10865	16864
	Mean/m2	361	334	298	329	351
10-100	No. of sites	24	25	26	18	25
	No. in sites	1020	985	1100	704	1028
	Mean/m2	43	39	42	39	41
Total	No. of sites	69	63	64	55	86
	No. in sites	25470	14657	19729	18869	42752
	Mean/m2	369	233	308	343	497
Maximum density/m2		3640	1300	2760	2780	4120

Table 29. *Hydrobia ulvae* - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

to as low as 10% seawater. On the Dee maximum densities of H.ulvae occurred at much higher salinities (assuming salinity at 0-2.5 cm in the sediment was representative of the water column) and would presumably be adapted to this salinity. He further noted that the gastropod did not occur upstream of salinities in which the floating ability was eliminated by lowering of salinity. Experiments to verify these findings were not carried out on the Dee but Stopford (1951) noted in her experiments that H.ulvae from off Parkgate when placed in 12‰ salinity remained submerged indefinitely. However, adaptation to lower salinities than this on the Dee must occur. McMillan (1948) noted H.ulvae with normal behaviour in pools at Burton Marsh in a salinity of 1.75‰. McMillan suggested there were distinct biological races differing in salinity tolerance. Higher numbers and area covered were recorded in the Autumn series, and there was a mean 78% loss in numbers and a 31% loss in area over the winter. However, the general variability within the frequency groups in the Autumn series and Spring series was small. Bird observations on the Dee have shown it to be a constituent of the diet of various waders. Anderson (1972) on the Ythan also found that it was a common prey of waders and that the number of H.ulvae may have influenced the breeding success and numbers of the birds in some years. There are records of H.ulvae also being eaten by fish (Bacesco and Dumitresco (1958) and Rees (1940) reported H.ulvae being taken by N.diversicolor. However, there are problems in looking at the effects of predation on the density distributions due to the floating habit in the tidal cycle. Although Anderson (1972) indicated that the floating habit was reduced in December, January and February on the Ythan and was never actually observed on the

Dee, migration obviously could have had an effect on distribution patterns. The very high density at one site on Mostyn Bank in Autumn 1971 could have been caused by this migration (this one site accounted for 38% of the total numbers in that survey). Although remarkably few H.ulvae were found in areas outside the main distributions one could not ignore the possibility that a proportion of the population was lost to the open sea during floating, but in such an apparently successful species this appears unlikely.

(o) Eurydice pulchra (Maps 190-197, Table 30)

E.pulchra is an isopod crustacean growing to approximately 6 mm. It occurred in the Outer, Middle and Inner Estuary generally low on the shore. The majority were probably stranded by the tide and tended to be in coarse sediments. Very large numbers have been observed in the water body of the advancing tide, especially during boat work. The impression was given of an active scavenger searching out food material on the return of the tide. Its importance as an invertebrate predator needs further investigation.

(p) Corophium sp. (Maps 198-205, Table 31)

Corophium sp. was found either on the surface of the substrate, occasionally swimming in the water column, but usually in burrows which it constructed to various depths generally 3 - 4 cm, but in dry sediments near high tide to approximately 10 cm. Distribution of Corophium sp. on the Dee was associated with sediments ranging from fine sand to mud which were areas away from the main channels and excessive turbulance. The numbers of Corophium sp. were lower in the Inner Estuary possibly due to low salinities. Beanland (1935) found an increase in number near freshwater. Maximum densities were centred on the MHWN tide line

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	1 1280 1280	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	13 3560 274	6 2180 363	- - -
10-100	No. of sites No. in sites Mean/m2	31 960 31	25 760 30	7 275 39
Total	No. of sites No. in sites Mean/m2	45 5800 129	31 2940 95	7 275 39
Maximum density/m2		1280	880	75

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	6 1420 237	6 2718 453	5 740 148	1 500 500	7 1700 243
10-100	No. of sites No. in sites Mean/m2	36 1070 30	18 566 31	21 720 34	12 420 35	37 1200 32
Total	No. of sites No. in sites Mean/m2	42 2490 59	24 3284 137	26 1460 56	13 920 71	44 2900 66
Maximum density/m2		360	950	240	500	740

Table 30. *Eurydice pulchra* - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	20 507360 25386	8 121980 15248	13 213120 16394
1,000-10,000	No. of sites No. in sites Mean/m2	37 123498 3338	27 98825 3660	30 87274 2909
100-1,000	No. of sites No. in sites Mean/m2	26 9670 372	25 9275 371	25 9875 395
10-100	No. of sites No. in sites Mean/m2	33 1120 34	31 1185 38	36 1363 38
Total	No. of sites No. in sites Mean/m2	116 641648 5531	91 231265 2541	104 311632 2996
Maximum density/m2		64900	29920	26550

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	1 13480 13480
1,000-10,000	No. of sites No. in sites Mean/m2	15 33310 2221	- - -	- - -	8 17160 2145	18 50900 2828
100-1,000	No. of sites No. in sites Mean/m2	40 15070 377	18 6952 386	13 5020 386	11 3940 358	25 8060 322
10-100	No. of sites No. in sites Mean/m2	49 2100 43	39 1325 34	16 593 37	27 919 34	35 1282 37
Total	No. of sites No. in sites Mean/m2	104 50480 485	57 8277 145	29 5613 194	46 22019 479	79 73722 933
Maximum density/m2		4120	900	840	4460	13480

Table 31. Corophium sp. - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

but in sheltered conditions the maximum densities extended to MT. Corophium sp. numbers were on average in the Autumn series 92% higher than in the Spring. In the variable Spring surveys the maximum difference between years was 94% and there was also a large difference between years (72%) in the areas covered. The fluctuation in numbers apparently had a trend with lowering of numbers and areas in 1973 and 1974 followed by a rise to 1976. Corophium sp. did not figure largely in the ornithological investigations on the Dee, but several records exist of it forming an important component of the diet of waders (Goss-Custard 1967). The fish investigations indicated that Corophium sp. was a common prey of P.flesus and several other records exist of it as a food source for fish (Hart 1930; Segerstråle 1937; Williams Perkins and Hinde 1965). In the laboratory Corophium sp. was seen to be eaten by C.vulgaris and this was also noted by Havinga (1930). A factor which could have influenced the recorded variation in density was migration. Corophium sp. was observed migrating in the water column like H.ulvae and numerous records exist of its rhythmic tidal activity (Schodduyn 1926; Hart 1930; Thamdrup 1935; Wohlenberg 1937; Vader 1964; Morgan 1965). Remarkably like H.ulvae even with these activities the distributions were maintained. A reduction in the maximum densities together with area was observed, but the levelling of densities to a uniform minimum density was not as distinct as in M.balthica.

(q) Bathyporeia sp. (Maps 206-213, Table 32)

Distribution of Bathyporeia sp. was limited to the Outer and Middle Estuary, particularly on Mostyn and West Kirby Banks. The genus was generally restricted to coarse sediments (<250u). Very occasionally Bathyporeia sp. was recorded in the

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	1 1075 1075
100-1,000	No. of sites No. in sites Mean/m2	23 5660 246	11 3320 302	16 3400 213
10-100	No. of sites No. in sites Mean/m2	28 880 31	300 1220 41	24 1025 43
Total	No. of sites No. in sites Mean/m2	51 6540 128	41 4540 111	41 5500 134
Maximum density/m2		740	580	1075

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	2 2420 1210	- - -
100-1,000	No. of sites No. in sites Mean/m2	12 4620 385	12 4451 371	5 1000 200	10 3600 360	20 5900 295
10-100	No. of sites No. in sites Mean/m2	21 710 34	25 934 37	4 240 60	11 520 47	42 1606 38
Total	No. of sites No. in sites Mean/m2	33 5330 162	37 5385 146	9 1240 138	23 6540 284	62 7506 121
Maximum density/m2		980	667	380	1220	580

Table 32. Bathyporeia sp. - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Inner Estuary near the main channel. It was not recorded as being eaten by fish or birds in the Dee studies.

(r) Haustorius arenarius (Maps 214-221, Table 33)

H.arenaria had a characteristic distribution coinciding with areas of heavy turbulance. It was not recorded as a food item of either birds or fish in the Dee.

(s) Crangon vulgaris (Maps 222-228, Table 34)

All the specimens of C.vulgaris recorded in the surveys were juveniles and their presence in the intertidal substrate was probably due to stranding on the ebb tide. C.vulgaris was known to be present in large numbers in the deep channels of the Outer Estuary throughout the year and supported a prosperous fishing industry. It is probable that like the fish populations the, as yet unquantified population of C.vulgaris,move into the invertebrate rich areas of the Estuary with the flood tide returning to the deep channels of the Outer Estuary on the ebb. C.vulgaris was not recorded as a prey item by the bird investigations on the Dee, but it was a common prey of P.flesus. Hancock and Urquhart (1965) also recorded its presence in the gut of P.flesus on the Burry Inlets.

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	15 2380 159	7 1120 160	- - -
10-100	No. of sites No. in sites Mean/m2	25 1050 42	20 640 32	8 250 31
Total	No. of sites No. in sites Mean/m2	40 3430 86	27 1760 65	8 250 31
Maximum density/m2		340	300	75

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	5 960 192	8 1217 152	- - -	- - -	7 1200 171
10-100	No. of sites No. in sites Mean/m2	23 850 37	18 652 36	4 80 20	3 60 20	24 920 38
Total	No. of sites No. in sites Mean/m2	28 1810 65	26 1869 72	4 80 20	3 60 20	31 2120 68
Maximum density/m2		300	217	20	20	520

Table 33. Haustorius arenarius - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites	-	-	-
	No. in sites	-	-	-
	Mean/m2	-	-	-
1,000-10,000	No. of sites	-	-	-
	No. in sites	-	-	-
	Mean/m2	-	-	-
100-1,000	No. of sites	4	-	-
	No. in sites	820	-	-
	Mean/m2	205	-	-
10-100	No. of sites	34	9	7
	No. in sites	1080	170	200
	Mean/m2	32	19	29
Total	No. of sites	38	9	7
	No. in sites	1900	170	200
	Mean/m2	50	19	29
Maximum density/m2		400	20	50

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites	-	-	-	-	-
	No. in sites	-	-	-	-	-
	Mean/m2	-	-	-	-	-
1,000-10,000	No. of sites	-	-	-	-	-
	No. in sites	-	-	-	-	-
	Mean/m2	-	-	-	-	-
100-1,000	No. of sites	1	-	-	-	-
	No. in sites	240	-	-	-	-
	Mean/m2	240	-	-	-	-
10-100	No. of sites	9	2	-	3	2
	No. in sites	240	27	-	50	33
	Mean/m2	27	14	-	17	17
Total	No. of sites	10	2	-	3	2
	No. in sites	480	27	-	50	33
	Mean/m2	48	14	-	17	17
Maximum density/m2		240	17	-	20	20

Table 34 Crangon vulgaris - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	5 760 152	2 220 110	- - -
10-100	No. of sites No. in sites Mean/m2	33 1160 35	31 980 32	4 155 39
Total	No. of sites No. in sites Mean/m2	38 1920 51	33 1200 36	4 155 39
Maximum density/m2		260	120	80

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
10-100	No. of sites No. in sites Mean/m2	- - -	3 44 15	3 100 33	5 100 20	5 100 20
Total	No. of sites No. in sites Mean/m2	- - -	3 44 15	3 100 33	5 100 20	5 100 20
Maximum density/m2		-	17	60	40	20

Table 35. Carcinus maenas - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

Frequency group		Autumn 1971	Autumn 1975	Autumn 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	1 240 240	3 425 142
10-100	No. of sites No. in sites Mean/m2	2 40 20	10 380 38	15 535 36
Total	No. of sites No. in sites Mean/m2	2 40 20	11 620 56	18 960 53
Maximum density/m2		20	240	125

Frequency group		Spring 1972	Spring 1973	Spring 1974	Spring 1975	Spring 1976
10,000-100,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
1,000-10,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	- - -
100-1,000	No. of sites No. in sites Mean/m2	- - -	- - -	- - -	- - -	2 260 130
10-100	No. of sites No. in sites Mean/m2	- - -	4 100 28	8 200 25	3 60 20	7 180 26
Total	No. of sites No. in sites Mean/m2	- - -	4 100 28	8 200 25	3 60 20	9 440 49
Maximum density/m2		-	60	60	20	160

Table 36. Diptera larvae - Frequency of sample sites in relation to density/m2 on logarithmic scale for Autumn & Spring surveys

3.1.3 Association Analysis

Prior to the AA two procedures were adopted -

(1) Removal of temporary members - these were defined as species the presence of which in the sample was by chance stranding by the tide, they were species more generally associated with the water column, e.g. C.vulgaris, E.pulchra and Mysids.

(2) The removal of 'rare' species - defined as species which total only one individual for the whole survey. The presence of 'rare' species in the analysis were considered would not appreciably affect the hierarchy or add to the ecological interpretation of the results.

The analysis of the three Autumn surveys and five Spring surveys are presented in the form of -

(a) dendrograms (Figs. 19 - 26) showing the hierarchical divisions involved in the Normal AA analysis and the devisive attributes (codes for the identification of the devisive attributes are given in Table 37);

(b) Tables (38 - 45) showing the percentage species composition of each association and the percentage species composition of the complete survey;

(c) distribution maps (Maps 244-251) of the main ecological associations and

(d) species composition of the Normal AA map groups (Tables 46-51).

For ecological interpretation of the results, in the analysis the significance level was set at χ^2 3.64 but for the purposes of ecological interpretation this was set at an arbitrary higher limit of approximately χ^2 10. This gave five distinct associations

Species	Code
Phyllodoce sp.	1
Nereis diversicolor	2
Nephthys sp.	3
Eteone longa	4
Scoloplos armiger	5
Nerine cirratulus	6
Pygospio elegans	7
Arenicola marina	8
Pectinaria koreni	9
Lanice conchilega	10
Tubificids	12
Nematodes	13
Mytilus edulis	14
Cerastoderma edule	15
Tellina tenuis	16
Scrobicularia plana	17
Macoma balthica	18
Mya arenaria	21
Hydrobia ulvae	22
Eurydice pulchra	23
Corophium sp.	25
Bathyporeia sp.	26
Haustorius arenarius	27
Crangon vulgaris	28
Carcinus maenas	29
Mysids	30
Diptera larvae	31

Table 37. Species Codes used in conjunction with divisive attributes of Normal Association Analysis Dendrograms (Figs. 19 - 26).

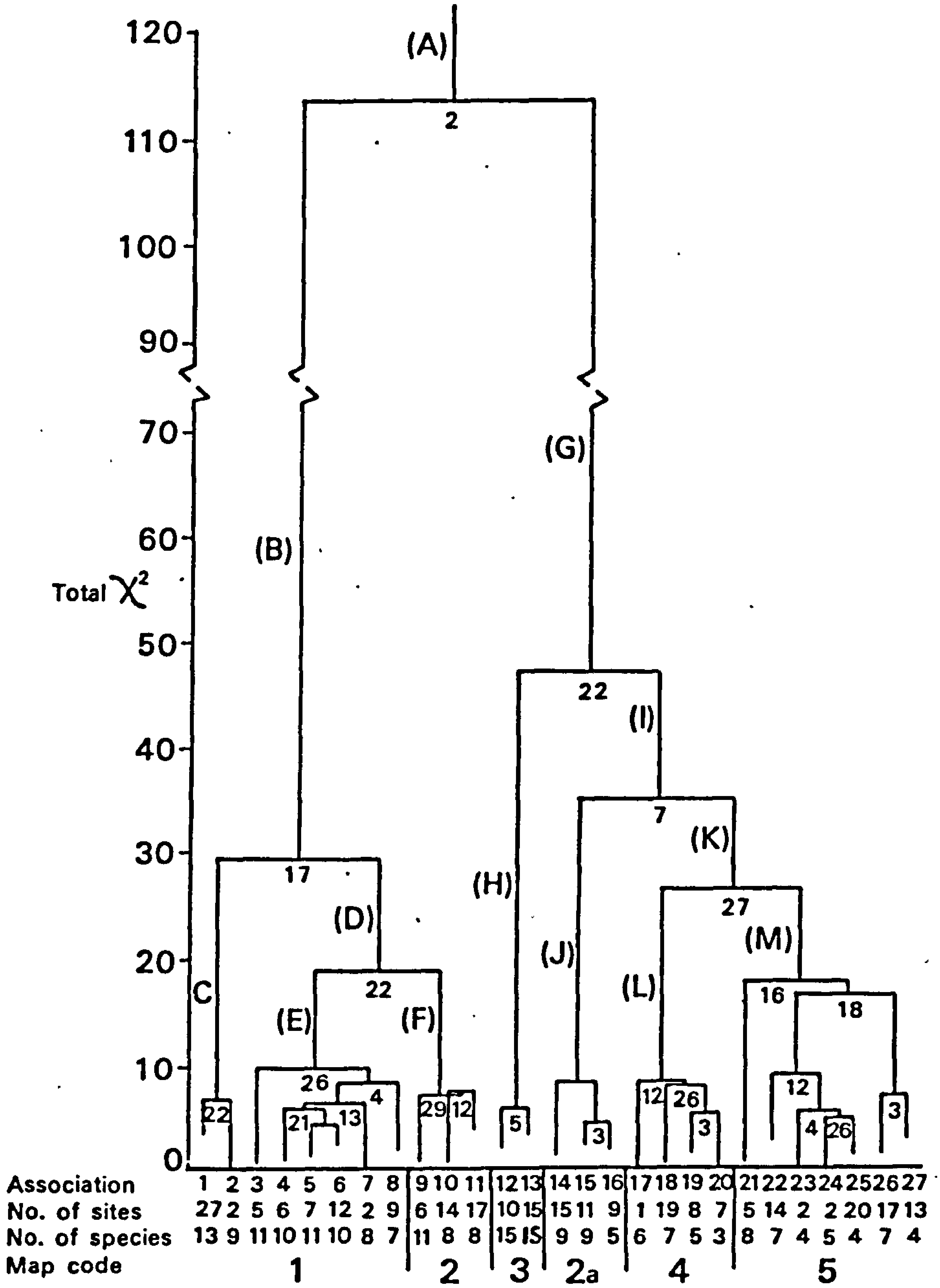


Figure 19. Distribution of Normal Association Analysis Groups in Autumn 1971.

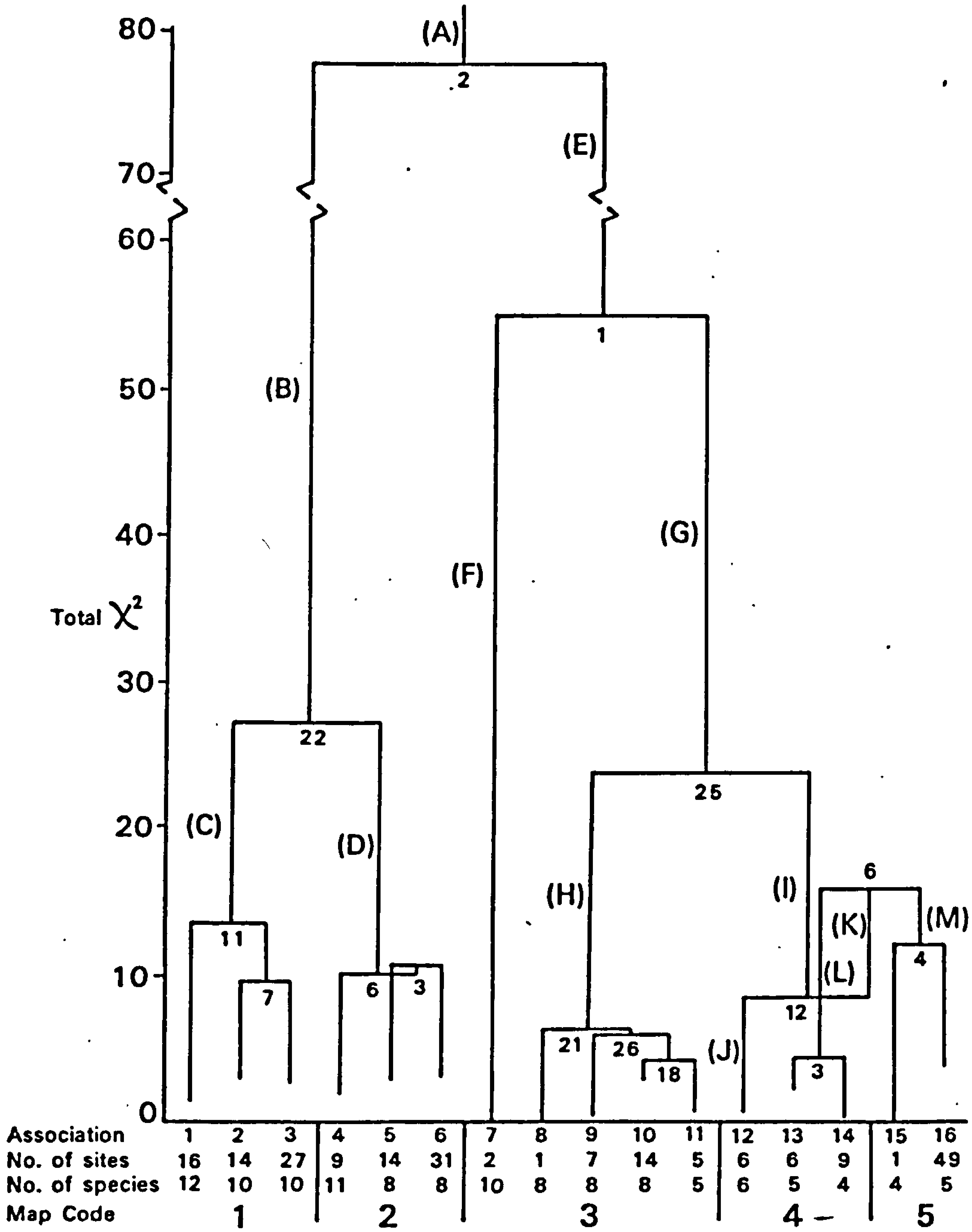
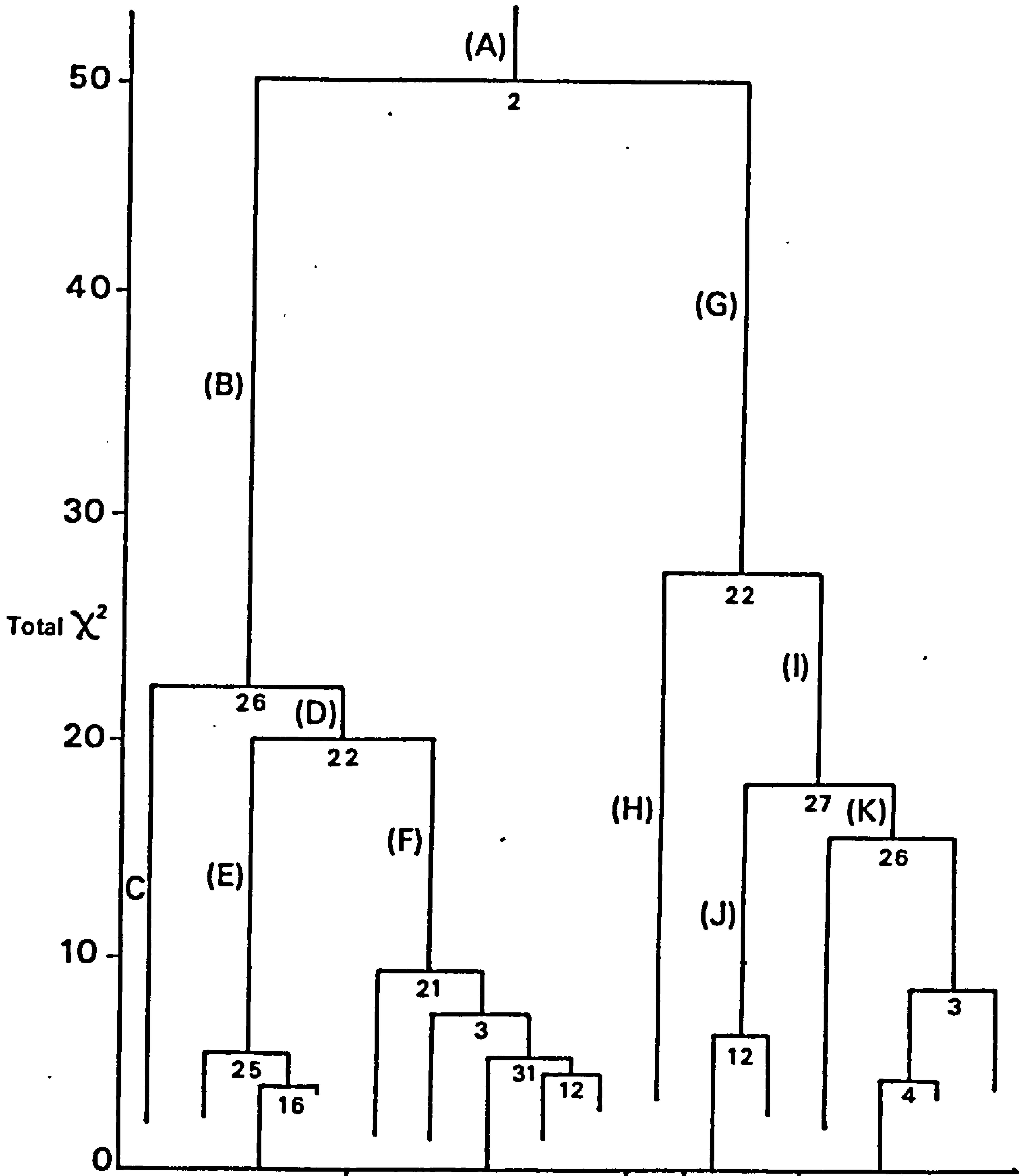
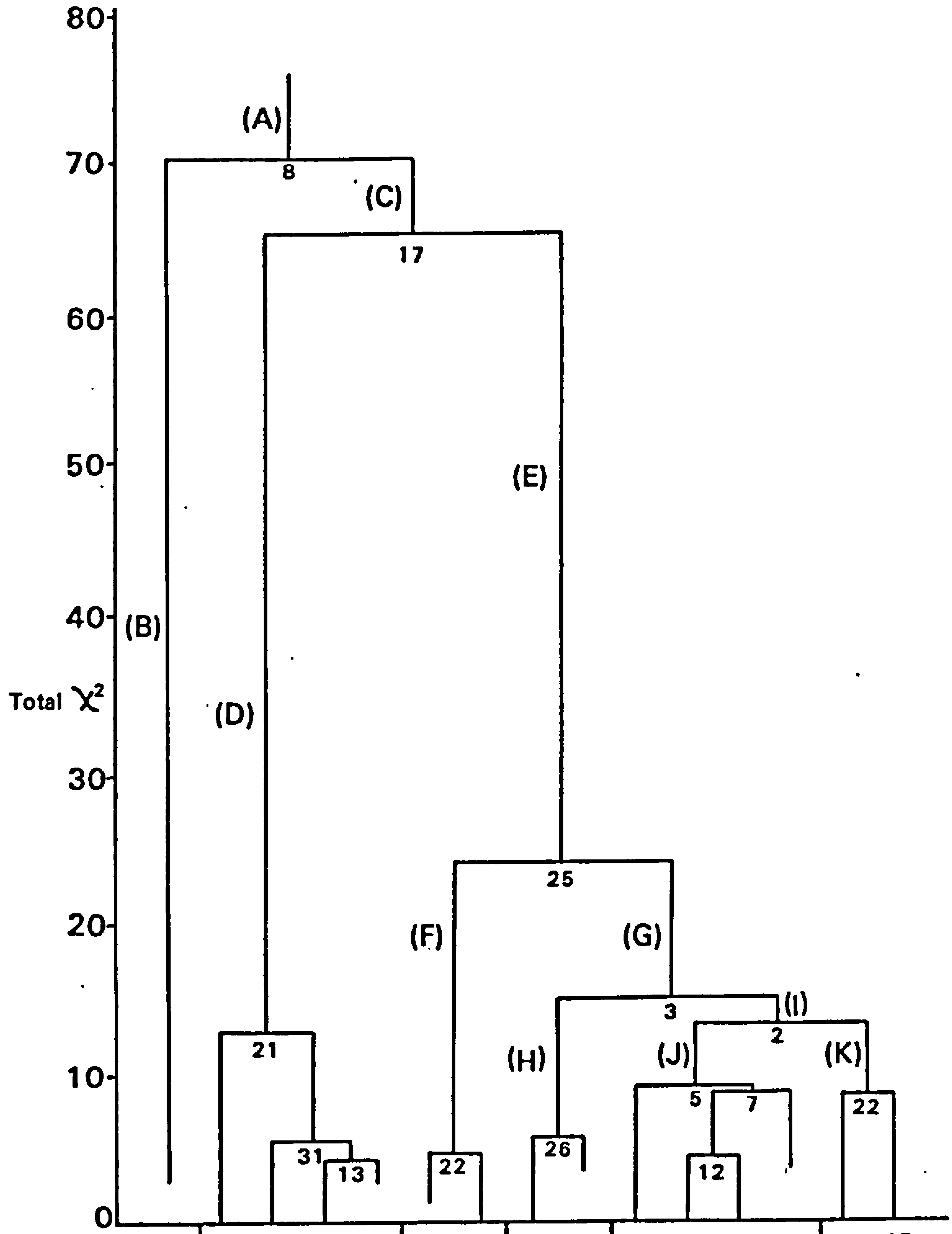


Figure 20. Distribution of Normal Association Analysis Groups in Spring 1972.



Association	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
No. of sites	10	24	1	17	8	8	2	8	13	15	1	26	10	3	16	17
No. of species	15	13	10	9	9	6	4	7	6	11	3	8	9	5	6	7
Map code	1				2					3	4		5			

Figure 21. Distribution of Normal Association Analysis Groups in Spring 1973.



Association	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No. of sites	9	2	3	9	13	20	1	3	15	1	1	19	6	5	12
No. of species	14	8	7	9	8	9	5	6	7	5	5	5	6	5	3
Map code	3	1				2		4		2				5	

Figure 22. Distribution of Normal Association Analysis Groups in Spring 1974.

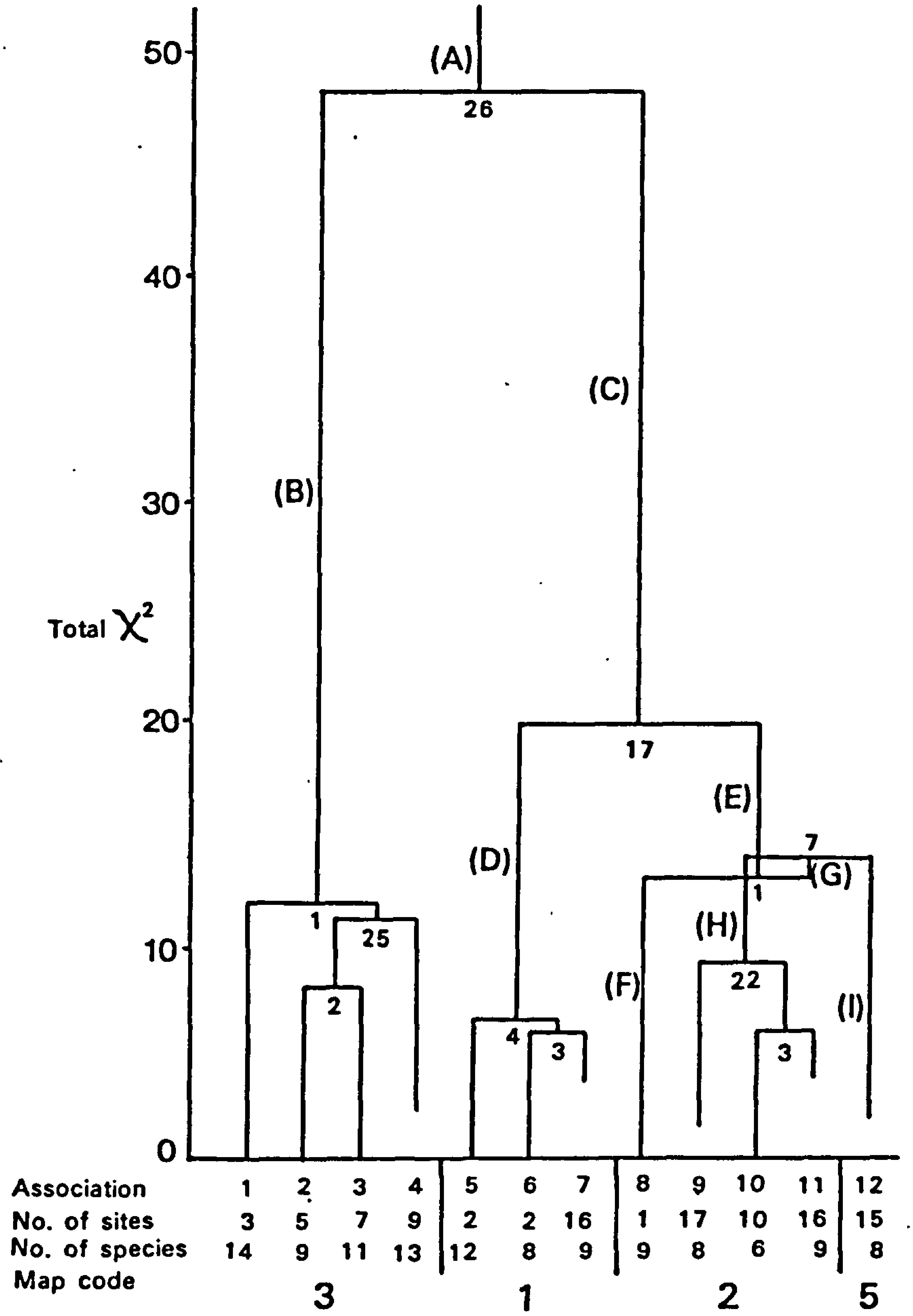


Figure 23. Distribution of Normal Association Analysis Groups in Spring 1975.

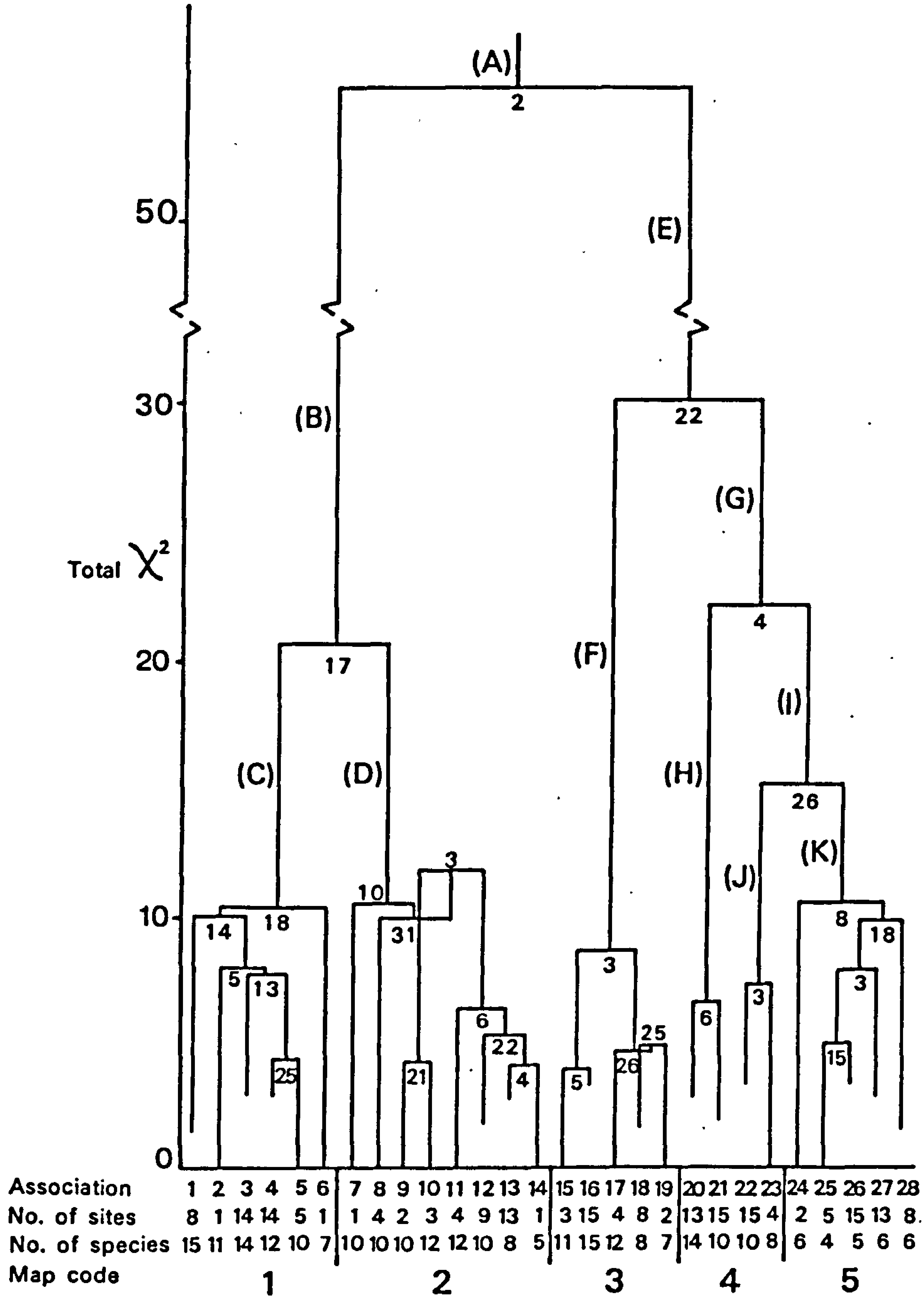


Figure 24. Distribution of Normal Association Analysis Groups in Autumn 1975.

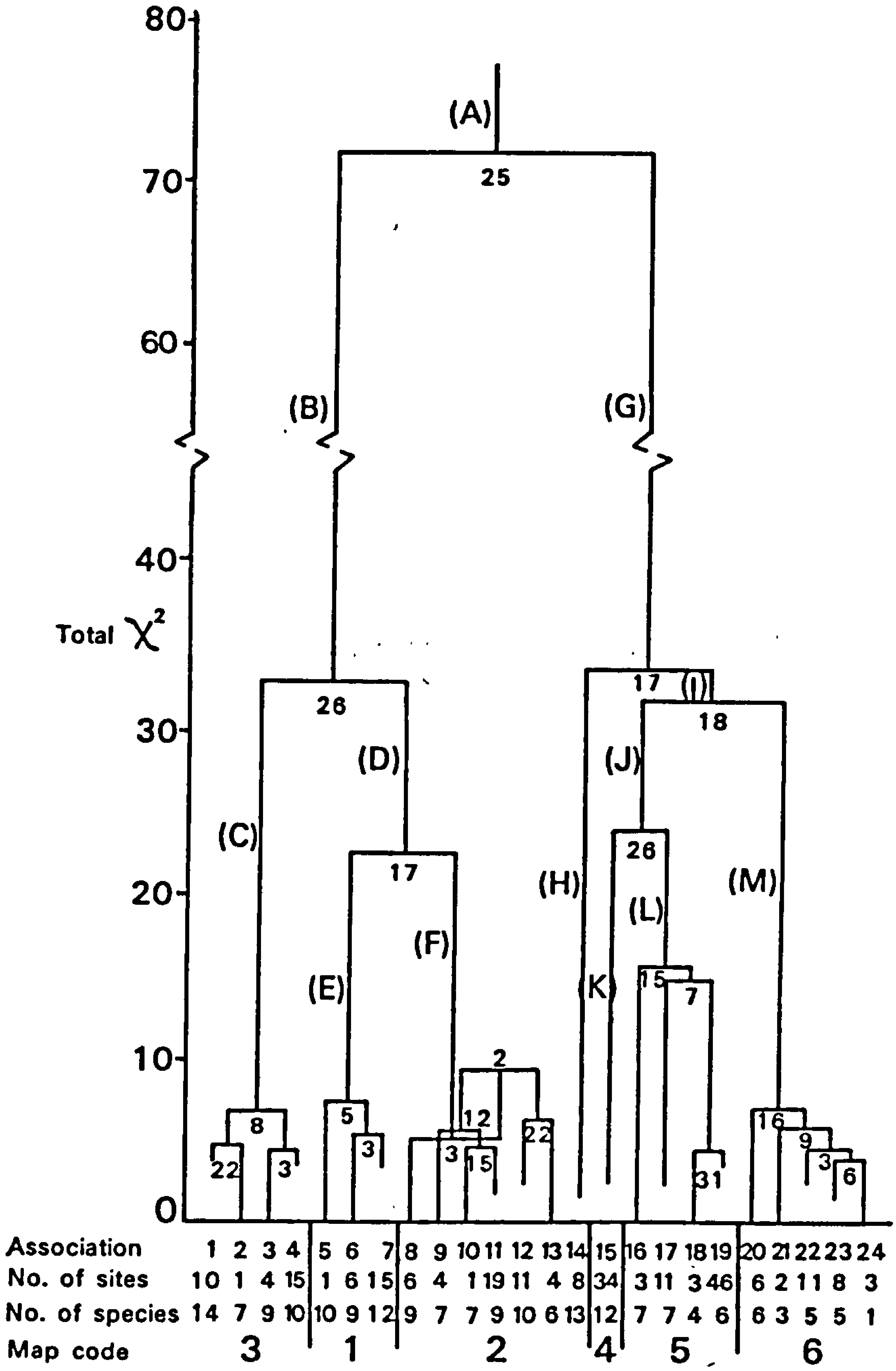


Figure 25. Distribution of Normal Association Analysis Groups in Spring 1976.

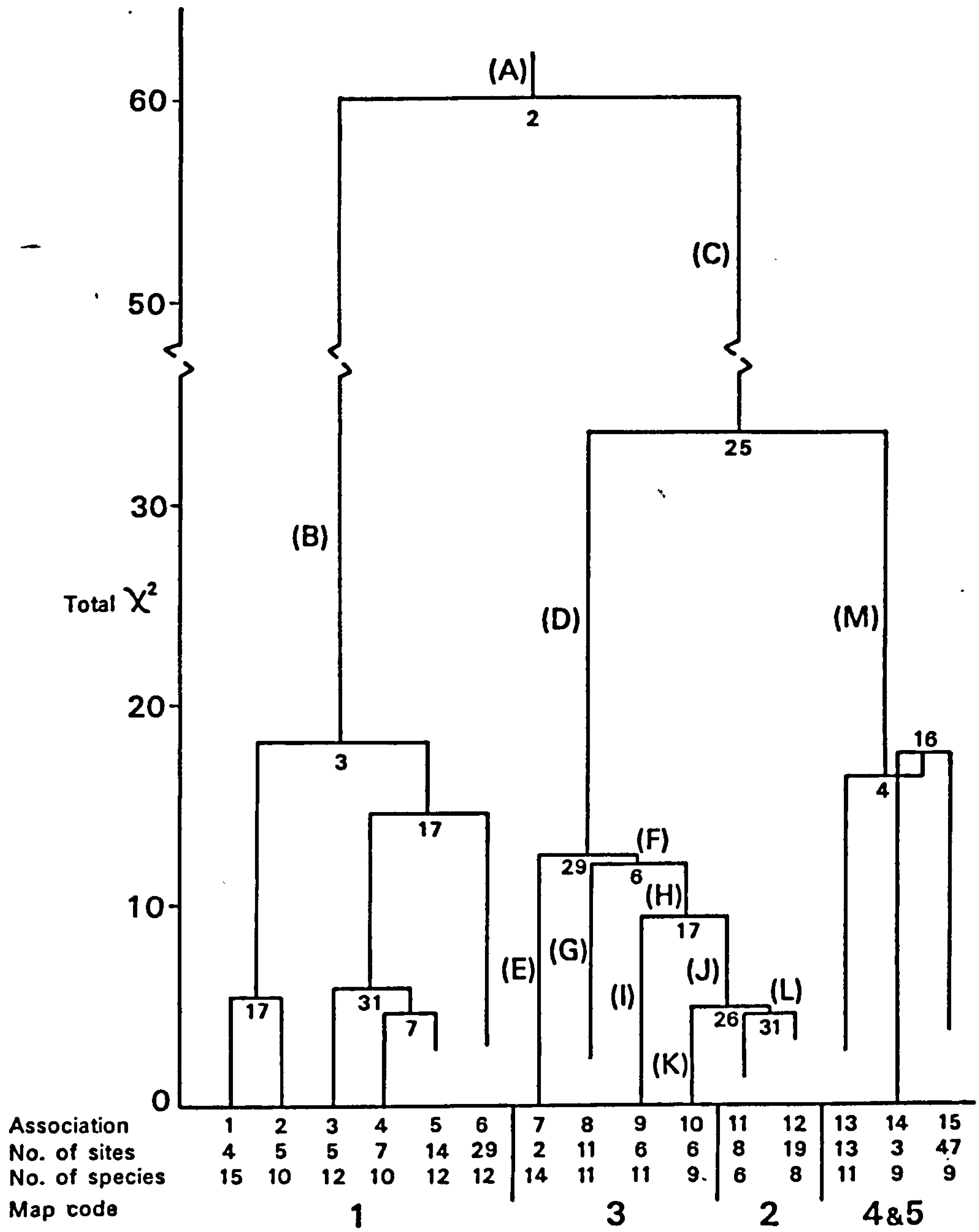


Figure 26. Distribution of Normal Association Analysis Groups in Autumn 1976.

SPECIES	% Frequency																											⊕
Phyllodoce sp.	-	-	-	-	14	-	-	-	-	-	-	20	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-	1
Nereis divers.	100	100	100	100	100	100	100	100	100	100	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	39
Nephthys sp.	22	50	20	17	43	8	-	-	17	7	18	90	47	27	100	-	100	68	100	-	100	64	100	100	85	100	-	45
Eteone longa	66	100	100	100	100	100	100	-	100	79	47	70	67	73	45	11	-	-	-	-	20	29	100	-	-	18	8	44
Scoloplos arm.	-	-	-	-	-	8	-	-	-	-	-	100	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	4
Nerine cirr.	-	-	60	-	14	8	50	-	33	21	-	20	27	100	-	-	-	63	13	86	-	50	-	100	10	12	8	24
Pygospio eleg.	59	100	60	100	86	67	50	67	100	71	82	40	40	100	100	100	-	-	-	-	-	-	-	-	-	-	-	45
Arenicola mar.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Pectinaria kor.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	1
Lanice conch.	-	-	20	-	-	-	-	-	-	-	-	-	7	-	-	-	-	5	-	-	20	-	-	-	-	-	8	2
Tubificids	7	-	40	33	100	-	-	11	67	100	-	50	13	60	27	33	100	-	-	-	20	100	-	-	-	18	-	27
Nematodes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Mytilus ed.	-	-	-	-	-	-	-	-	-	-	-	10	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Cerastoderma ed.	15	100	-	-	-	-	-	-	-	-	-	-	13	7	9	-	100	-	-	-	-	-	-	-	-	-	-	4
Tellina tenuis	-	-	-	-	-	-	-	-	-	-	-	40	13	-	-	-	-	21	-	-	100	-	-	-	-	-	-	5
Scrobicularia pl.	100	100	-	-	-	-	-	-	-	-	-	-	-7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Macoma balthica	100	100	100	100	100	100	100	89	100	100	100	90	87	100	91	67	100	26	25	71	60	100	100	100	100	-	-	77
Mya arenaria	33	-	-	100	-	-	100	-	50	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
Hydrobia ulvae	100	-	100	100	100	100	100	100	-	-	-	100	93	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33
Eurydice pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Corophium sp.	100	50	100	100	100	100	-	89	83	21	59	40	73	33	9	-	-	-	13	-	-	7	-	50	25	12	-	42
Bathyporeia sp.	-	-	100	-	-	-	-	-	17	-	6	70	20	13	9	-	100	100	-	-	60	-	-	100	-	24	8	18
Haustorius aren.	-	-	-	-	-	-	-	-	-	-	-	20	7	-	18	-	100	100	100	100	-	-	-	-	-	-	-	15
Crangon vul.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Carcinus maenas	41	100	-	83	43	50	100	22	100	-	-	-	-	-	-	-	-	-	-	-	-	-	50	-	-	-	-	14
Mysids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Diptera larvae	4	-	-	-	-	-	-	-	-	-	-	10	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	1
ASSOCIATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
No. OF SITES	27	2	5	6	7	12	2	9	6	14	17	10	15	15	11	9	1	19	8	7	5	14	2	2	20	17	13	
No. OF SPECIES	13	9	11	10	11	10	8	7	11	8	8	15	15	9	9	5	6	7	5	3	8	7	4	5	4	7	4	
MAP CODE	1								2			3		2a			4				5							

Table 38. Autumn 1971, Normal Association Analysis - percentage frequency of genera and species in each association (⊕ - % of sample sites genera and species present)

SPECIES	% Frequency																⊕
Phyllodoce sp.	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	-	1
Nereis diversicolor	100	100	100	100	100	100	-	-	-	-	-	-	-	-	-	-	53
Nephthys sp.	19	7	19	22	100	-	100	100	29	29	20	33	100	-	100	73	38
Eteone longa	13	-	-	33	-	10	50	-	29	-	-	-	-	-	100	-	6
Scoloplos armiger	-	-	7	11	7	-	100	-	-	-	-	-	-	-	-	-	3
Nerine cirratulus	-	7	11	100	-	-	-	-	43	21	-	17	100	100	-	-	17
Pygospio elegans	44	100	-	33	-	39	-	100	-	7	20	33	-	-	-	2	20
Arenicola marina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Pectinaria koreni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Lanice conchilega	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Tubificids	19	14	-	33	14	13	50	100	14	7	-	83	-	-	-	-	11
Nematodes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Mytilus edulis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cerastoderma edule	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Tellina tenuis	-	-	4	-	-	-	100	-	-	-	-	-	-	-	-	-	1
Scrobicularia plana	50	-	30	-	14	6	-	-	-	-	-	-	-	-	-	-	10
Macoma balthica	100	100	100	89	100	97	100	100	100	100	-	67	33	56	100	78	87
Mya arenaria	-	7	-	-	-	-	-	100	-	-	-	-	-	-	-	-	1
Hydrobia ulvae	100	100	100	-	-	-	100	-	57	14	40	17	17	-	-	-	33
Eurydice pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Corophium sp.	88	93	85	33	43	55	100	100	100	100	100	-	-	-	-	-	50
Bathyporeia sp.	13	14	19	22	14	-	100	100	100	-	-	-	33	22	100	6	15
Haustorius arenarius	-	-	-	33	-	-	-	100	-	7	-	-	-	67	-	33	13
Crangon vulgaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Carcinus maenas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Mysids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Diptera larvae	13	-	-	-	-	10	-	-	-	-	20	-	-	-	-	-	3
ASSOCIATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
No. OF SITES	16	14	27	9	14	31	2	1	7	14	5	6	6	9	1	49	
No. OF SPECIES	12	10	10	11	8	8	10	8	8	8	5	6	5	4	4	5	
MAP CODE		1			2				3				4			5	

Table 39. Spring 1972, Normal Association Analysis - percentage frequency of genera and species in each association (⊕ - % of sample sites genera and species present)

SPECIES	% Frequency																⊕
Phyllodoce sp.	-	-	-	-	13	-	-	-	-	-	-	-	-	-	-	-	1
Nereis diversicolor	100	100	100	100	100	100	100	100	100	-	-	-	-	-	-	-	51
Nephthys sp.	40	25	100	6	25	100	-	-	-	47	-	73	90	100	100	-	42
Eteone longa	30	46	100	6	-	13	-	13	-	7	-	-	20	100	-	6	14
Scoloplos armiger	20	-	-	-	-	13	-	-	-	20	-	-	30	-	-	-	5
Nerine cirratulus	40	13	-	-	-	-	-	38	15	40	-	73	10	33	6	6	17
Pysgospio elegans	30	83	100	76	100	25	100	50	69	60	-	-	20	33	6	53	47
Arenicola marina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Pectinaria koreni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Lanice conchilega	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Tubificids	-	13	100	24	-	-	-	100	-	-	100	-	-	-	6	29	13
Nematodes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Mytilus edulis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cerastoderma edule	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Tellina tenuis	-	-	100	-	-	-	-	-	-	-	-	8	50	-	6	-	5
Scrobicularia plana	20	42	100	65	38	-	-	-	8	7	-	-	-	-	-	-	16
Macoma balthica	100	100	100	100	100	88	50	100	92	87	-	42	70	66	75	94	83
Mya arenaria	10	21	100	59	100	-	-	-	-	20	-	-	-	-	-	6	16
Hydrobia ulvae	70	100	100	100	-	-	-	-	-	100	-	-	-	-	-	-	36
Eurydice pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Corophium sp.	90	100	-	-	25	-	-	13	23	73	-	8	50	-	-	-	32
Bathyporeia sp.	100	-	-	-	-	-	-	-	-	40	-	42	100	-	-	-	21
Haustorius arenarius	10	-	-	-	-	-	-	-	-	-	100	100	-	-	-	-	16
Crangon vulgaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Carcinus maenas	-	8	-	-	-	-	-	-	-	-	-	4	-	-	-	-	2
Mysids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Diptera larvae	10	8	-	-	13	-	100	-	-	-	100	-	-	-	-	6	4
ASSOCIATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
No. OF SITES	10	23	1	17	8	8	2	8	13	15	1	26	10	3	16	17	
No. OF SPECIES	15	13	10	9	9	6	4	7	6	11	3	8	9	5	6	7	
MAP CODE		1					2			3	4			5			

Table 40. Spring 1973, Normal Association Analysis - percentage frequency of genera and species in each association (⊕ - % of sample sites genera and species present)

SPECIES	% Frequency															⊕
Phyllodoce sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Nereis diversicolor	56	100	100	56	77	60	-	33	73	100	100	100	100	-	-	68
Nephthys sp.	33	50	-	-	15	30	100	100	93	-	-	-	-	-	-	24
Eteone longa	33	-	-	-	8	25	-	-	-	-	100	16	6	20	-	12
Scoloplos armiger	44	-	-	11	-	-	-	-	7	100	-	-	-	-	-	2
Nerine cirratulus	11	-	-	-	-	15	-	-	13	-	-	-	6	-	8	6
Pygospio elegans	33	50	100	56	46	70	100	-	7	-	100	100	-	40	42	48
Arenicola marina	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Pectinaria koreni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Lanice conchilega	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Tubificids	-	-	-	22	-	-	-	-	-	-	100	-	-	-	-	2
Nematodes	-	-	-	67	-	5	-	-	-	-	-	-	-	-	-	6
Mytilus edulis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cerastoderma edule	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Tellina tenuis	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Scrobicularia plana	11	100	100	67	100	-	-	-	-	-	-	-	-	-	-	20
Macoma balthica	100	100	100	67	100	100	100	66	93	100	100	95	88	40	58	90
Mya arenaria	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Hydrobia ulvae	89	50	100	67	77	100	-	33	20	100	-	42	31	100	-	56
Eurydice pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Corophium sp.	89	-	33	11	8	100	100	-	-	-	-	-	-	-	-	25
Bathyporeia sp.	56	-	-	-	-	-	100	100	-	100	-	-	6	-	-	9
Haustorius arenarius	22	-	-	-	-	-	-	66	-	-	-	-	-	-	-	3
Crangon vulgaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Carcinus maenas	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Mysids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Diptera larvae	-	-	100	-	-	-	-	-	-	-	-	-	-	80	-	6
ASSOCIATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
No. OF SITES	9	2	3	9	13	20	1	3	15	1	1	19	16	5	12	
No. OF SPECIES	14	8	7	9	8	9	5	6	7	5	5	5	6	5	3	
MAP CODE	3			1			2		4			2			5	

Table 41. Spring 1974, Normal Association Analysis - percentage frequency of genera and species in each association (⊕ - % of sample sites genera and species present)

SPECIES	% Frequency												⊕
Phyllodoce sp.	100	-	-	-	-	-	-	100	-	-	-	-	4
Nereis diversicolor	-	100	-	67	100	50	94	100	71	100	94	47	70
Nephthys sp.	100	-	14	67	50	100	-	100	12	100	-	27	24
Eteone longa	-	40	14	100	100	-	-	100	12	66	-	7	21
Scoloplos armiger	100	40	29	22	-	-	-	-	-	-	-	-	9
Nerine cirratulus	33	-	29	44	-	-	-	-	12	-	6	13	13
Pygospio elegans	66	60	57	33	100	-	94	100	100	100	100	-	69
Arenicola marina	-	-	86	33	-	-	-	-	-	-	-	-	9
Pectinaria koreni	-	-	-	-	-	-	-	-	-	-	-	-	
Lanice conchilega	-	-	-	-	-	-	-	-	-	-	-	-	
Tubificids	-	-	-	-	50	50	13	-	-	-	13	-	6
Nematodes	-	-	-	-	50	50	25	-	-	-	-	-	5
Mytilus edulis	33	-	-	-	-	-	-	-	-	-	-	-	1
Cerastoderma edule	66	-	-	-	-	-	-	100	-	-	-	-	3
Tellina tenuis	-	-	-	22	-	-	-	-	-	-	-	-	2
Scrobicularia plana	33	20	-	-	100	100	94	-	-	-	-	-	22
Macoma balthica	100	100	100	100	100	100	100	100	100	100	88	80	95
Mya arenaria	33	-	-	11	100	-	6	-	-	-	19	-	8
Hydrobia ulvae	33	60	100	44	100	100	88	100	100	-	-	33	58
Eurydice pulchra	-	-	-	-	-	-	-	-	-	-	-	-	
Corophium sp.	100	100	100	-	100	50	75	-	71	-	19	13	49
Bathyporeia sp.	100	100	100	100	-	-	-	-	-	-	-	-	25
Haustorius arenarius	-	-	14	22	-	-	-	-	-	-	-	-	3
Crangon vulgaris	-	-	-	-	-	-	-	-	-	-	-	-	
Carcinus maenas	33	-	-	-	50	-	-	100	-	33	6	-	5
Mysids	-	-	-	-	-	-	-	-	-	-	-	-	
Diptera larvae	-	-	-	-	-	-	-	-	-	-	6	13	3
ASSOCIATION	1	2	3	4	5	6	7	8	9	10	11	12	
No. OF SITES	3	5	7	9	2	2	16	1	17	10	16	15	
No. OF SPECIES	14	9	11	13	12	8	9	9	8	6	9	8	
MAP CODE			3			1				2		5	

Table 42. Spring 1975, Normal Association Analysis - percentage frequency of genera and species in each association (⊕ - % of sample sites genera and species present)

SPECIES	% Frequency																												⊕
Phyllodoce sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Nereis divers.	100	100	100	100	100	100	100	100	100	100	75	100	100	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40
Nephthys sp.	25	100	14	-	20	100	100	-	100	100	25	-	-	-	100	100	-	-	-	31	67	100	-	-	100	100	-	50	43
Eteone longa	88	100	86	100	100	-	-	25	100	71	100	100	100	-	-	33	100	88	50	100	100	-	-	-	-	-	-	-	57
Scoloplos arm.	-	100	-	-	-	-	100	-	-	14	-	-	-	-	100	-	-	-	-	-	7	7	-	-	-	-	-	-	8
Nerine cirr.	-	-	-	-	-	-	100	-	50	29	75	-	-	-	-	7	100	13	50	100	-	13	100	100	-	-	23	25	19
Pygospio eleg.	25	-	36	79	40	100	-	25	50	-	75	89	69	100	33	13	50	50	-	15	33	7	25	-	-	-	8	-	31
Arenicola mar.	13	100	7	-	-	-	100	-	-	14	75	11	-	-	67	33	25	-	-	8	-	7	-	100	-	-	-	-	10
Pectinaria kor.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	25	-	-	-	-	-	1
Lanice conch.	13	-	-	-	-	100	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Tubificids	-	-	14	7	-	-	-	25	-	14	-	-	8	100	-	-	-	-	-	8	-	-	-	-	-	-	-	-	4
Nematodes	38	-	100	-	-	-	-	25	-	-	25	11	-	-	-	7	25	-	-	-	-	-	-	-	-	-	-	-	11
Mytilus ed.	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	4
Cerastoderma ed.	75	100	71	50	40	-	100	-	100	29	25	-	15	-	100	73	50	-	50	38	13	13	-	50	100	-	8	-	33
Tellina tenuis	-	-	-	-	-	-	100	-	-	-	-	-	-	-	33	-	-	-	-	-	-	-	25	-	-	7	-	13	2
Scrob. pl.	100	100	100	100	100	100	-	-	-	-	-	-	-	-	-	20	25	13	50	-	-	-	-	-	-	-	-	-	24
Macoma balthica	100	100	100	100	100	-	100	50	100	86	100	100	100	100	100	100	100	100	100	92	100	40	50	50	100	100	100	-	88
Mya arenaria	38	-	7	7	20	100	-	-	100	-	-	11	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Hydrobia ulvae	75	100	86	86	60	-	-	75	-	29	100	100	-	-	100	100	100	100	100	-	-	-	-	-	-	-	-	-	41
Eurydice pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Corophium sp.	88	100	79	100	-	100	-	75	100	29	100	89	31	100	100	40	100	100	-	23	33	-	25	50	-	7	23	13	46
Bathyporeia sp.	-	-	-	-	-	-	100	-	-	14	25	-	-	-	33	20	100	-	-	54	20	100	100	-	-	-	-	-	19
Haustorius aren.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	23	20	53	75	-	-	7	15	63	13
Crangon vul.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Carcinus maenas	100	100	50	14	40	-	-	75	100	-	-	33	-	-	-	20	25	-	100	23	-	-	-	-	20	-	-	-	18
Mysids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Diptera larvae	-	-	-	7	-		-	100	-	-	-	-	-	-	-	-	-	13	-	8	13	-	-	50	-	-	-	13	5
ASSOCIATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
No. OF SITES	8	1	14	14	5	1	1	4	2	7	4	9	13	1	3	15	4	8	2	13	15	9	4	2	5	15	13	8	
No. OF SPECIES	15	11	14	12	10	7	10	10	10	12	12	10	8	5	11	15	12	8	7	14	10	10	8	6	4	5	6	6	
MAP CODE				1						2							3				4					5			

Table 43. Autumn 1975, Normal Association Analysis - percentage frequency of genera and species in each association
(⊕ - % of sample sites genera and species present)

SPECIES	% Frequency																								⊕
Phyllodoce sp.	-	-	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Nereis diversicolor	20	-	-	40	100	67	93	33	100	100	89	-	-	50	24	66	63	66	35	-	-	-	-	-	39
Nephthys sp.	20	-	100	-	-	100	-	100	-	-	-	-	-	50	76	100	27	-	26	83	100	100	13	33	36
Eteone longa	10	-	-	33	100	-	13	-	50	-	26	36	-	-	15	-	9	-	-	-	-	-	-	-	12
Scoloplos armiger	50	-	-	7	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Nerine cirratulus	40	100	-	33	100	-	7	-	-	100	11	18	25	13	21	-	-	-	9	17	-	18	100	-	18
Pygospio elegans	-	-	25	33	-	17	53	33	100	100	47	55	-	-	9	-	100	-	-	-	-	-	-	-	22
Arenicola marina	10	100	-	-	-	-	-	-	-	-	-	18	-	13	6	33	-	-	-	33	-	-	-	-	8
Pectinaria koreni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	1
Lanice conchilega	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50	-	-	-	1
Tubificids	-	-	-	-	-	-	27	-	100	-	-	-	-	25	-	33	-	-	-	-	-	-	-	-	5
Nematodes	-	-	-	-	-	33	73	-	-	-	5	9	-	25	-	-	9	-	-	-	-	-	-	-	8
Mytilus edulis	-	-	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Cerastoderma edule	40	-	50	13	100	67	7	17	-	100	-	-	75	63	6	100	-	-	-	17	-	-	-	-	13
Tellina tenuis	10	100	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	100	-	-	-	-	5
Scrobicularia plana	10	-	25	-	100	100	100	-	-	-	-	-	25	100	-	-	-	-	-	-	-	-	-	-	14
Macoma balthica	100	100	100	87	100	100	100	83	100	100	95	91	100	100	100	100	100	100	100	-	-	-	-	-	85
Mya arenaria	-	-	-	-	100	-	7	-	-	-	-	-	-	38	-	-	-	-	-	-	-	-	-	-	2
Hydrobia ulvae	100	-	75	67	100	67	93	50	25	100	63	100	-	75	18	100	18	66	9	-	-	9	13	-	41
Eurydice pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Corophium sp.	100	100	100	93	100	100	100	100	100	100	95	100	100	-	-	-	-	-	-	-	-	-	-	-	41
Bathyporeia sp.	100	100	100	93	-	-	-	-	-	-	-	-	-	25	100	-	-	-	-	67	-	64	38	-	34
Haustorius arenarius	-	100	-	-	-	-	-	33	-	-	-	-	-	-	41	-	-	-	11	-	-	55	88	-	15
Crangon vulgaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Carcinus maenas	20	-	-	-	-	-	-	-	-	-	-	9	25	13	-	-	-	-	-	-	-	-	-	-	2
Mysids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Diptera larvae	-	-	-	-	-	-	-	-	-	-	16	36	-	-	-	-	-	100	-	-	-	-	-	-	4
ASSOCIATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
No. OF SITES	10	1	4	15	1	6	15	6	4	1	19	11	4	8	34	3	11	3	46	6	2	11	8	3	
No. OF SPECIES	14	7	9	10	10	9	12	9	7	7	9	10	6	13	12	7	7	4	6	6	3	5	5	1	
MAP CODE			3			1					2				4			5				6			

Table 44. Spring 1976, Normal Association Analysis - percentage frequency of genera and species in each association (⊕ - % of sample sites genera and species present)

SPECIES	% Frequency															⊕
Phyllodoce sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Nereis diversicolor	100	100	100	100	100	97	-	-	-	-	-	-	-	-	-	35
Nephthys sp.	100	100	100	-	-	-	50	18	33	50	-	53	38	66	49	35
Eteone longa	100	20	-	100	71	72	100	91	50	-	13	37	100	-	-	44
Scoloplos armiger	-	-	-	-	-	-	50	-	-	17	-	-	-	66	-	2
Nerine cirratulus	-	-	-	14	7	10	50	100	-	-	-	-	-	-	17	14
Pygospio elegans	25	40	80	100	-	69	100	27	17	33	50	26	46	-	9	34
Arenicola marina	25	40	-	-	-	14	50	55	-	33	-	11	-	33	-	11
Pectinaria koreni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Lanice conchilega	25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Tubificids	-	-	-	-	7	-	-	-	17	-	-	-	-	-	-	1
Nematodes	50	-	20	43	57	-	-	-	17	-	-	-	8	-	-	9
Mytilus edulis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Cerastoderma edule	100	40	20	71	57	31	100	36	100	67	-	47	15	66	13	36
Tellina tenuis	25	-	-	-	-	-	50	-	-	-	-	-	8	100	-	3
Scrobicularia plana	100	-	100	100	100	-	-	9	100	-	-	-	8	-	-	21
Macoma balthica	100	100	100	100	100	97	100	91	100	100	88	89	100	66	87	93
Mya arenaria	25	-	20	-	-	7	-	-	-	-	-	-	-	-	-	2
Hydrobia ulvae	100	40	100	100	100	86	100	100	100	100	75	58	62	33	21	66
Eurydice pulchra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Corophium sp.	75	40	80	71	100	72	100	100	100	100	100	100	-	-	-	56
Bathyporeia sp.	-	80	20	-	7	3	50	55	17	100	-	-	15	66	38	24
Haustorius arenarius	-	-	-	-	-	-	-	-	-	-	-	-	8	33	15	5
Crangon vulgaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Carcinus maenas	25	-	-	-	7	-	100	-	-	-	-	-	-	-	-	2
Mysids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Diptera larvae	-	-	100	-	-	3	50	-	-	-	100	-	-	-	4	9
ASSOCIATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
No. OF SITES	4	5	5	7	14	29	2	11	6	6	8	19	13	3	47	
No. OF SPECIES	15	10	12	10	12	12	14	11	11	9	6	8	11	9	9	
MAP CODE	1						3				2		4 & 5			

Table 45. Autumn 1976, Normal Association Analysis - percentage frequency of genera and species in each association (⊕ - % of sample sites genera and species present)

Species	Mean % presence in surveys		
	Complete Series	Autumn Series	Spring Series
Macoma balthica	98	98	98
Nereis diversicolor	90	99	85
Hydrobia ulvae	88	88	89
Corophium sp.	73	83	67
Scrobicularia plana	68	63	72
Pygospio elegans	57	56	58
Eteone longa	37	77	13
Nematodes	22	21	22
- - - - -	- - - - -	- - - - -	- - - - -
Nephthys sp.	19	19	18
Cerastoderma edule	18	38	6
Carcinus maenas	14	31	3
Mya arenaria	14	15	13
Tubificids	12	10	14
Bathyporeia sp.	7	6	3
Nerine cirratulus	6	6	6
Arenicola marina	4	9	-
Diptera larvae	4	4	4
Scoloplos armiger	2	<1	3
Mytilus edulis	2	6	-
Lanice conchilega	1	3	-
Tellina tenuis	<1	<1	<1
Phyllodoce sp.	<1	<1	-
Haustorius arenarius	<1	-	<1

Table 46. Mean % presence of species in Normal Association Analysis Group 1 for surveys Autumn 1971 to Autumn 1976 (broken line indicates 20% presence for complete series)

Species	Mean % presence in surveys		
	Complete Series	Autumn Series	Spring Series
Macoma balthica	94	92	95
Nereis diversicolor	71	49	84
Pygospio elegans	59	60	59
Corophium sp.	52	64	45
Hydrobia ulvae	35	36	34
Eteone longa	31	57	15
Nephthys sp.	24	31	21
- - - - - -	- - - - - -	- - -	- - -
Tubificids	13	19	10
Nerine cirratulus	13	15	11
Cerastoderma edule	10	19	4
Diptera larvae	9	14	6
Mya arenaria	6	5	7
Carcinus maenas	4	7	3
Arenicola marina	4	7	1
Scrobicularia plana	4	-	7
Bathyporeia sp.	3	5	2
Scoloplos armiger	2	2	2
Nematodes	2	2	3
Haustorius arenarius	2	1	2
Phyllodoce sp.	<1	-	<1
Lanice conchilega	<1	-	<1
Mytilus edulis	<1	-	<1
Tellina tenuis	<1	<1	-

Table 47. Mean % presence of species in Normal Association Analysis Group 2 for surveys Autumn 1971 to Autumn 1976 (broken line indicates 20% presence for complete series)

Species	Mean % presence in surveys		
	Complete Series	Autumn Series	Spring Series
Macoma balthica	93	95	93
Corophium sp.	83	80	84
Hydrobia ulvae	82	99	73
Bathyporeia sp.	56	40	65
Nephthys sp.	41	51	35
Eteone longa	38	60	24
Pygospio elegans	34	33	35
Arenicola marina	30	20	35
Nerine cirratulus	28	30	27
Scoloplos armiger	23	19	26
Cerastoderma edule	20	42	7
Nereis diversicolor	16	-	26
Scrobicularia plana	11	17	7
Tellina tenuis	9	10	9
Haustorius arenarius	8	5	9
Tubificids	6	11	3
Carcinus maenas	5	9	2
Phyllodoce sp.	4	3	4
Mya arenaria	4	-	6
Mytilus edulis	2	4	1
Diptera larvae	2	4	1
Nematodes	1	3	-

Table 48. Mean % presence of species in Normal Association Analysis Group 3 for surveys Autumn 1971 to Autumn 1976 (broken line indicates 20% presence for complete series)

Species	Mean % presence in surveys: Complete Series	Autumn Series	Spring Series
Macoma balthica	66	56	71
Nephthys sp.	56	63	52
Haustorius arenarius	53	68	45
Bathyporeia sp.	49	60	44
Nerine cirratulus	30	20	35
Nereis diversicolor	27	-	40
Eteone longa	22	57	4
Hydrobia ulvae	8	-	13
Pygospio elegans	7	8	6
Tubificids	6	3	8
Corophium sp.	5	11	2
Tellina tenuis	5	7	5
Cerastoderma edule	5	11	1
Scoloplos armiger	2	2	2
Arenicola marina	2	2	2
Carcinus maenas	2	3	1
Diptera larvae	1	2	1
Nematodes	1	-	1
Lanice conchilega	<1	2	-
Pectinaria koreni	<1	2	-
Phyllodoce sp.	<1	1	-

Table 49. Mean % presence of species in Normal Association Analysis Group 4 for surveys Autumn 1971 to Autumn 1976 (broken line indicates 20% presence for complete series)

Species	Mean % presence in surveys		
	Complete Series	Autumn Series	Spring Series
Macoma balthica	76	70	78
Nephthys sp.	45	64	38
Nereis diversicolor	13	-	18
Pygospio elegans	13	1	18
Hydrobia ulvae	11	-	16
Nerine cirratulus	10	18	7
Haustorius arenarius	8	10	8
Corophium sp.	7	13	5
Diptera larvae	7	2	9
Bathyporeia sp.	6	8	6
Eteone longa	6	8	6
Tubificids	6	13	3
Tellina tenuis	4	6	3
Cerastoderma edule	3	8	1
Arenicola marina	1	2	<1
Scoloplos armiger	<1	<1	<1
Carcinus maenas	<1	2	-
Nematodes	<1	-	<1
Mya arenaria	<1	-	<1
Phyllodoce sp.	<1	<1	-
Pectinaria koreni	<1	<1	-
Lanice conchilega	<1	<1	-

Table 50. Mean % presence of species in Normal Association Analysis Group 5 for surveys Autumn 1971 to Autumn 1976 (broken line indicates 20% presence for complete series)

	% presence in survey		
Species	-	-	Spring 1976
Nephthys sp.			67
Bathyporeia sp.			52
Haustorius			48
Nerine cirratulus			41
Tellina tenuis			22
Arenicola marina			7
Pectinaria koreni			7
Hydrobia ulvae			7
Eteone longa			4
Lanice conchilega			4
Cerastoderma edule			4

Table 51. Mean % presence of species in Normal Association Analysis Group 6 for survey Spring 1976 (broken line indicates 20% presence)

or communities in all surveys, except for Spring 1976 which extended beyond the limits of the Estuary, here the increased number of sample sites effectively enabled a further division of Group 5 into a distinct association - Group 6.

(a) Associations

Group 1 This contained 8 common species supplemented by two other species in the Autumn series, i.e. C.edule and C.maenas. The two most common species were M.balthica and N.diversicolor but S.plana was particularly distinctive of the Group.

Group 2 This group contained 7 common species but was dominated by M.balthica. The list of common species was very similar to Group 1 with the exclusion of S.plana.

Group 3 The increased number of common species in the group indicated more stable environmental conditions and the group was restricted to the outer more marine sediments of the Estuary. Main species were M.balthica, Corophium sp. and H.ulvae but distinctive, even though present in smaller numbers, was S.armiger. Other typical members included Bathyporeia sp., A.marina and C.edule. Variability between seasons was low.

Group 4 Although M.balthica was the most numerous, other distinctive members of the group were H.arenarius, Bathyporeia sp. and Nephthys sp. Seasonal variability was low with the exception of the two annelids N.diversicolor and E.longa.

Group 5 Group 5 was an amorphous group found in difficult environmental conditions either high on the shore near the saltmarsh where there were the effects of dessication or low on the shore near the main channel with rapid changes in salinity and high water velocities. These difficult conditions are reflected in the low number of common species, restricted to only two species, M.balthica and Nephthys sp.

Group 6 The increased area of sampling in Spring 1976 (Map 23) including the East Hoyle Bank, revealed a group distinct from all others by the notable absence of M.balthica but strong affinities were shown to Group 4 with the presence of Nephthys sp., Bathyporeia sp. and H.arenarius.

(b) Relation to physical/chemical factors

An analysis of variance was performed on the relation of the physical/chemical variables from Autumn 1971, Spring 1974 and Spring 1976 to the Normal AA groups, the results have been presented in Tables 52 - 56, Figs. 27 - 31).

(i) Salinity (Tables 52 & 53, Figs 27 & 28)

A significant difference could be detected between the 5 groups in 1971 at both depths in the sediment (P<005) but although similar patterns were presented in 1974 the difference between the groups was not significant. Although similar trends were also detected at the two depths, 0-2.5 cms and 17.5-20 cm, definition between groups was more significant at17.5-20 cm.

(ii) Median phi (Table 54, Fig. 29)

A highly significant difference between the AA groups (P<005) was detected. Each year there was a similar trend from AA Group 1 correlated with fine sediments to Group 6 correlated with coarse sediments. An exception to the sequence was AA Group 5, here there was a significant rise in phi value. Important in any future multivariate analysis was the demarcation between Groups 1 and 2.

(iii) Percentage loss on ignition (Table 55, Fig. 30)

In all three years a highly significant difference was recorded between the AA group means (P<.005) and a trend was

Survey	A.A. Groups	$\bar{X}$	d.f.	Sum of Squares	Mean Square	Standard error	F ratio
Autumn 1971	1	31.64	53	295.61	5.58	0.32	
	2	29.00	72	3371.28	46.82	0.80	
	3	33.02	23	94.06	4.09	0.41	
	4	32.94	31	183.72	5.93	0.43	
	5	30.89	66	2625.22	39.78	0.77	
			245	6569.89	26.82	0.73	
		30.97	4	531.25	132.81		4.95
Spring 1974	1	29.93	14	210.23	15.02	1.00	
	2	32.70	32	1533.87	47.93	1.21	
	3	31.73	4	13.63	3.41	0.83	
	4	29.83	9	73.50	8.17	0.90	
	5	27.80	5	194.24	38.85	2.54	
			64	2025.47	31.65	1.51	
		31.19	4	187.38	46.82		1.48

Table 52. Analysis of variance of Interstitial Salinity (‰) at depth of 0 - 2.5 cms in the sediment, in relation to the Normal Association Analysis map groups for Autumn 1971 and Spring 1974

Survey	A.A. Groups	$\overline{X}$	d.f.	Sum of Squares	Mean Square	Standard error	F ratio
Autumn 1971	1	30.32	53	917.02	17.30	0.57	
	2	27.43	70	1466.70	17.30	0.57	
	3	33.54	23	212.66	9.25	0.62	
	4	31.54	30	508.03	16.93	0.74	
	5	30.07	59	1707.90	28.95	0.69	
			235	4812.31	20.48	0.65	
		29.88	4	846.50	211.63		10.33
Spring 1974	1	28.13	16	399.33	24.96	1.21	
	2	28.24	32	826.37	25.82	0.88	
	3	31.66	4	26.29	6.57	1.15	
	4	31.66	9	268.47	29.83	1.73	
	5	26.97	5	345.68	69.14	3.39	
			66	1866.13	28.27	1.41	
		28.83	4	160.97	40.24		1.42

Table 53. Analysis of variance of Interstitial Salinity (‰) at a a depth of 17.5 - 20 cms in the sediment, in relation to the Normal Association Analysis map groups for Autumn 1971 and Spring 1974

Survey	A.A. Groups	$\bar{X}$	d.f.	Sum of Square	Mean Square	Standard error	F ratio
Spring 1974	1	3.43	22	6.64	0.30	0.11	
	2	3.12	48	9.69	0.20	0.06	
	3	2.71	8	0.70	0.09	0.10	
	4	2.66	13	0.68	0.05	0.06	
	5	3.23	9	2.71	0.30	0.17	
			100	20.42	0.20	0.10	
		3.10	4	6.77	1.69		8.30
Spring 1976	1	3.33	17	5.27	0.31	0.13	
	2	3.12	40	11.50	0.29	0.08	
	3	2.71	19	1.99	0.10	0.07	
	4	2.61	27	1.11	0.04	0.04	
	5	2.96	48	7.30	0.15	0.06	
	6	2.24	19	2.05	0.11	0.07	
			170	29.22	0.17	0.08	
		2.87	5	17.14	3.43		19.94

Table 54. Analysis of variance of Sediment Particle size (Median Ø value) at a depth of 0 - 2.5 cms, in relation to the Normal Association Analysis map groups for Spring 1974 and Spring 1976

Survey	A.A. Groups	$\overline{X}$	d.f.	Sum of Squares	Mean Square	Standard error	F ratio
Autumn 1971	1	5.59	50	170.68	3.41	0.25	
	2	4.34	73	248.83	3.40	0.21	
	3	3.70	22	44.86	2.04	0.30	
	4	2.73	31	32.62	1.05	0.18	
	5	3.59	64	194.60	3.04	0.22	
			240	691.59	2.88	0.24	
			4	197.24	49.31		17.11
Spring 1974	1	4.11	20	245.11	12.26	0.76	
	2	1.83	46	50.33	1.09	0.15	
	3	1.61	8	3.79	0.47	0.23	
	4	1.04	13	3.64	0.28	0.14	
	5	1.74	9	27.04	3.00	0.55	
			96	329.91	3.44	0.41	
		2.16	4	107.07	26.77		7.79
Spring 1976	1	3.33	18	51.39	2.86	0.39	
	2	2.40	44	61.51	1.40	0.18	
	3	1.48	28	7.14	0.26	0.09	
	4	1.27	32	8.06	0.25	0.09	
	5	1.68	48	56.26	1.17	0.15	
	6	1.26	26	6.33	0.24	0.09	
			196	190.70	0.97	0.17	
		1.84	5	80.92	16.18		16.63

Table 55. Analysis of variance of Sediment Loss on Ignition (%wt) at a depth of 0 - 2.5 cms, in relation to the Normal Association Analysis map groups for Autumn 1971, Spring 1974 and Spring 1976

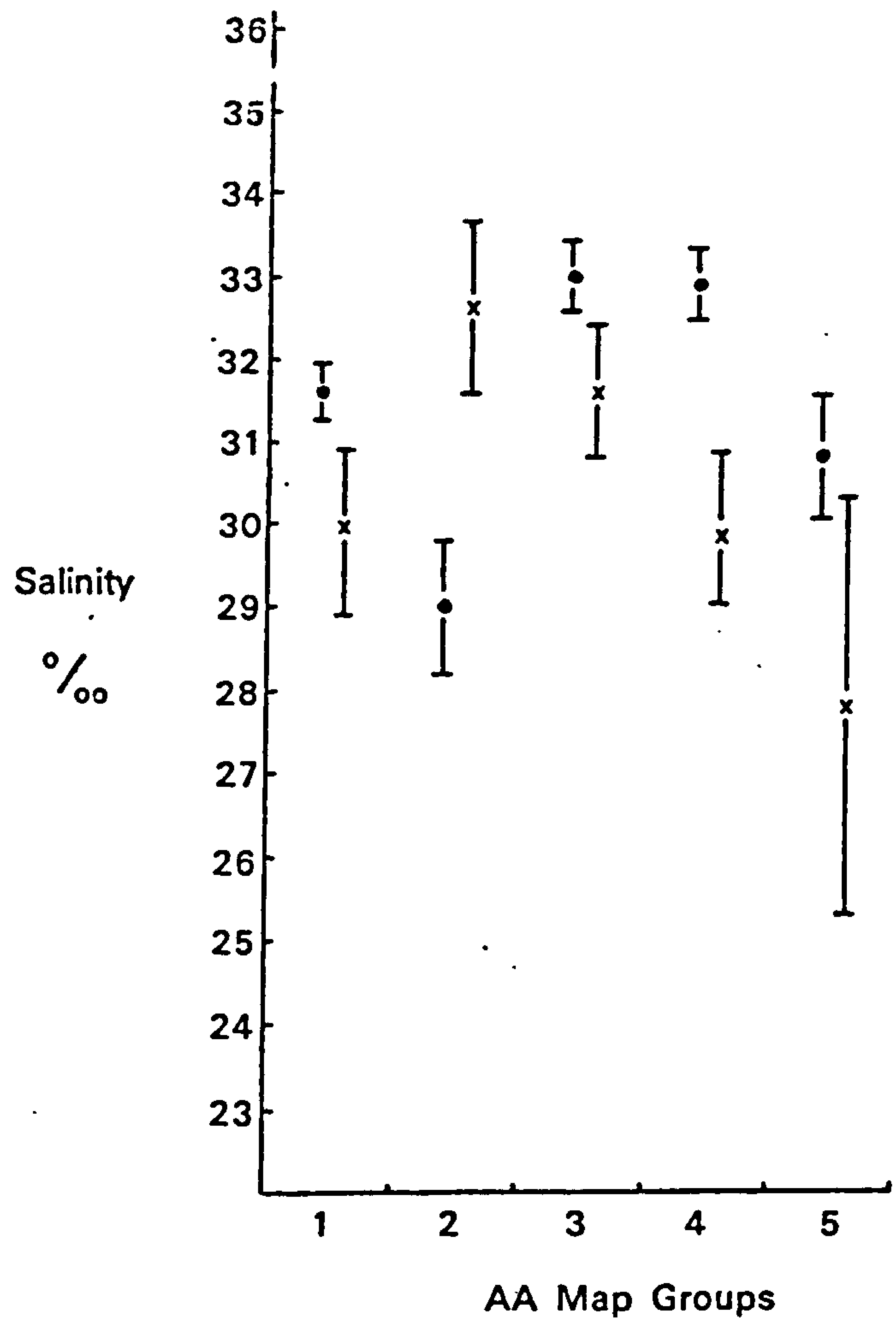


Figure 27. Relation between Normal Association Analysis groups and interstitial salinity at 0-2.5 cms depth in the substratum for 2 surveys. • - Autumn 1971; x - Spring 1974; vertical lines - ± 1 S.E.

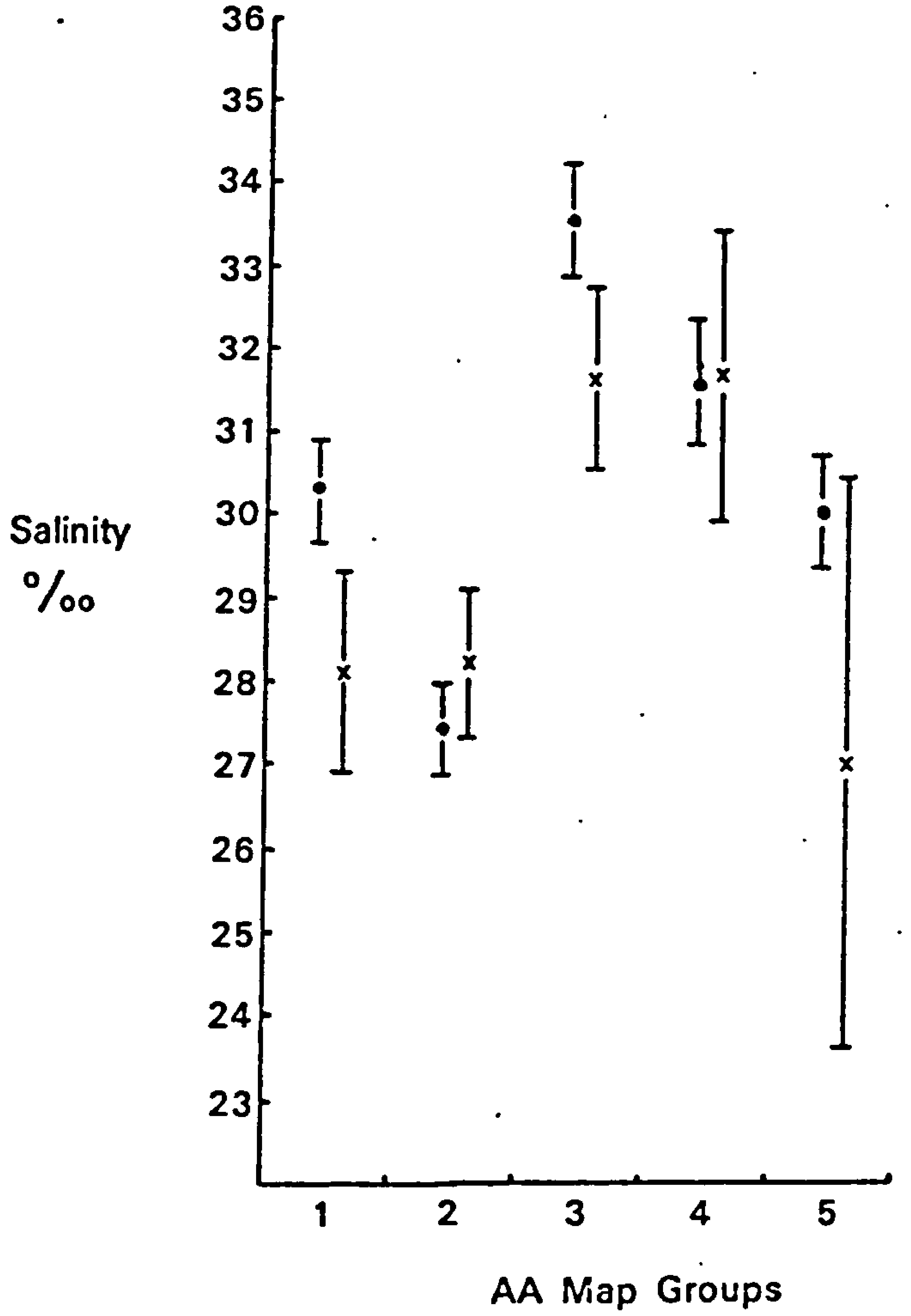


Figure 28. Relation between Normal Association Analysis groups and interstitial salinity at 17.5-20 cms depth in the substratum for 2 surveys. • - Autumn 1971; x - Spring 1974; vertical lines - ±.1 S.E.

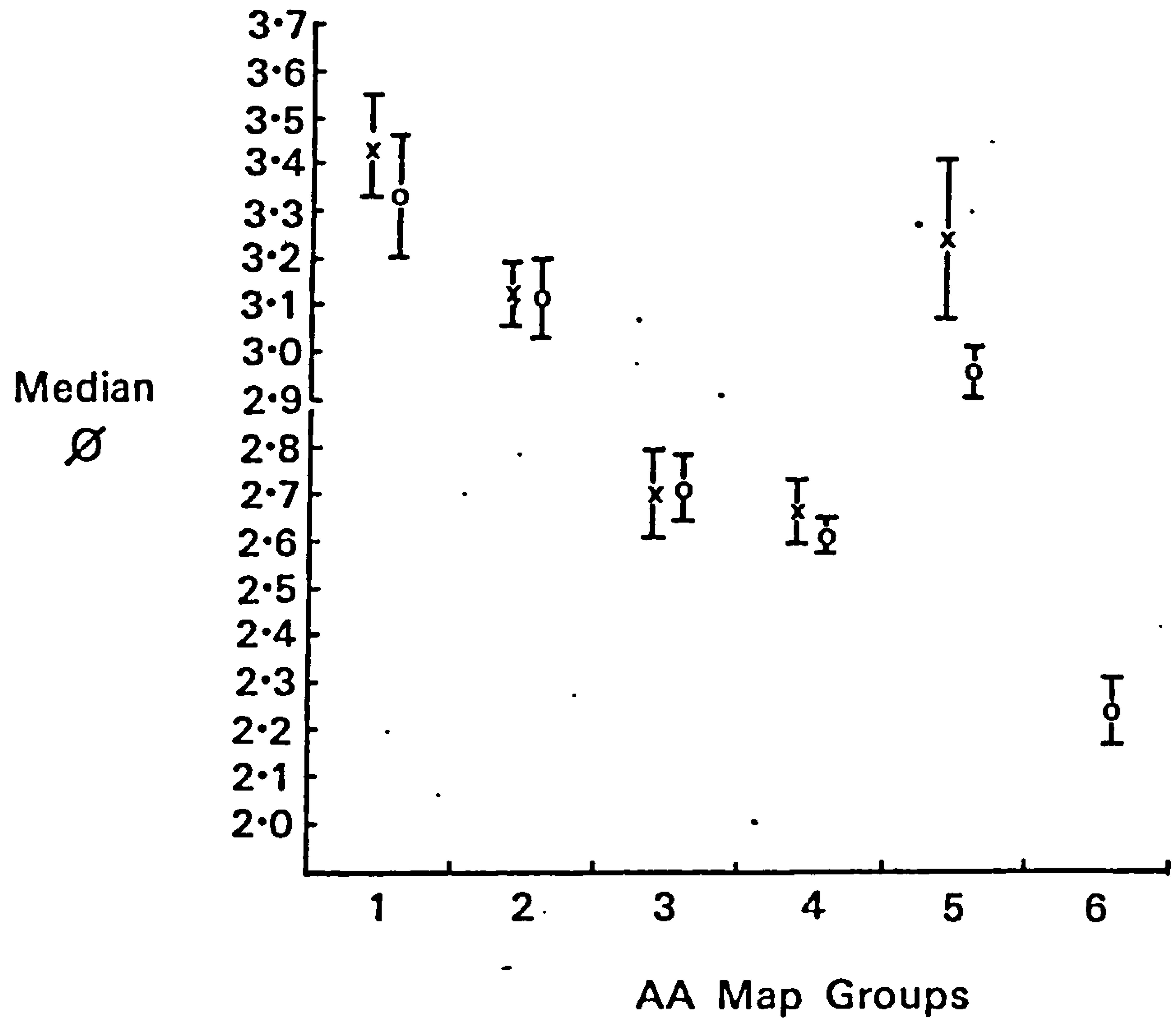


Figure 29. Relation between Normal Association Analysis groups and Median phi value of the sediment at 0-2.5 cms depth in the substratum. x - Spring 1974; o - Spring 1976; vertical lines - ± 1 S.E.

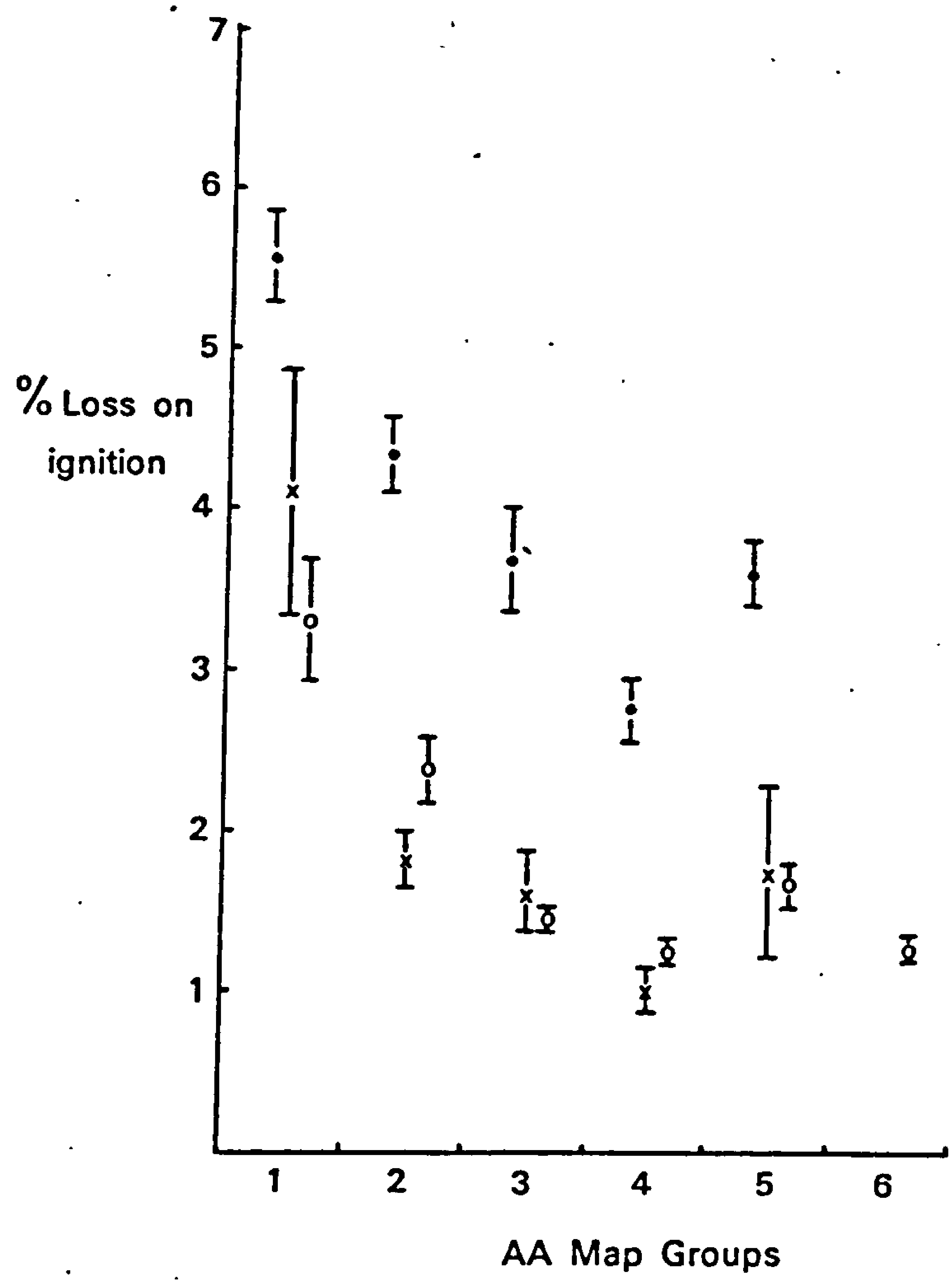


Figure 30. Relation between Normal Association Analysis groups and percentage loss on ignition at 0-2.5 cms depth in the substratum for 3 surveys. • - Autumn 1971; x - Spring 1974; o - Spring 1976. Vertical lines ± 1 S.E.).

apparent from high percentage loss on ignition in Group 1 to low % loss on ignition in Group 4, again the exception was Group 5. A correlation existed between the two Spring surveys but the percentage loss on ignition for the Autumn 1971 survey was approximately 50% higher. A possible explanation was the seasonal increase in benthic diatoms, algae and detritus during the relative calm and more favourable growing conditions of the Summer. Although macroinvertebrates were removed before analysis an increase in meio and micro fauna could also have been a contributory effect.

(iv) Elevation (Table 56, Fig. 31)

A highly significant difference was recorded between the groups in each of the three years ($P < .005$). The importance of the region 1 metre below MHWN in the distribution of the Groups 1 - 3 was clearly demonstrated. The variability between the three years was small with the exception again of Group 5.

The results indicated that each AA Group had a unique combination of particle size, elevation and salinity which over the limited number of surveys studied, and with the exception of percentage loss on ignition in 1971, were consistent.

Survey	A.A. Groups	$\overline{X}$	d.f.	Sum of Squares	Mean Square	Standard error	F ratio
Autumn 1971	1	1.50	54	54.10	1.00	0.13	
	2	1.23	74	127.55	1.72	0.15	
	3	1.13	24	22.06	0.92	0.19	
	4	-0.12	26	56.35	2.17	0.28	
	5	-0.55	63	158.60	2.52	0.20	
			241	418.66	1.74	0.19	
		0.67	4	179.38	44.84		25.81
Spring 1974	1	1.21	24	37.25	1.55	0.25	
	2	1.51	56	52.25	0.93	0.13	
	3	1.83	8	2.54	0.32	0.19	
	4	-0.03	16	10.76	0.67	0.20	
	5	2.03	16	14.64	0.91	0.23	
			120	117.41	0.98	0.20	
		1.33	4	44.14	11.04		11.28
Spring 1976	1	1.35	19	20.95	1.10	o.23	
	2	1.30	50	78.03	1.56	0.17	
	3	1.58	20	15.24	0.76	0.19	
	4	0.12	27	35.25	1.31	0.22	
	5	0.93	60	119.31	1.99	0.18	
	6	0.42	14	34.00	2.43	0.40	
			190	302.79	1.59	0.22	
		0.99	5	41.16	8.23		5.17

Table 56. Analysis of variance of Elevation (metres relative to Ordnance Datum, Newlyn) in relation to the Normal Association Analysis map groups for Autumn 1971, Spring 1974 and Spring 1976

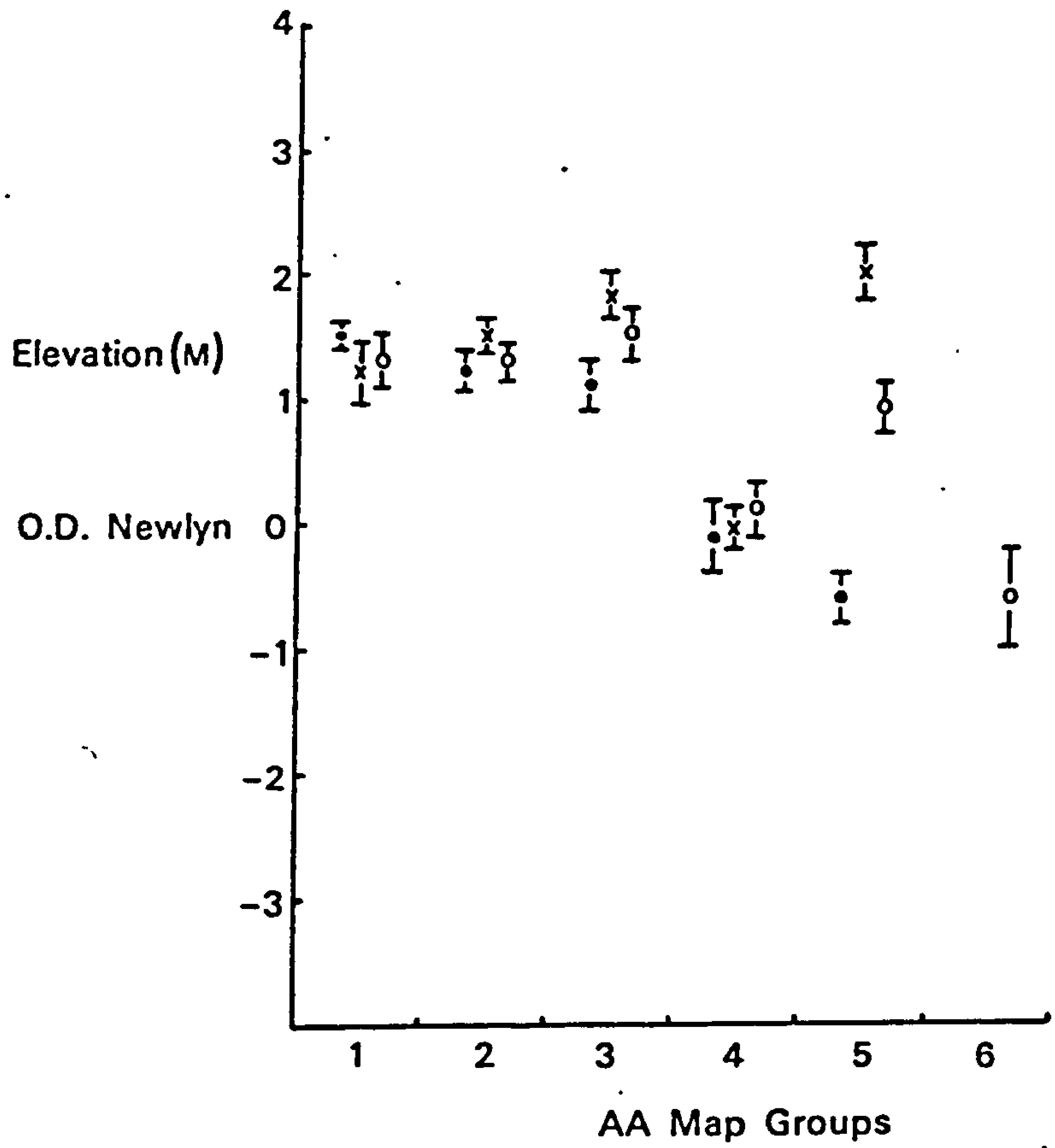


Figure 31. Relation between Normal Association Analysis groups and height on the shore for 3 surveys. • - Autumn 1971; x - Spring 1974; o - Spring 1976; vertical lines - ± 1 S.E.

3.2 Intensive surveys

3.2.1 Environmental factors

Physical/Chemical

The emphasis in the examination of the physical/chemical variables on the transect was slightly different from the extensive surveys. Here I was looking at the seasonal variation of the invertebrates and required more detailed knowledge of the corresponding seasonal variation in environmental factors, e.g. temperature assumes a greater importance but other factors investigated included predation, for which results have been presented (Fig 16-18) percentage loss on ignition, erosion/deposition of the sediment, saltmarsh advance, salinity and selected heavy metals.

(i) Salinity

The extensive grid survey distributions of salinity within the Estuary (Map 27-30) had already suggested that river water was a major factor. Others possibly included precipitation and ground water. Fig.32 has been presented to show the daily variations in river flow at Chester wier for 1972. No clear seasonal pattern was observed and large variations occurred, e.g. in September and October the river flow was below 10 m^3/sec but in the early part of December reached nearly 170m^3/sec. The chance of organising two test surveys where this large variation in salinity was recorded would have been very difficult but the following two surveys outlined were carried out on the 11.8.72 with a river flow of 35 m^3/sec and on the 14.7.72 with a river flow of 7.1 m^3/sec on the Gayton transect. The results of these surveys are presented in Figs 33-35. These surveys along the transect were carried out by myself during a detailed water quality survey along the Estuary by Binnie & Partners and the WNWDA (HMSO 1974).

In addition to relate the water column to the sediments

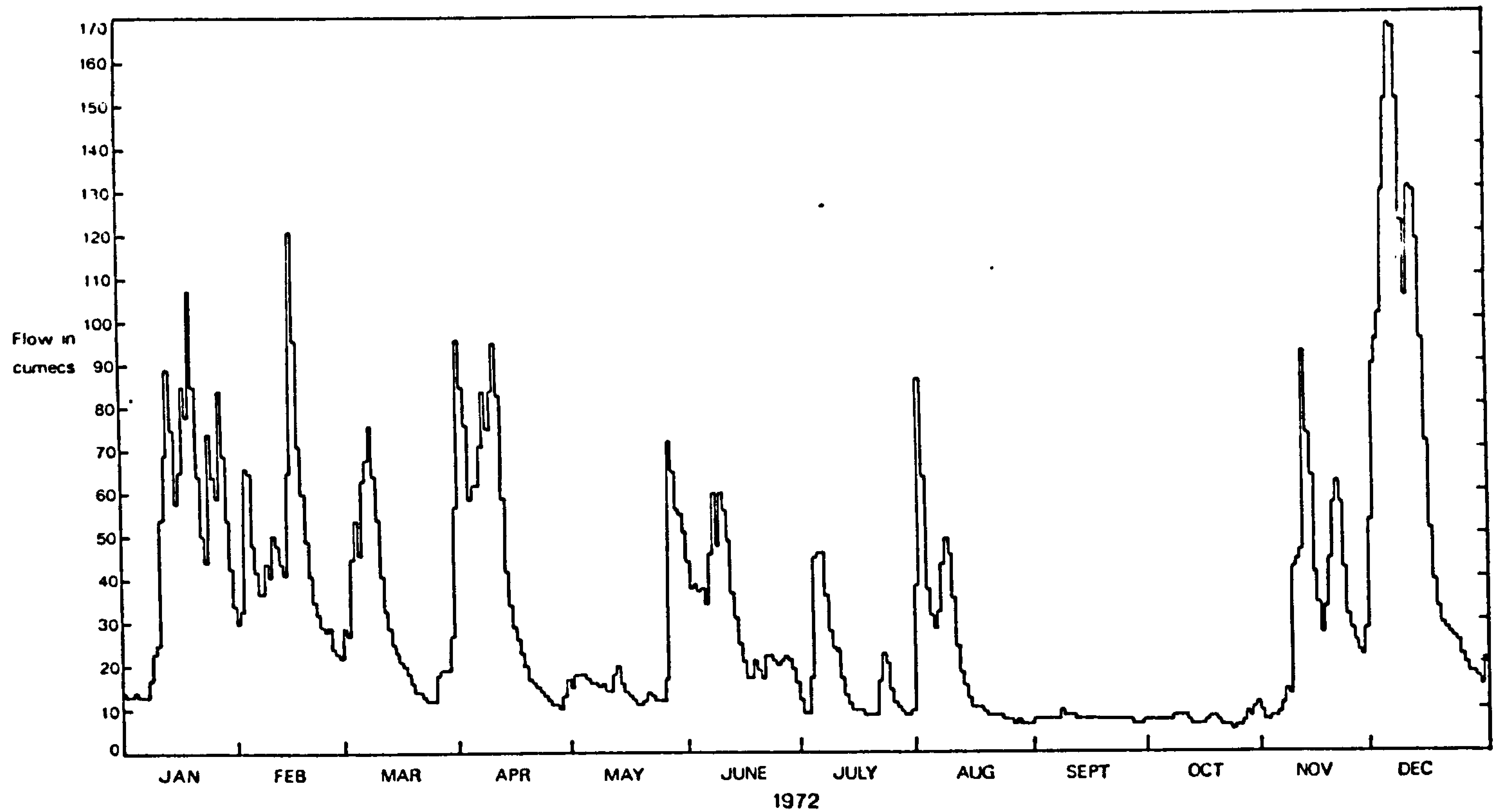


Figure 32. Daily variation in river flow at Chester Wier for 1972.

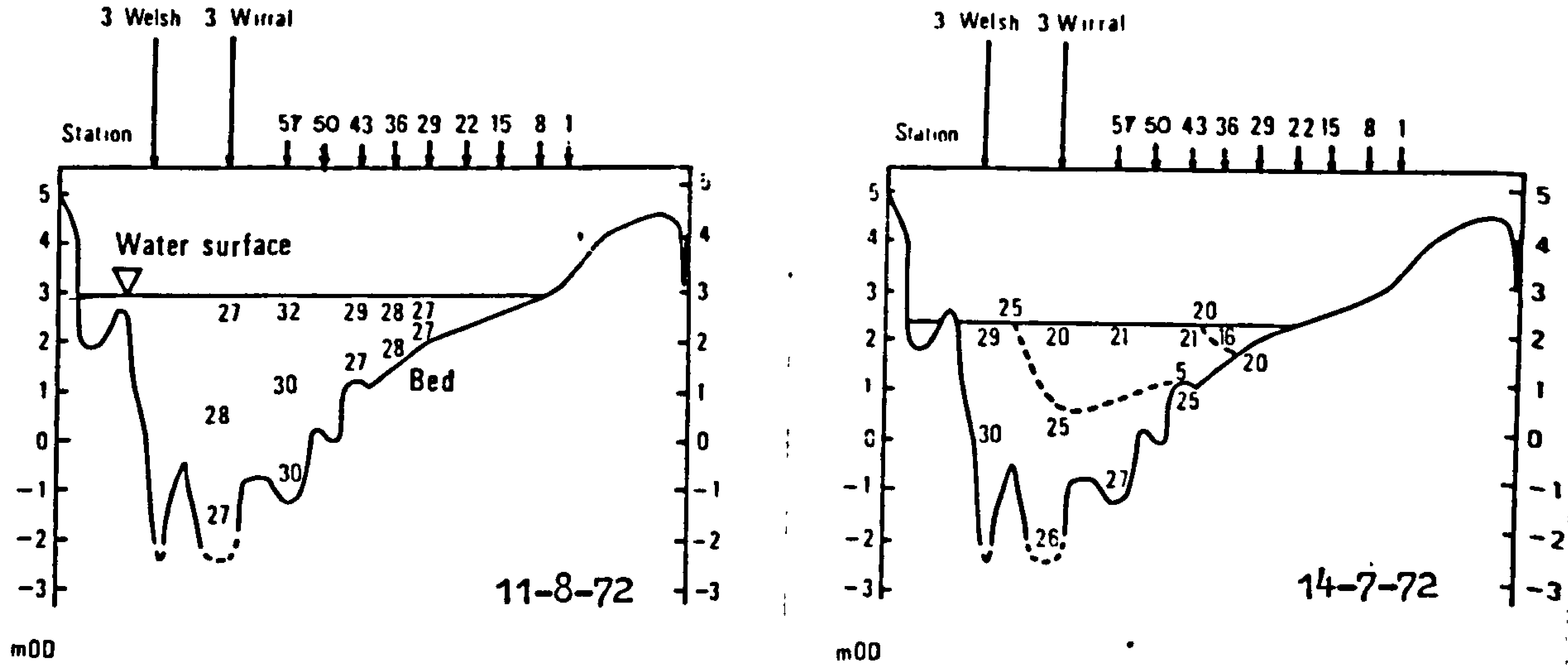


Figure 33. Salinity (g/l) variations on the Gayton transect at approximately ½ flood (H.W. Hilbre -½ hr.).

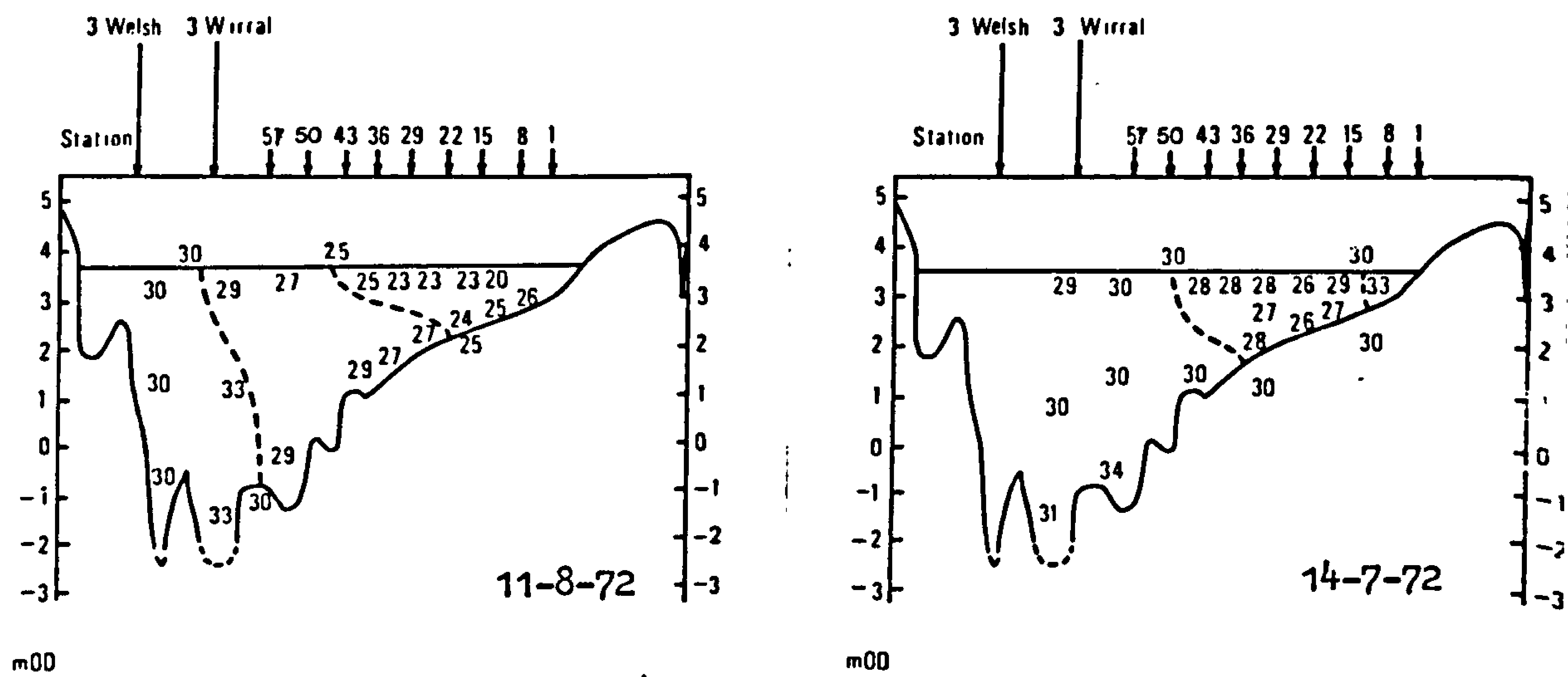
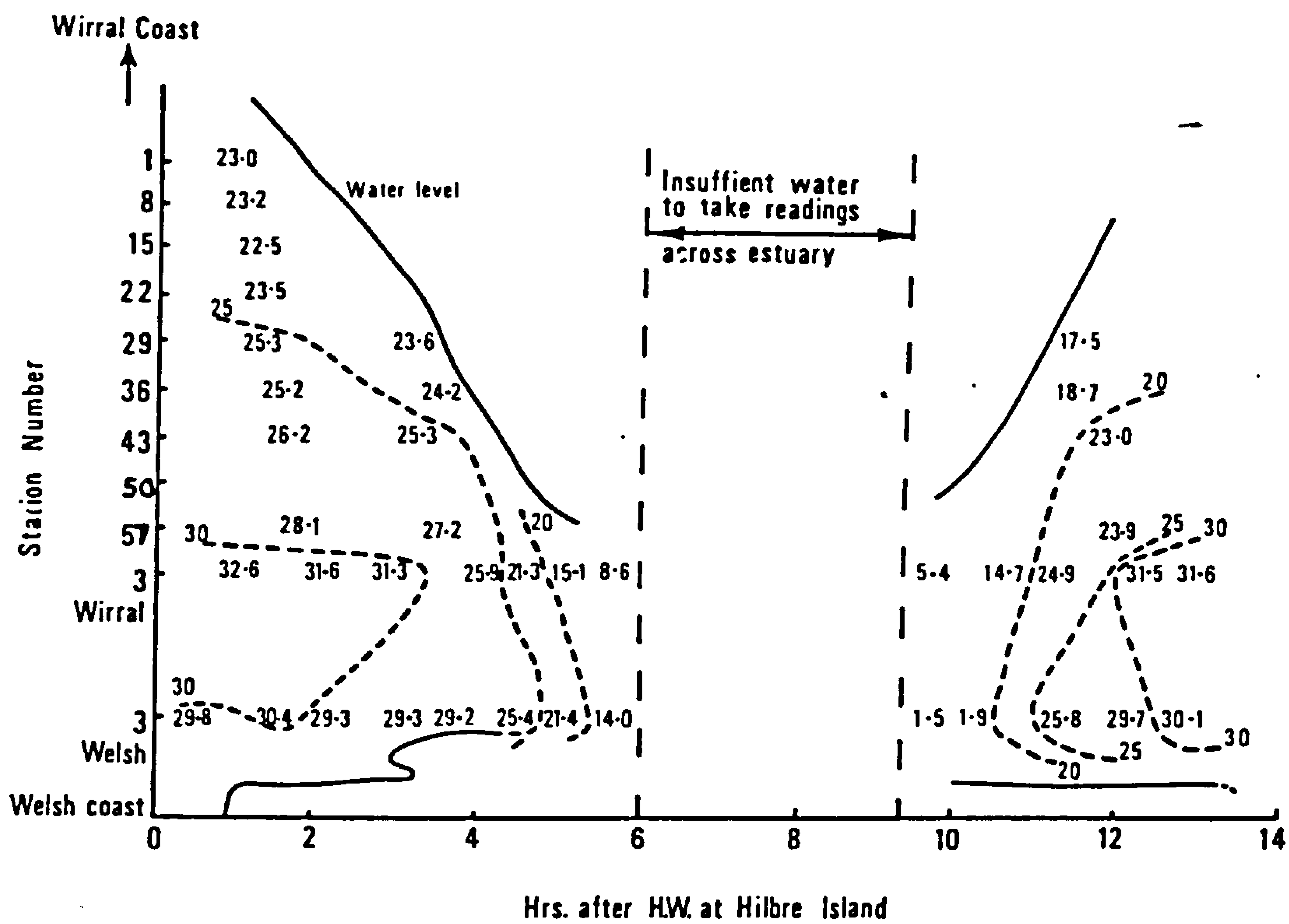


Figure 34. Salinity (g/l) variations on the Gayton transect at approximately high tide (H.W. Hilbre +1½ hrs.).

N.B. 11-8-72* - tide range 8.9 metres L.D, river flow 35 m^3/sec.

14-7-75 - tide range 8.75 metres, river flow 7.1 m^3/sec.

* For interstitial salinity readings on 11-8-72 see Figure



Interstitial Salinity

Depth	1	8	15	22	29	36	43	50
0-2.5 cms	30.34	30.51	20.68	22.95	25.05	27.22	27.05	25.39
17.5-20 cms	32.67	24.17	26.44	20.85	24.52	21.38	21.20	24.79

Figure 35. Salinity (g/l) variations of the water column with time and the corresponding L.W. interstitial salinity of the underlying sediments down the Gayton transect on the 11.8.72.

(an understanding of which is so important in invertebrate studies) on the 11.8.72 interstitial readings were taken at 0-2.5 cm and 17.5-20 cm at low water along the transect (Fig. 35).

The salinities on the 14.7.72 for half flood suggest a transverse stratification occurring across the Estuary, the remains of lower salinities being pushed up the transect. On the 11.8.72 no such clear stratification occurred.

At high water on the 11.8.72 stratification indicated lower salinities at the upper regions of the transect. On the 14.7.72, although lower salinities were in the middle regions of the transect, salinities comparable to the main channel were recorded at Stations 1 and 8. The surface salinity variations with time (Fig. 35) emphasise the non-uniform distribution across the Estuary with less saline waters occurring towards the upper shore pushed by the advancing wedge of marine water. Comparison of these with the interstitial salinity revealed no clear pattern (other than a similar range) in the relationship with the overlying water column. Capstick (1957) noticed that salinity variations in the tidal water during a 12 hour cycle caused little variation to the interstitial salinities only affecting the upper and lower ends of his transect in certain months. The trends in the interstitial salinity results indicated higher salinities at the upper regions of the transect probably related to drying of the sediments during the previous neap cycle, although the particularly low value of 24.17‰ at a depth of 17.5-20 cm at Station 8 is difficult to explain. Salinities at 17.5-20 cm tended to be lower (except Station 15). This could have been due to general conditions over a longer period but the effects of the geology, i.e. ground water, need further investigation. The general conclusion can be made that there was no precise relationship, although the general range was similar, between the water column salinities on the 11.8.72 and the interstitial salinities.

An indication of the salinity variations occurring in the main channel at the base of the Gayton transect over a tidal cycle can be seen from the results of a further survey carried out on the 18.9.72 (Fig. 36). The tidal range was 6.8 m Liverpool Datum (L.D.) and the freshwater flow at Chester wier was 7.1 m^3/sec. The existence of stratification was observed both on the flood and the ebb. There was evidence at half ebb of plugs of freshwater flowing out on the tide. Salinities ranged from a high tide value of 29‰ to 8‰ in the main channel at low water, giving a salinity difference of 21‰ over the tide cycle at the base of the Gayton transect.

To give an indication of the salinity variation throughout a year. Table 57 has been presented which shows the interstitial salinity on the invertebrate sampling dates from 13.9.71 to 18.9.72. Although there was variation throughout the year no clear pattern emerged and the effects of high freshwater inputs to the Estuary were not distinctive. The mean value over the 12 months indicated marginally lower salinities at greater depth. Although the approximate average was 24‰ the highest figures registered ranged between 8.83‰ at Station 43 on the 14.2.72 and 47.64‰ at Station 8 on the 13.9.71, but the upper values were higher.

(ii) <u>Percentage loss on ignition</u> (Table 58)

Percentage loss on ignition values were recorded over one year from 13.9.71 to 18.9.72 at two depths in the sediment. The results revealed no obvious seasonal variation but the 0-2.5 cm depth values, particularly at Stations 1 and 8, possible reflecting the increased deposition of sediment and organic material adjacent to the saltmarsh.

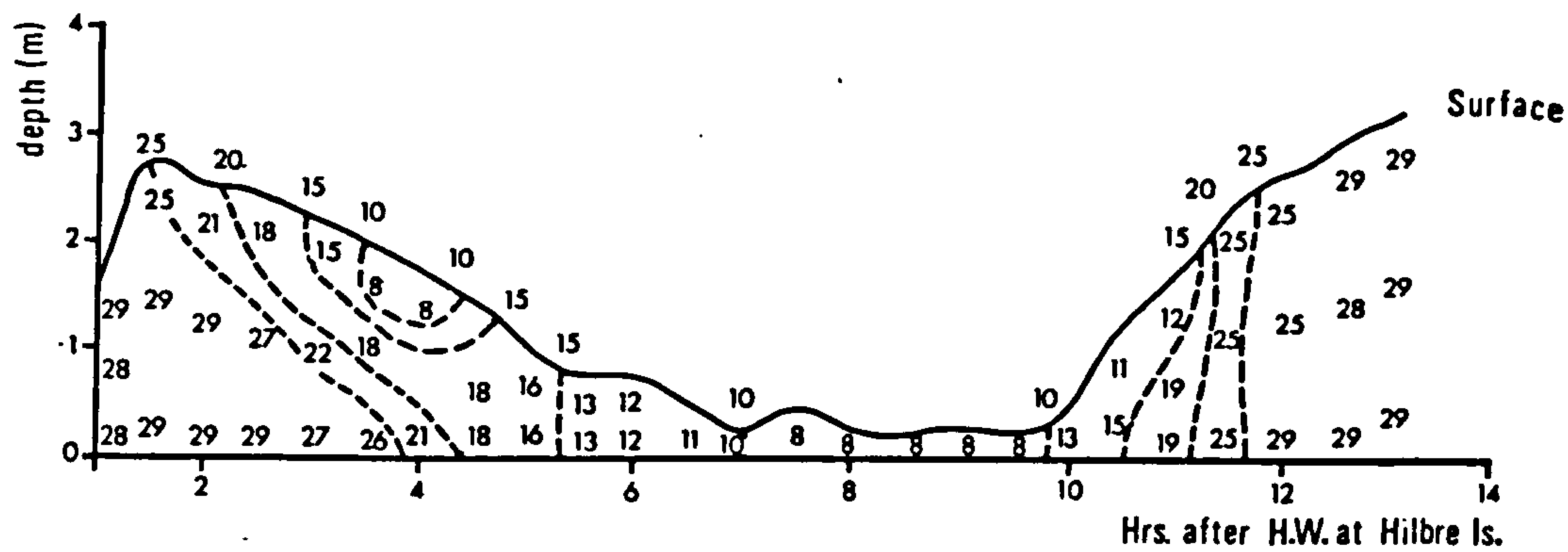


Figure 36. Salinity (g/l) variations in the main Dee Channel at the end of the Gayton Transect on 18-9-72. (Tidal range 6.8 m Liverpool Datum, freshwater flow Chester Wier 7.1 m^3/sec. (For salinities taken on the same day in the substrate along the transect see Table

Date		13-9-71	1-11-71	15-12-71	25-1-72	14-2-72	14-3-72	5-4-72	2-5-72	6-6-72	5-7-72	11-8-72	18-9-72	Mean
Freshwater flow (cumecs.)		7.0	9.0	17.0	64.0	41.0	25.0	62.0	18.0	34.0	45.0	35.0	7.1	-
Tidal height (m) (Liv. datum)		6.8	8.6	7.7	7.1	8.6	8.7	7.4	8.1	7.6	7.8	8.9	6.8	-
Precipitation (mm)		0.5	0	0	0.2	3.4	1.6	1.7	0.1	11.8	0	0	0	-
Depth 0-2.5cm														
Station	1		28.35	29.73	24.49	18.04	32.32	18.22	33.44	34.04	32.84	30.34		28.18
	8	47.64	28.69	18.92	21.73	19.89	30.16	20.85	19.45	23.3	24.96	30.51	31.03	26.43
	15	27.65	26.26	21.90	23.65	20.33	28.78	17.87	28.09	19.89	30.08	20.68	28.52	24.48
	22	28.07	26.7	20.68	18.76	19.45	28.26		24.7	17.25	27.65	22.95	34.22	24.43
	29	29.9	24.44	20.33	18.04	20.85	28.87	21.55	29.39	20.06	30.91	25.05	25.83	24.60
	36	27.05	28.0	22.43	19.18	23.3	26.44	23.65	31.11	21.03	31.11	27.22	21.99	25.21
	43	27.27	31.03	20.33	12.03	20.85	28.61	15.93	31.11	21.03	29.61	27.05	28.87	24.48
	50	28.97	28.61	25.66	22.6	24.17	29.13	22.16	30.25	23.83	25.05	25.39	31.8	26.47
	57	28.69	31.46	24.7	18.22									25.77
Depth 17.5-20cm														
Station	1		29.39	25.92	40.47	21.55	25.92	21.90	11.50	22.86	22.78	32.67		25.50
	8	31.89	20.85	24.17	19.27	20.17	22.43	27.31	22.08	31.46	28.87	24.17	45.32	26.50
	15	25.78	24.87	23.3	26.61	23.13	30.51	23.04	23.65	19.27	21.9	26.44	37.56	25.51
	22	27.64	20.85	20.68	24.52	19.62	22.08	26.0	23.21	20.15	28.0	20.85	27.31	23.41
	29	29.25	20.5	21.2	22.95	18.57	24.87	19.34	18.83	26.09	28.0	24.52	26.61	23.39
	36	24.66	21.03	20.15	23.74	19.45	19.45	26.0	25.39	24.87	23.91	21.38	26.61	23.05
	43	30.60	21.47	18.74	21.03	8.83	9.97	26.09	25.39	26.61	25.01	21.20	27.83	21.90
	50	30.42	28.52	25.66	27.57	23.48	29.04	22.95	26.35	20.33	32.67	24.79	25.92	26.48
	57	25.22	27.48	22.25	15.75									22.68

Table 57. Variations in river flow, tidal height, precipitation and interstitial salinity recorded on the invertebrate sampling dates at each Station down the Gayton transect.

		13-9-71	1-11-71	15-12-71	25-1-72	14-2-72	14-3-72	5-4-72	2-5-72	6-6-72	5-7-72	11-8-72	18-9-72	Mean
Depth 0-2.5cm														
Station	1		8.71	7.62	6.63	7.8	8.92	8.01	8.06	7.59	8.67	9.98		8.19
	8	5.02		3.81	2.43	6.56	5.81	5.58	3.66	5.73	7.32	8.38	3.73	5.28
	15	5.89		5.76	4.6	4.01	3.68	4.31	4.18	3.29	4.81	4.98	3.67	4.47
	22	3.53		3.94	3.65	3.64	4.01		4.26	4.03	3.95	4.03	4.19	3.92
	29	4.31		3.46	3.06	3.2	3.24	3.36	3.41	3.53	3.2	3.23	3.52	3.41
	36	4.32	4.4	4.04	3.29	3.77	4.17	3.73	4.02	4.18	4.32	4.39	4.49	4.09
	43	2.4	4.43	3.1	3.09	3.2	3.44	2.78	4.02	3.08	3.78	4.23	3.85	3.45
	50	3.56	3.08	3.54		3.36	3.42	3.31	3.52	3.4	3.3	3.35	3.24	3.37
	57	3.27	3.85	2.08										3.07
Depth 17.5-20cm														
Station	1		5.75	5.42	6.17	5.65	5.62	6.37	5.67	5.77	5.88	5.67		5.79
	8	4.53	4.16	6.26	4.26	4.03	3.94	4.02	6.23	5.07	4.91	3.97	7.4	4.9
	15	4.85	3.56	5.04	4.64	5.71	5.04	5.76	5.28	5.47	5.25	5.1	7.95	5.3
	22	4.52		3.78	3.92	3.74	4.0	3.72	3.83	3.81	3.94	3.86	4.34	3.95
	29	4.24		4.12	3.78	4.14	3.9	4.02	4.0	3.8	4.04	4.02	4.27	4.03
	36	3.58		3.53	3.44	3.17	3.0	3.4	3.37	3.6	3.41	3.37	4.97	3.53
	43	3.96	3.88	3.62	3.47	3.03	3.7	3.29	3.37	3.06	3.46	3.61	3.13	3.47
	50	3.37	3.44	3.32		3.51	3.58	3.7	3.21	3.12	2.72	3.14	3.19	3.3
	57	2.24	3.18	2.84										2.75

Table 58. Variation in percentage loss on ignition values recorded on the invertebrate sampling dates at each Station down the Gayton transect.

(iii) Erosion/Deposition of Sediment

To check the rate of deposition of sediment, particularly near the saltmarsh, stakes were placed at each Station down the transect and at equal distances between each Station.
The method adopted was to push two metre long bamboo canes deeply into the sediment and record any change in sediment depth on later invertebrate sampling dates. A small amount of scour was usually present at the base of the stakes but the effect was localized and there was no obvious movement of the canes in the sediment.
The results have been presented in Table 60. No clear trend was apparent either during the year or along the transect. Maximum increases in sediment occurred at Stations 8, 36 and 39.5. Clearly deposition was not confined to the upper regions of the transect over the relatively short period of the study and major variations were found near the main channel at the base of the transect.
Very similar observations were made by Hydraulic Research Station (HRS 1970) with similar minor changes in level in the upper foreshore on a nearby transect at Heswall, and over the whole of their transect there appeared to be an approximate balance between accretion and erosion.

(iv) Saltmarsh advance

To gain an impression of the long-term changes in accretion (assuming saltmarsh colonization occurs when the sediment reaches +3.3 m O.D. (Ranwell 1964)) and at the same time indicate the rate of advance of the saltmarsh along the Gayton transect, Table 59 is presented.

Year	1950	1955	1960	1965	1968	1971	1976
Width (m)	820	140	700	660	940	1550	1700

Table 59. Width of vegetated zone of foreshore adjacent to Gayton transect.

Date	Station 1	3.5	8	11.5	15	18.5	22	25.5	29	32.5	36	39.5	43	46.5	50
6- 6-72					22.7		58.4	50.0	30.1		73.2		65.3		12.8
					+(0.4)		+(1.4)	-(1.0)	-(0.3)		+(3.9)		-(0.4)		-(1.0)
5- 7-72	59.7		47.0	70.2	22.3	57.7	57.0	51.0	30.4	63.3	69.3		65.7		13.8
	+(1.5)		+(3.3)	-(2.3)	+(0.7)		+(0.6)	+(2.3)	-(0.4)	+(3.1)	-(0.3)				-(2.8)
10- 8-72	58.2	70.8	43.7	72.5	21.6		56.4	48.7	30.8	60.2	69.6		43.6*		15.8
					+(1.6)	-(1.8)	+(0.4)	+(0.2)	+(0.7)	(0)			-(8.9)		-(0.2)
18- 9-72					20.8	59.5	56.0	48.5	30.1	60.2			52.5		16.0
				+(3.2)	+(2.1)	+(3.5)	-(2.0)	+(3.0)	-(4.1)		+(5.0)		+(1.7)		+(3.5)
2-11-72				69.3	17.9	56.0	58.0	45.5	34.2		64.6	71.6	50.8	48.3	12.5
		+(2.9)	+(10.1)	-(2.7)	+(3.4)	-(3.0)	-(2.5)	+(0.4)	-(1.5)	+(1.8)	+(2.7)		-(0.9)		
8-12-72		67.9	33.6	72.0	14.5	59.0	60.5	45.1	35.7	58.4	61.9		51.7		
		+(1.4)	+(0.8)		+(3.6)	+(1.8)	-(0.3)	+(1.0)		+(2.4)	+(1.2)	+(12.7)			-(3.4)
14- 1-73		66.5	32.8	64.6*	10.9	57.2	60.8	44.1		56.0	60.7	58.9			15.9
			-(2.3)	-(2.2)	-(0.3)		-(2.0)	(0)		-(0.2)	+(14.5)	+(6.1)	-(1.6)		-(12.8)
11- 2-73			35.1	66.8	17.2		62.8	44.1		56.2	46.2	52.8	53.3		28.7
		-(3.8)	+(1.9)	+(0.7)	(0)	-(0.2)	+(2.6)			+(0.8)	+(1.3)	+(7.7)	+(1.5)		
18- 3-73		70.3	33.2	66.1	11.2	57.4	60.2			55.4	59.4	45.1	51.8		
		+(9.5)	-(2.2)	-(0.4)	-(7.2)		+(2.7)	+(3.1)	-(1.5)	+(2.1)	+(5.6)	+(2.7)	-(1.0)		-(32.1)
30- 4-73	67.2*	60.8	35.4	67.2	18.4		57.5	41.0	37.2	53.3	53.8	42.4	52.8		60.8
	-(0.5)	+(2.1)	-(2.0)	+(0.6)	+(2.2)	-(6.2)	-(0.4)	+(1.7)	+(1.0)	+(3.1)	+(2.8)	+(5.0)	(0)		
3- 6-73	67.7	58.7	37.4	66.6	16.2	63.6	57.9	39.3	36.2	50.2	50.9	37.4	52.8		
	-(0.3)	-(0.2)	+(1.5)	+(1.2)	+(1.0)	(0)	+(1.3)								
10- 7-73	68.0	58.9	35.9	65.4	15.6	63.6	56.6								
	-(0.2)	-(8.8)	+(2.8)	-(0.6)	+(1.2)	+(0.2)	+(3.2)								
24- 9-73	68.2	67.7	33.1	66.0	14.4	63.4	53.4								
Net change	+0.5	+3.1	+13.9	-2.5	+8.7	-5.7	+5.0	+10.7	-6.8	+13.1	+36.7	+34.2	-9.6		-48.8

Table 60. Variations in the erosion/deposition of sediment recorded on the invertebrate sampling dates at each Station down the Gayton transect. Figures in brackets, relative change between recordings. (* denotes new pole).

The steady increase in width of the saltmarsh in this area indicates a more long-term accretion occurring in the upper regions of the transect.

During the course of the study Station 1 on the transect changed from being an open mudflat with scattered small S.anglica clumps to dense cover. During the period also the sediment surface changed from being a broad flat expanse with no significant drainage channels to an area with saltmarsh gutters approximately 1 metre deep. The appearance of these deep channels occurred rapidly during 1974/75.

(v) Temperature

To gain an indication of the temperature effects on the invertebrates, temperatures of river, sea and air were obtained from a variety of local monitoring stations, e.g. in Fig. 37 the mean annual monthly variation in the river water at Shotton Steelworks, the sea at Holyhead, the air at Hawarden Bridge Meteorological Station, Shotton Steelworks and the sea nearby at the Mersey Bar Lightship.

The mean monthly figures were not obtained, for practical reasons, over the same length of time but were sufficient to indicate general trends, e.g. sea water temperatures at less annual variation than the river temperatures, and there was a pronounced time lag in the sea temperatures.

A more detailed distribution was prepared for the period 1971-73 (Fig. 38). The mean air temperatures were obtained from Hawarden Meteorological Station, Shotton Steelworks and the river temperatures from the water intakes of Shotton Steelworks at low water to separate them from marine influence. The sea water temperatures presented problems. Ideally a continuous recorder would have been preferred on the Estuary but this proved

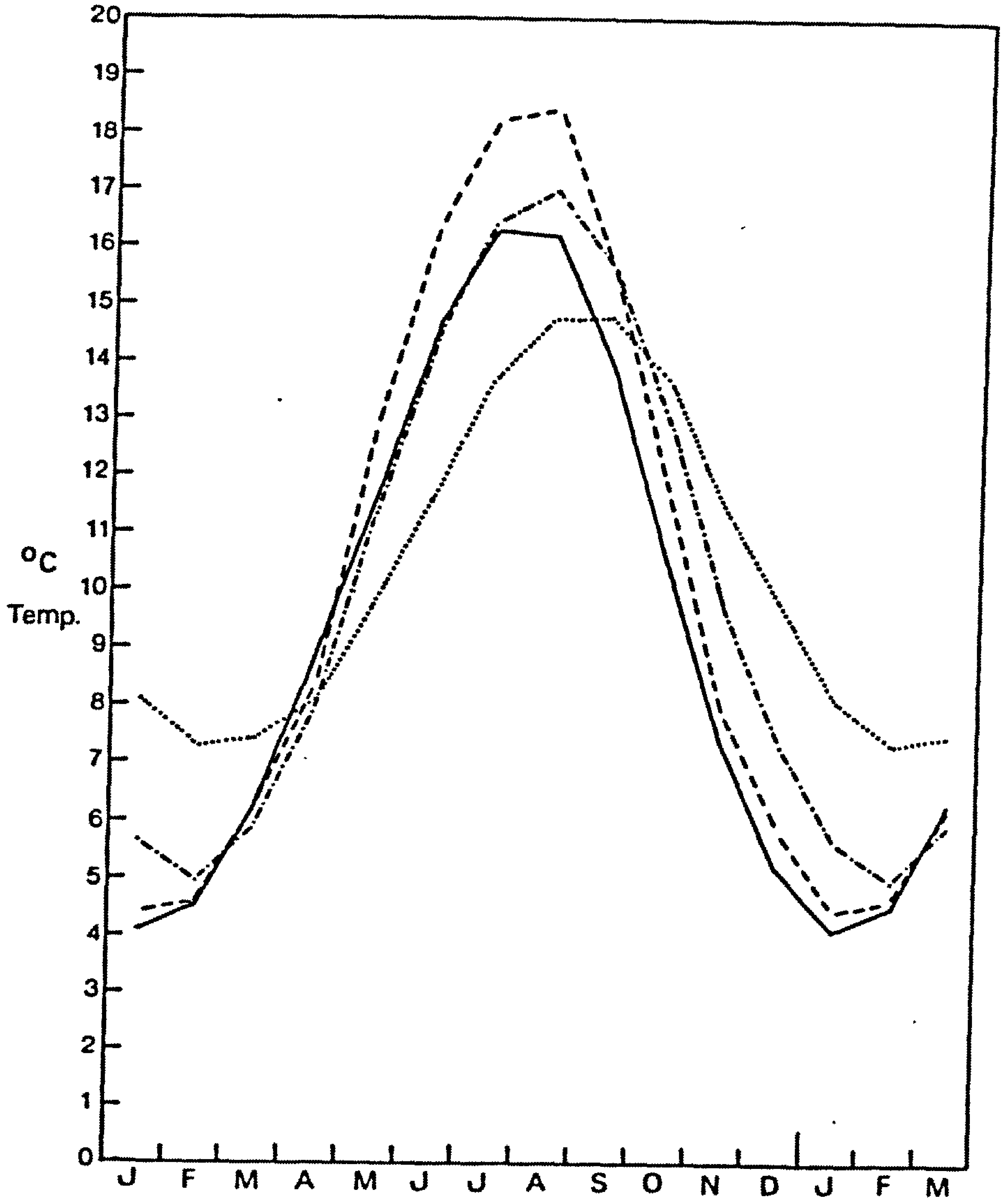


Figure 37. Mean annual temperature.

- - - - - = River (Shotton)
.... = Sea (Holyhead)
———— = Air (Shotton)
-·-·-·- = Sea (Bar Lightship)

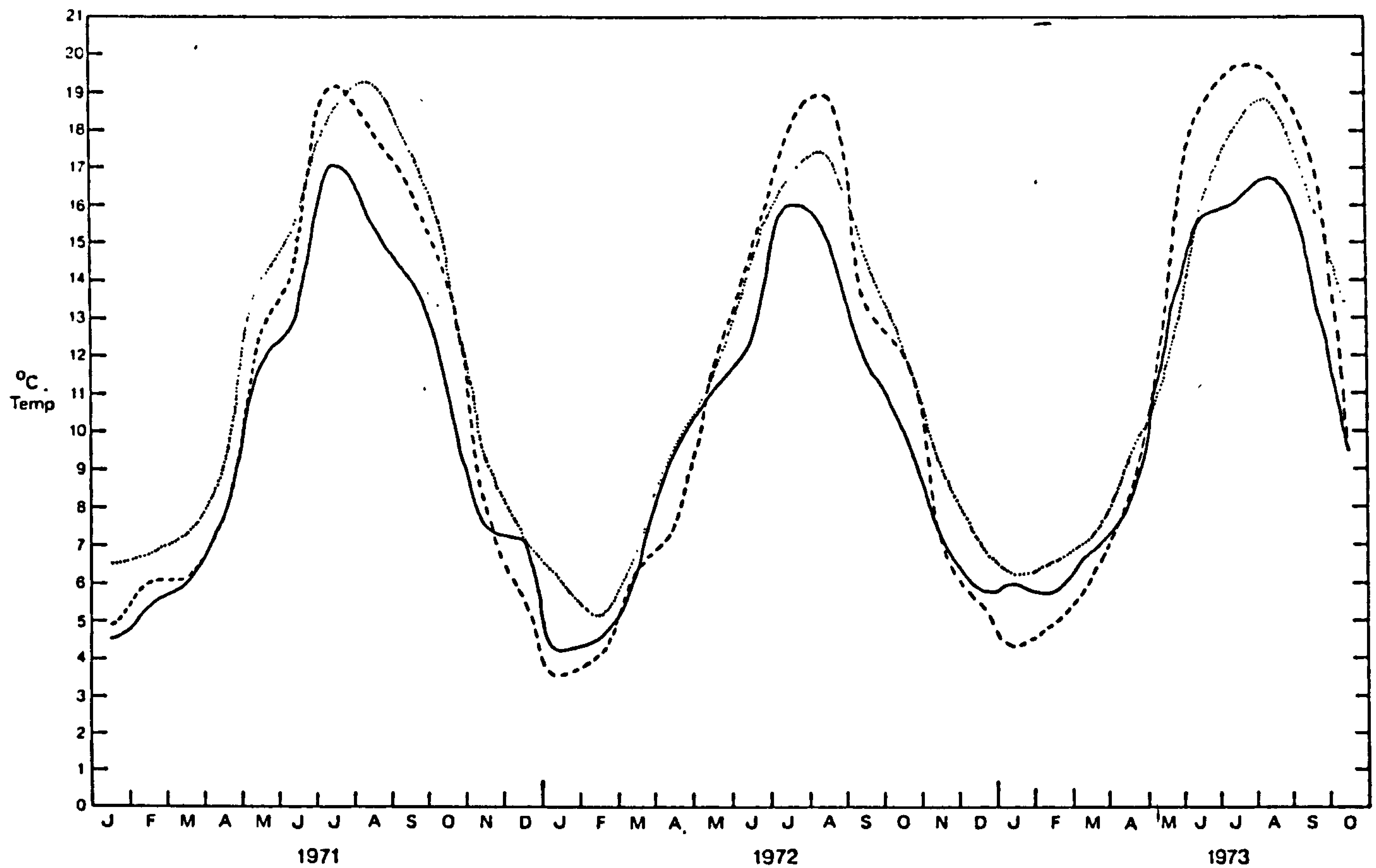


Figure 38. Seasonal mean variation in temperature. ----- River (Shotton Steelworks water intake; ——— Air (Shotton Steelworks Met. Station); ·········· Sea (Clarence Dock Power Station).

unpractical, therefore temperature records were obtained from the nearest source, and this proved to be the water intakes of the Clarence Dock Power Station in Liverpool. Records were taken two hours into flood, so avoiding problems as much as possible of River Mersey temperatures. In addition, temperature records were taken in the sediment with maximum/minimum thermometers at each of the sample stations along the transect at 2.5 cm and 10 cm depth. Unfortunately this method proved unsuitable as the thermometers generally survived only one month. The thermometers proved particularly attractive to the longer billed waders presumably by the vermiform shape of the glass. However, the maximum recorded temperature along the transect was 27.8°C, at Station 22 at a depth of 2.5 cm between 5-7-72 and 10-8-72. The minimum temperature was 0.5°C at Station 43 at a depth of 2.5 cm between 11-2-73 and 18-3-73.

(iv) Pollutants

The policy over a number of years of the Pollution Prevention Department of the River Authority has been to encourage full treatment of domestic sewerage outfalls into the Estuary. At the end of the study only one outfall, at Heswall, remained partially treated. During the study 3 crude sewerage outfalls onto West Kirby Bank were redirected to the North Wirral offshore sewerage discharge pipeline in 1975. However, the infrequent occurrence of tomato seeds along the Gayton transect indicated a source but the origin was unknown.

A factor which I felt important during the early stages of the study was the investigation of heavy metals in particular Zinc. An industrial plant was present at Greenfield on the southern shore which was the largest rayon factory in Europe and water quality surveys revealed that large quantities of soluble $ZnSO_4$ was being discharged into the Estuary. To note any major concentrations and variations throughout the year material was provided from the intensive sampling locations for the Pollution Prevention Department to form part of their pollution control programme (Table 61). Shortly after the study began a reclamation process was installed and the levels of heavy metal discharged into the Estuary was considerably reduced. Samples were also regularly provided of the invertebrates, these samples indicated that although Zinc was accumulated (Mehran and Tremblay 1966) levels were comparable with samples from other unpolluted estuaries.

3.2.2 Macroinvertebrates (Figs. 39 - 92)

Sampling intensity was directed at common species. Ecological interpretation of the less common species has not been attempted but the results have been presented. Analysis involved calculation of the normal statistical parameters, e.g. standard error, but for clarity of graphical presentation these have been omitted in the 1971-73 Gayton transect frequencies. Effort at this stage using the material available was on detecting significant trends in the frequency distributions over a number of years, in particular, detecting periods of recruitment and noting evidence of predation activity.

Station	13-9-71	1-11-71	15-12-71	25-1-72	14-2-72	14-3-72	5-4-72	2-5-72	6-6-72	5-7-72	11-8-72	18-9-72	Mean
Depth 0-2.5cm													
1		1.17	0.41	0.67	0.08	1.24	0.46	1.45	<0.03	<0.03	0.61		0.62
8	0.54	0.72	0.46	0.57	0.97	0.75	0.68	0.48	0.03	0.67	0.24	0.67	0.57
15	0.53	0.5	0.87	0.26	0.5	1.23	2.7	0.35	0.22	0.49	<0.03	0.46	0.68
22	0.3	0.62	1.58	0.47	0.36	0.87	0.72	0.66	0.62	0.62	0.08	0.34	0.6
29	0.47	0.52	0.99	0.43	0.58	0.87	0.72	0.97	0.46	0.57	<0.03	0.47	0.59
36	0.16	0.21	0.77	0.43	0.55	0.44	0.57	0.73	<0.03	1.02	<0.03	0.12	0.42
43	0.45	0.39	0.69	0.9	0.56	1.18	0.5	0.73	1.22	1.27	0.06	0.51	0.7
50	0.27	0.74	1.02	0.64	0.55	0.68	0.46	0.69	0.87	1.77	0.31	0.21	0.68
57	0.48	0.42	0.79	0.35									0.51
Depth 17.5-20cm													
1		0.99	0.68	0.32	0.49	0.57	1.08	0.47	0.72	0.76	<0.03		0.61
8	0.52	0.67	1.43	0.36	0.36	0.35	0.46	0.92	0.68	0.59	0.14	<0.03	0.54
15	0.48	0.62	3.36	0.25	0.44	1.13	0.64	0.72	1.04	1.01	0.26	0.28	0.85
22	0.27	0.63	0.85	0.42	0.23	0.44	0.73	1.17	1.33	0.57	0.22	0.26	0.59
29	0.48	0.52	0.42	0.37	0.45	0.57	0.96	0.71	0.16	0.55	<0.03	0.23	0.45
36	0.39	0.41	0.63	0.26	0.33	0.46	0.48	0.42	1.02	1.76	0.13	0.28	0.55
43	0.57	0.53	1.73	0.25	0.16	0.46	0.46	0.42	0.72	0.76	0.28	0.27	0.55
50	0.43	0.62	0.64	0.42	0.42	0.7	0.5	0.6	0.49	0.72	0.18	0.4	0.51
57	0.44	0.44	0.82	0.31									0.50

Table 61. Variation in soluble zinc (ppm) in the interstitial water recorded on the invertebrate sampling dates at each Station down the Gayton transect.

(a) Nereis diversicolor (Figs. 39 - 42)

The polychaete on the Gayton transect had a seasonal variation in density, maximum numbers occurring in the Autumn of each year at Stations 15, 22, 29 and 36. The timing of the maximum densities was in general agreement with Dales (1951) but varied from Chambers & Milne (1975a) on the Ythan where maximum densities were in mid-Summer. In both these estuaries the increases represented recruitment by young. Following the rapid increases in density there was a gradual reduction with the indication that the effects of a recruitment period extended over more than one year, e.g. Station 15 in 1971-72 and Stations 22 and 29 in 1975-76. Particularly good recruitment was also recorded following low summer densities in 1973. The data indicated that at the end of each two-year cycle there were uniform minimum densities, e.g. 1973, 1975 and 1977. Very similar densities were recorded by Dales (1951) and Chambers and Milne (1975a).

(b) Eteone longa (Figs. 45 and 46)

Well defined seasonal variations were present for this this species each year. Maximum densities occurred in late Summer and Autumn but in contrast with other species which in general had a minimum residual number of individuals present this species became rare in the Estuary. The reasons for this phenomenon are not understood but there was an indication of a predation in the curvilinear shape of the loss.

(c) Pygospio elegans (Figs. 49 and 50)

The wide variation in densities of P.elegans with no apparent seasonal preference was in agreement with published work showing that there is an extended breeding season (Hempel 1957).

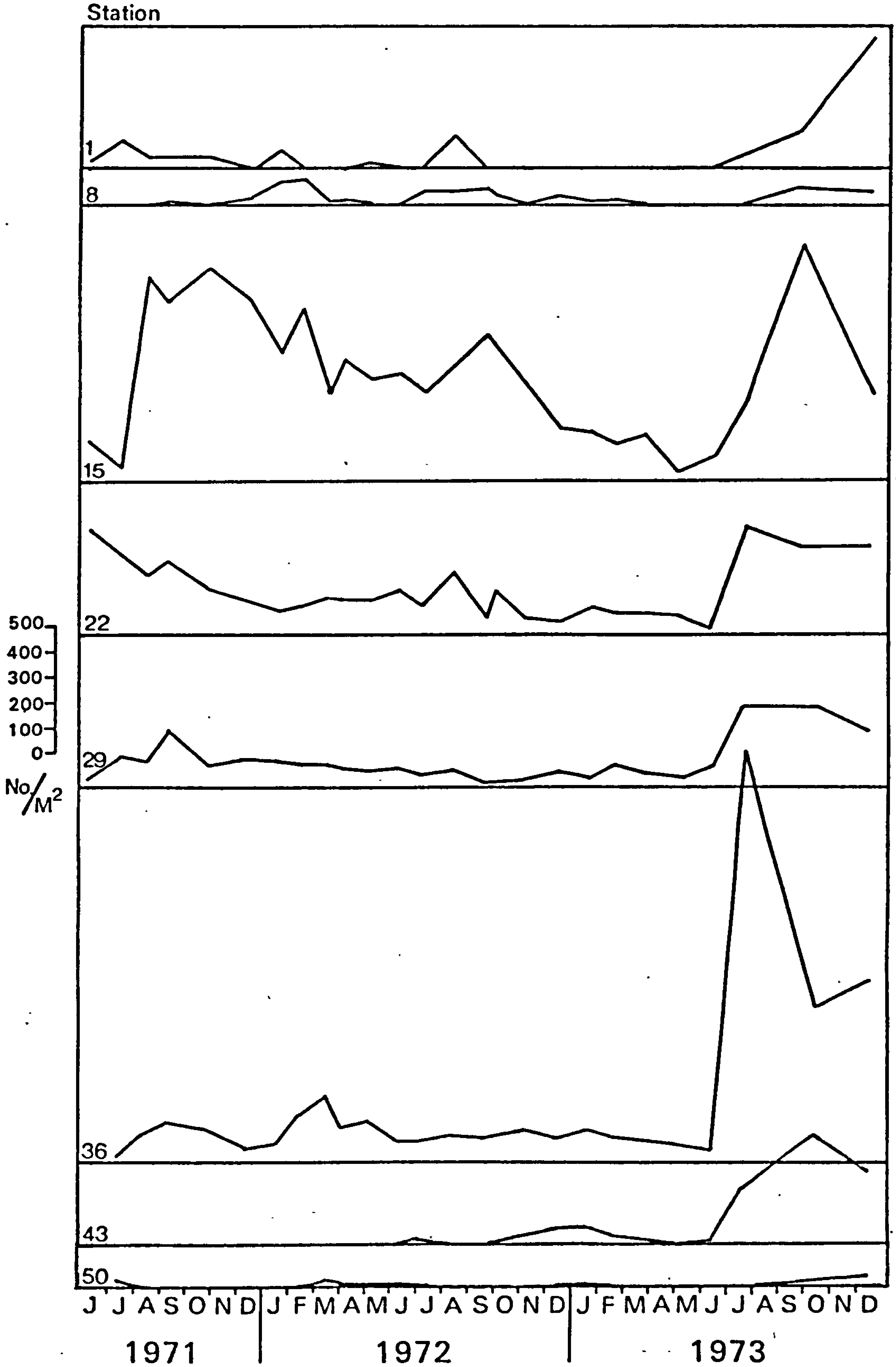


Figure 39. Seasonal variation in density of Nereis diversicolor at each sampling station on the Gayton transect 1971-73.

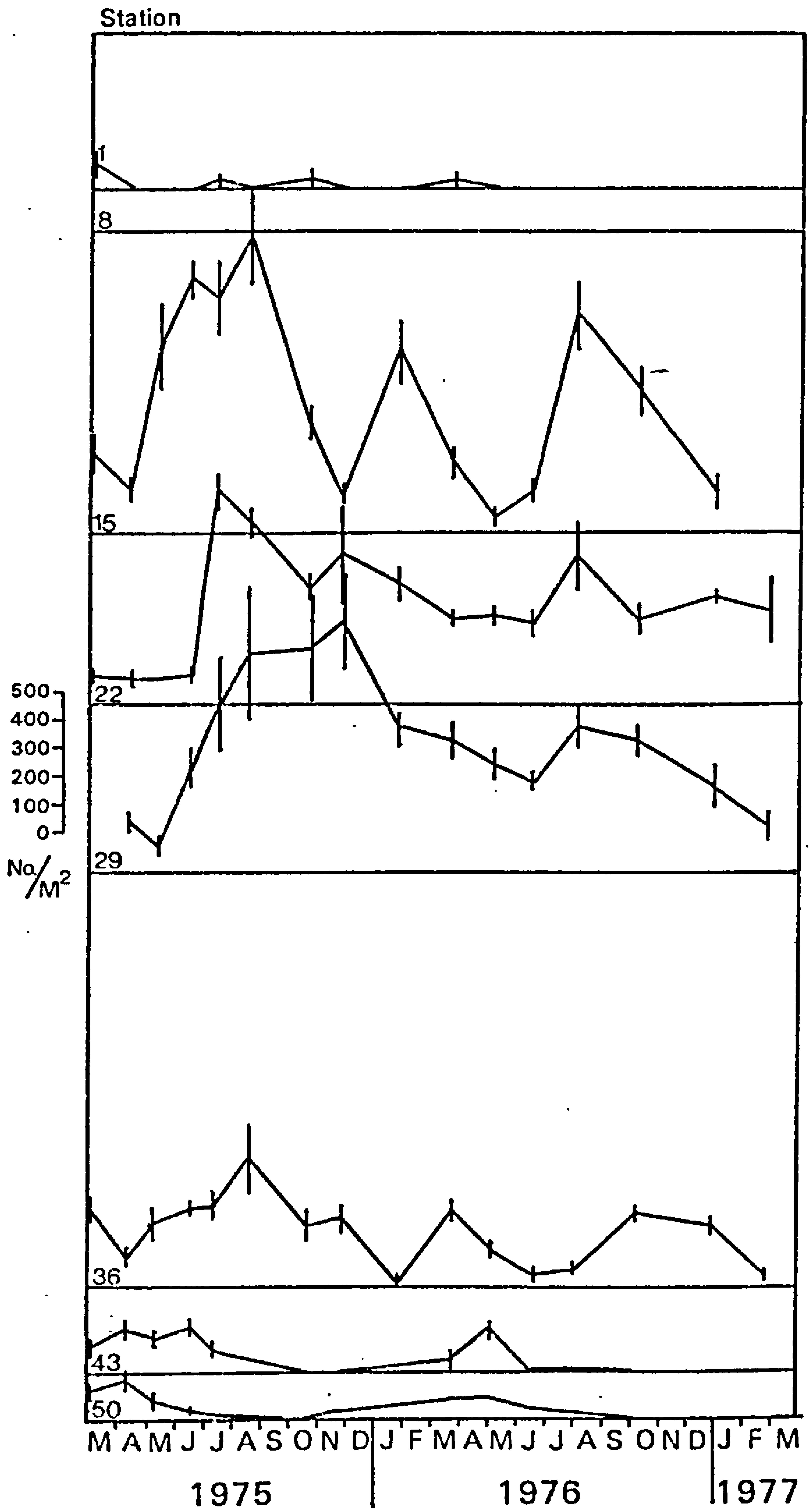
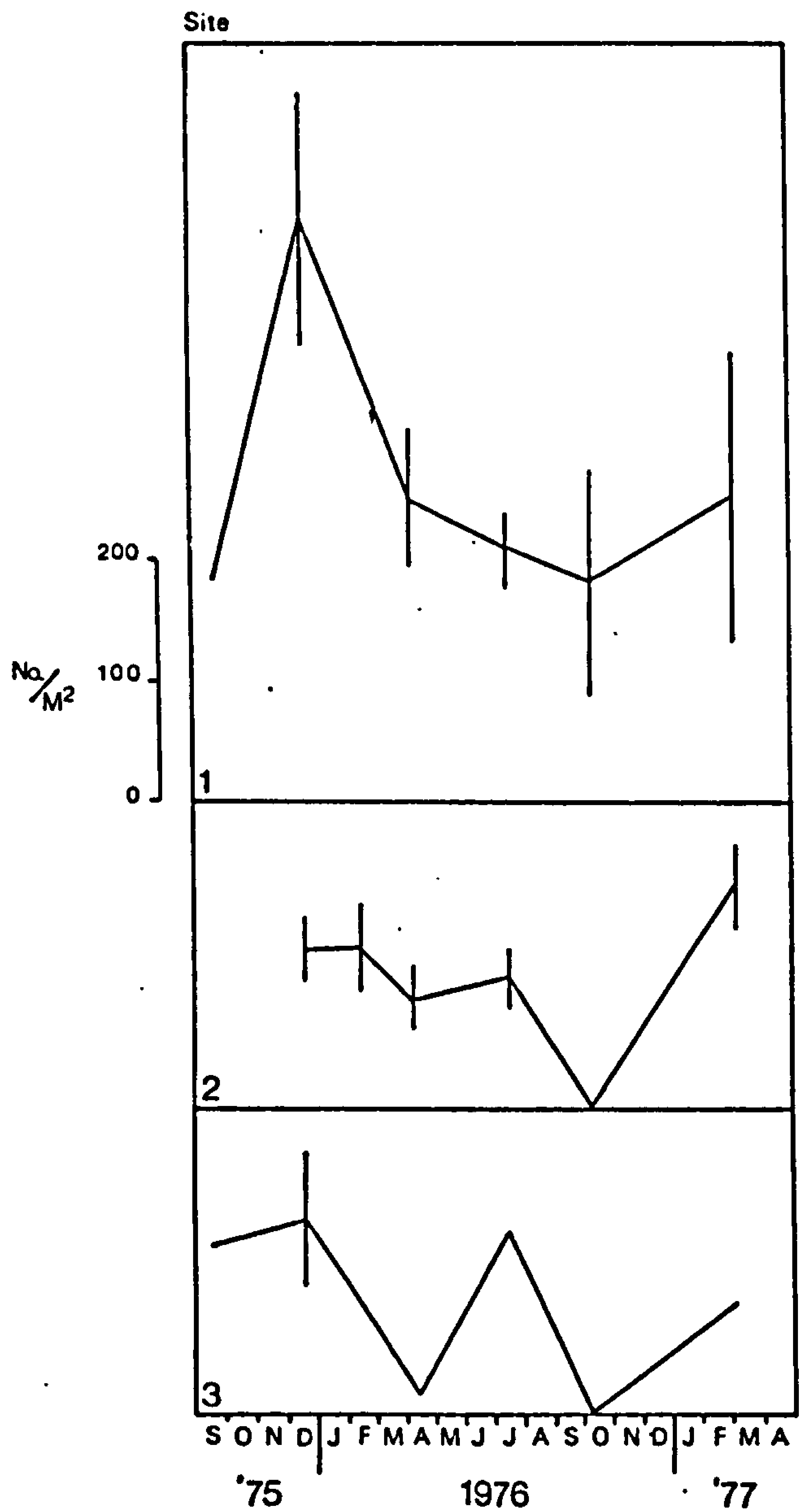


Figure 40. Seasonal variation in density of Nereis diversicolor (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.



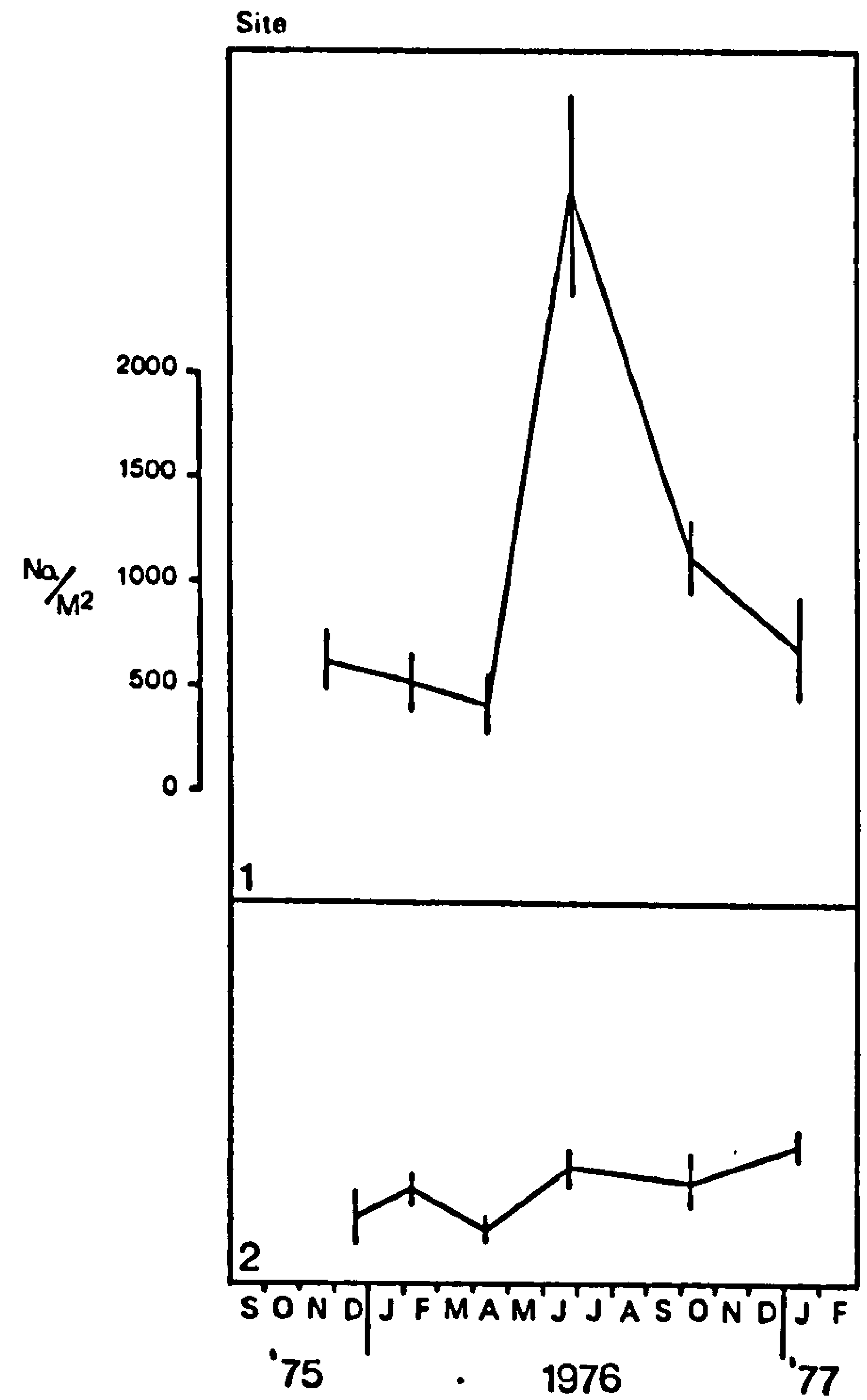


Figure 42. Seasonal variation in density of <u>Nereis diversicolor</u> (± 1 S.E.) at Mostyn.

Figure 41. Seasonal variation in density of <u>Nereis diversicolor</u> (± 1 S.E.) at Thurstaston.

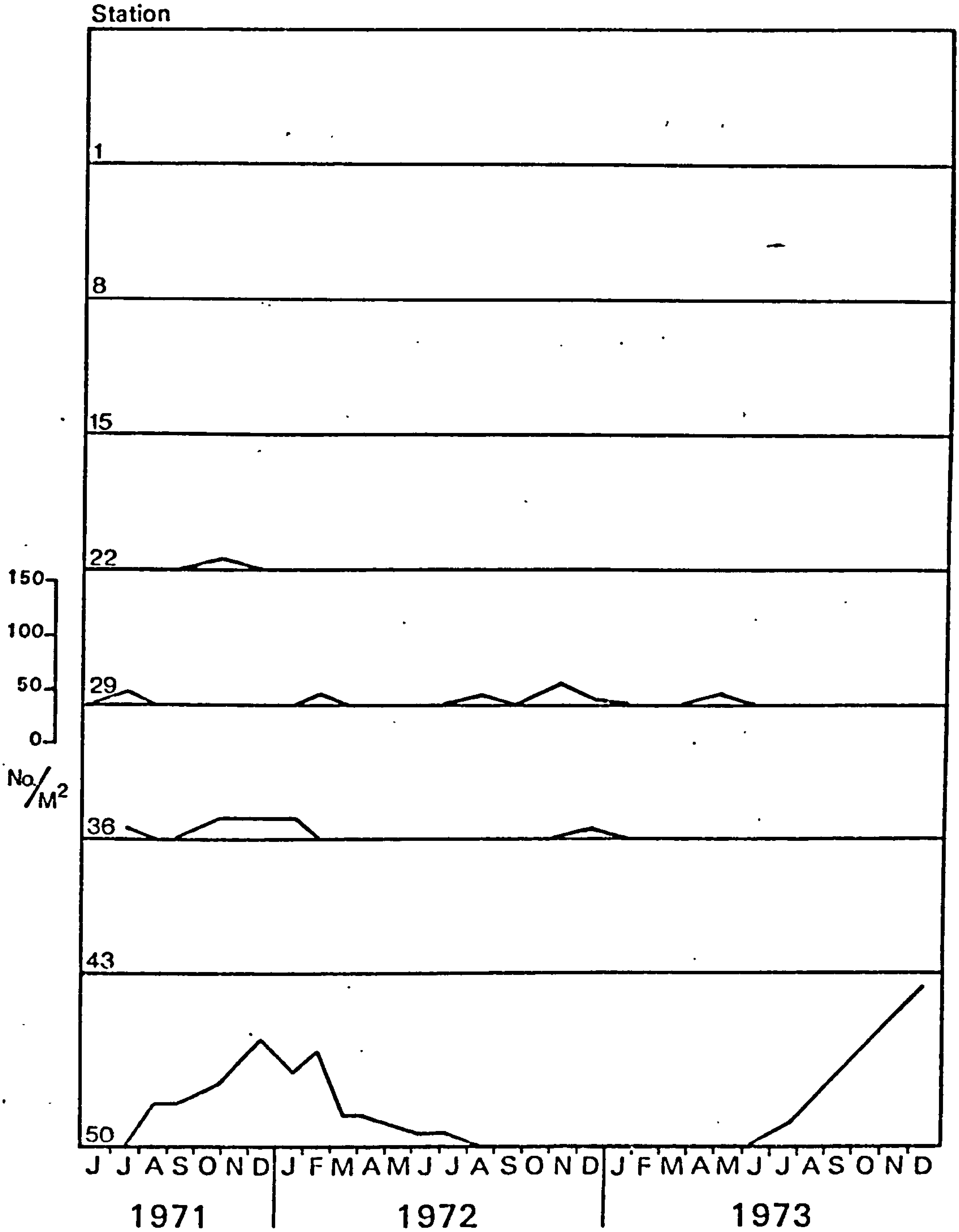


Figure 43. Seasonal variation in density of Nephthys sp. at each sampling station on the Gayton transect 1971-73.

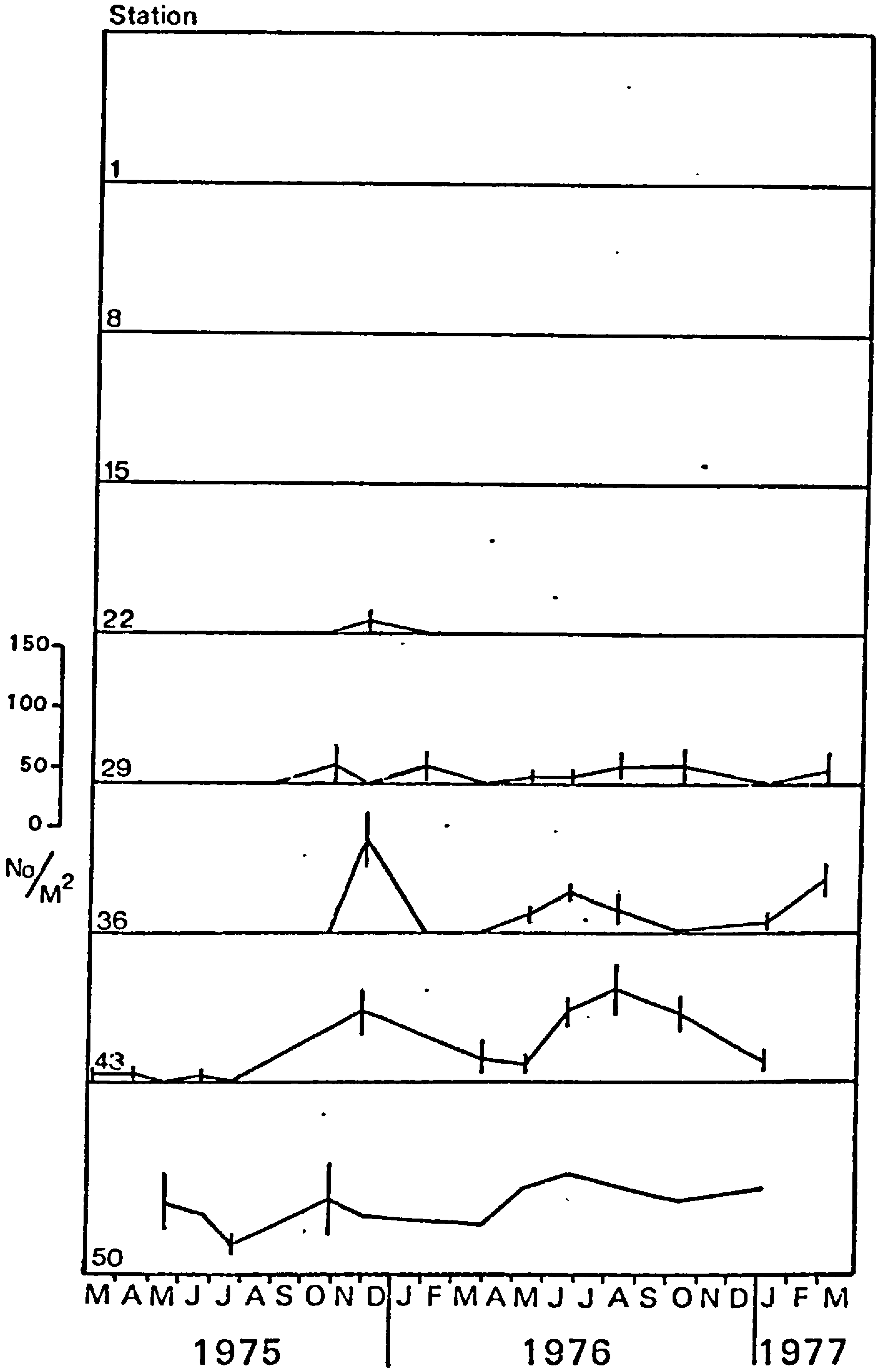


Figure 44. Seasonal variation in density of Nephthys sp. (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

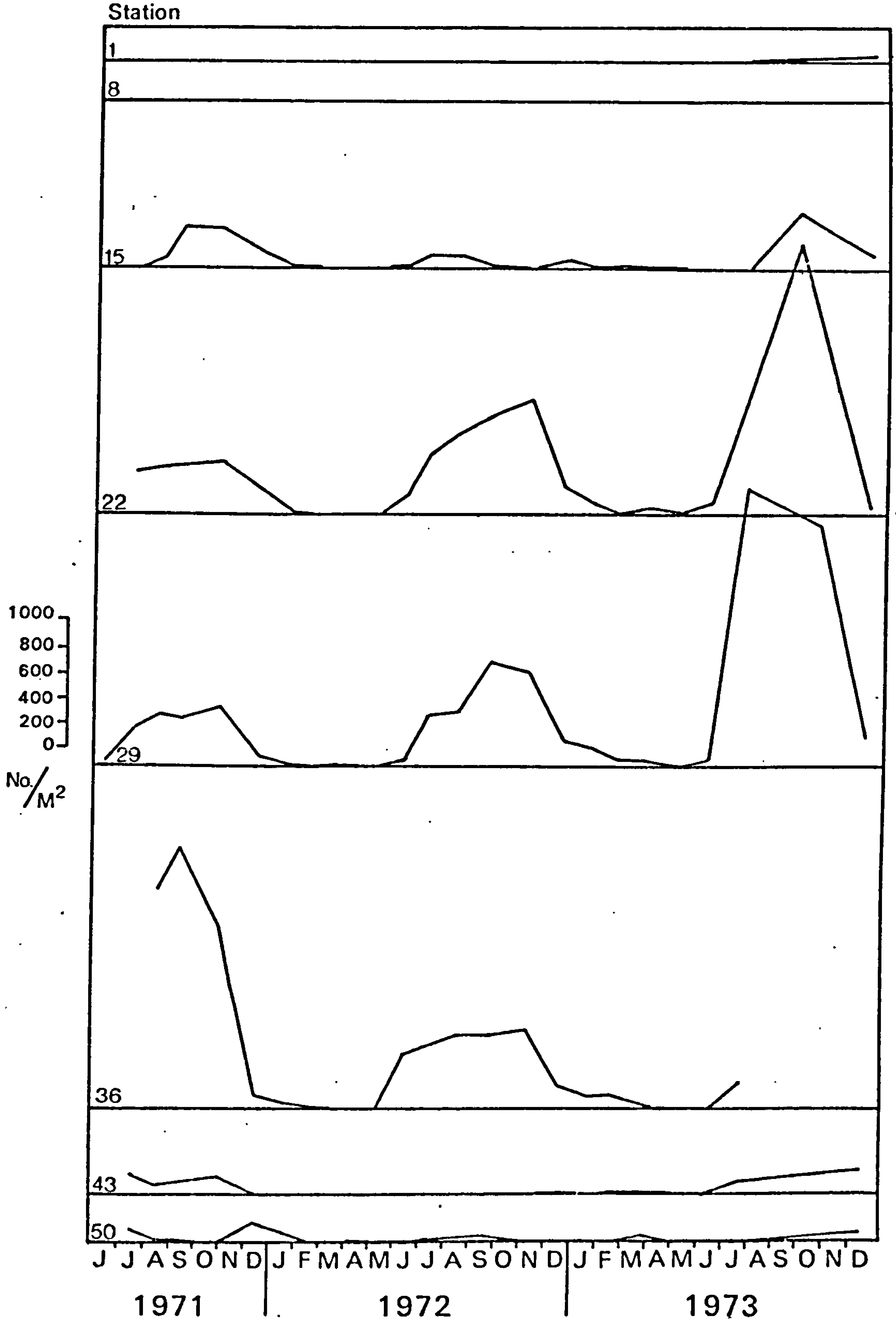


Figure 45. Seasonal variation in density of Eteone longa at each sampling station on the Gayton transect 1971-73.

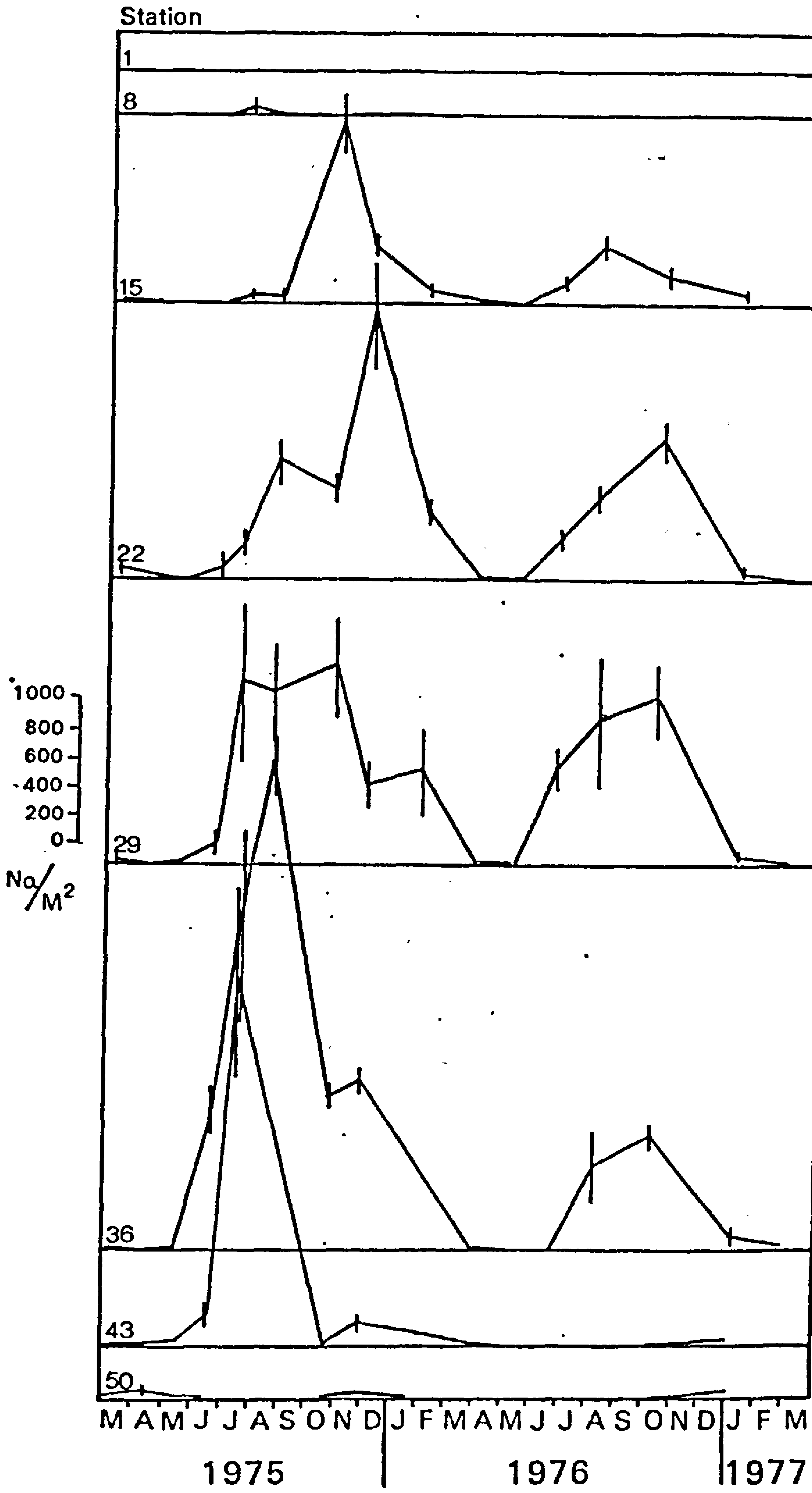


Figure 46. Seasonal variation in density of Eteone longa (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

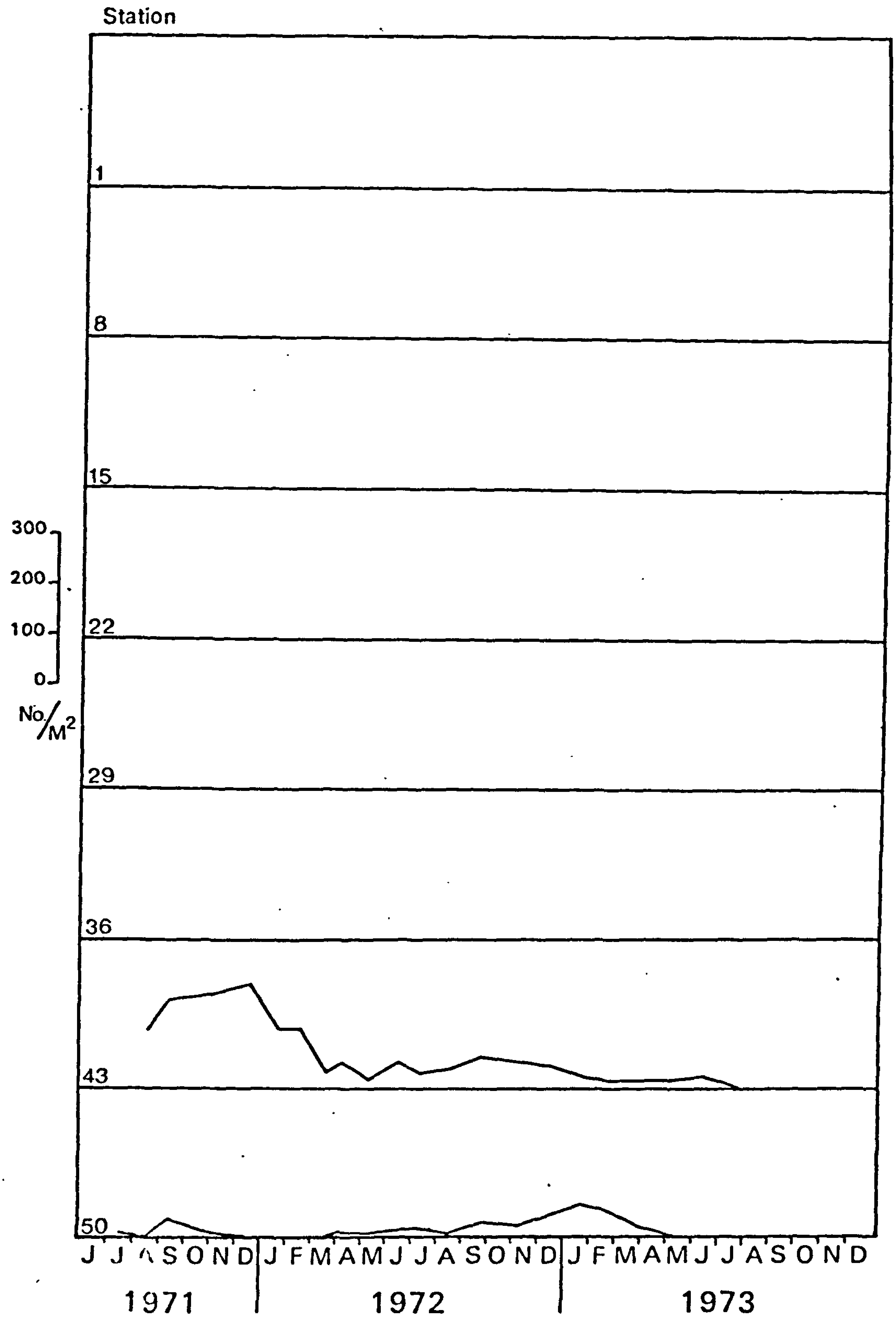


Figure 47. Seasonal variation in density of Nerine cirratulus at each sampling station on the Gayton transect 1971-73.

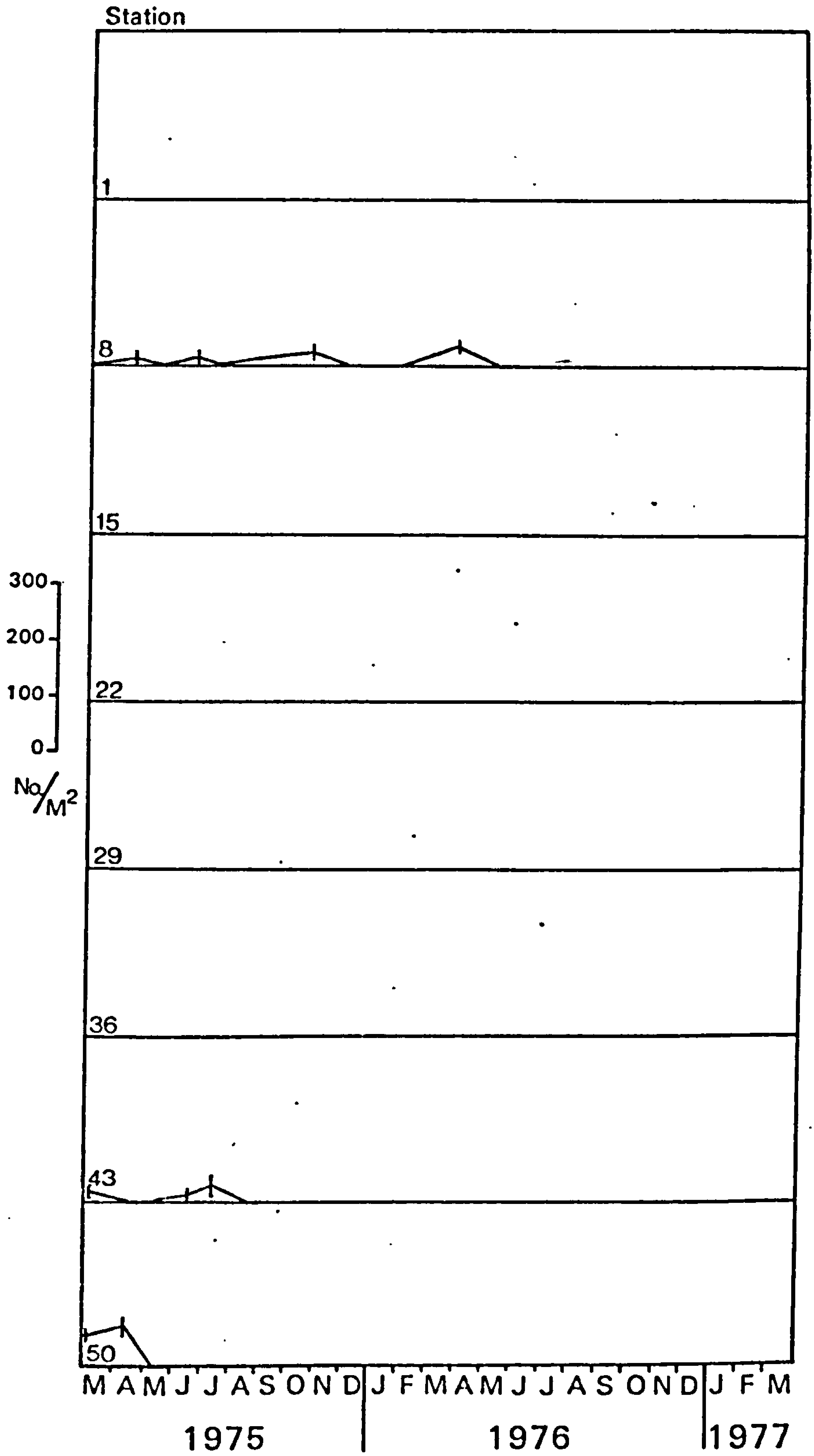


Figure 48. Seasonal variation in density of Nerine cirratulus (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

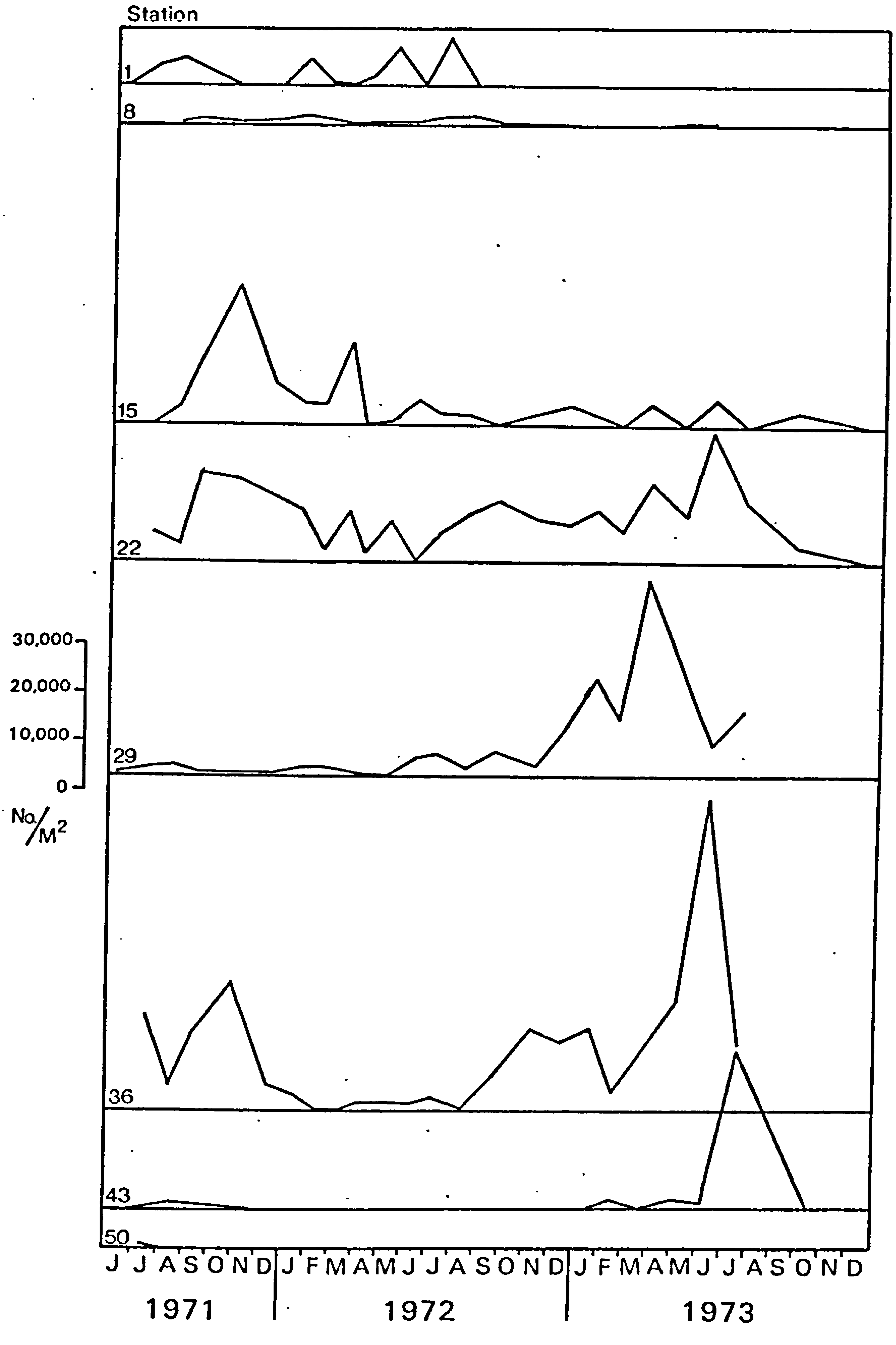


Figure 49. Seasonal variation in density of Pygospio elegans at each sampling station on the Gayton transect 1971-73.

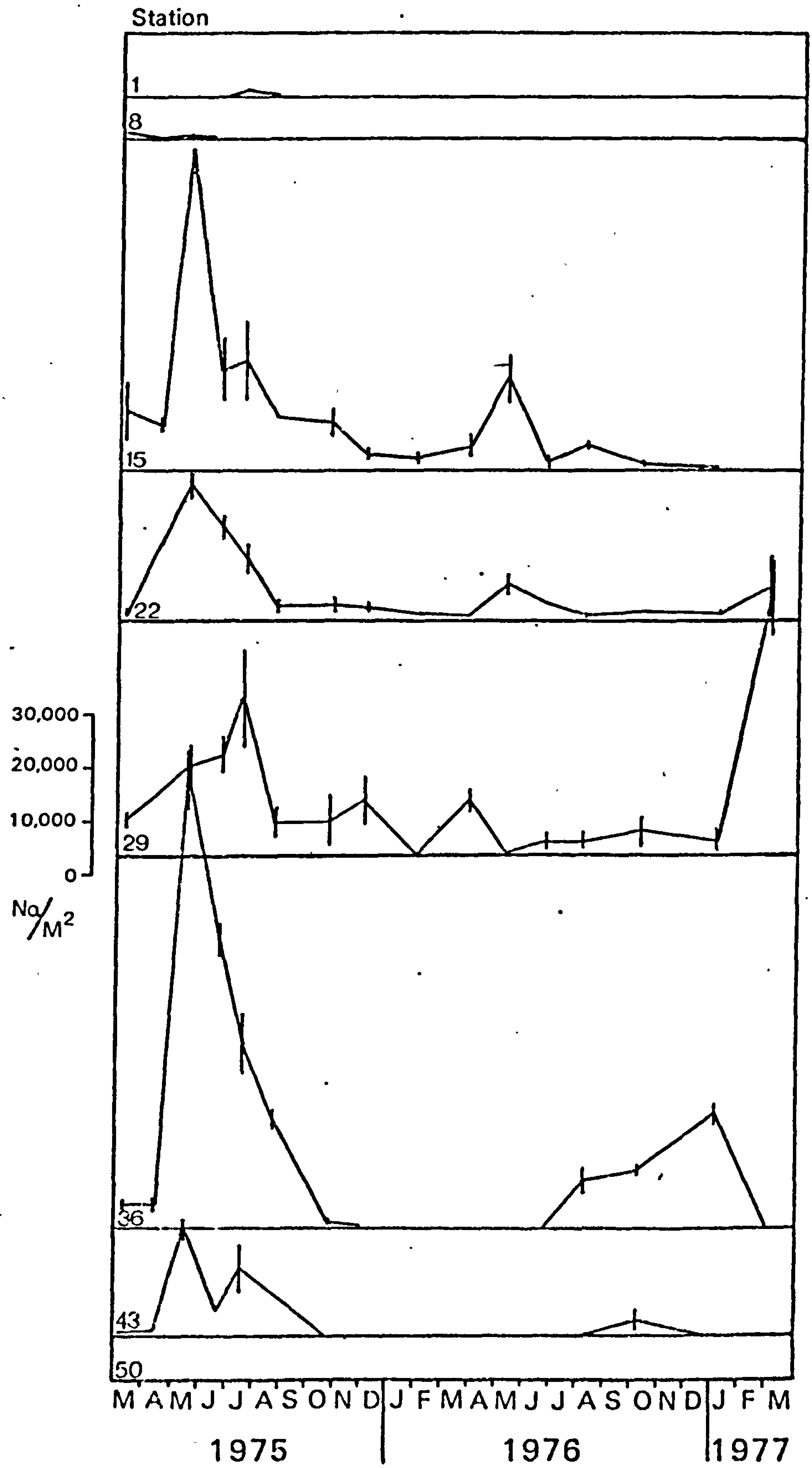


Figure 50. Seasonal variation in density of Pygospio elegans (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

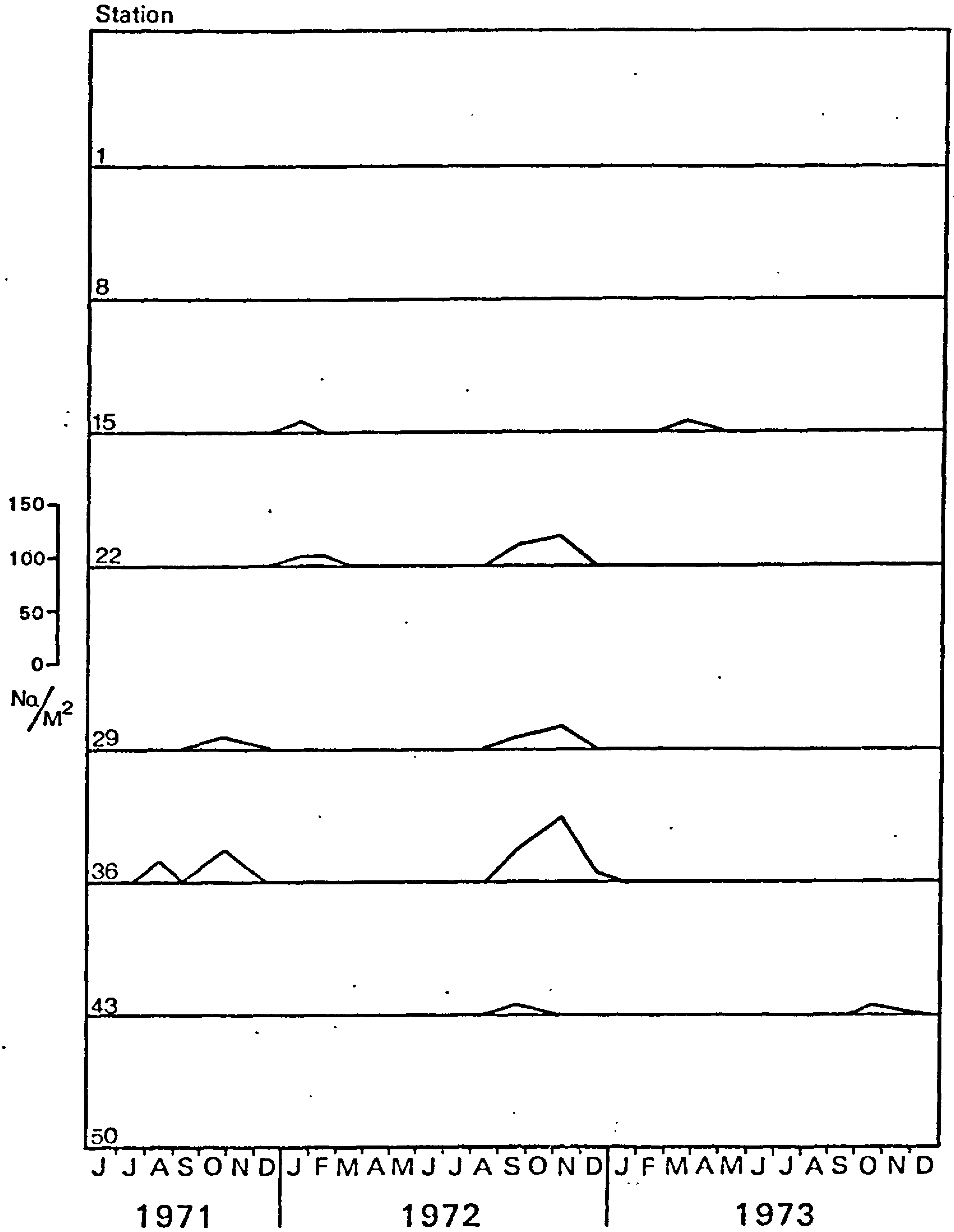


Figure 51. Seasonal variation in density of Cerastoderma edule at each sampling station on the Gayton transect 1971-73.

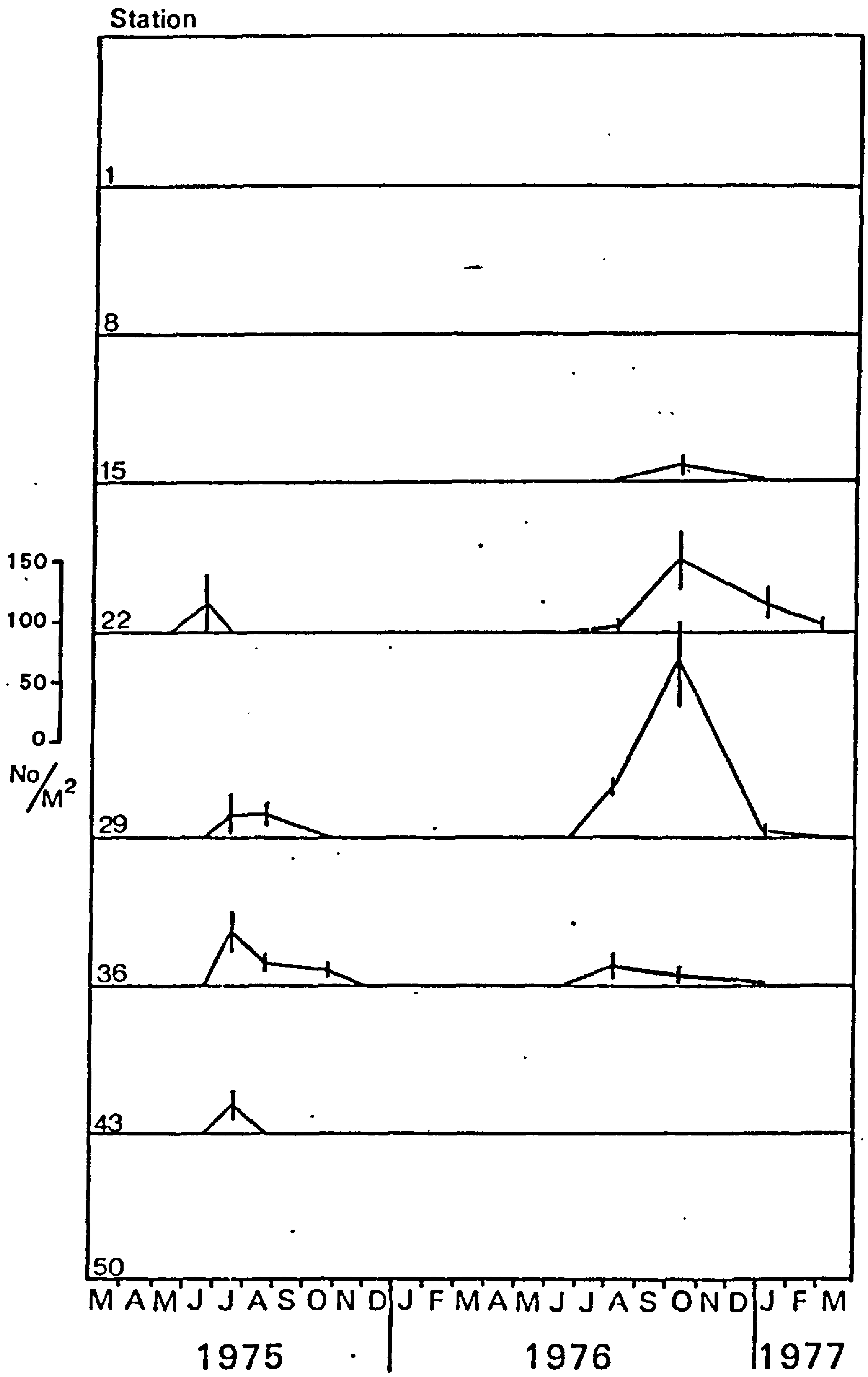


Figure 52. Seasonal variation in density of Cerastoderma edule (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

Young larvae have been reported throughout the year (Marine Biological Association 1957; Hannerz 1956; Söderström 1920; Thorson 1946). However, other factors were possibly influencing the distributions, e.g. effects of gales and exposure to wave action. The species was also apparently favoured by other invertebrates as a food source, e.g. C.vulgaris. The presence of a predation effect was supported by the curvilinear form of the data following maximum densities in 1975. A two year density cycle was indicated.

(d) Scrobicularia plana (Figs. 53 - 56)

S.plana was found at Stations 15, 22, 29 and 36. Seasonal variation in densities was evident, maximum densities occurring in late Summer but the numbers involved in all years except 1975 were small. Significantly high densities were recorded ($590 \pm 244/m^2$) at Station 22 in June 1975 corresponding with an increase at other stations, but there was a later unexpected increase in November 1975 ($1120 \pm 244/m^2$).

In contrast to the Gayton transect seasonal variation was much less at Thurstaston and Mostyn. At Thurstaston sites 1 and 2 and at Mostyn 2 densities were higher than the other sites. Mostyn 2 recorded a uniform high density of approximately 3,000/m2. Thurstaston 2 was the only site to register any significant loss in numbers, December 1976 ($1780 \pm 124/m^2$) to March 1977 ($540 \pm 101/m^2$). Size (length) frequency measurements were undertaken at Thurstaston 1 and Mostyn 2 (Figs. 57 & 58). The results had a close agreement to the polymodal distributions of Hughes (1970a) for a mudflat 50 miles distant on the North Wales Coast. A distinctive feature of the curves was the drop in the size of the mode in the early months of 1976 up until April. This apparent negative growth was more distinct in the larger size frequencies at Thurstaston and the smaller size

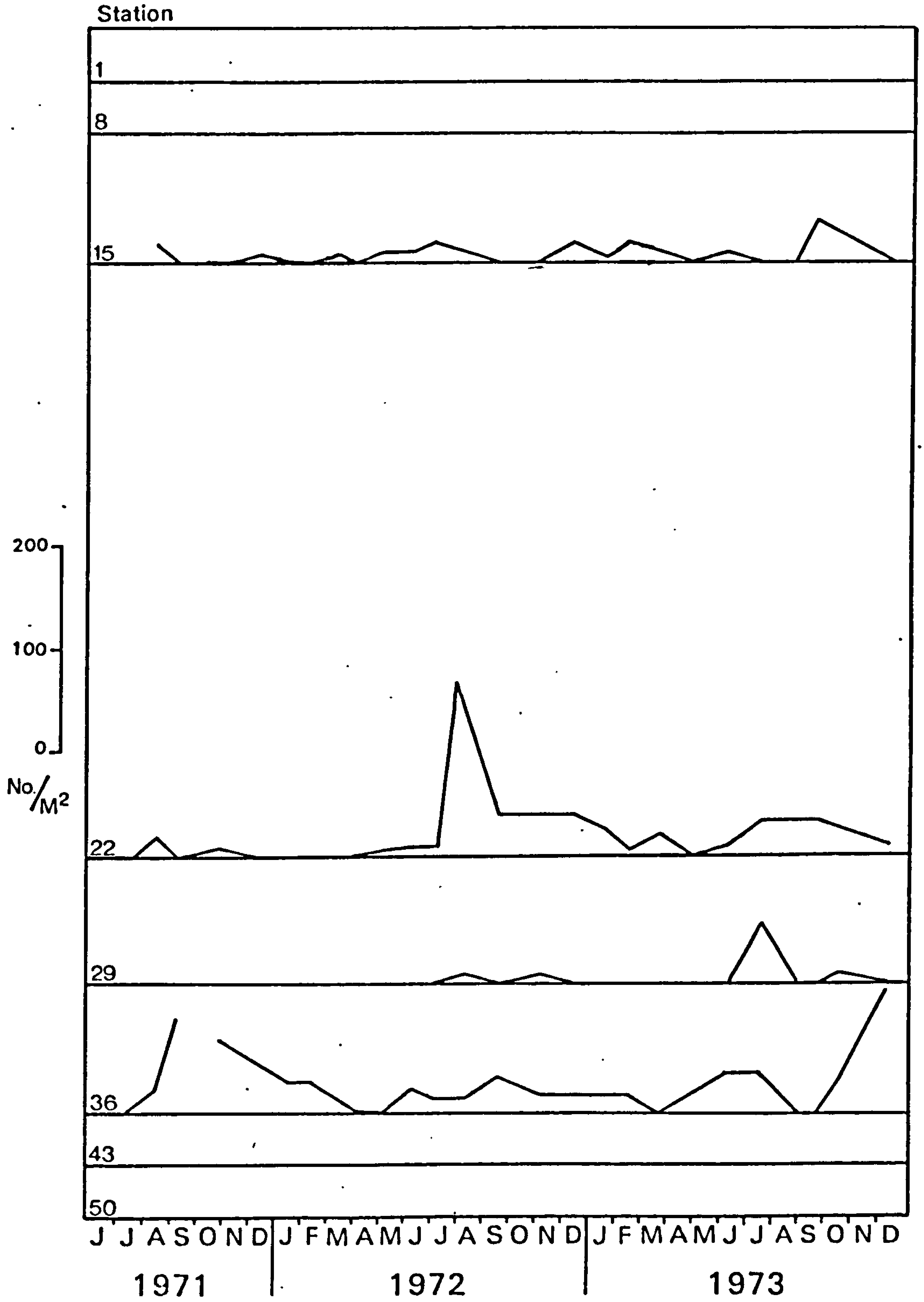


Figure 53. Seasonal variation in density of Scrobicularia plana at each sampling station on the Gayton transect 1971-73.

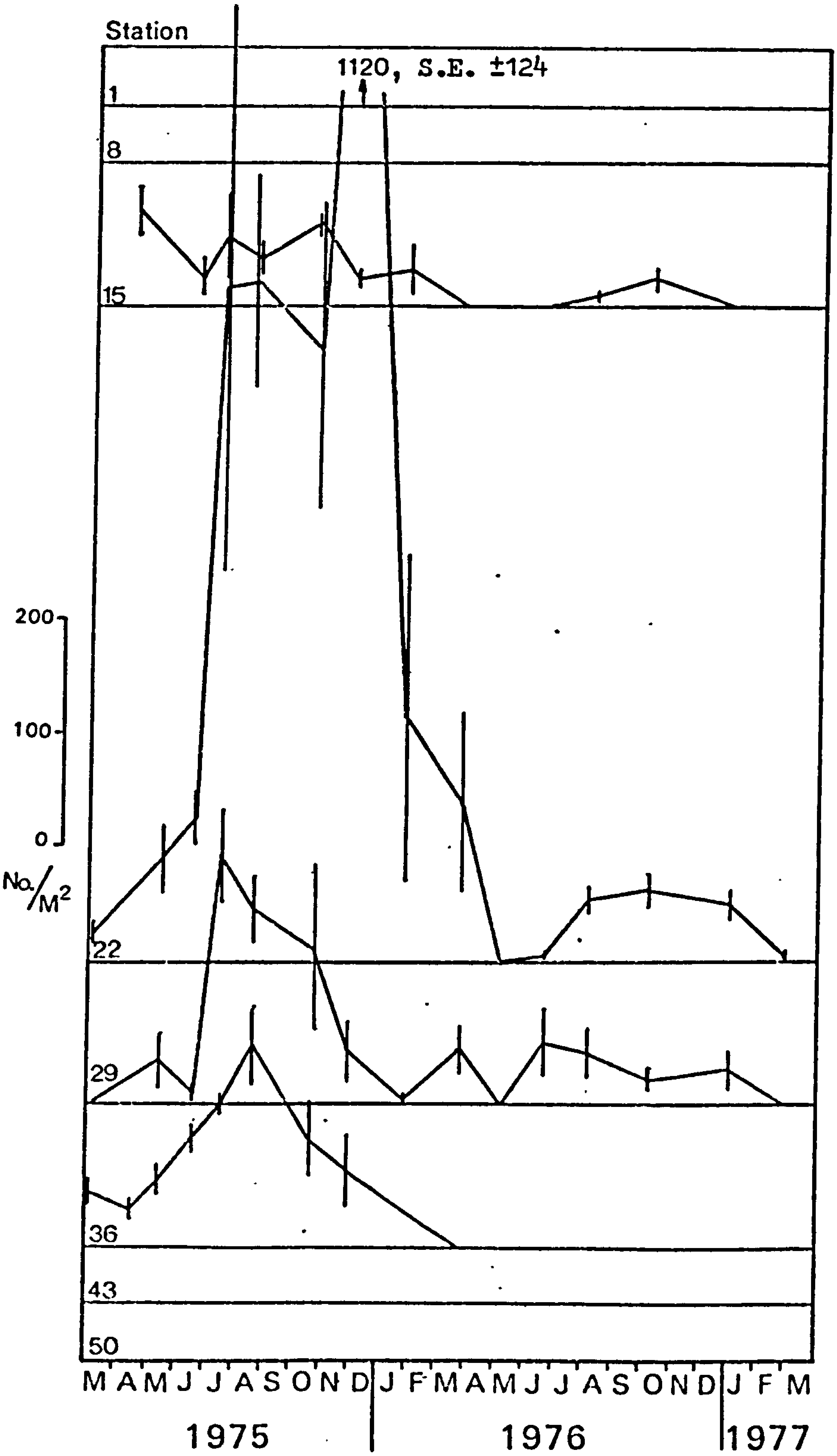


Figure 54. Seasonal variation in density of Scrobicularia plana (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

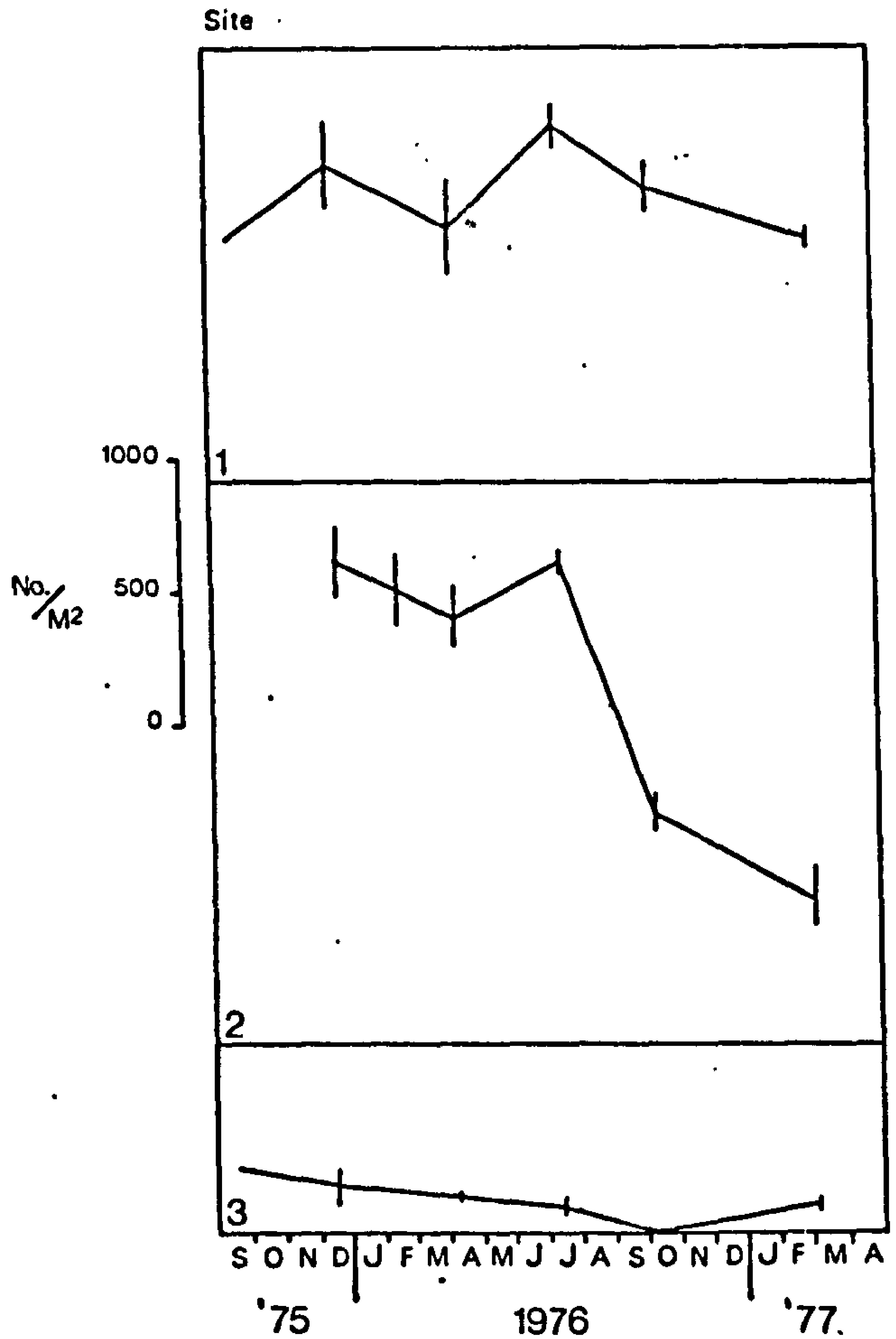


Figure 55. Seasonal variation in density of Scrobicularia plana (± 1 S.E.) at Thurstaston.

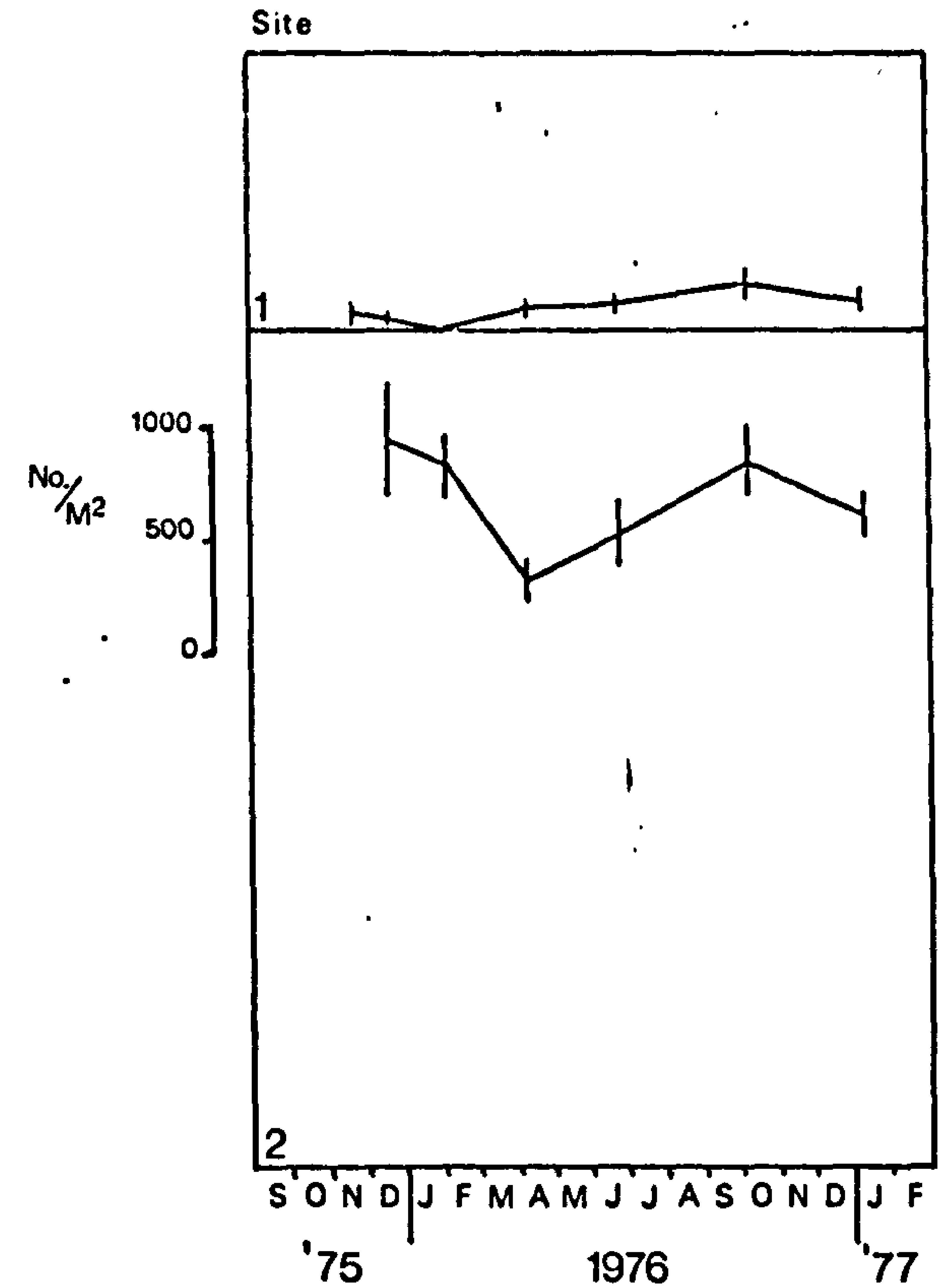


Figure 56. Seasonal variation in density of Scrobicularia plana (1 S.E.) at Mostyn.

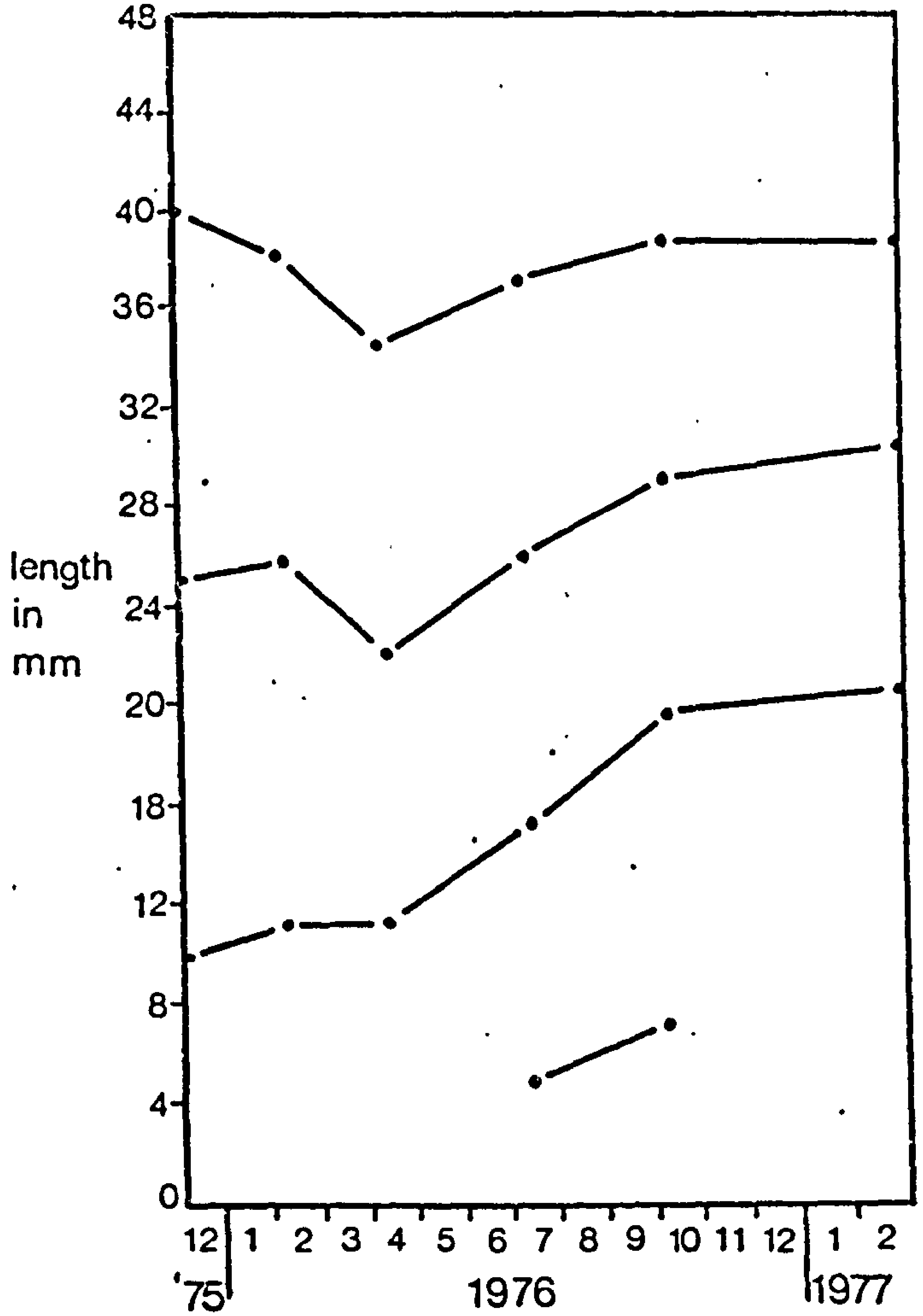


Figure 57. Growth of Scrobicularia plana at Thurstaston Site 2, plotted from the modes of the size frequency distributions.

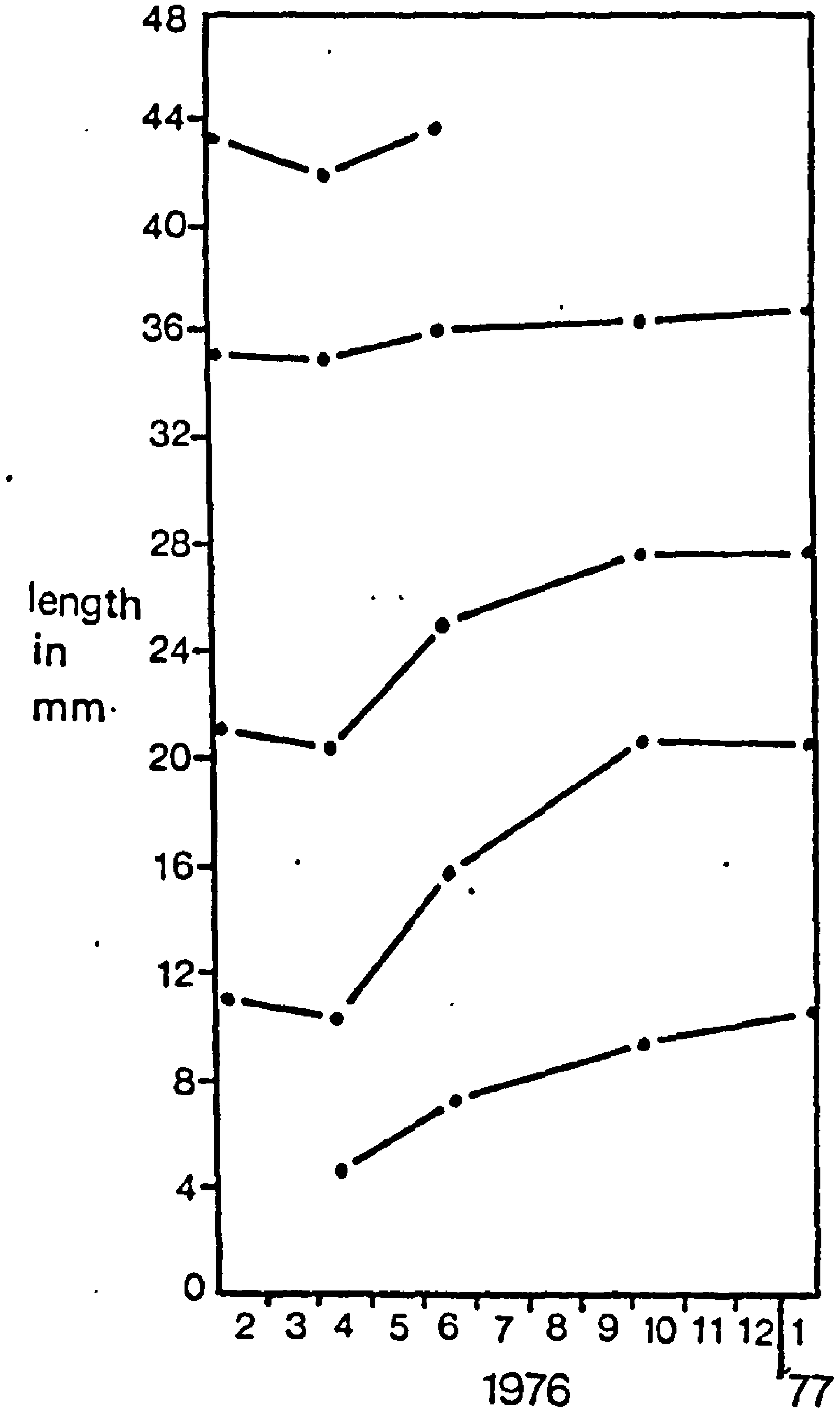


Figure 58. Growth of Scrobicularia plana at Mostyn Site 2, plotted from the modes of the size frequency distributions.

frequencies at Mostyn. A possible explanation was the fact that H.ostralegus were feeding on the larger year classes of the polymodal distributions at Thurstaston and the younger year classes at Mostyn Buxton(1978), and Norton-Griffiths (1967) found that H.ostralegus selected the larger S.plana..

(e) Macoma balthica (Figs 59 and 60)

The density distributions had a rapid increase in numbers over a short period, followed by a first rapid decrease in numbers which gradually levelled out to a relatively constant base line figure before the next annual increase. This seasonal increase was mainly restricted to the four central stations on the transect. The maximum densities fluctuated each year, 1972 being a particularly 'poor' year. However, even with this variation in 'peak' densities, it was particularly noticeable that by May, at the majority of sample sites, a relatively uniform minimum density was recorded, e.g.

Station	1975	1976
15	310 ± 50	631 ± 107
22	575 ± 59	894 ± 54
29	670 ± 75	463 ± 70
36	905 ± 95	731 ± 142
43	780 ± 52	994 ± 134

When 1975 and 1976 densities were compared this gave a mean of $648/m^2$ in 1975 and $743/m^2$ in 1976. Very similar densities were recorded for other years. The evident curvilinear shape of the loss was found to have a significant log regression, e.g. the curve at Station 36 during the period 1972/73 was $Y = 525.4e^{-.216X}$ ($P<.05$) and at Station 29 during the period 1971/72 the regression was $Y = 413.7e^{-.243X}$ ($P<.05$).

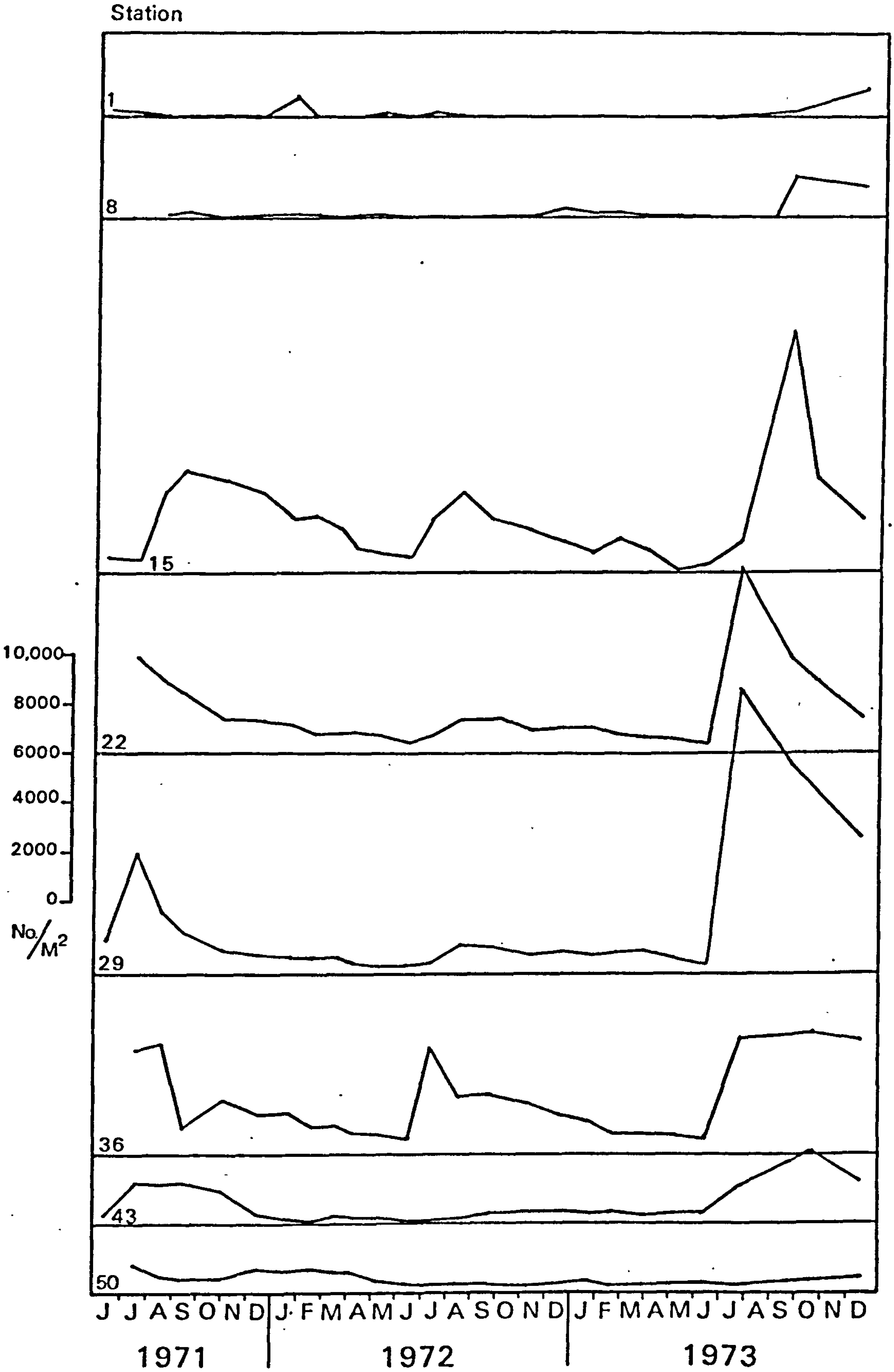


Figure 59. Seasonal variation in density of Macoma balthica at each sampling station on the Gayton transect 1971-73.

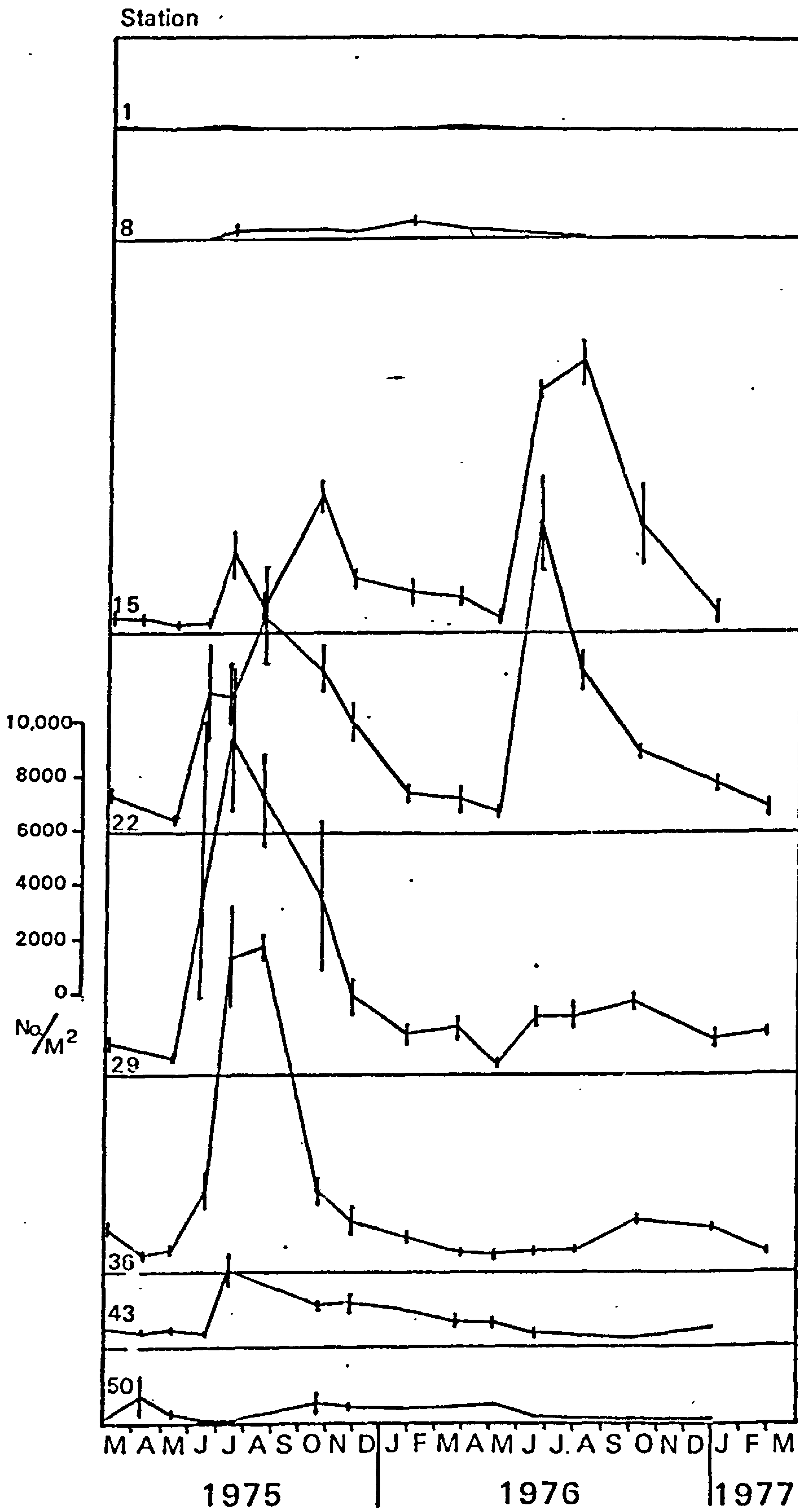


Figure 60. Seasonal variation in density of Macoma balthica (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

Size frequency measurements of M.balthica were made over the study period at three Stations down the transect, Stations 15, 22 and 43 in the period 1971-74 and Stations 15, 29 and 43 for 1975-77. The results, expressed as change in modes of size (length) frequency distributions with time, are shown in Figs. 61 - 62. The results substantiate the decision to divide the M.balthica population into two groups ≤10 mm and >10 mm. Each year after recruitment growth was rapid but became retarded during the Winter, growth resumed in the Spring and between approximately June - August the mode of the 1+ group had increased to above 10 mm in length.

(f) Macoma balthica ≤10 mm (Figs. 63 - 66)

The size frequency histograms indicated that the periods of rapid increase in numbers were due to recruitment by young forms. The start of settlement (bearing in mind that spawning and the pelagic stage would have been earlier (Battle 1932 and Caddy 1967)) was first registered in mid-June/July in most years. Spatfall tended to vary slightly in position down the shore each year but within the region 15 - 36 along the transect. A feature in the distribution was for the maximum densities to occur slightly later upshore and downshore of the initial settlement, e.g. in 1973 the first high density peak was in July at Stations 22 and 29 but maximum densities were not recorded until October at Stations 15 and 43. A very similar situation occurred in 1975, and evidence from the size frequency data suggests that these were not primary settlements of spat but were secondary settlements of M.balthica approximately 4-5 cm in length. Beukema (1973) noted very similar results, but later in the year, on the Danish Waddens and accounted for them as due to migration.

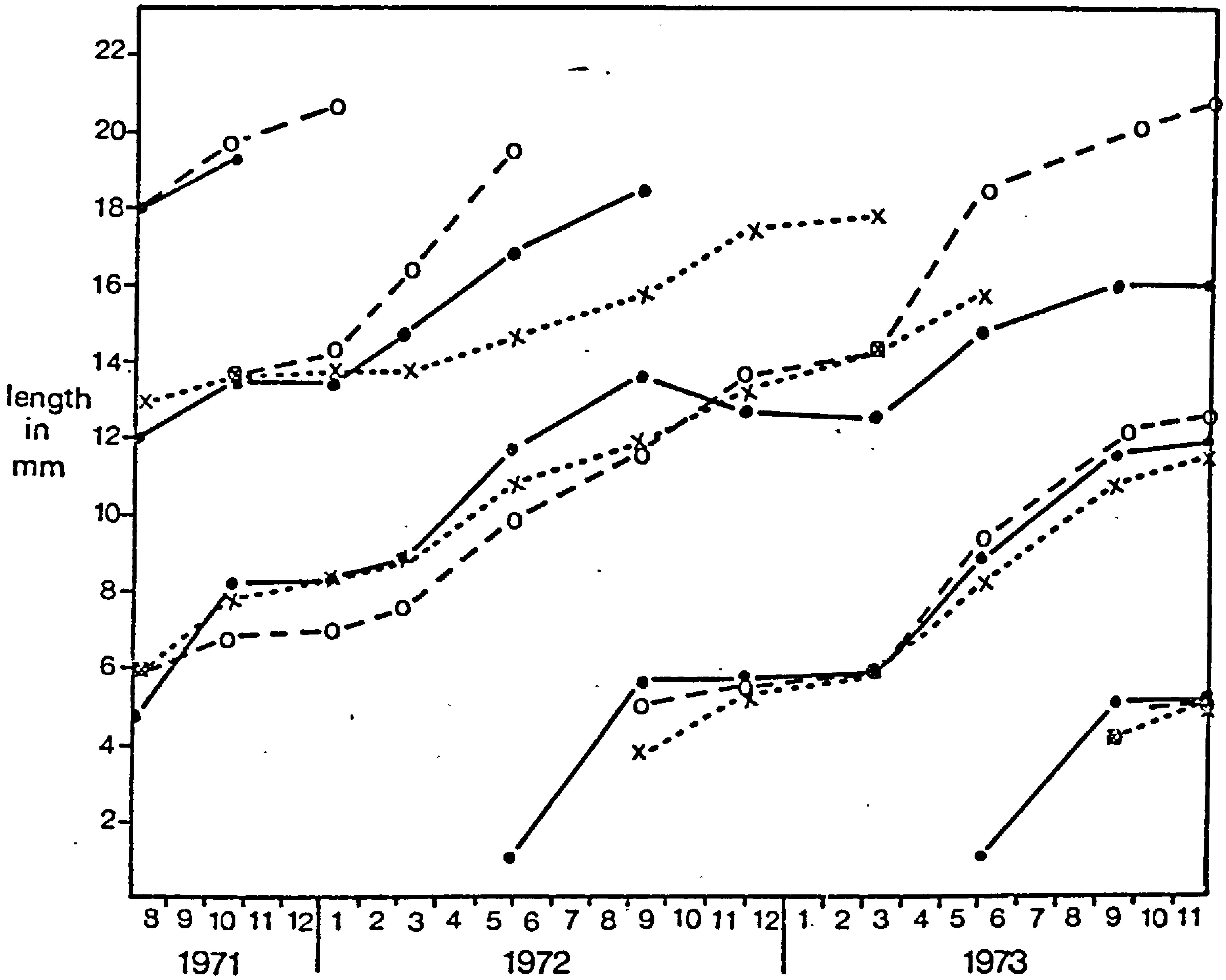


Figure 61. Growth of Macoma balthica at 3 Stations on the Gayton transect, plotted from the modes of the size frequency distributions. (Site 15---x--- ; Site 22 —•— ; Site 43 —o— —).

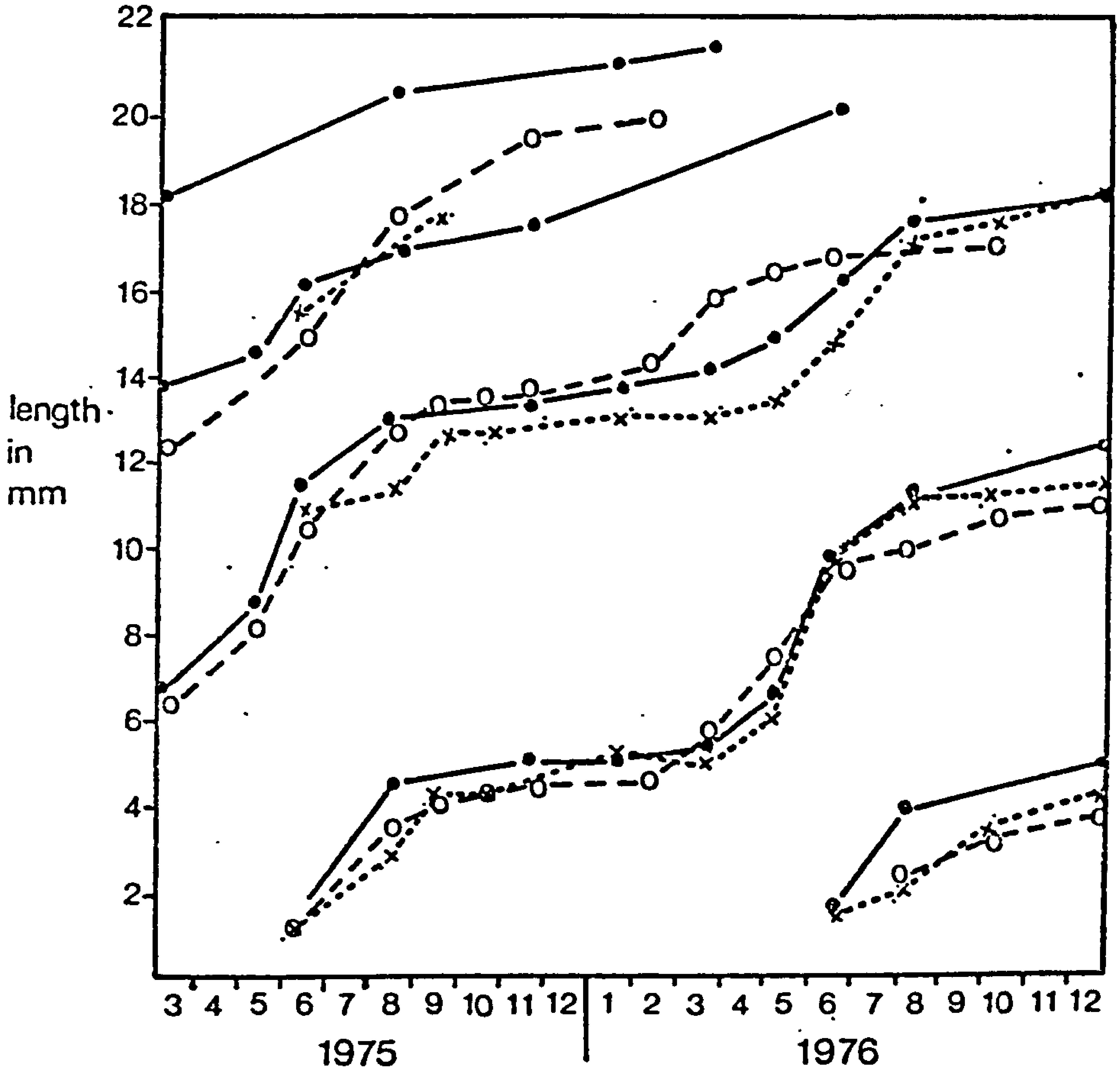


Figure 62. Growth of Macoma balthica at 3 Stations on the Gayton transect, plotted from the modes of the size frequency distributions. (Site 15 --*-- ; Site 29 —•— ; Site 43 – – o –).

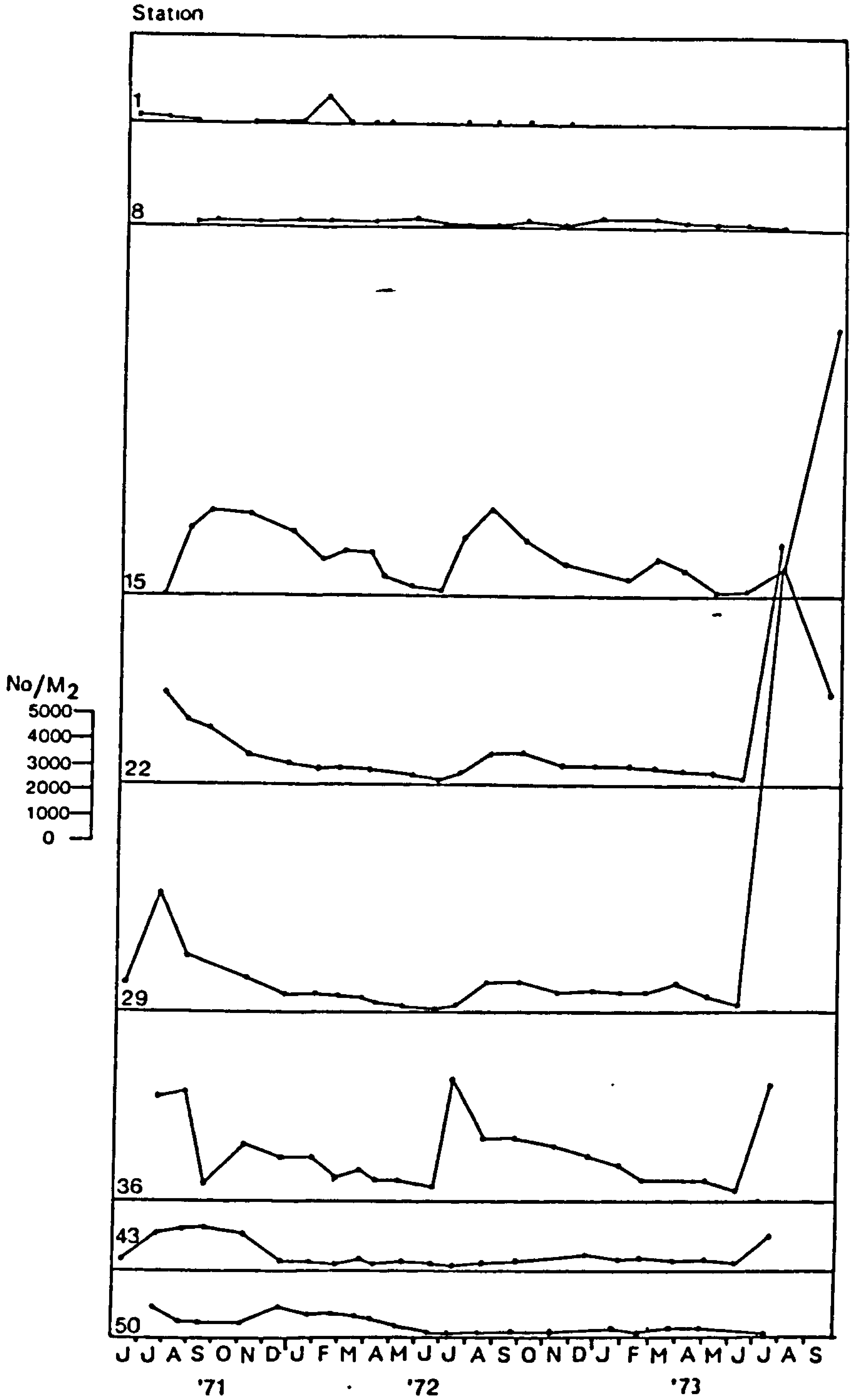


Figure 63. Seasonal variation in density of <u>Macoma balthica</u> 10 mm and less in length at each Station down the Gayton transect, 1971-73.

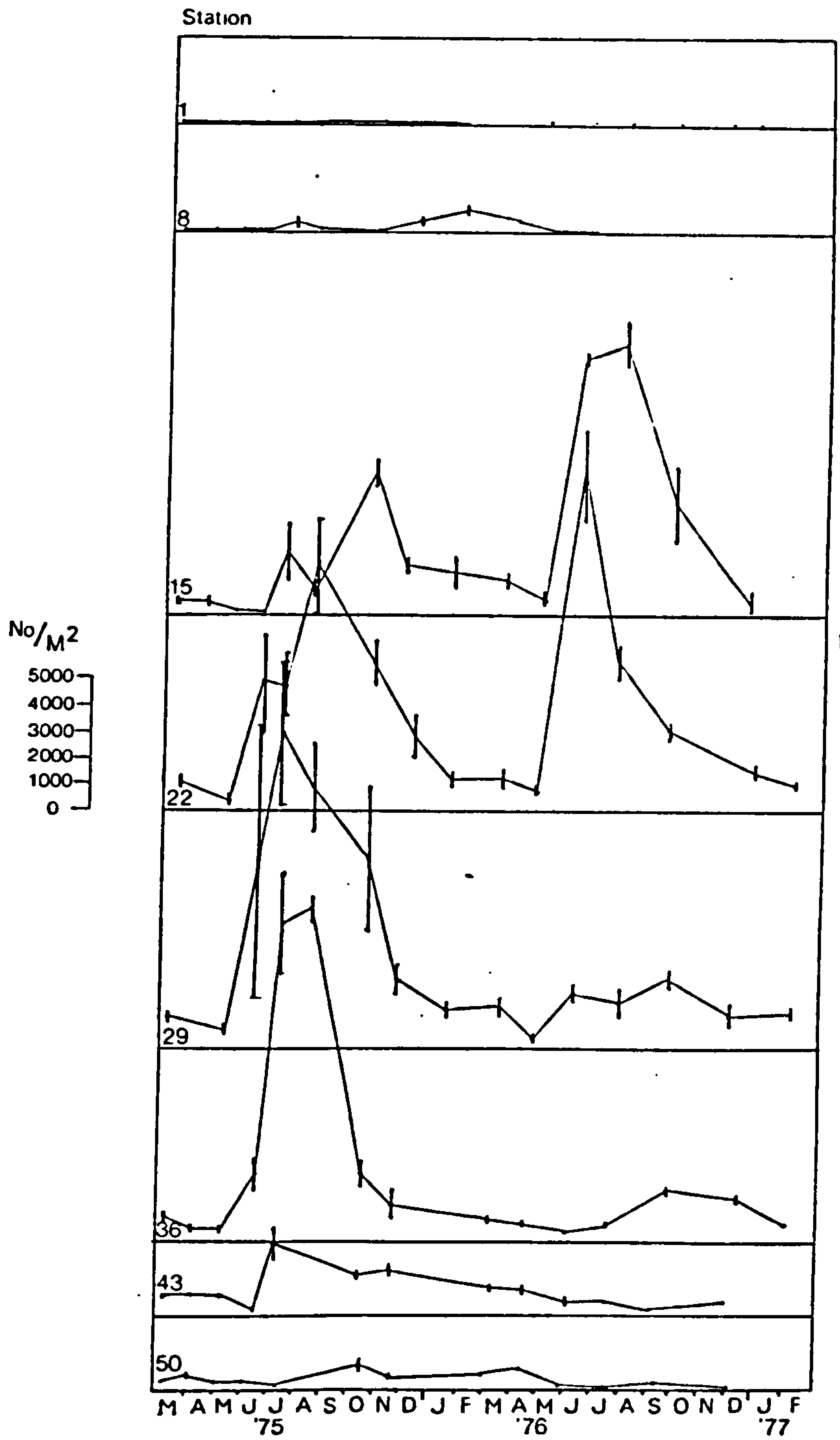
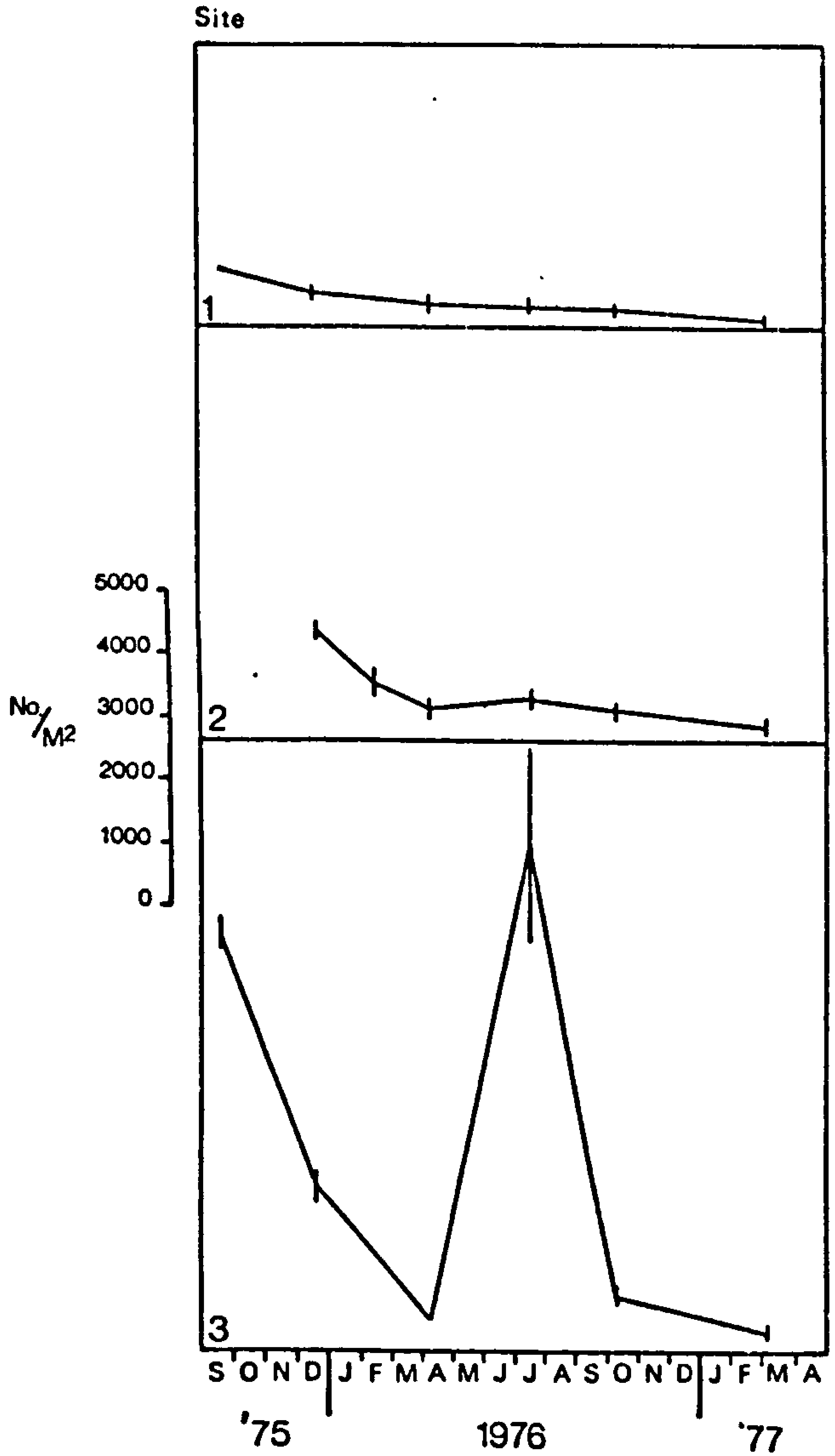


Figure 64. Seasonal variation in density of Macoma balthica 10 mm and less in length (±1 S.E.) at each sampling station on the Gayton transect, 1975-77.



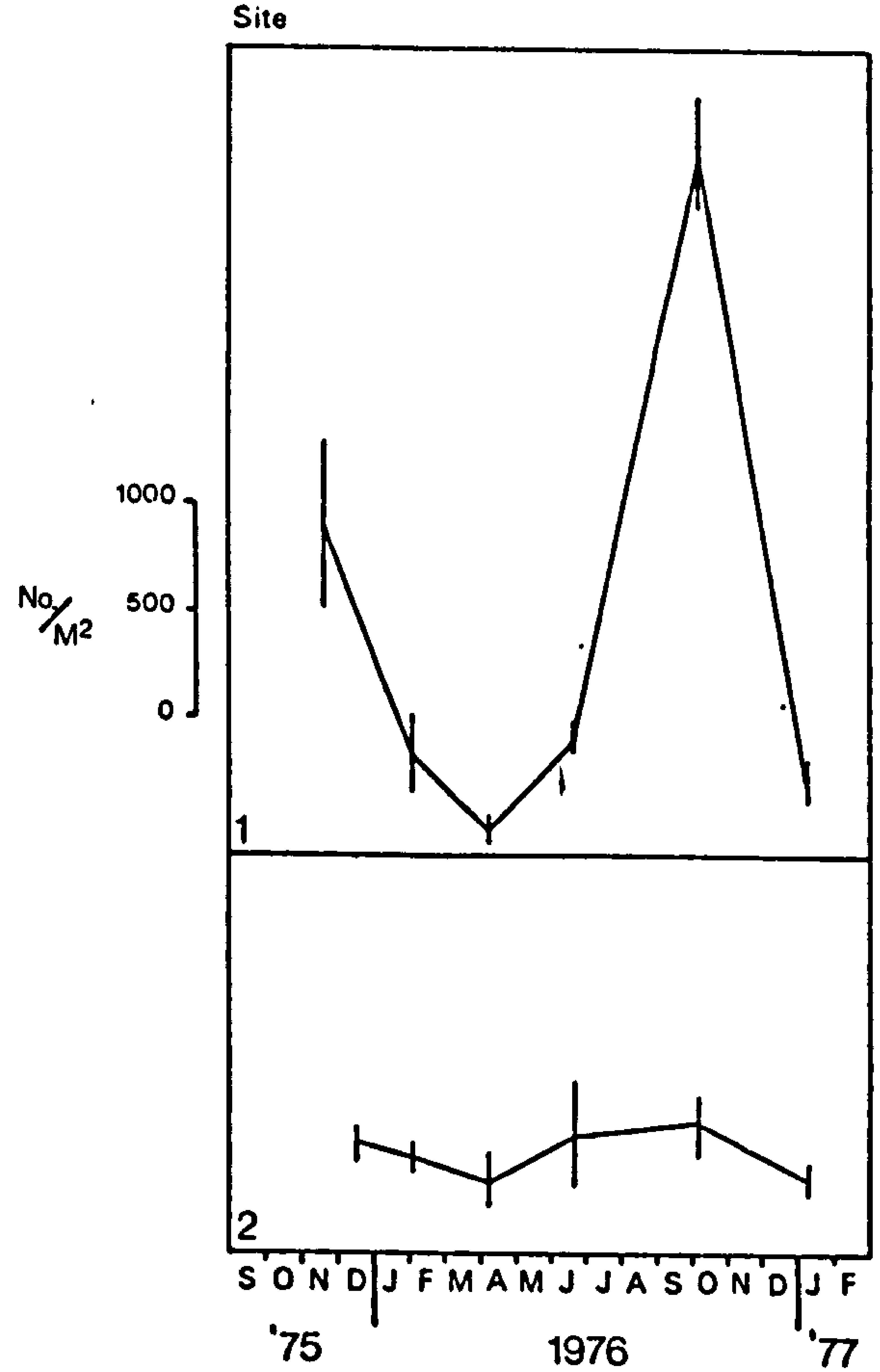


Figure 66. Seasonal variation in density of Macoma balthica 10 mm and less in length (± 1 S.E.) at Mostyn.

Figure 65. Seasonal variation in density of Macoma balthica 10 mm and less in length (± 1 S.E.) at Thurstaston.

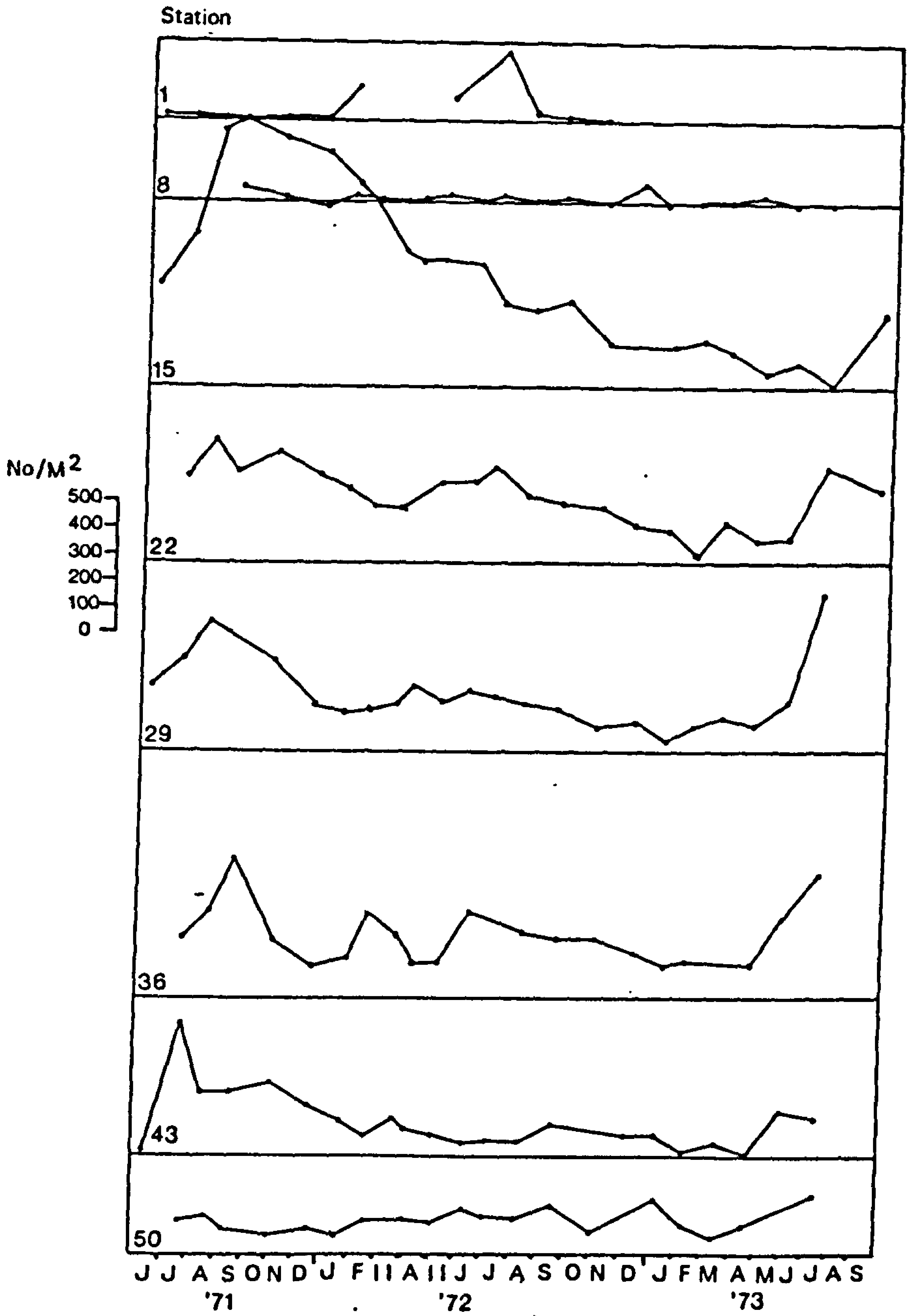


Figure 67. Seasonal variation in density of <u>Macoma balthica</u> more than 10 mm in length at each Station down the Gayton transect, 1971-73.

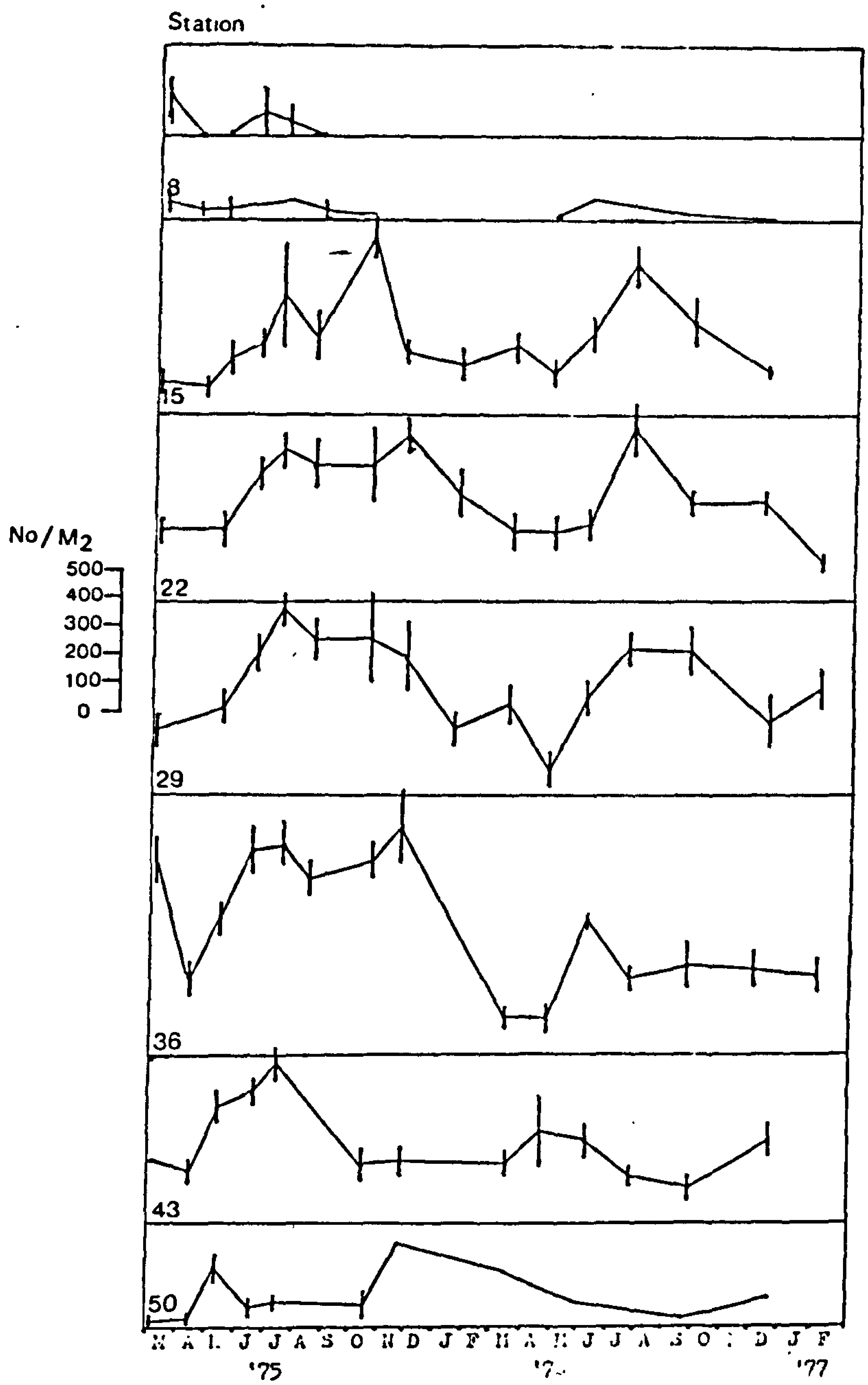
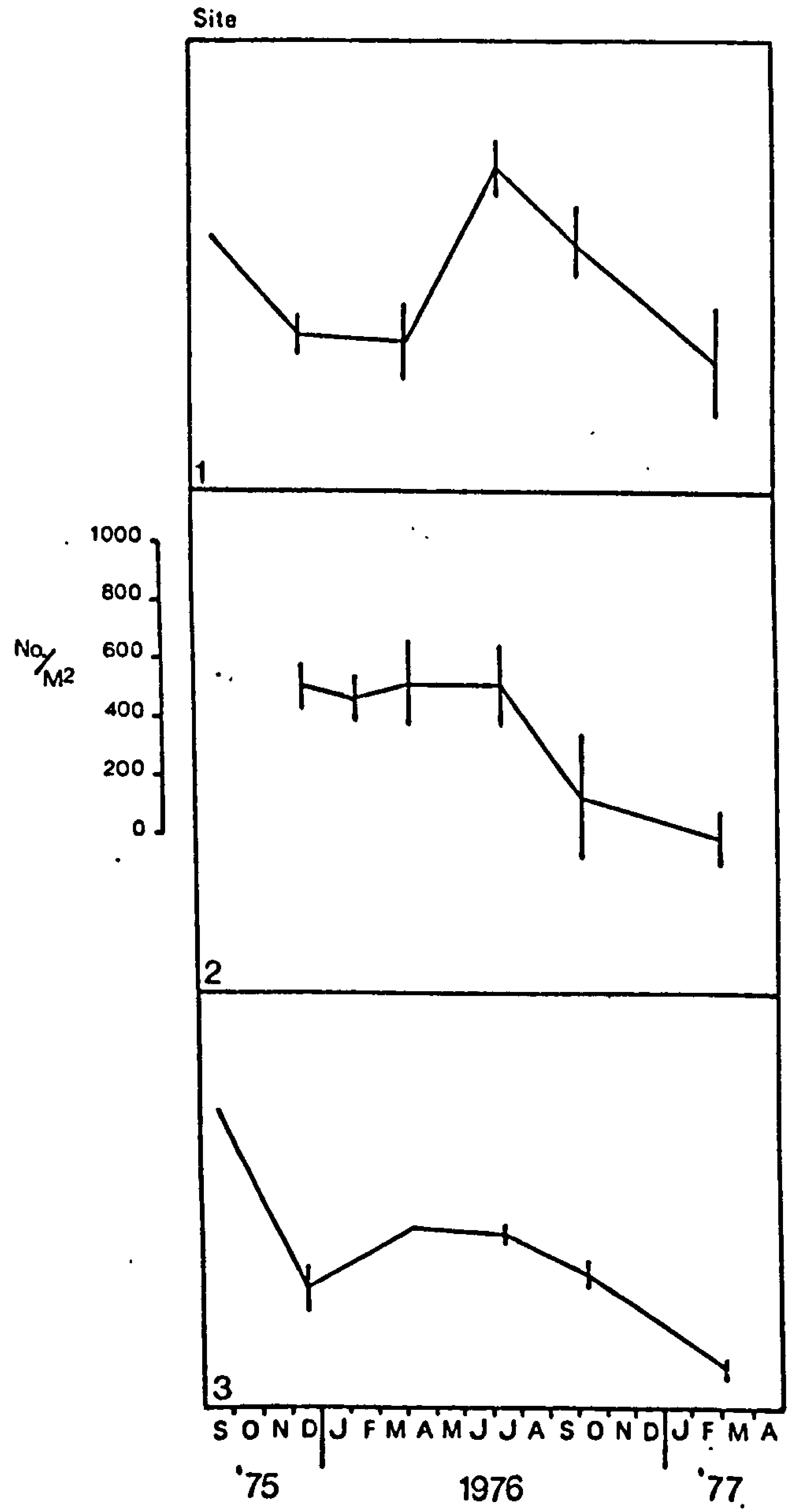


Figure 68. Seasonal variation in density of *Macoma balthica* more than 10 mm in length (±1 S.E.) at each sampling Station on the Gayton transect, 1975-77.



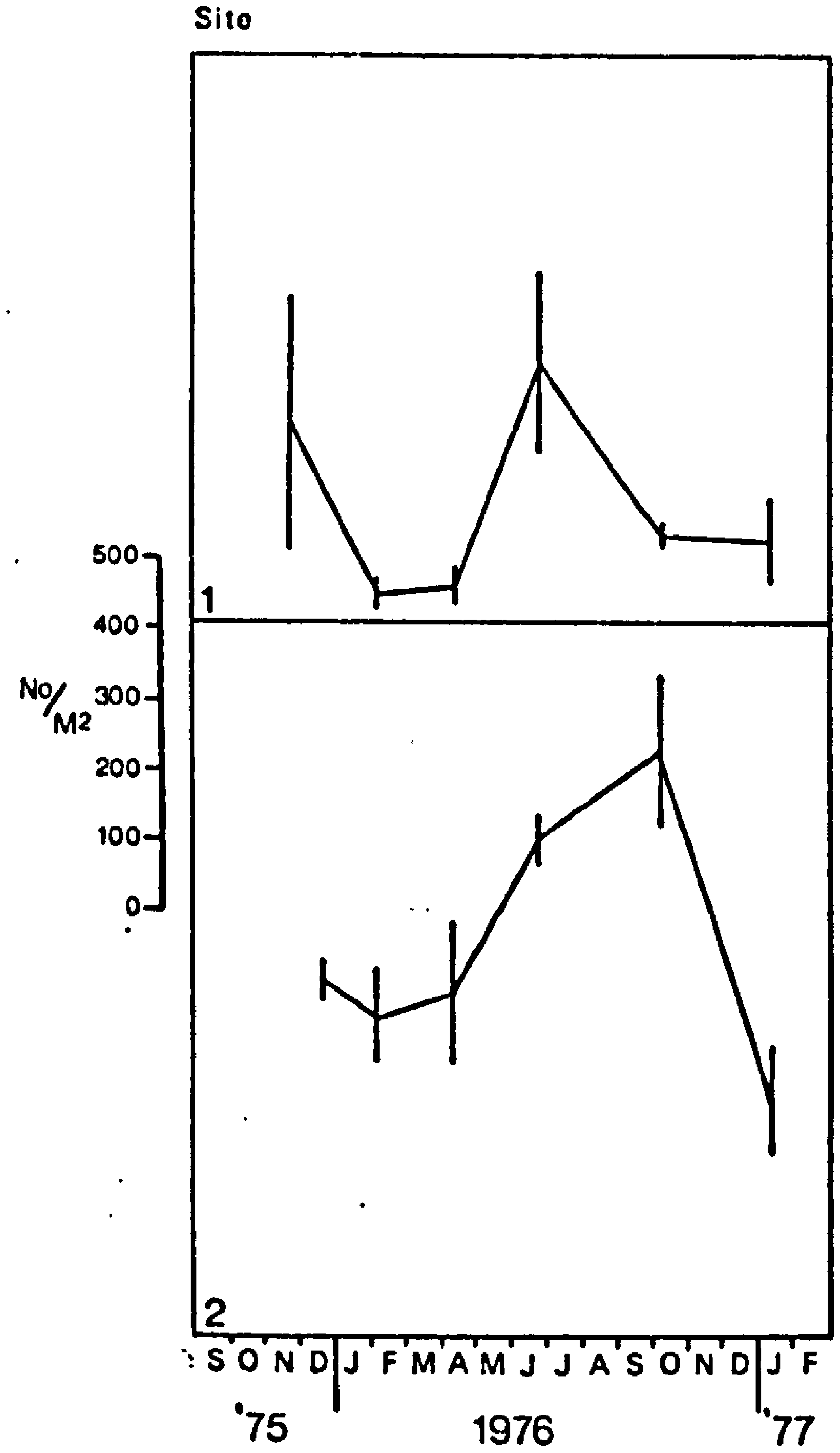


Figure 70. Seasonal variation in density of Macoma balthica more than 10 mm in length (± 1 S.E.) at Mostyn.

Figure 69. Seasonal variation in density of Macoma balthica more than 10 mm in length (± 1 S.E.) at Thurstaston.

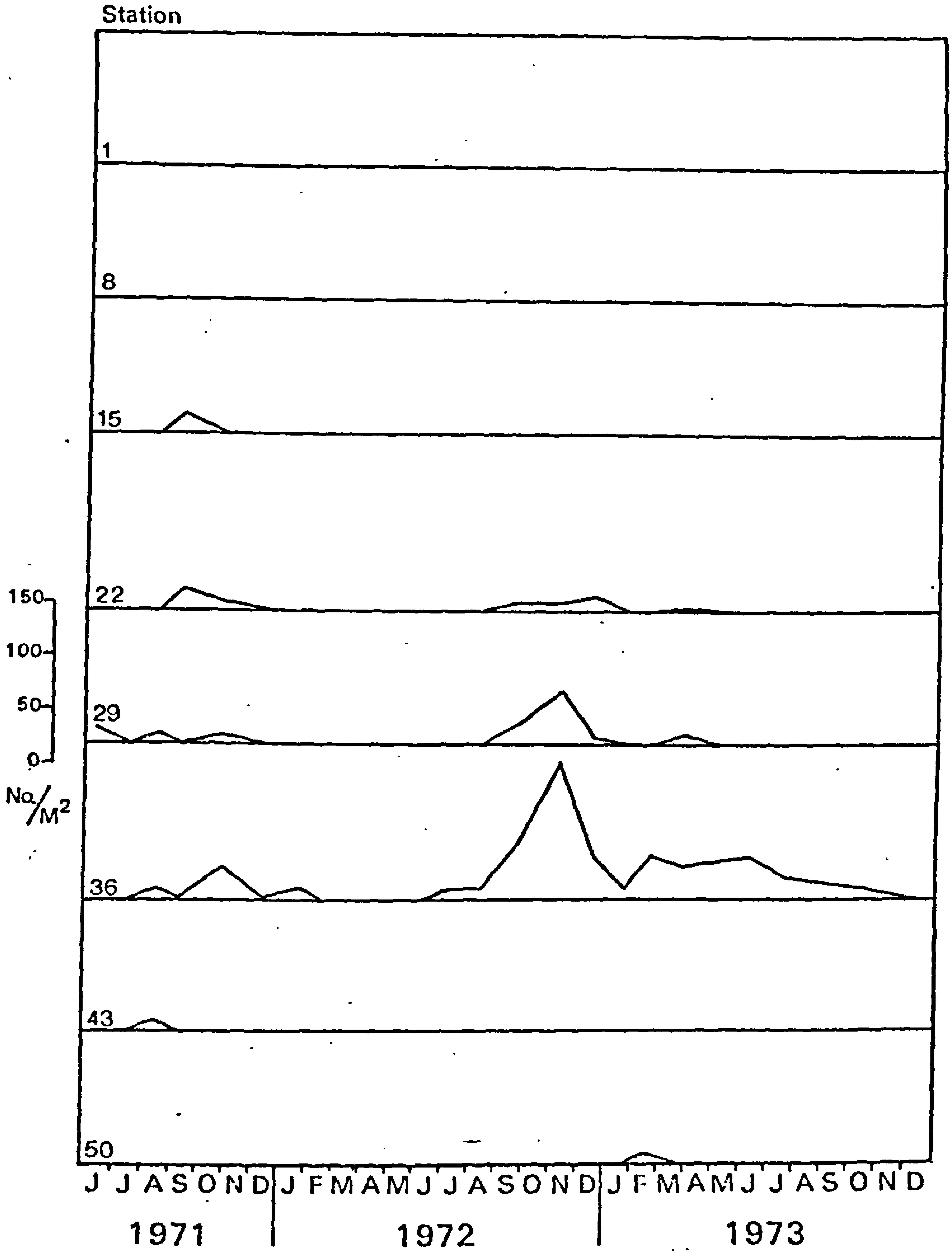


Figure 71. Seasonal variation in density of Mya arenaria at each sampling station on the Gayton transect 1971-73.

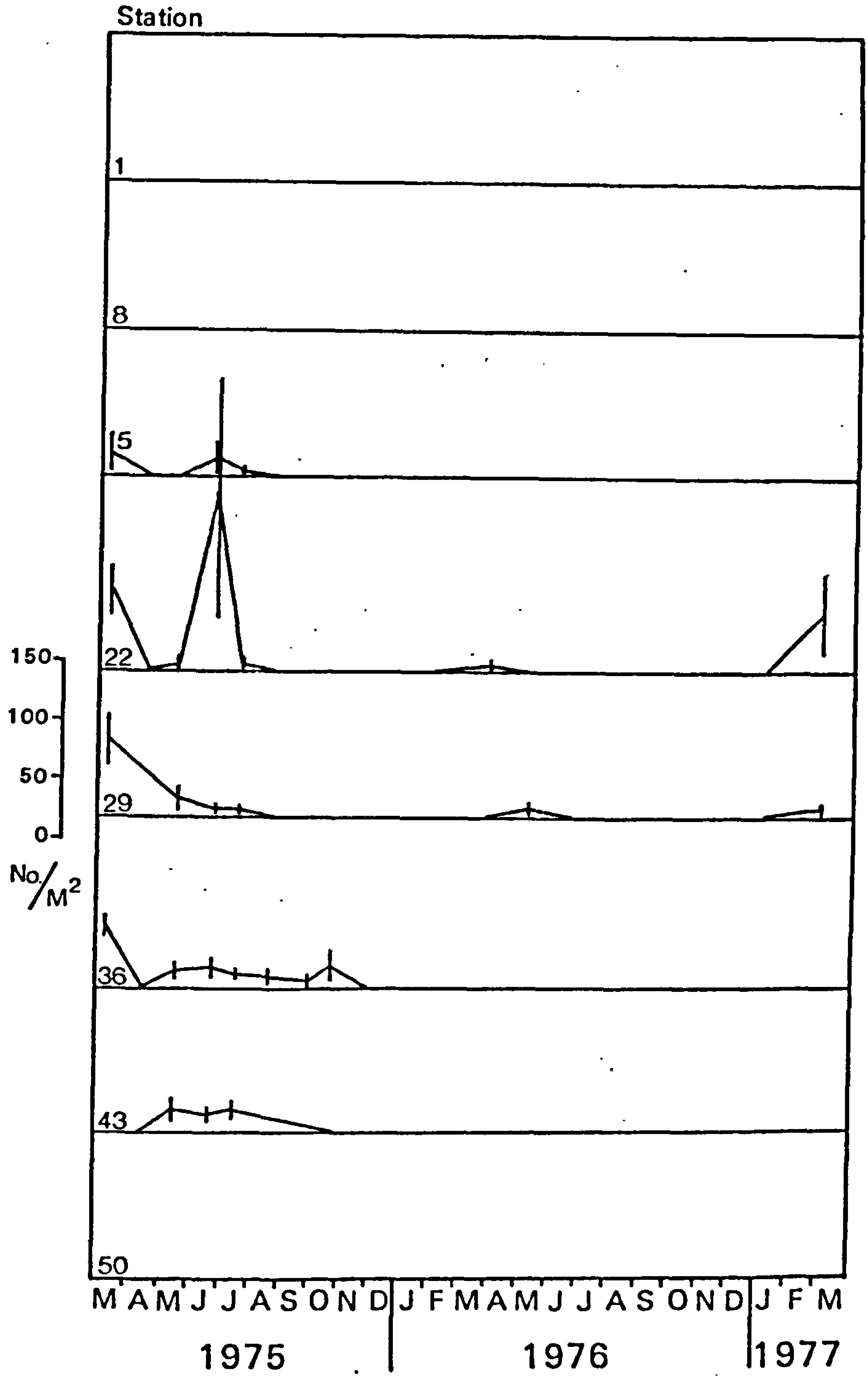


Figure 72. Seasonal variation in density of Mya arenaria (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

The gradual reduction in the numbers of M.balthica (outlined above) throughout the year could have been caused by any one of a number of environmental factors.

(i) Migration

Although there was evidence of a secondary migration of young M.balthica 4-5 mm in length there is no clear evidence that the source of this migration was from the middle regions of the transect. The prevailing water movements were not up and down the transect but across, so the source of the late increase in numbers at Station 15 was presumably from lower down the Estuary. However, without further detailed marking experiments movement of the very young stages has to be borne in mind as a contributory factor at certain sites in the loss.

(i) Nutrition

There is also the possibility that nutrition requirement could act as a control directly or indirectly, directly with regard to nutrition and indirectly by affecting the behaviour which Brayfield and Newell (1961) accounted for as due to the searching activities for fresh food supplies but this would presumably make the invertebrate more obvious to predators. However, the rapid growth (Figs. 61 & 62) indicated that detritus and benthic algae were not a limiting factor in the Summer. The retarded growth of loss of body flesh weight during the Winter (Chambers and Milne 1975b) indicated that food could be in short supply. Unfortunately, investigation of the supply of detritus and benthic algae was not undertaken, however, it appears more probably that the retarded growth and loss of body flesh weight were due primarily to a temperature effect reducing the feeding activities. No direct evidence was observed of mortality over the Winter period. Another contributory factor to a reduction of feeding could be the equinoctial neap cycle during the Winter period. During this period much of the upper shore would be exposed for an increased time so that a reduced growth rate could be expected at Station 15 compared with Stations 22 and 43. The growth curves presented in Figs. 60-61 were not conclusive. Although a lower growth rate was witnessed at certain times it was usually associated with one particular year group.

(iii) Pathogens

Another factor which could be contributing to the loss was the effect of pathogens. Cheng (1967); Swennen (1969) found M.balthica infected by variable quantities of the trematode Paravatrema affinis. Infection by other parasites is possible but further work is required. During this study no external evidence of severe effects of parasitism were noted on the M.balthica examined. However, the indirect effects of parasitism by P.affinis could be contributing to mortality by affecting the behaviour of M.balthica. Sweenen and Ching (1974) noted there was a greater quantity of infection in M.balthica exhibiting crawling tracks. This could indirectly affect the mortality curve by making M.balthica more obvious and available to predators.

(iv) Oxygen deficiency

The effect of differences in position of M.balthica in the substrate was also influenced by the oxygen content of the sediment (Brayfield 1964; Hulscher 1973). No direct observations were made on the Dee of depth in the substrate of M.balthica related to oxygen content, but no actual sightings were made of M.balthica surfacing with gaping shells as seen by Brayfield (1964).

(v) Erosion/Deposition of sediment

Another factor contributing to the loss could be the rapid removal or addition of sediment. Rates of accretion were investigated and the results are shown in Fig.60. However, in a species exhibiting rapid movements within the sediment (Stopford 1951; Brayfield and Newell 1961; Sweenen 1969) it appears unlikely that this would have a decisive effect under the rates of accretion and erosion recorded. Periods of severe storms were found to have an effect on the redistribution of surface sediment but the effects were generally limited to the Winter and early Spring when adults were well protected at lower levels in the sediment.

(vi) Salinity

The annual variations in salinity are seen in Fig. 57. At the salinities recorded it seems unlikely they were having a major effect on the seasonal variation in numbers of *M.balthica*. The salinity of interstitial water is perhaps not a true reflection of the environment in which *M.balthica* is found since the feeding activities occur when covered by the tide. However, in extremes in the environment *M.balthica* could presumably be tolerant by ceasing feeding and closing the shell valves.

(vii) Temperature

Either very high or very low temperatures could be contributing to the mortality. Data for the period 1971-73 on air, river and seawater temperatures, together with limited information on maximum/minimum temperatures within the sediment at 2.5 cm and 10 cm below the surface have been presented in Fig. 38. *M.balthica* is an artic boreal species (Clay 1967) and therefore tolerance to low temperatures is expected. However, a heavy mortality of *M.balthica* was reported for the Solway Firth during the 1962-63 Winter (Crisp 1964; Williams et al 1964; Williams et al 1965), but these temperatures were far below those recorded during the study on the Dee. High temperatures may be more of a problem, especially as it was noted that the highest temperatures, particularly of sediment, over the three years occurred in July, the approximate period when settlement of young M.balthica was taking place. The maximum temperature in the sediment at 2.5 cm depth recorded was 27.8°C. Tests were carried out in the laboratory to estimate the lethal temperature in a range of size groups. Facilities and other conditions imposed restraints on the stringency of these tests, for example, the effect of the salinity range was not investigated nor were varying oxygen concentrations and the limitations of the equipment did not allow effects of acclimatization to be investigated. Consequently the results expressed represent a primary investigation of the problem and a much more detailed physiological experiment is required. The test took place in August 1972 using newly settled M.balthica in the size range 3-5 mm, 1+ M.balthica in the range of 10-13 mm and 2+ in the range 19-24 mm, which were placed in flasks in a water bath. Throughout the tests the oxygen content of the water was kept uniform and high by constant aeration and the salinity of the water was 30‰. The temperature was raised from an initial temperature of 19°C to a maximum of 50°C at a rate of 1°C every 10 minutes. At 5°C intervals flasks of M.balthica were removed from the water and allowed to return to initial ambient temperature. Recovery of M.balthica was found to cease at a temperature between 37.5°C and 42°C for all three size ranges. More comprehensive experiments were carried out by Kennedy and Mihursky (1971). Using acclimatized material they ascertained the LC 50 temperatures for large and small M.balthica, 33.3°C for the large and 33.5°C for the small and they attributed the differential temperature tolerances as indicative of a physiological adaptation of young M.balthica to higher temperatures experienced in the surface sediments. Henderson (1929) determined the lethal temperatures by raising the temperature 1°C every 5 minutes. He ascertained the average lethal temperature for M.balthica to be 42.3°C. Therefore at the temperatures recorded on the Dee of 27.8°C at 2.5 cm depth in the sediment, it does not appear likely that temperature was having a major effect on the young M.balthica, but further observations are required as to whether a critical temperature is being approached on the actual surface of the sediment and whether newly settled M.balthica can evade these high temperatures by burrowing deeper into the sediment.

It would appear from the observations that none of these environmental factors can account fully for the logarithmic decrease in densities throughout the year. Other important factors needed investigation.

(viii) Invertebrate predation

The importance of M.balthica as a prey species for P.flesus and estuarine birds has been outlined in the extensive survey results, but to these two groups of predators should be added a less well understood group, the other invertebrates which occur both in the sediment and in the water column. For example, it was observed from the transect data that at the time of M.balthica settlement each year, without exception, there was a corresponding settlement of C.maenas. Close observations in the field of the surface sediment at the time of this occurrence, emphasised the large numbers of C.maenas involved and occasionally, particularly where the sediment had been disturbed, C.maenas was seen to predate on newly settled M.balthica.

To investigate these observations further an experiment was carried out under laboratory conditions to determine whether young *C.maenas* could contribute to the initial stage in the mortality curve. The experiments took place in plastic buckets in the laboratory at a temperature of 19°C and a salinity of 30‰. No allowance in the experiment was made for distribution of *M.balthica* in the sediment, no sediment being present in the buckets. The two species were placed together in varying size combinations as seen in Table 62. Biological material for the experiment was obtained from the transect but large C.maenas were supplemented by material from Mostyn Dock. A period of 3 hours elapsed between the collection of the material and the start of the experiment. Six hours after the commencement of the experiment all the small sized *M.balthica* had been predated and progressively larger *M.balthica* were taken by the larger size *C.maenas* but the largest *M.balthica* remained unaffected after nine days. It was also noted after this length of time that the *C.maenas* were beginning to predate other *C.maenas* of similar size. Similar observations have been recorded by Perkins et al (1965). Supplementary experiments indicated that *C.maenas* also predates on other invertebrates in the sediment, e.g. *P.elegans*. A similar experiment carried out with *C.vulgaris* indicated that only very large *C.vulgaris* could break open the shell of small *M.balthica*. In this species, annelids and other crustacea and particularly *Corophium* sp. were found to be more important.

The effects of predation from *C.maenas* were of a transitory nature since there was a very rapid decline in the numbers of small *C.maenas* along the transect.

(ix) Vertebrate predation

The curvilinear shape of the mortality and the reduction of a large variable density to an apparent minimum uniform density at all Stations on the transect and over all years suggested

Date	Tank No.	Size Range (mm)	No. of C.maenas	No. of M.balthica & size range (mm)			
				2 - 4	4 - 8	8 - 10	10 - 15
23 Sept '73	I	2.5 - 5.0	14	7	6	3	3
	II	5.0 - 6.0	16	7	6	3	3
	III	6.0 - 7.5	20	7	6	3	3
	IV	7.5 - 9.0	13	7	6	3	3
6 hrs later (23-9-73)	I	2.5 - 5.0	14	0	4	3	3
	II	5.0 - 6.0	16	0	3	3	3
	III	6.0 - 7.5	20	0	1	3	3
	IV	7.5 - 9.0	13	0	1	3	3
2 days later (25-9-73)	I	2.5 - 5.0	13	0	4	3	3
	II	5.0 - 6.0	15	0	1	3	3
	III	6.0 - 7.5	20	0	1	3	3
	IV	7.5 - 9.0	13	0	0	3	3
9 days later (1-10-73)	I	2.5 - 5.0	9	0	3	3	3
	II	5.0 - 6.0	10	0	1	3	3
	III	6.0 - 7.5	15	0	0	3	3
	IV	7.5 - 9.0	13	0	0	3	3

Table 62. Invertebrate predation experiment - mortality of Macoma balthica by Carcinus maenas.

the strong possibility of a density dependant predation mechanism controlling the post-settlement populations of M.balthica. Similar mechanisms have been observed in other environments but with the possible important difference that the estuarine environment mechanism had to work on a single prey population recruitment per year. Other investigators have concentrated their attentions on looking at the reactions and behaviour of the predators to varying prey densities and not the effects of predation on the densities of prey (Gibb 1958; Holling 1959; Royama 1971; Hassall and May 1973; Goss-Custard 1977).

I felt the establishment of an exclosure was the ideal opportunity to investigate this hypothesis. If the other environmental factors were relatively unimportant the density under a net should remain at the density near settlement, if during the following Spring the net was removed exposing this artifial high density predation and, under a density dependance, had an increased rate compared with the density of the surrounding area.

The first netted area was established at Station 22 on the transect in 1972. The net was established at settlement and remained until the following Spring and during this time predation was successfully prevented under the net, the density remaining steady from settlement. The net was removed and increased predation occurred within this area to similar levels in the control. Unfortunately, although the experiment substantiated the hypothesis, Station 22 was selected which in 1972 proved to be a particularly poor year for settlement (Fig. 59). The significance of the difference between the populations inside and outside was not sufficiently marked for strong conclusions to be drawn.

Fortunately the opportunity arose to carry out further more comprehensive experiments in 1975 and these have been given in the section 3.2.2.

(g) Hydrobia ulvae (Figs. 73 - 76)

With the exception of Stations 43 and 50 large variations occurred in the numbers of this species along the transect. A seasonal trend, although not clearly defined, was for maximum densities to occur during the Autumn and for the minimum densities to be in the late Spring. The behaviour of H.ulvae in relation to the tidal cycle, in particular migration associated with the ability of the species to float in the water column and at the surface, made interpretation of the data limited. Separation of the rate of increase and decrease in densities due to reproduction, predation and migration would require further analysis of size frequency and reproductive developments. However, the very rapid changes in density at Station 1 in early 1975 were hard to explain except by a migration. At other stations rate of increase in density was very similar to rate of decrease. The curvilinear form of decrease in numbers, illustrated for less mobile species such as M.balthica, was not in evidence for this species, with the possible exception of Station 8 between August 1971 and May 1972.

At Thurstaston and Mostyn no clear density pattern emerged. H.ulvae was poorly represented in the upper two sites. The lower site indicated a maximum of approximately 2,000/m^2 followed by a significant loss.

(h) Corophium sp. (Figs. 79 - 82)

The frequency distributions indicated large seasonal variation at the central stations of the transect with maximum densities recorded during Winter and minimum during mid-Summer.

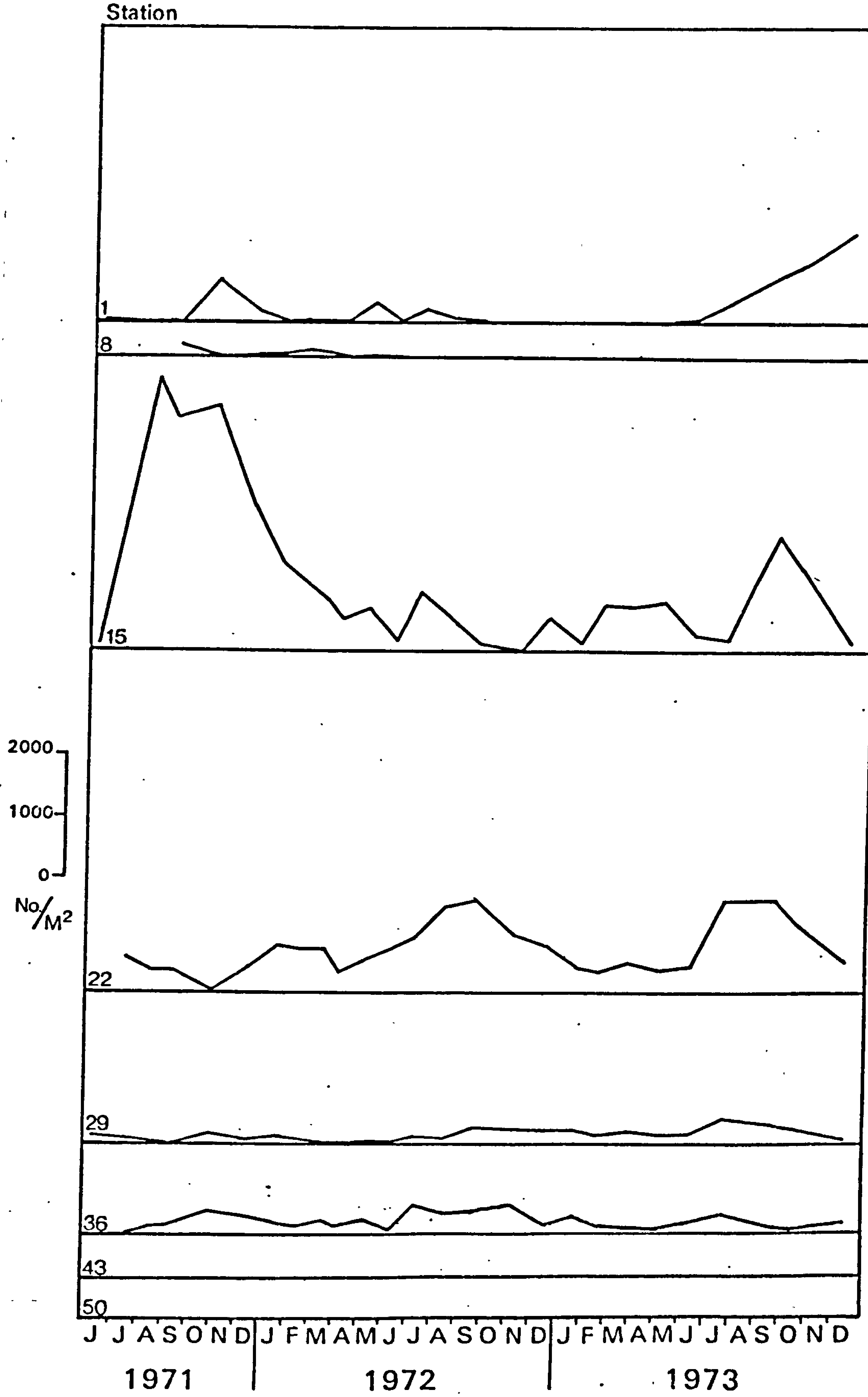


Figure 73. Seasonal variation in density of Hydrobia ulvae at each sampling station on the Gayton transect 1971-73.

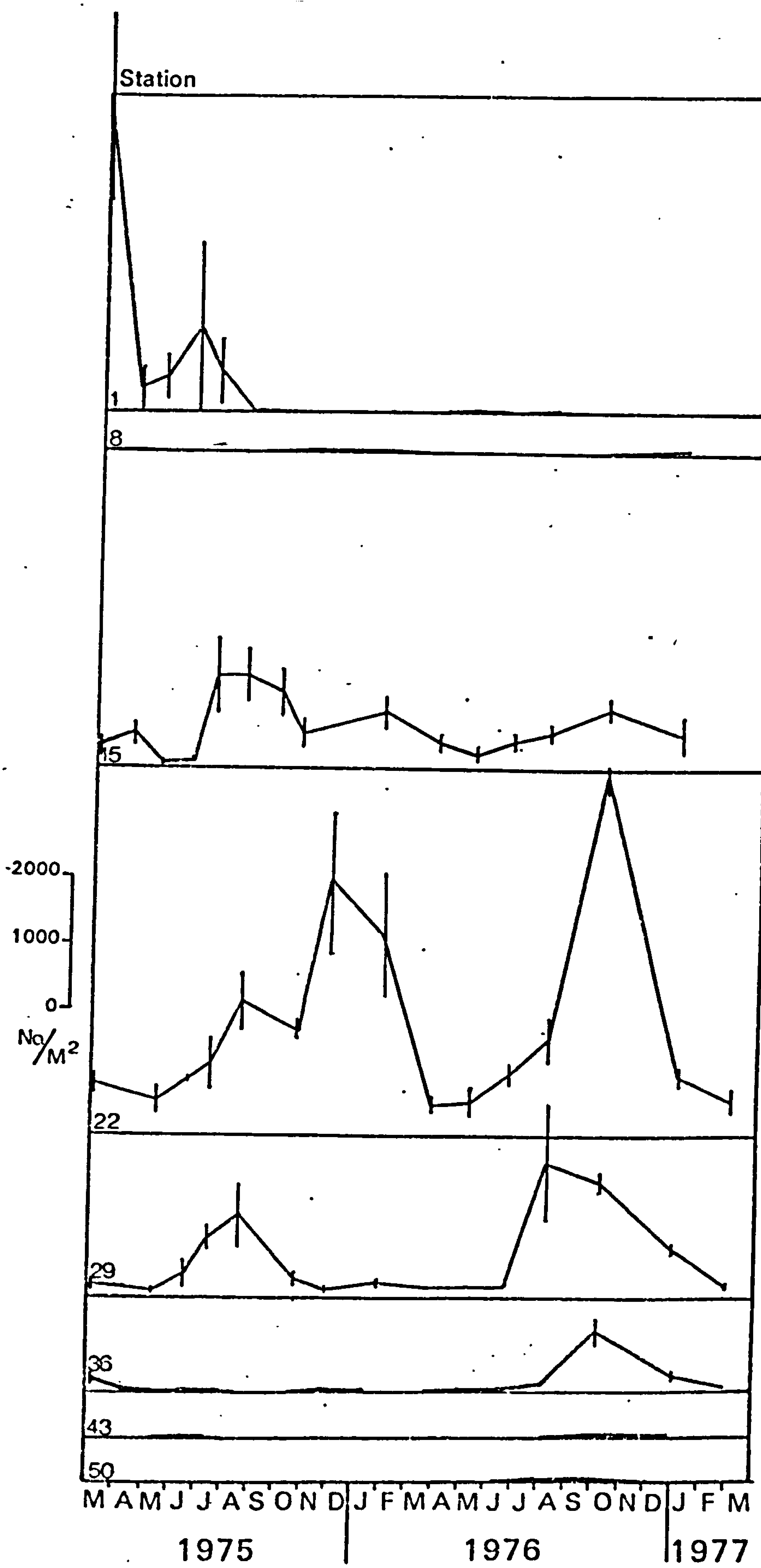
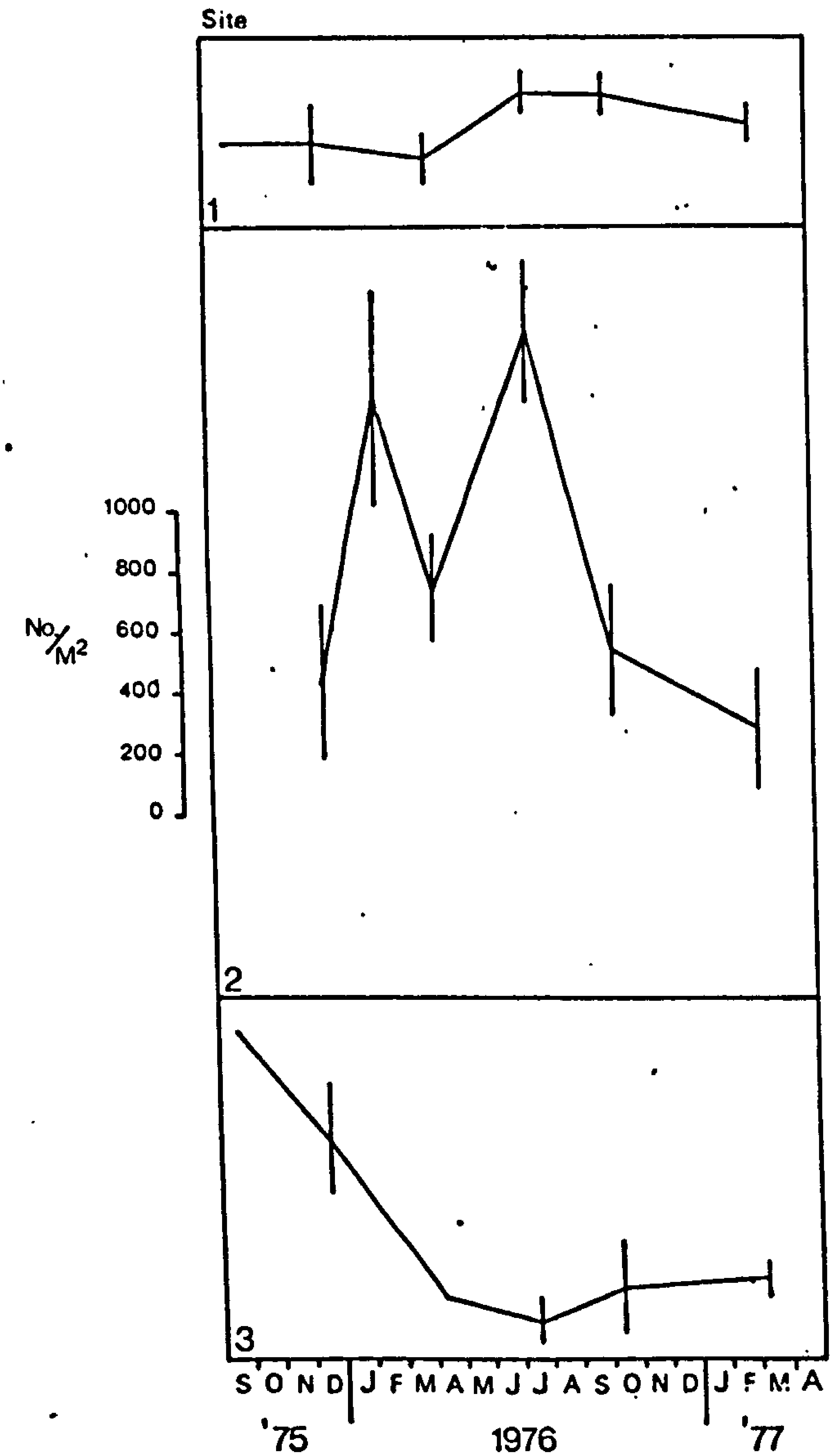


Figure 74. Seasonal variation in density of Hydrobia ulvae (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.



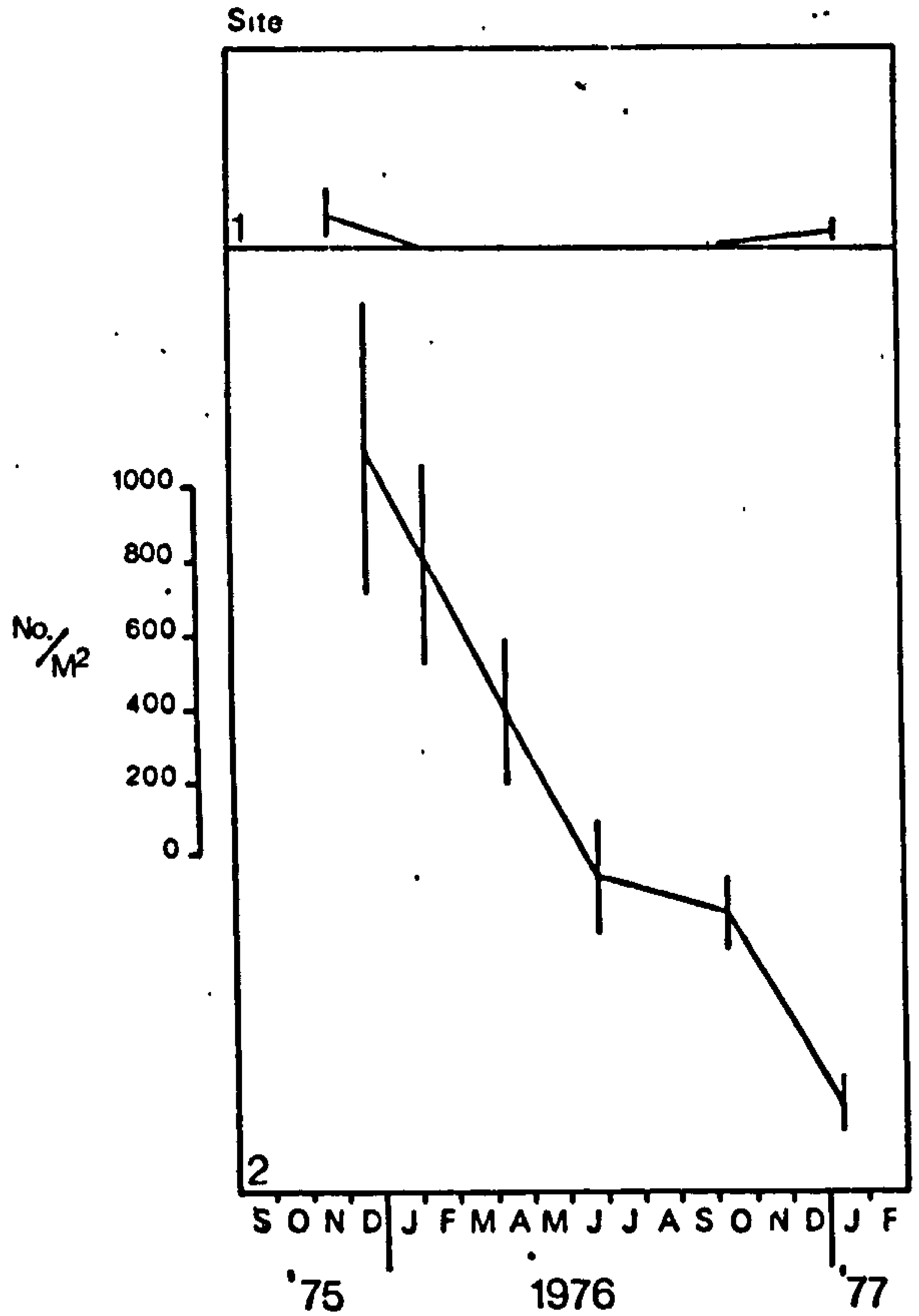


Figure 76. Seasonal variation in density of Hydrobia ulvae (± 1 S.E.) at Mostyn.

Figure 75. Seasonal variation in density of Hydrobia ulvae (± 1 S.E.) at Thurstaston.

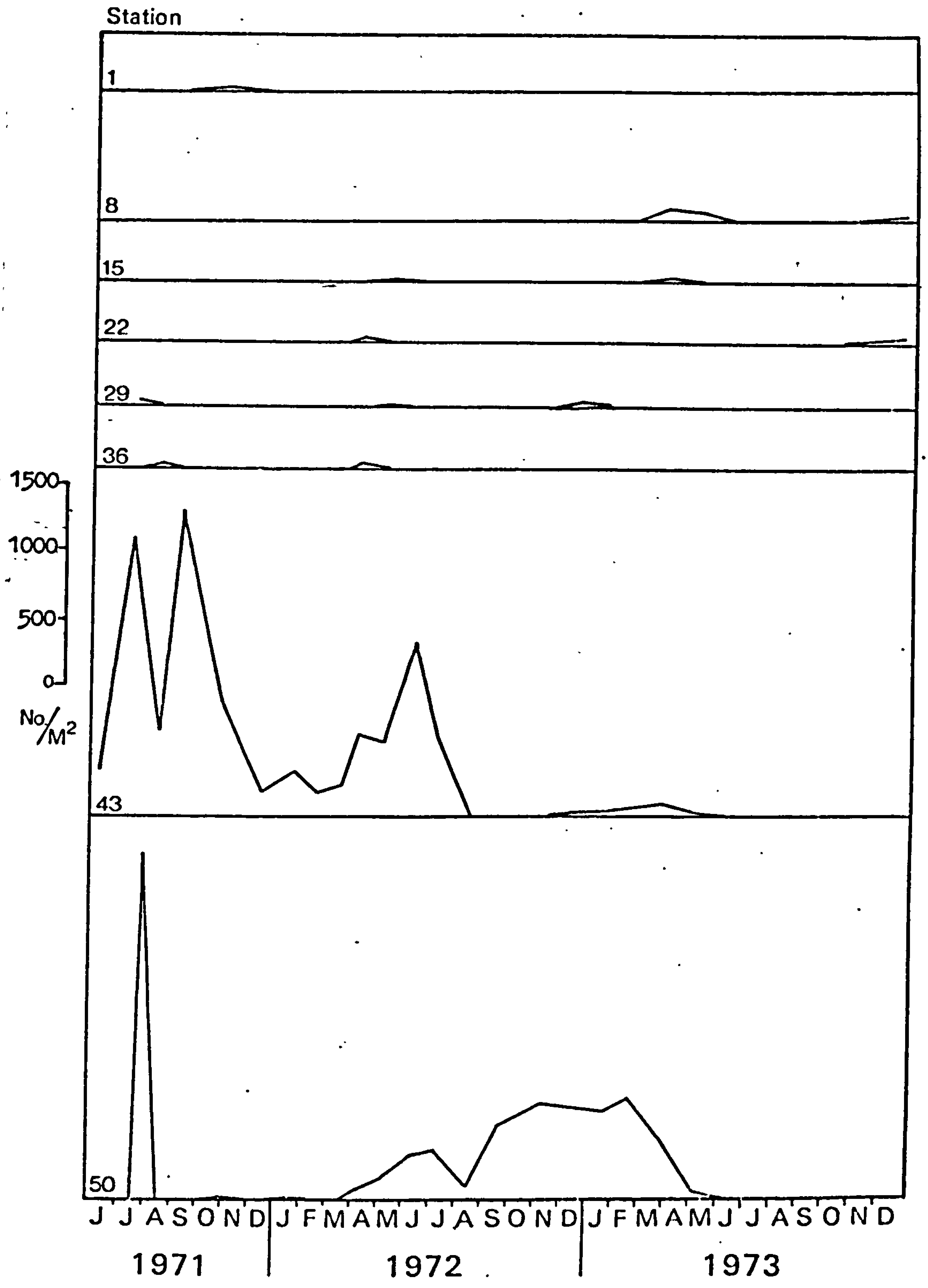


Figure 77. Seasonal variation in density of Eurydice pulchra at each sampling station on the Gayton transect 1971-73.

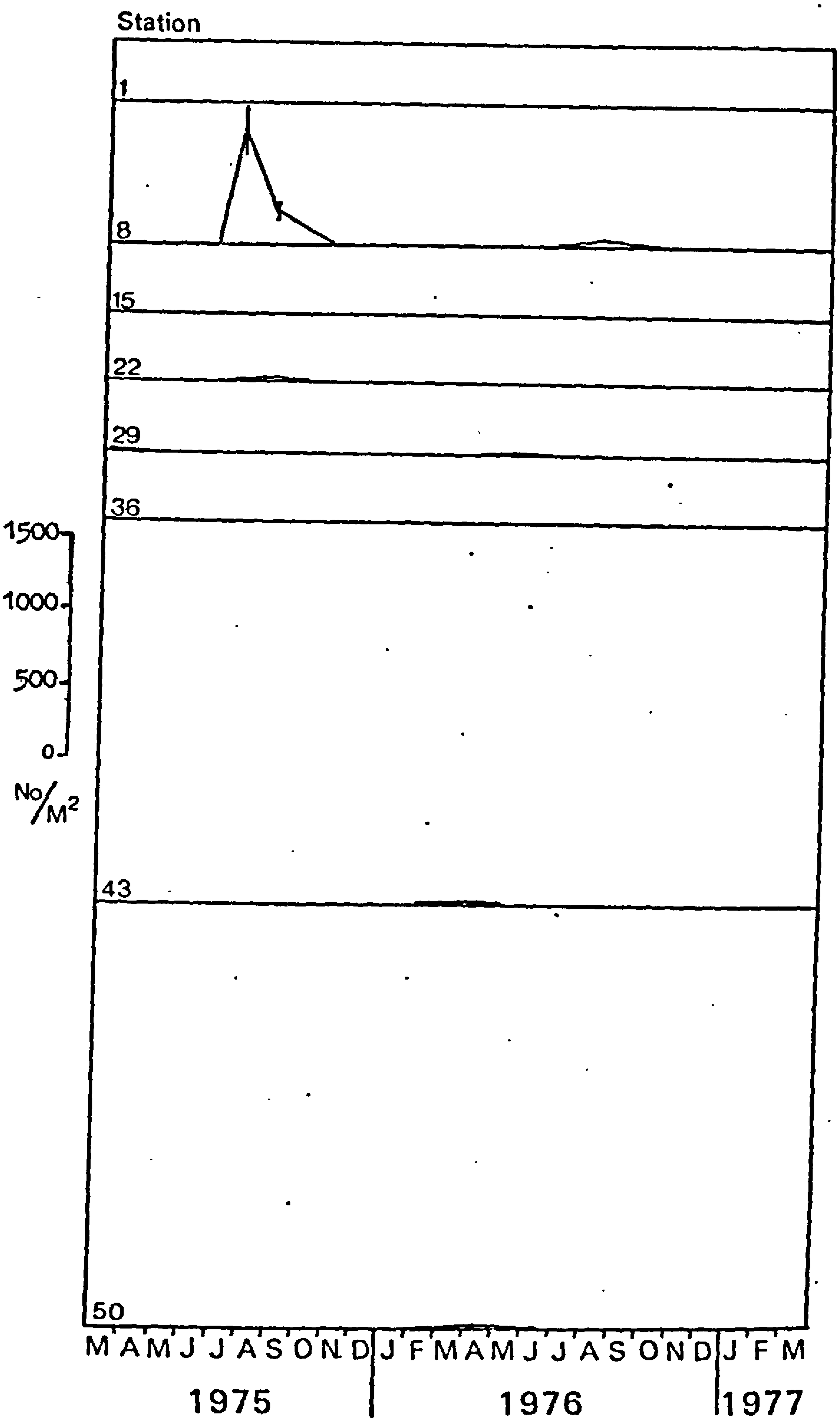


Figure 78. Seasonal variation in density of Eurydice pulchra (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

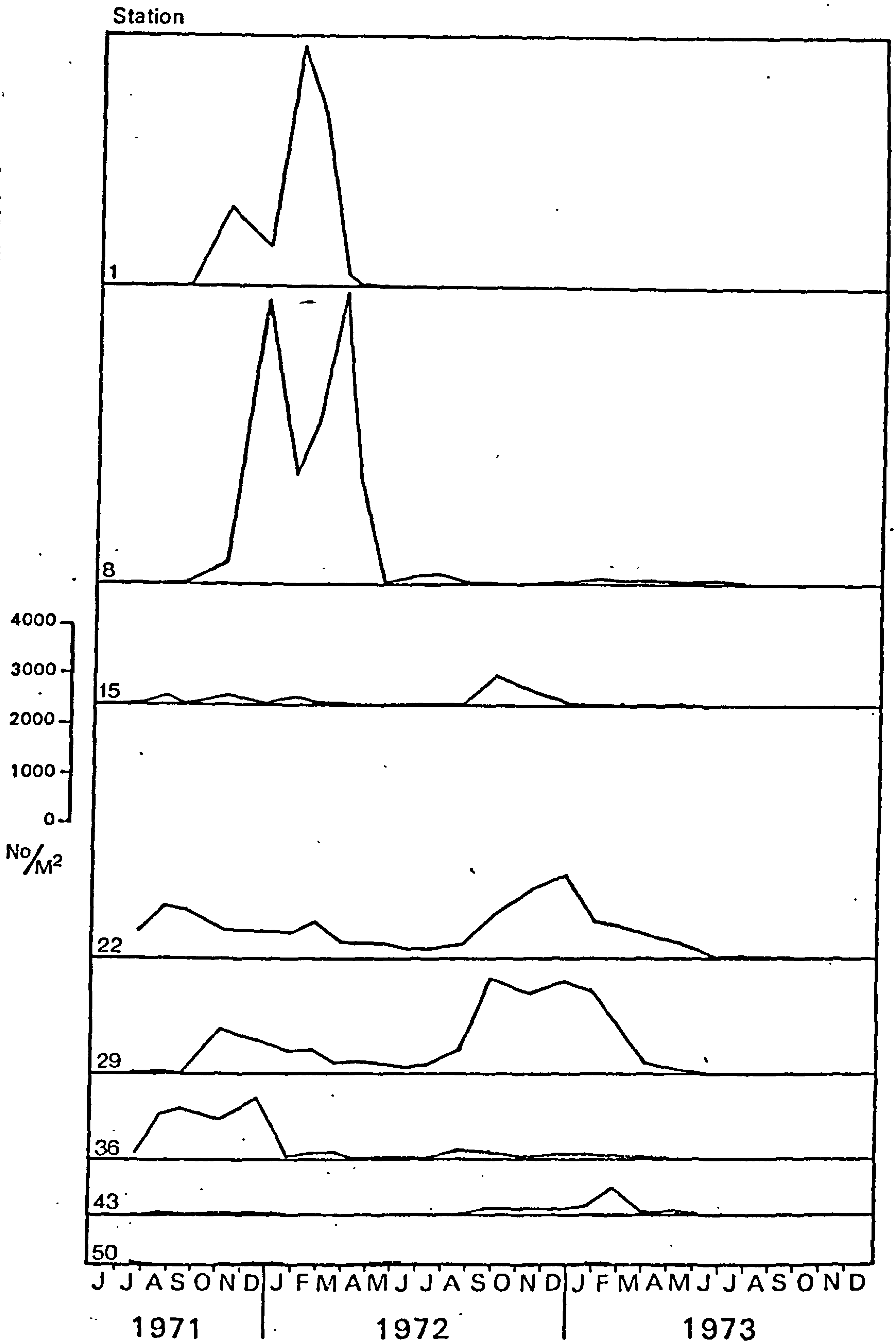


Figure 79. Seasonal variation in density of Corophium sp. at each sampling station on the Gayton transect 1971-73.

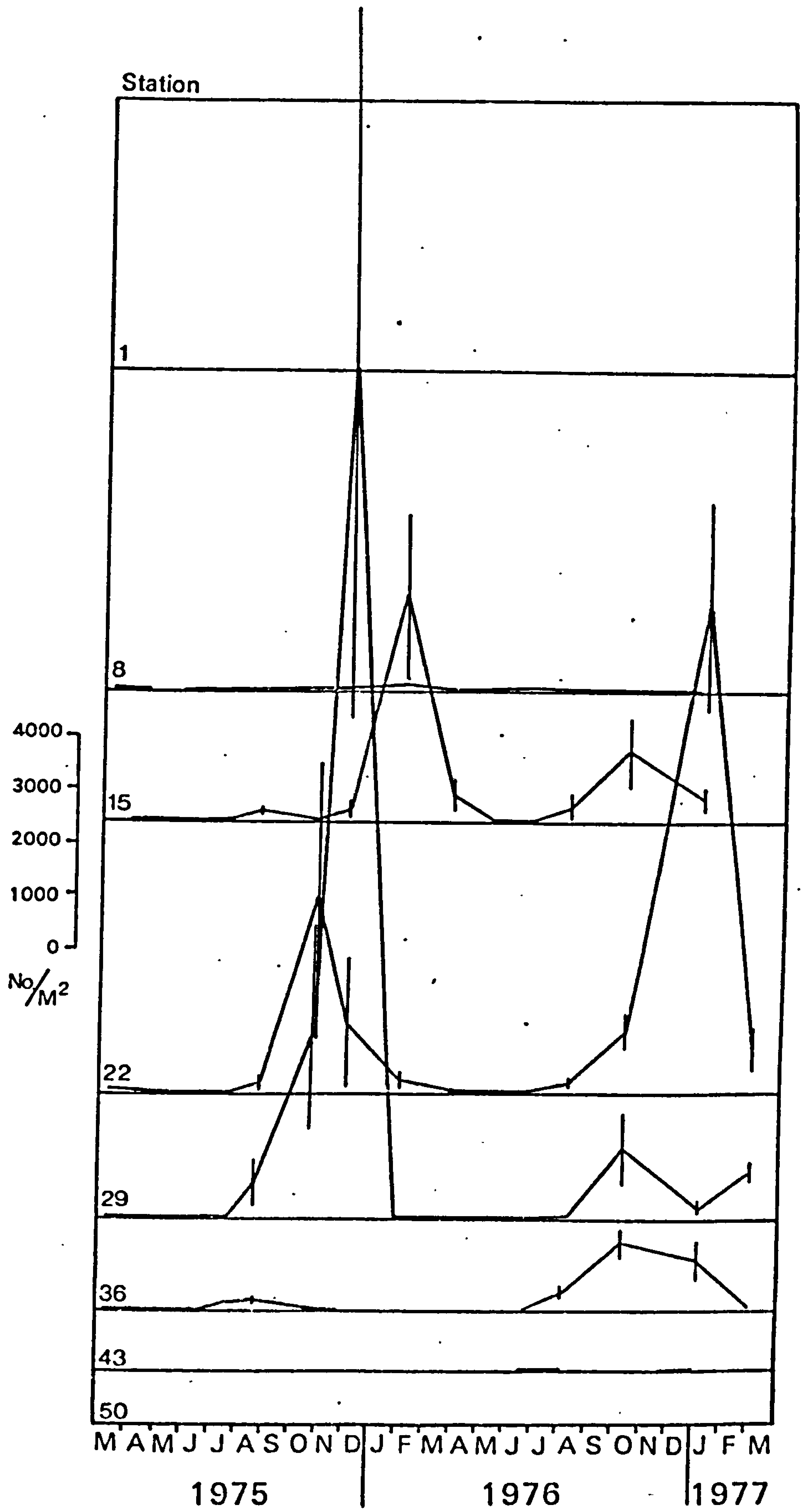


Figure 80. Seasonal variation in density of Corophium sp. (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

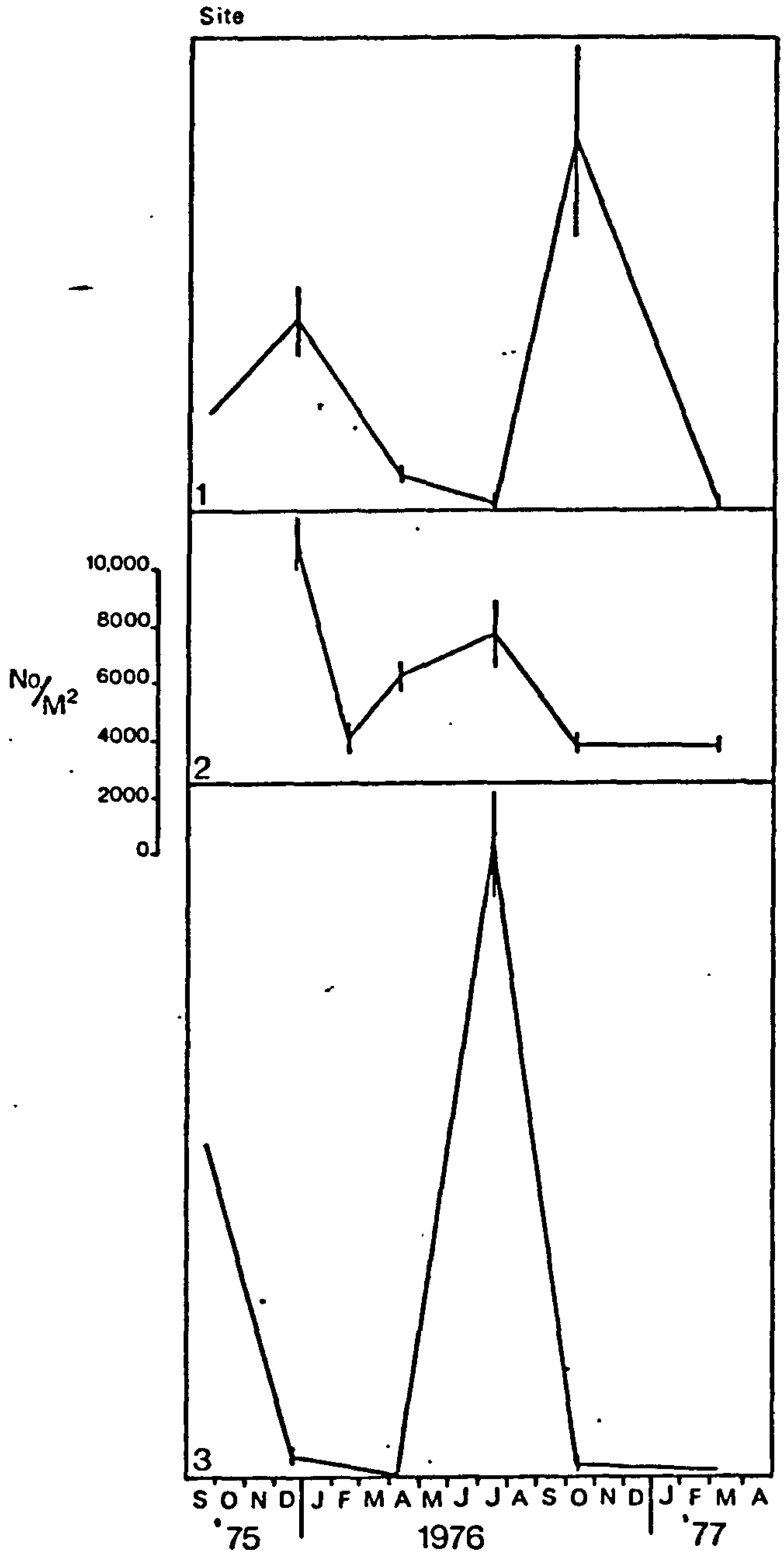


Figure 81. Seasonal variation in density of Corophium sp. (± 1 S.E.) at Thurstaston.

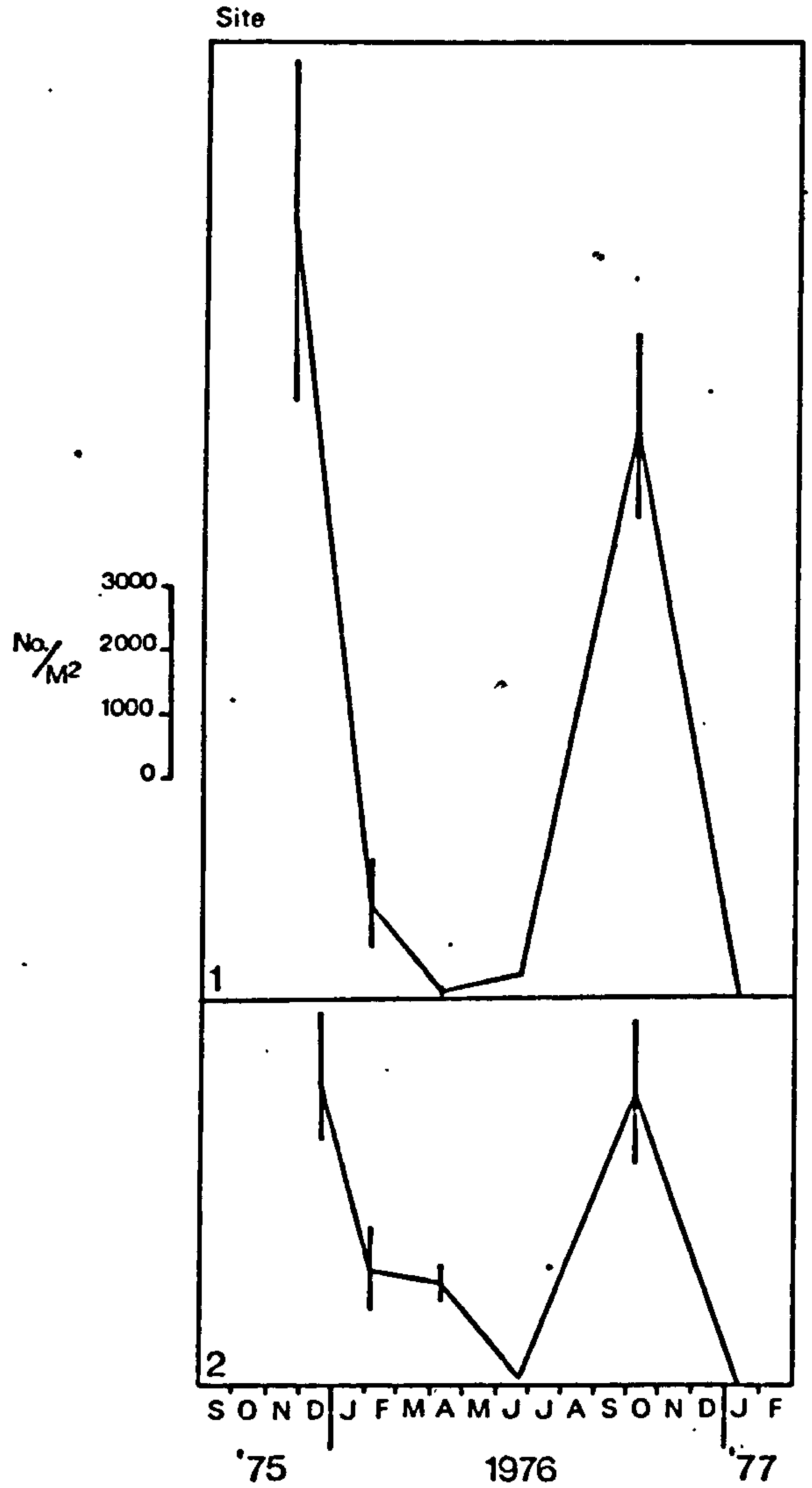


Figure 82. Seasonal variation in density of *Corophium* sp. (± 1 S.E.) at Mostyn.

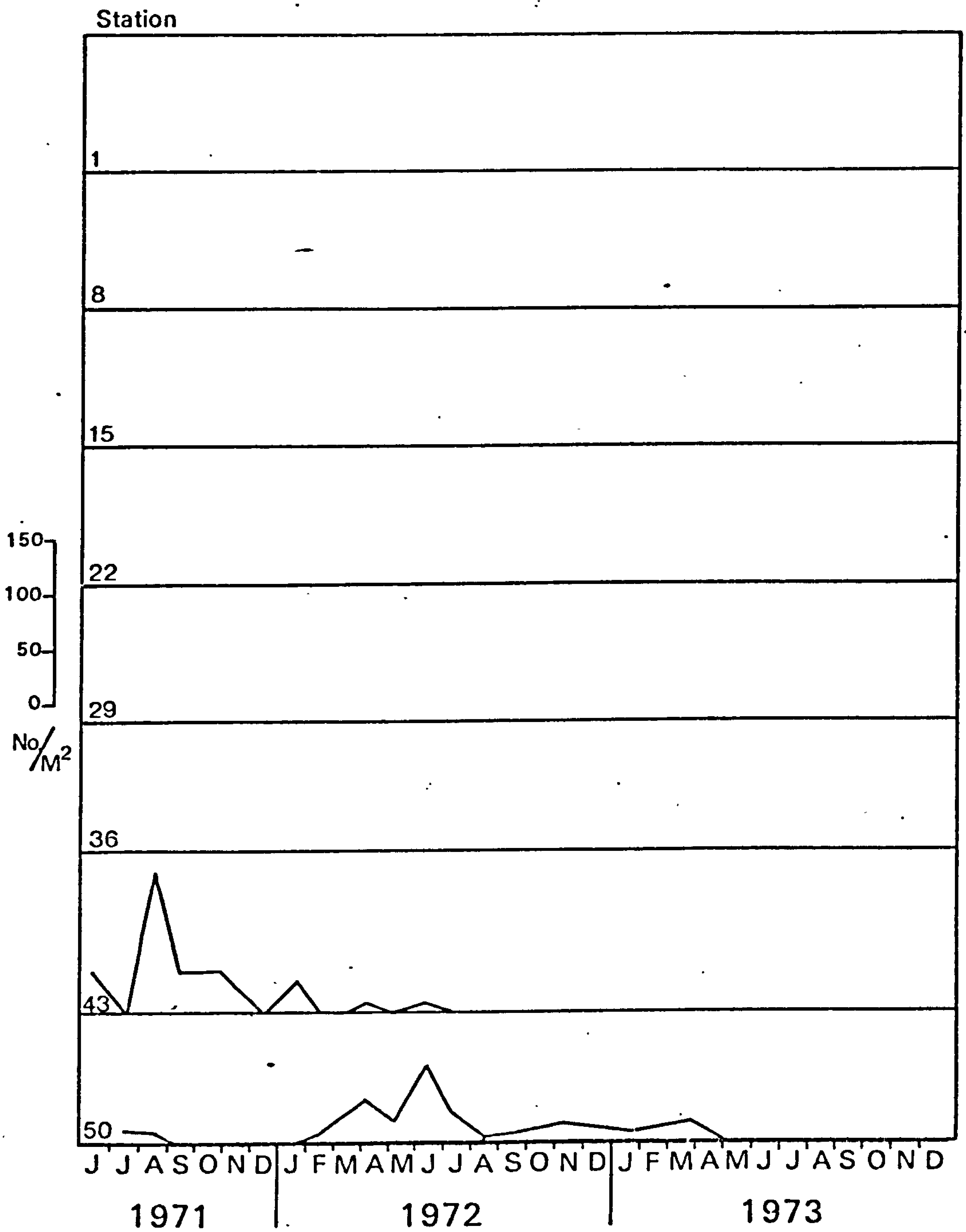


Figure 83. Seasonal variation in density of Bathyporeia sp. at each sampling station on the Gayton transect 1971-73.

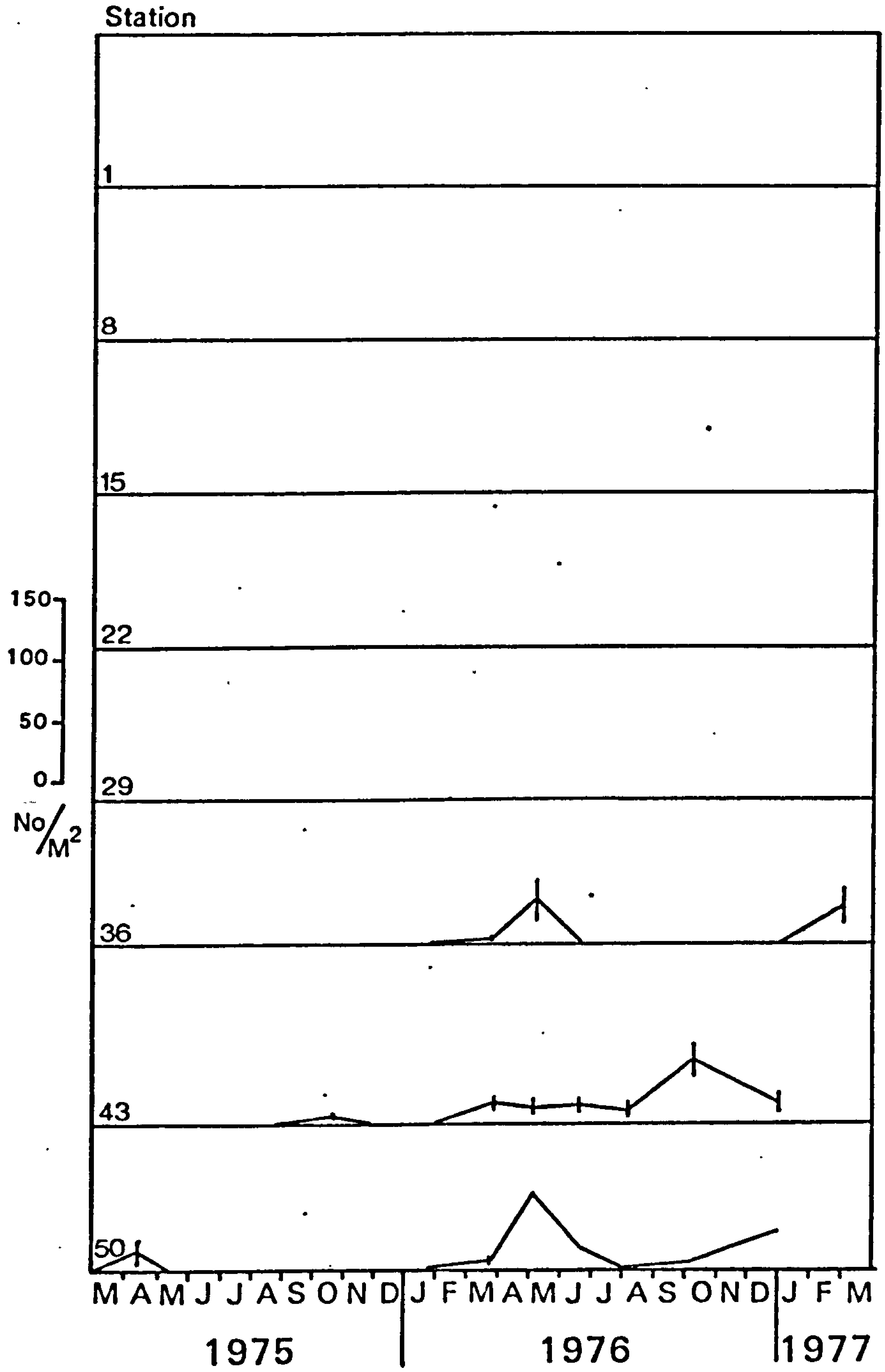


Figure 84. Seasonal variation in density of Bathyporeia sp. (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

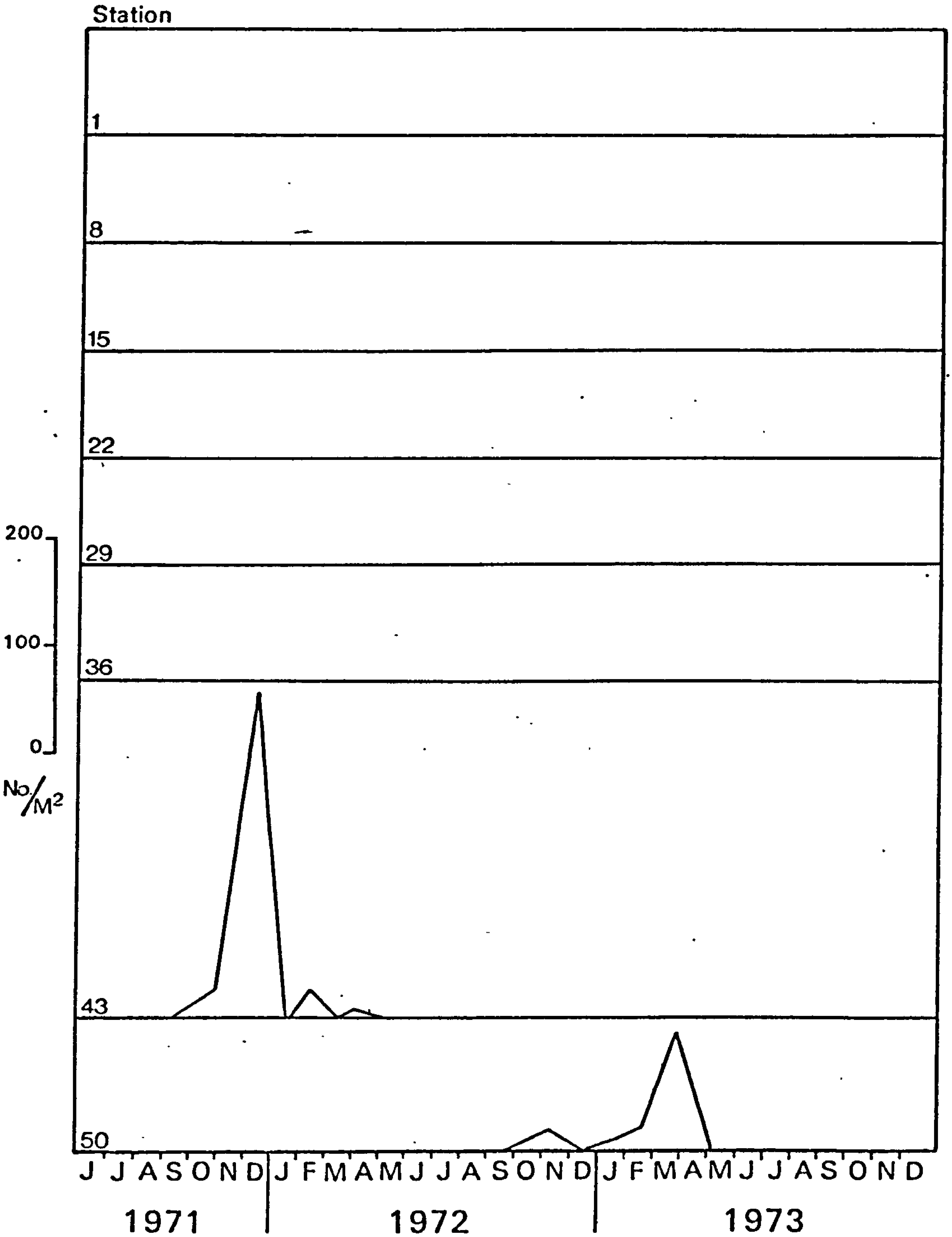


Figure 85. Seasonal variation in density of Haustorius arenarius at each sampling station on the Gayton transect 1971-73.

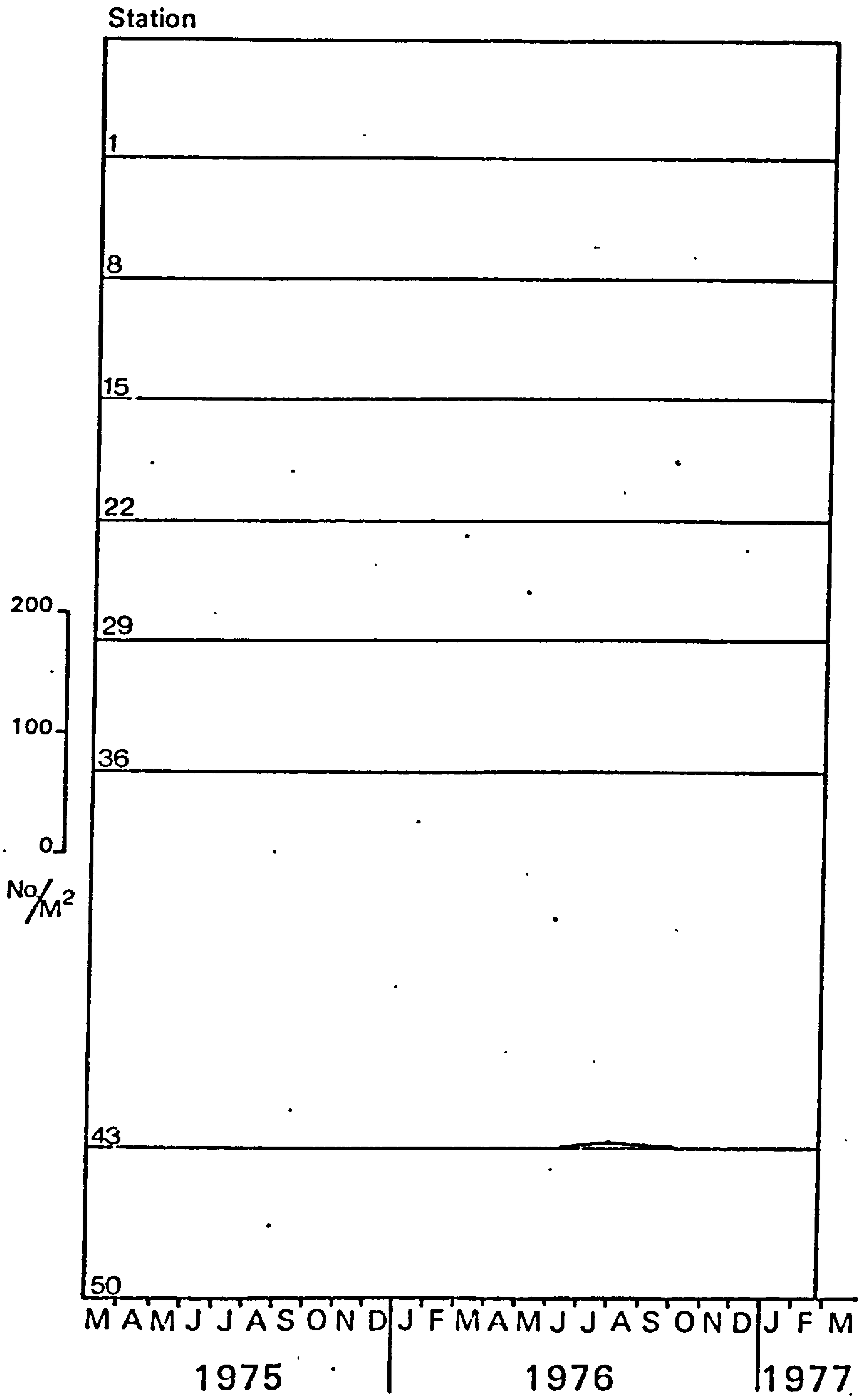


Figure 86. Seasonal variation in density of Haustorius arenarius (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

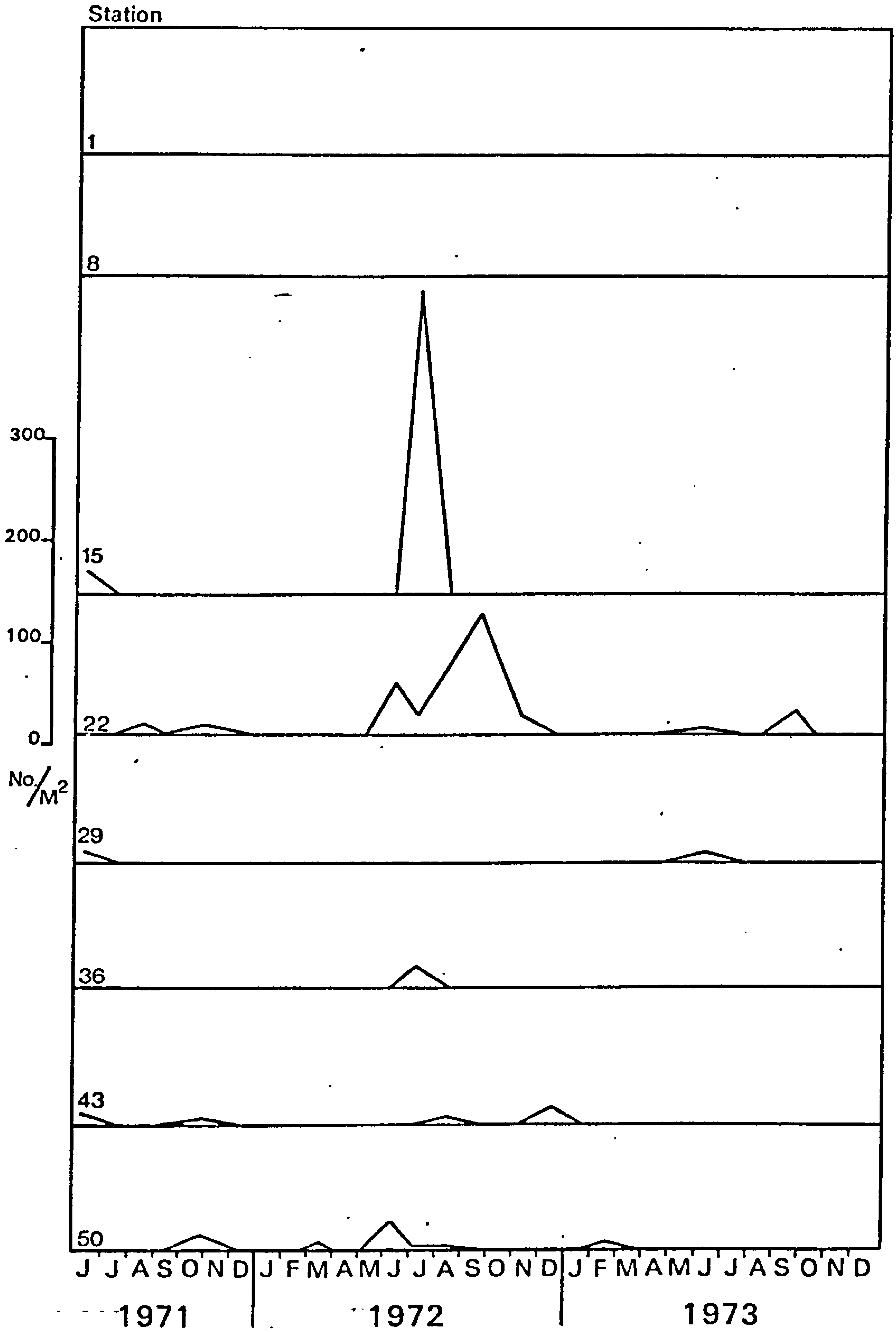


Figure 87. Seasonal variation in density of Crangon vulgaris at each sampling station on the Gayton transect 1971-73.

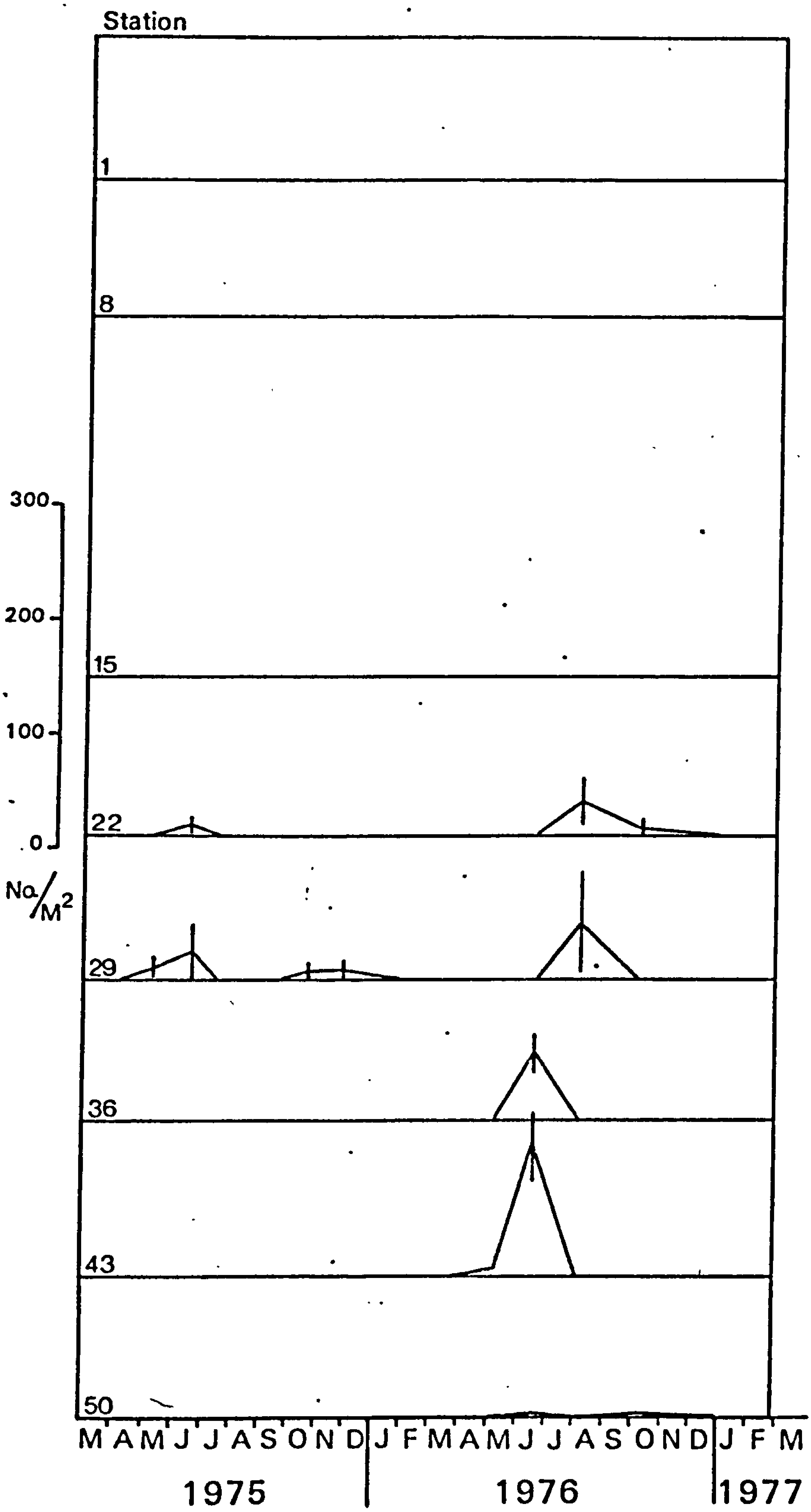


Figure 88. Seasonal variation in density of <u>Crangon vulgaris</u> (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

The rate of increase and decrease was equal. In each year a small uniform base density was recorded during June, but even at these low Summer densities <u>Corophium</u> sp. was never totally absent, a low residual population remained, e.g. June 1975 - mean $27/m^2$, June 1976 - mean $18/m^2$. In each year the time of maximum densities during the Winter varied along the transect but a clear pattern was not evident. The results were unexpected, the mid-Winter maxima differing from the other invertebrates. In a similar study on the Ythan (McLusky 1968) recorded maximum densities of <u>Corophium volutator</u> during late Summer.

The yearly life cycle of <u>C.volutator</u> (Hart 1930; Watkin 1941; McLusky 1968) indicated several possibilities to explain the seasonal nature of the populations but to draw conclusions at this stage on the Dee would be premature without detail of distribution of size frequency. Seasonal changes may well have been affected considerably by migration. Rhymic swimming activity in the genus has been reported by several authors (Schodduyn 1926; Thamdrup 1935; Vader 1964; Morgan 1965). If a predation density mechanism, already described for <u>M.balthica</u>, was working for this species the results indicate a very low survival density threshold on the Gayton transect, perhaps it was a relatively easy prey for the predators, particularly fish during the Summer. Similar seasonal variation in numbers was registered at Thurstaston and Mostyn but the maximum density at two sites in particular (Thurstaston 2 & 3) occurred earlier in the year than on the Gayton transect.

(i) <u>Carcinus maenas</u> (Figs. 89 and 90)

A marked seasonal variability was present. All the specimens found in mid-Summer represented newly settled young stages. The timing of the increase appeared to be correlated with the

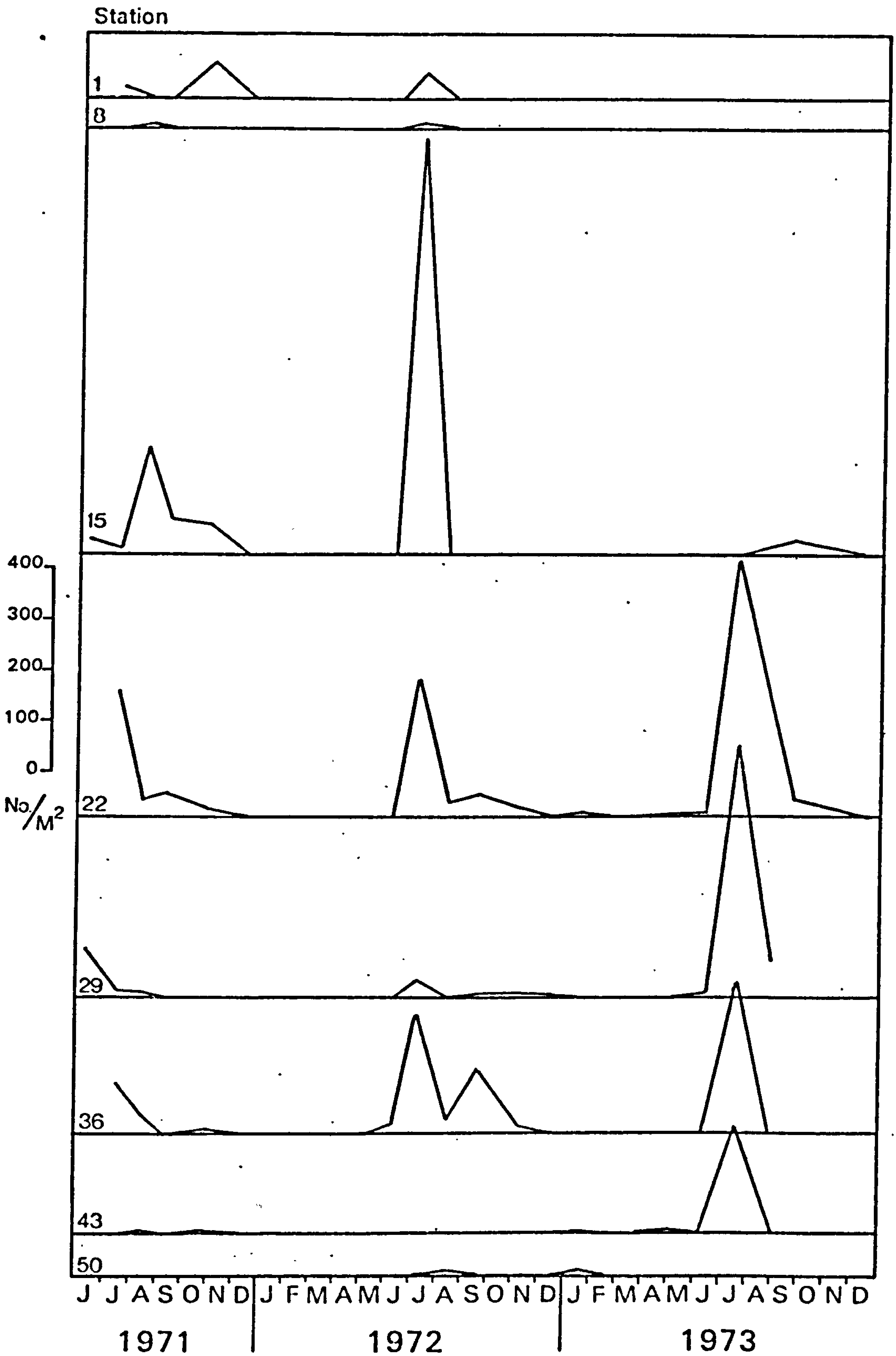


Figure 89. Seasonal variation in density of Carcinus maenas at each sampling station on the Gayton transect 1971-73.

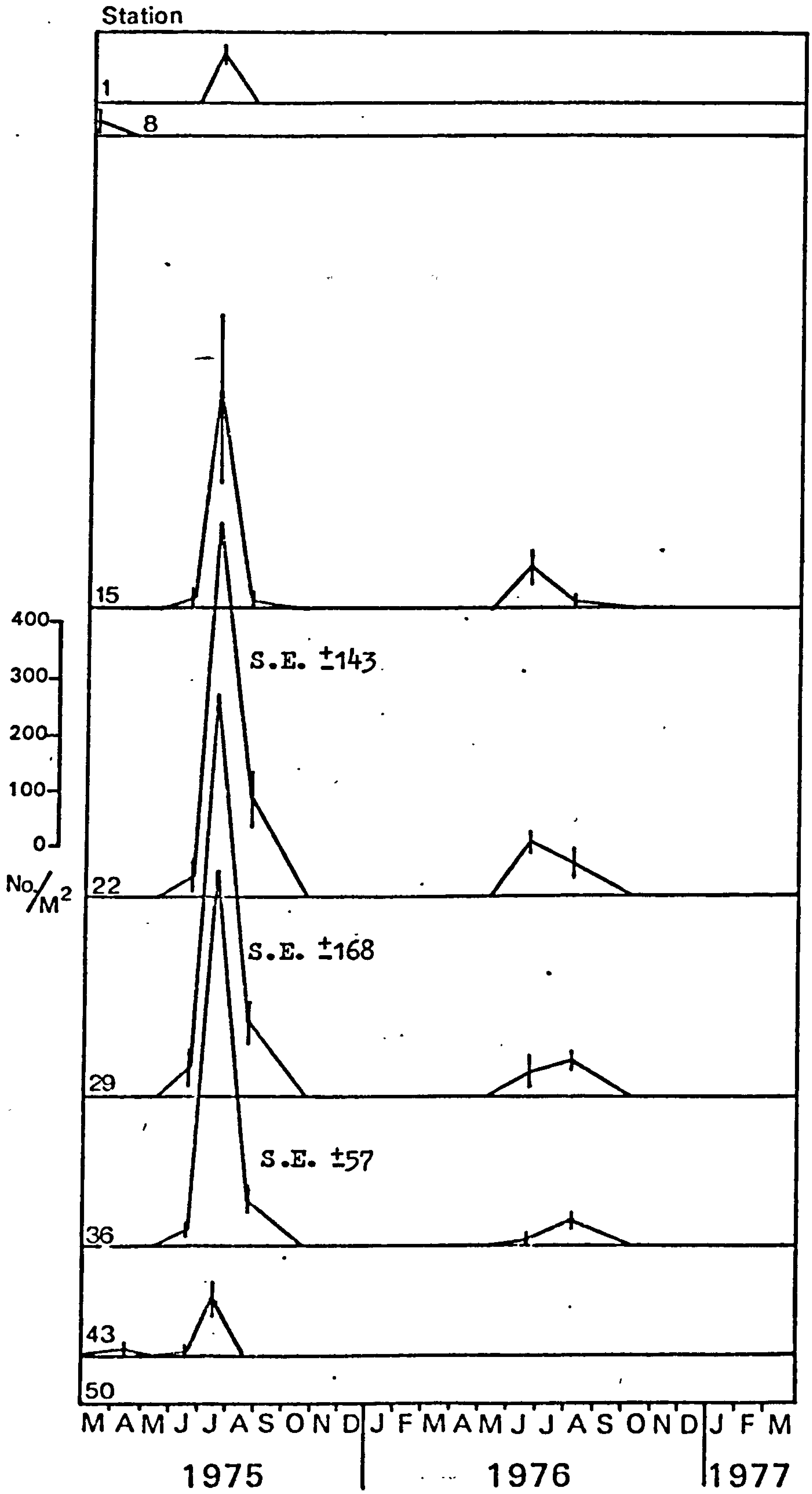


Figure 90. Seasonal variation in density of Carcinus maenas (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

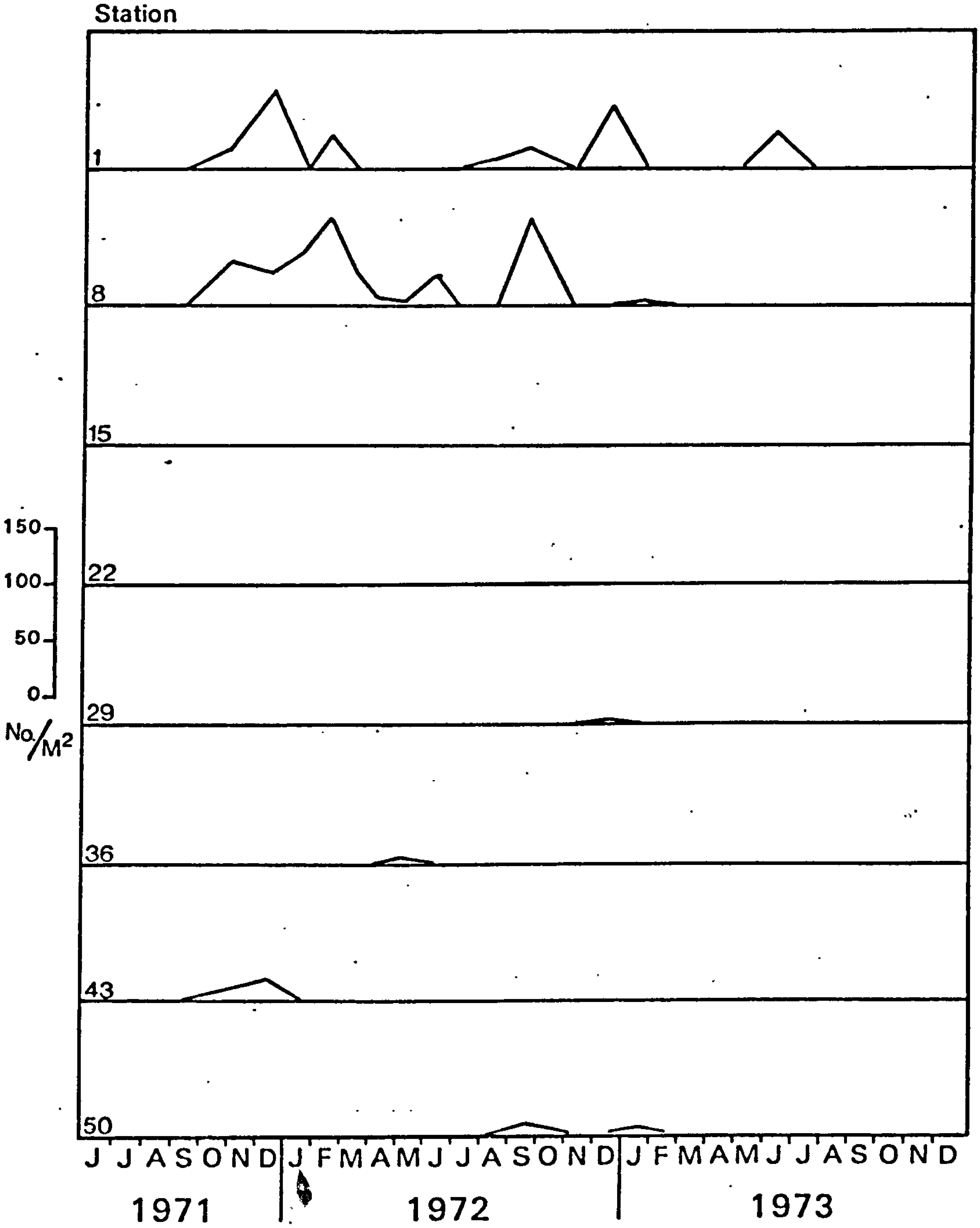


Figure 91. Seasonal variation in density of Diptera larvae at each sampling station on the Gayton transect 1971-73.

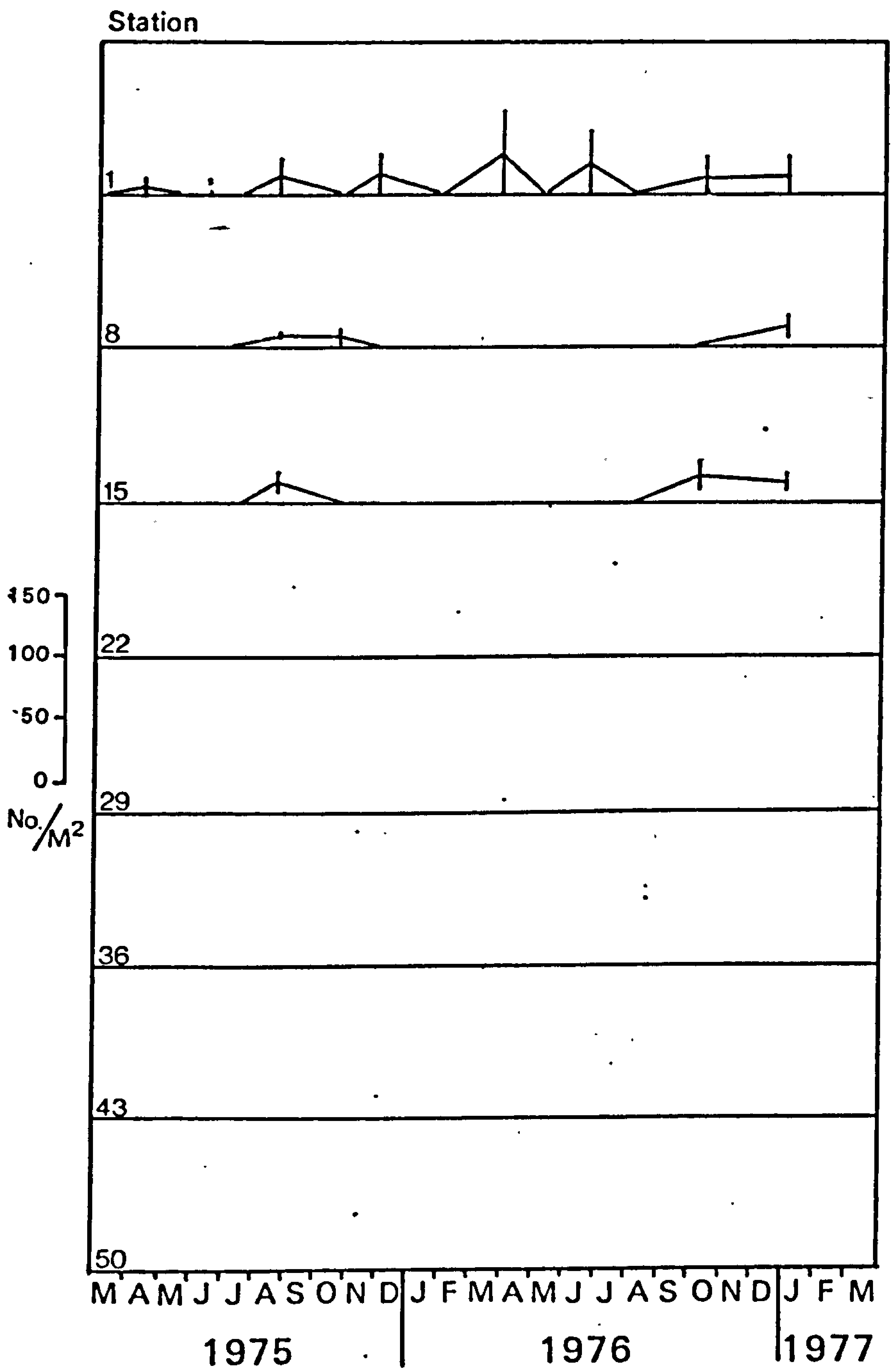


Figure 92. Seasonal variation in density of Diptera larvae (± 1 S.E.) at each sampling station on the Gayton transect 1975-77.

settlement of young M.balthica and it appeared likely that temperature was the controlling factor. The rapid increase in numbers in the Summer was closely followed by an equally rapid decrease. The possibility of migration of small individuals off the transect cannot be discounted but it would appear more likely that predation of C.maenas took place. Both the bird and fish studies have noted C.maenas as a prey species, particularly high numbers being taken by these predators.

Records exist of C.maenas (mainly adult) taking a variety of other invertebrates (Turner 1951a, 1951b; Smith et al 1955; Ebling et al 1964; Perkins et al 1965; Williams et al 1965; Crothers 1968). The relationship to M.balthica has been outlined in the previous section. The absence of adult C.maenas along the transect could be due to their burrowing habit when the tide recedes, their relatively low numbers preventing adequate sampling with the corer. Adults also appeared to be highly susceptible to attack from gulls if left stranded on the open mudflat. Conversely large populations of adults were present within the saltmarsh particularly in the early Spring. Naylor (1962) suggested temperature had an effect on the movement of large C.maenas on the shore and noted a movement up the shore in March and April.

(j) Exclosure experiments (Figs. 93 - 109)

(i) Introduction

In 1975 the netted area experiment (outlined in the previous section) was repeated but this experiment was extended in an attempt to differentiate the relative importance of the bird and fish populations. The hypothesis to be tested was that if both components were reacting to prey densities with predation occurring at an increased rates at the higher densities (density dependant mechanism), the probability existed that if one of the components could be excluded the other component, acting in a density dependant mechanism, would compensate and maintain the mortality curve. Therefore, in addition to the nets which excluded both vertebrate predators (Total Exclosures) I devised nets which floated on the tide over a defined substrate excluding each component separately yet allowing normal predation by the other (Bird and Fish Exclosures). Initial difficulties were encountered with the fish exclosure and a redesigned model was installed one month after the start of the experiment. The original intention was to remove the total exclosure in late Winter after an artificially high density had been maintained but severe north westerly gales caused damage to all the nets at the end of December 1975 and the remains were removed. Site location was determined by four main considerations :

The nets, for economy of effort, had to be situated in an area where investigations were taking place and there was apparent predation.

A productive area was required where there was known high densities of invertebrates and as rich as possible in species.

The area had to be relatively inaccessible to avoid vandalism.

In a protected area away from severe wave action.

The nets were positioned at Stations 22 and 29 on the Gayton transect. Two stations were selected to alleviate problems encountered in the previous net.

(ii) Construction

The main consideration in the construction of the nets was to exclude the feeding vertebrates without interfering with the normal physical chemical environment. The major problem to overcome was preventing major changes in the water velocity. From previous experience with net construction (Gillham 1974) it was noted that any poles or stakes should be thin, large poles caused severe scour at the base.

Total exclosures

Construction is seen in Fig 93. The net consisted of a square with sides 6.5 metres long. At each corner was placed a 5 x 5 cm stake driven deep into the substrate. At a height of 60 cm approximately was a 7 gauge perimeter wire. This was kept tensioned by wires at each corner anchored in the substrate by 60 cm metal discs dug deeply into the substrate. At intervals round the perimeter and within the experimental area were placed 20 thin bamboo canes to help support the perimeter wire and the polythene twine over the top of the net. Round the perimeter within the substrate was placed a thick polythene sheet to a depth of 30 cm. The upper 2-3 cm approximately were left free on the surface helping to prevent future covering of the sheet. At a depth of 5 cm was placed a polythene perimeter rope. The sides of the square were covered in 2.5 cm 'netlon' netting attached at the top and bottom by the 7 gauge perimeter wire and the polythene rope buried in the substrate. The top of the square was covered with 12 cm 'netlon' pea netting. 12 cm netting was used basically to help reduce changes in water velocity and prevent strain on the framework.

From observation it was noted that the waders, when on the ground, were not inclined to fly over the perimeter net. This was substantiated by a notable lack of footprints within the net on the occasions that it was visited and the perimeter net was not damaged. However, if the perimeter net was damaged, occasional tracks were visible. Similarly it was assumed that the P.flesus population would be found mainly near the surface of the sediment and the perimeter net would act as an effective barrier. It was envisaged that the upper net would act as a deterrent to entry. In practice it was found very few fish became trapped within the net. There was

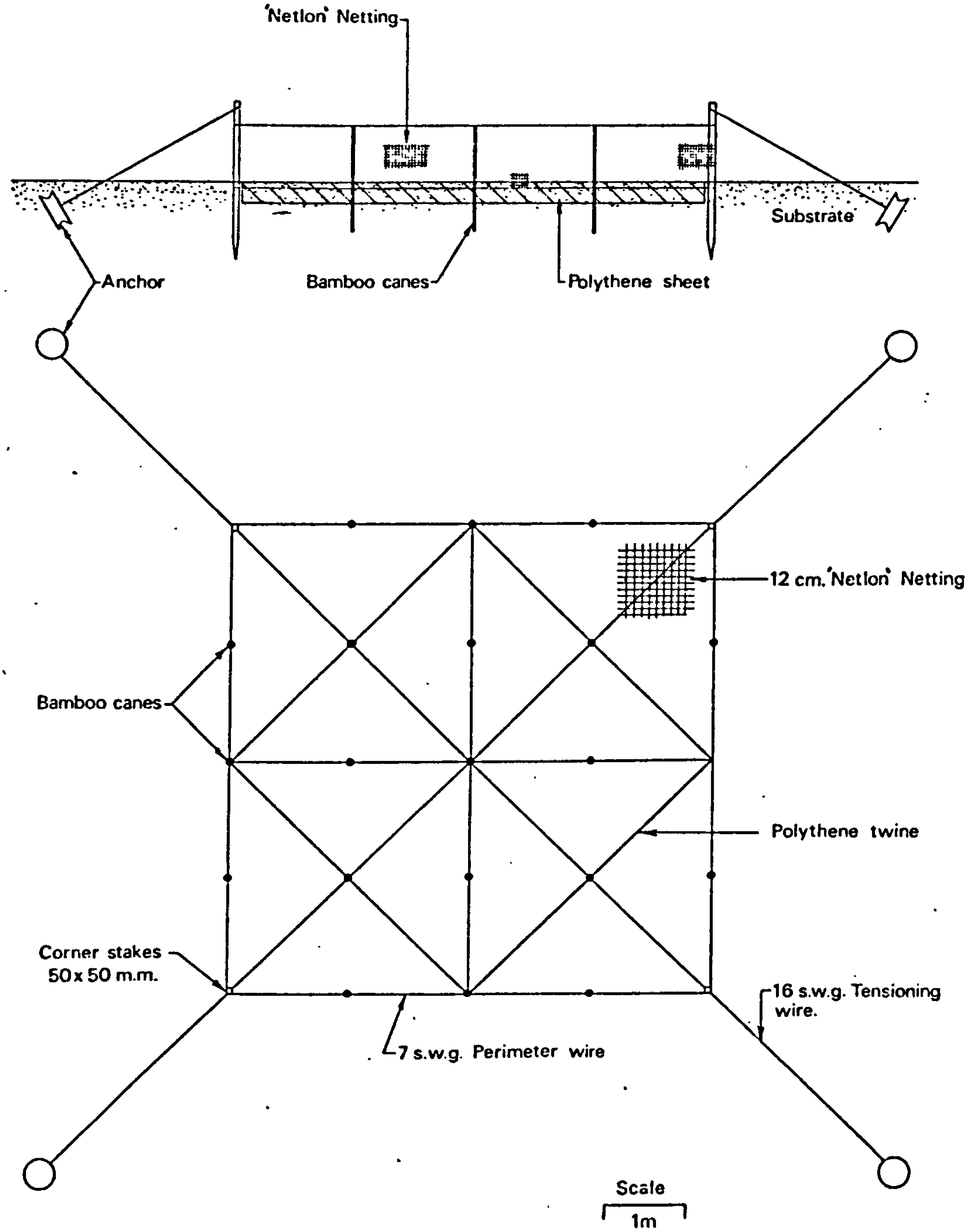


Figure 93. Construction of Total exclosure.

not, however, a 100% exclosure of fish.

The nets stood up well to moderately severe weather conditions but frequent repairs were necessary, particularly to the side netting. Scour was noted at the corner stakes but very little around the bamboo canes. The accumulation of material within the net due to reduced velocity did occur and was estimated at approximately 4 cm during periods of maximum accumulation.

Bird Exclosures (Fig 94)

This consisted of a 6 metre square. The basic idea was of a floating box covered with net on the sides and top which would rise with the tide allowing the fish to feed normally and lower on to the same position at the ebb, thereby excluding the birds.

Construction of the basic box was of 5 cm x 5 cm pine. To prevent waterlogging two coats of marine varnish and a rubberized inert paint top coat were applied. The sides of the exclosure were prefabricated on shore and later taken out by boat. At each corner was placed metal angles to strengthen the construction. To the four upper angles were attached the anchor ropes. 12 mm polypropolene rope was used, this was chosen particularly because it had less stretch characteristics than nylon and was, unlike nylon, unaffected by sunlight. The anchor ropes were 24 metres in length. This proved to be of sufficient length to allow the exclosure to float freely at least two metres vertically but at the same time prevented lateral movement.

In practice the net was observed to float to at least 2 metres, although it became submerged at Spring tides, this probably helped in its protection. On the ebb the exclosure was seen to settle on the same position each tide. Its position could be noted relative to the polythene sheet buried in the substrate around the

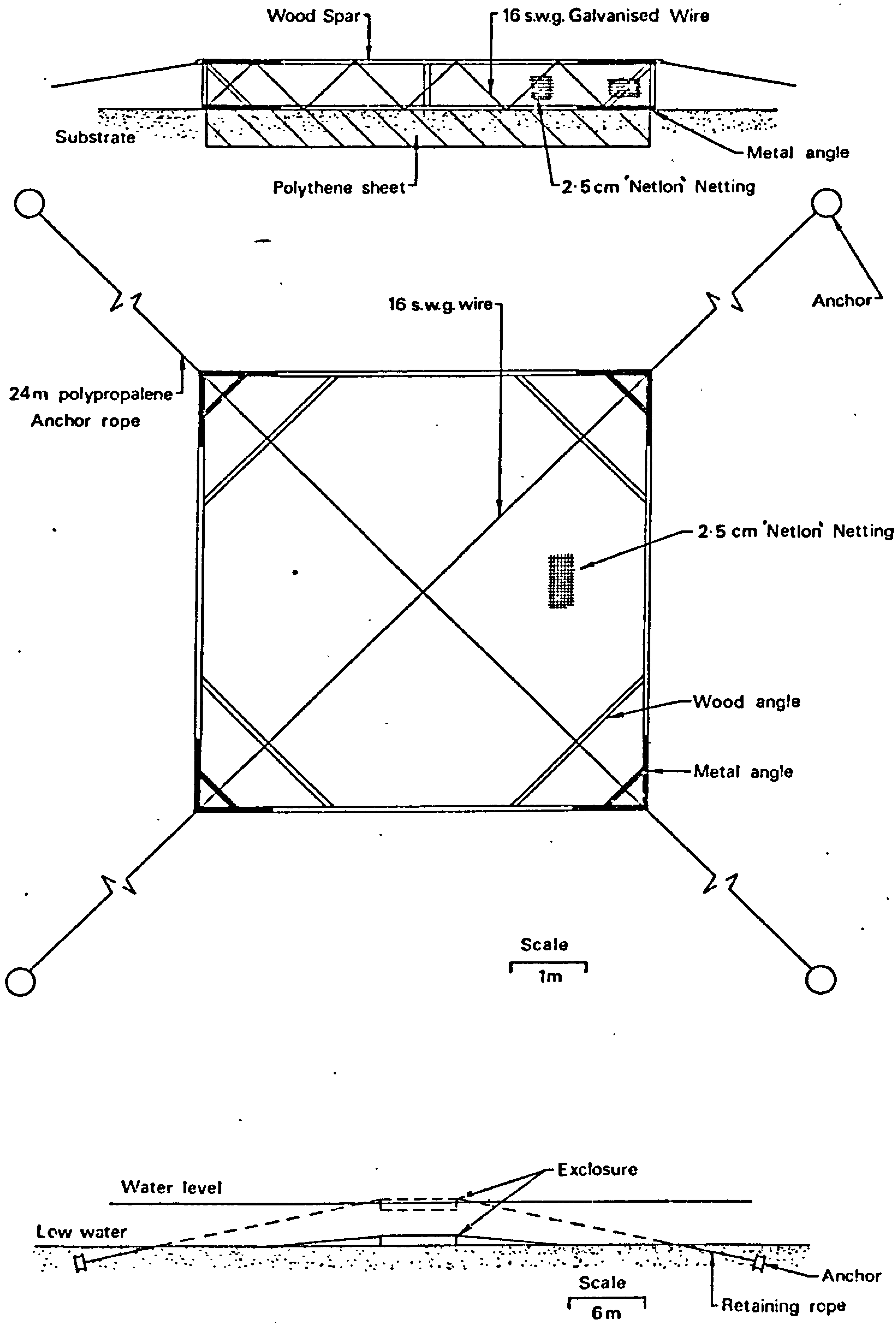


Figure 94. Construction and operation of Bird exclosure.

perimeter. The sides and top were covered in 2.5 cm 'netlon' netting fastened by staples to the timbers. The first net was constructed at Station 22 and a later net at Station 29. Sampling took place by disconnection of anchor ropes and then physically moving the net to allow entry to the square. In practice the side netting proved difficult, the staples easily breaking off and requiring constant maintenance.

Fish exclosure (Mark II) (Fig 95)

This consisted of two 6 metre square frames, one free to float in the water body, the other buried 15 cm in the substrate. Between the two frames was stapled a 2.2 m high 2.5 cm 'netlon' net. Around the perimeter was placed polythene sheeting to a depth of 30 cm. The angles of the upper frame was reinforced with metal angles of similar construction to the bird exclosure. To the metal angles were attached two anchor ropes at each corner, one to prevent excessive vertical movement, the other to prevent lateral movement. Each anchor rope was attached to a 40 cm metal disc 70 cm deep in the substrate.

The net apparently worked well causing no obvious build up of sediment within the area. Only occasional fish were found trapped within the net and from the evidence of bird tracks these were not affected by the presence of the net lying on the substrate and over which they would have to pass.

(iii) Results

Statistical significance of the difference between the control and the various exclosures was performed by a 't' test. Results of the variance ratio F test using the 5% significance level indicated that M.balthica and N.diversicolor could be tested further but the other species were not suitable. However the results have been

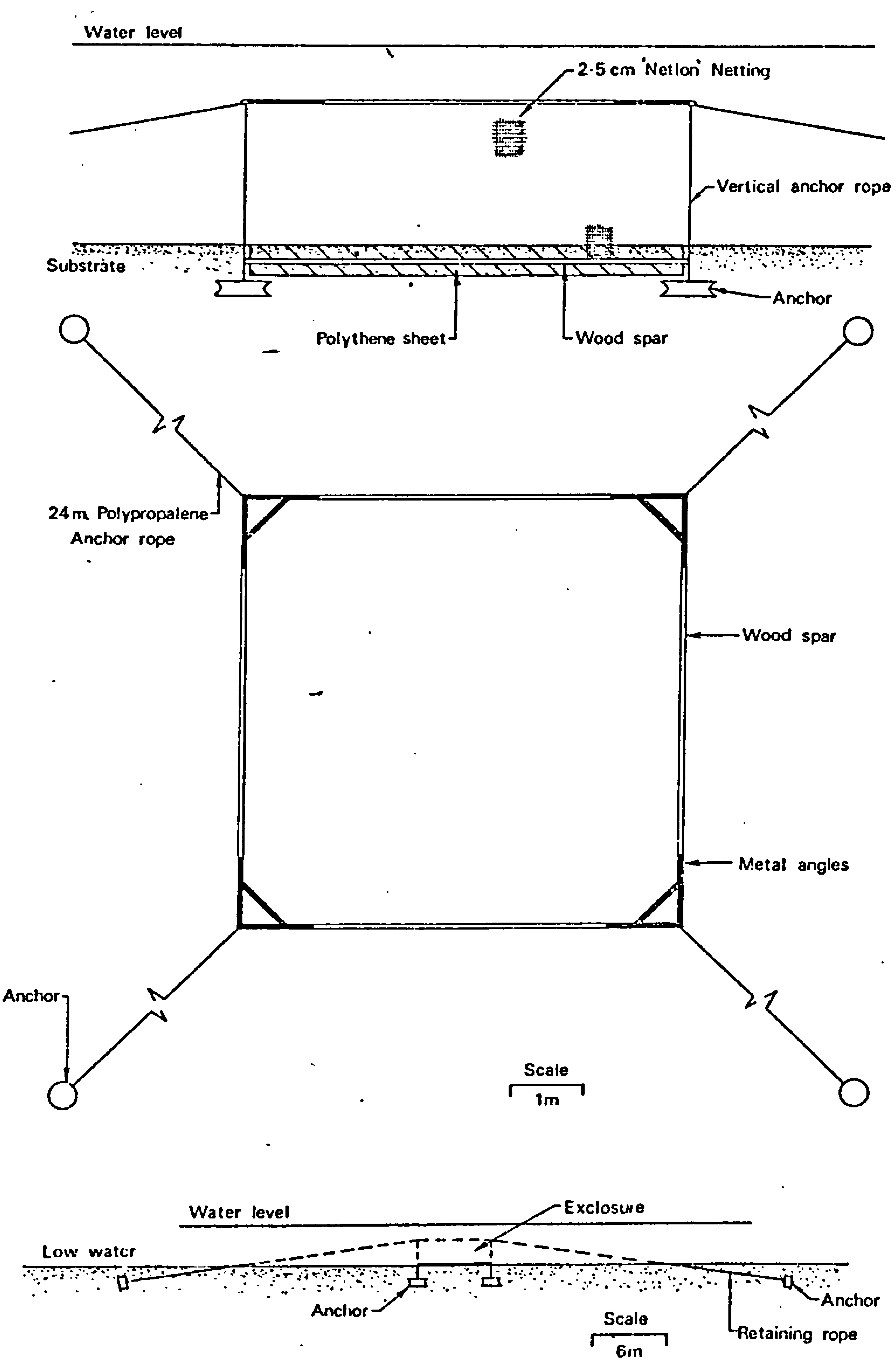


Figure 95. Construction and operation of Fish exclosure II.

presented graphically.

Macoma balthica (Figs. 96 - 98)

Station 22

When the exclosures were established densities did not differ significantly from the control. Settlement took place as seen in previous years and other stations. Maximum density occurred in August at the control. The densities under the total exclosures were not significantly different at Total Exclosure I but significant at Total Exclosure II (<.05). No sample was obtained from the bird exclosure at this time. There was then the normal exponential logarithmic loss curve at the control, a curve which was closely followed by the bird exclosure densities with no significant difference.

In the total exclosures, however, the typical loss curve was modified, there being the retention of a higher density, so that by November there was a very highly significant difference from the control (P<.001). Contrary to the theoretical ideal where this density would be maintained there was then a substantial loss in numbers, but the significance of the difference from the control was maintained at Total Exclosure I and slightly less at Total Exclosure II (P<.01). The nets were removed at this period and there followed a rapid decrease in numbers so that by March 1976 no significant difference could be detected between the former netted areas and the control.

Graphical presentation of the ≤10 mm and >10 mm M.balthica emphasised that these results (due to the higher numbers) were concerned with the ≤10 mm O group M.balthica. The significance values for the differences between the populations being almost identical to the M.balthica Total figures. The >10 mm M.balthica did not indicate a a significant difference between the nets and the numbers investigated.

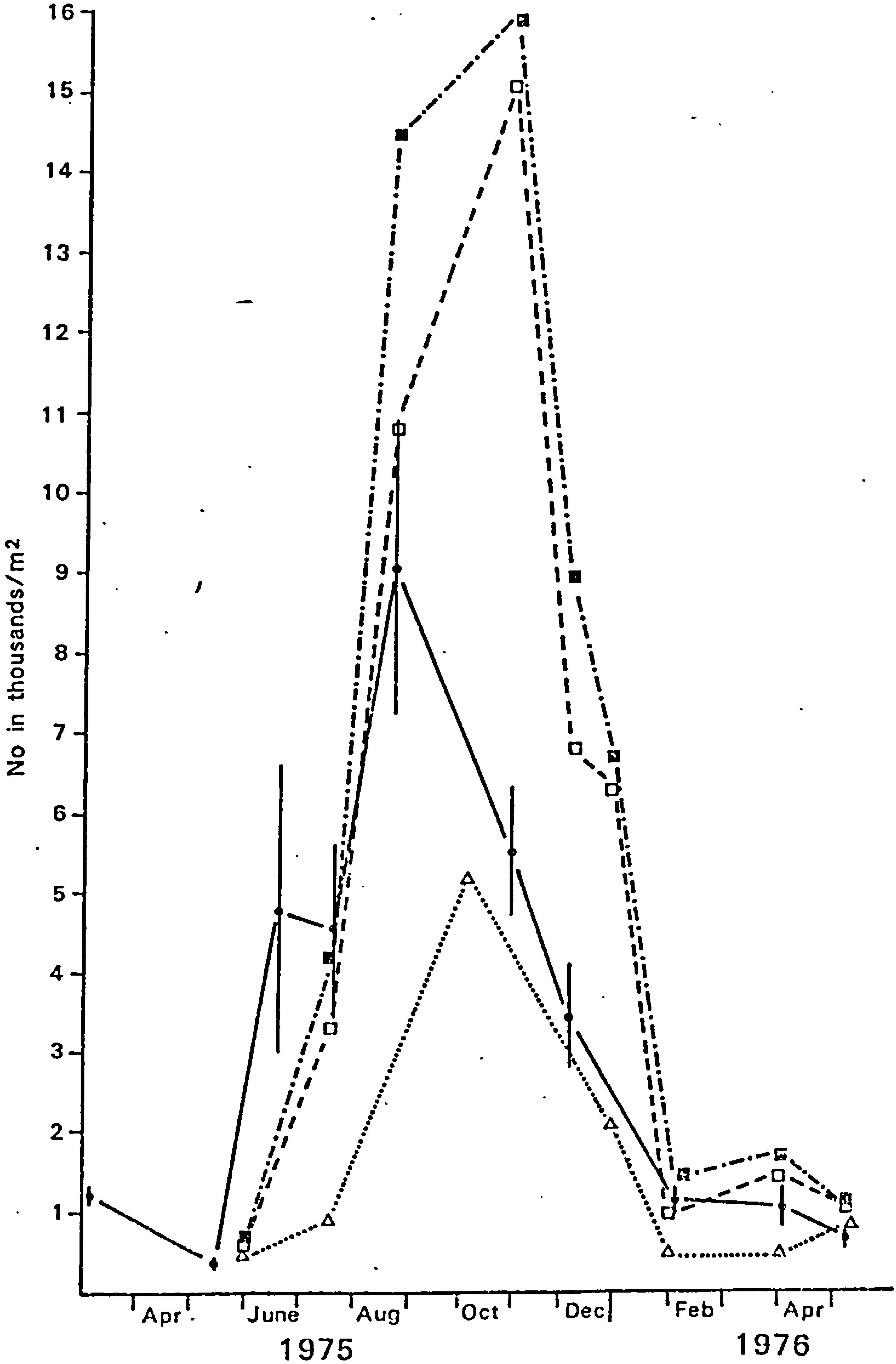


Figure 96. Variation in density of Macoma balthica at Station 22 experimental area, Gayton. ——•—— Control (± 1 S.E.); – – □ – – Total exclosure I; —·■—· Total exclosure II; ·····Δ····· Bird exclosure I.

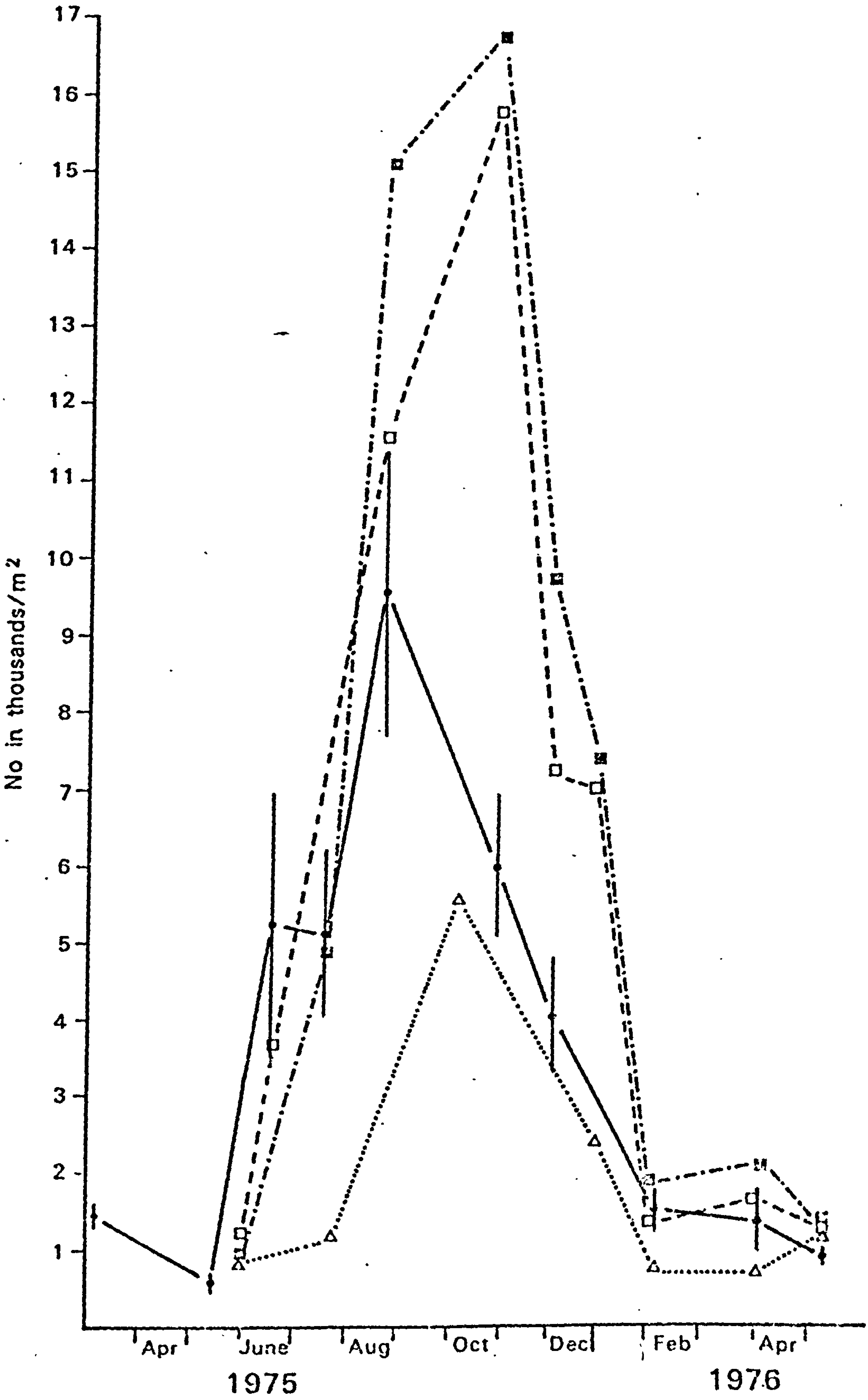


Figure 97. Variation in density of Macoma balthica 10 mm and less in length at Station 22 experimental area, Gayton. ——•—— Control (± 1 S.E.); --■-- Total exclosure I; ·-·□·-· Total exclosure II; ······Δ······ Bird exclosure I.

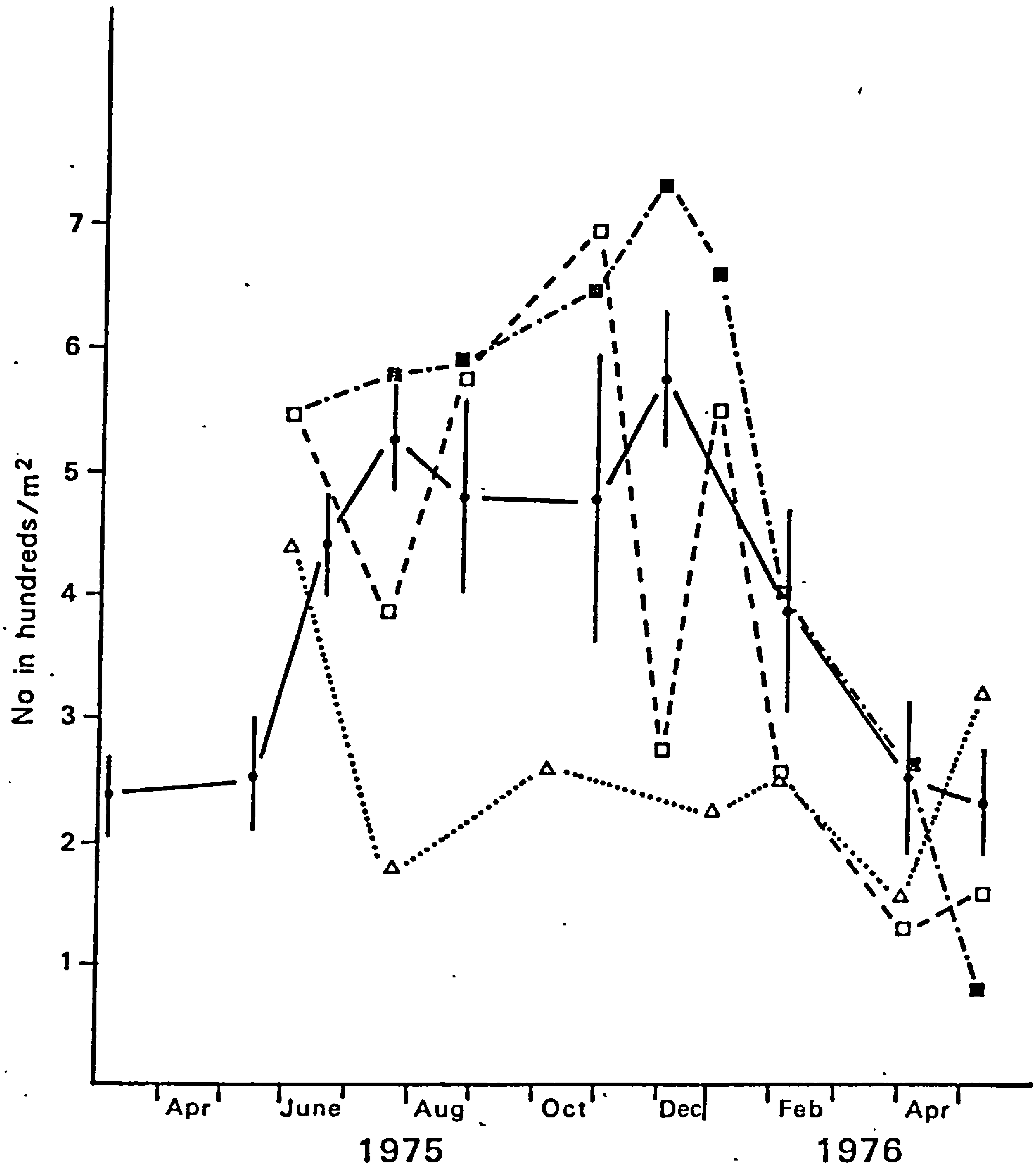


Figure 98. Variation in density of Macoma balthica more than 10 mm in length at Station 22 experimental area, Gayton. —•— Control (± 1 S.E.); --□-- Total exclosure I; ·—·■·—· Total exclosure II; ·····△····· Bird exclosure I.

Station 29

The control density indicated the normal settlement increase followed by the log regression seen at other stations and in previous years. Comparative sampling late in the experiment indicated significant differences between the control and the nets ($P<.01$) before the net was removed. After removal there was the rapid levelling of densities so that by March 1976 there was no significant difference.

The similarities of the graphs for M.balthica Total and ≤10 mm again emphasises the predominance of the ≤10 mm group. The >10 mm group densities allowed some significant results to be expressed, e.g. there was a significant difference between between the control and nets in November 1975. After net removal results indicated a non-significant difference.

Nereis diversicolor

Station 22

The control had an increase in density in late July followed by the usual decrease in density noted previously and at other stations on the transect. At the start of the experiment, when the nets were established, densities were similar but there was a significant difference between the control and Total Exclosure II and the Bird Exclosure I ($P<.05$). A higher recruitment occurred under the Total Exclosures ($P<.01$). Following recruitment densities under the total exclosures remained relatively constant but decreased prior to the net being removed. During this period at first highly significant ($P<.001$) and later significant ($P<.01$) differences from the control were noted. The situation under the Bird Exclosure I, however, closely followed the control, differences from the control not being significant. Following the removal of

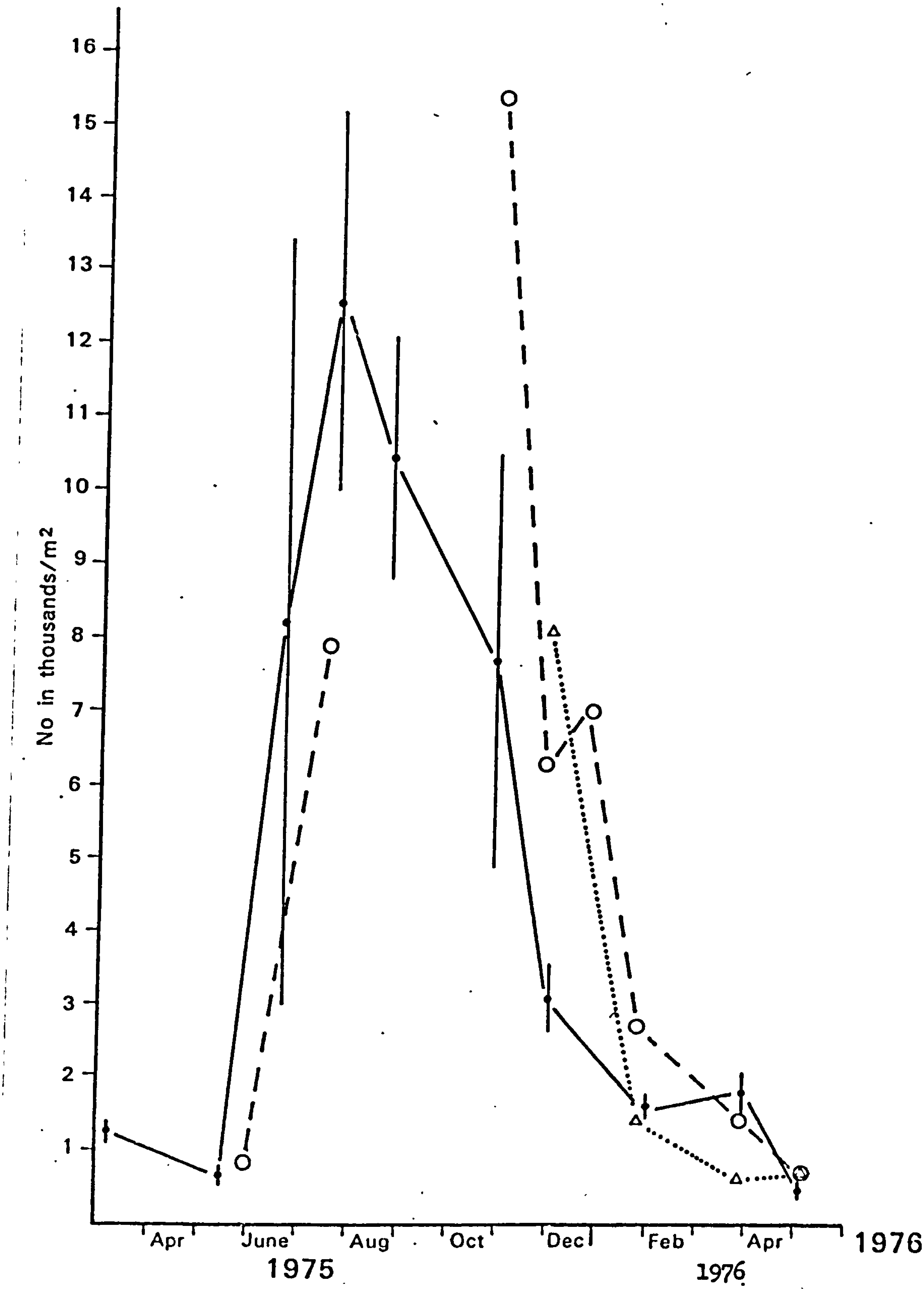


Figure 99. Variation in density of Macoma balthica at Station 29 experimental area, Gayton. —•— Control (± 1 S.E.); ······Δ······ Bird exclosure II; – – o – – Fish exclosure.

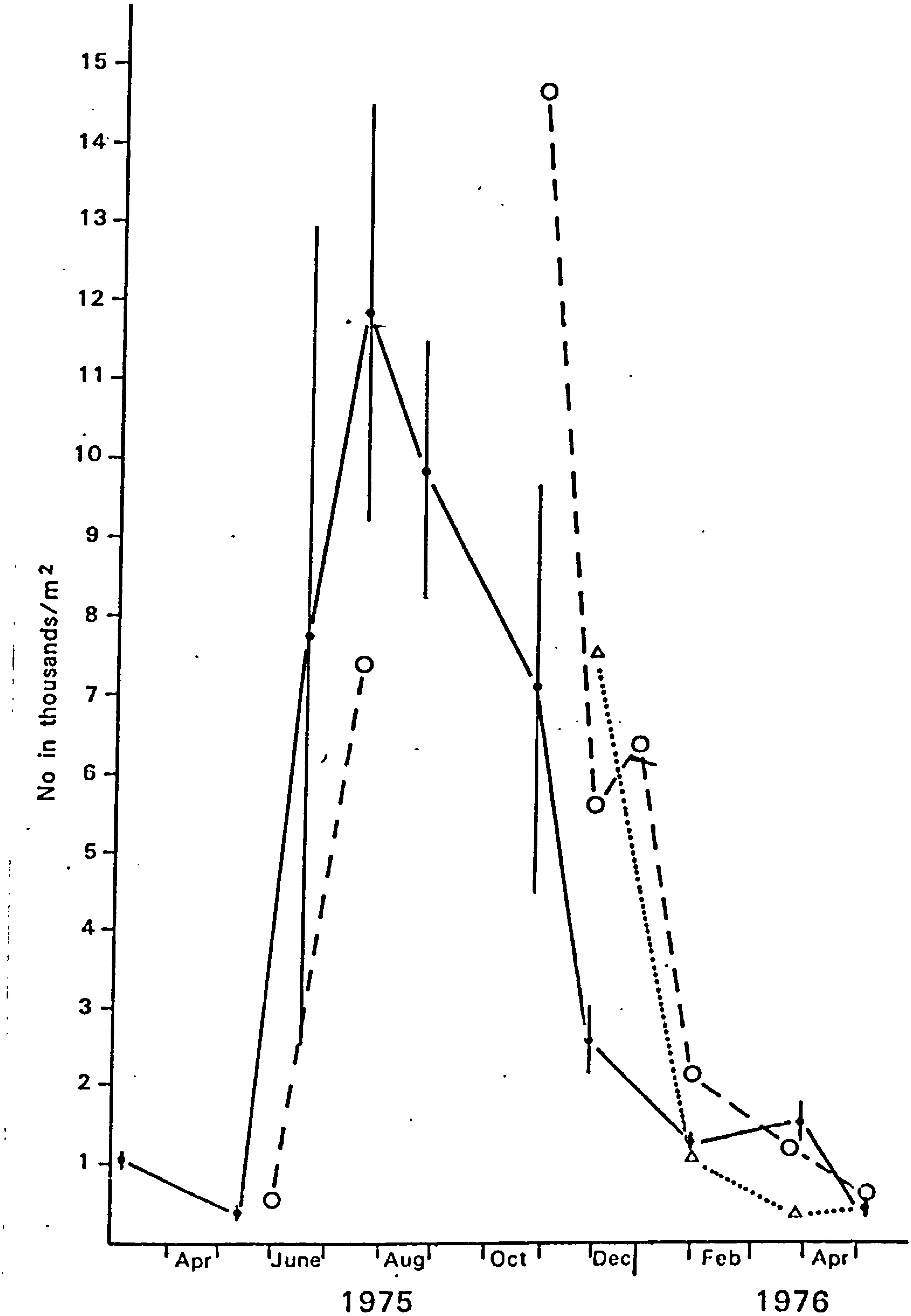


Figure 100. Variation in density of Macoma balthica 10 mm and less in length at Station 29 experimental area, Gayton. ——•—— Control (± 1 S.E.); ········Δ······ Bird exclosure II; – – O – – Fish exclosure.

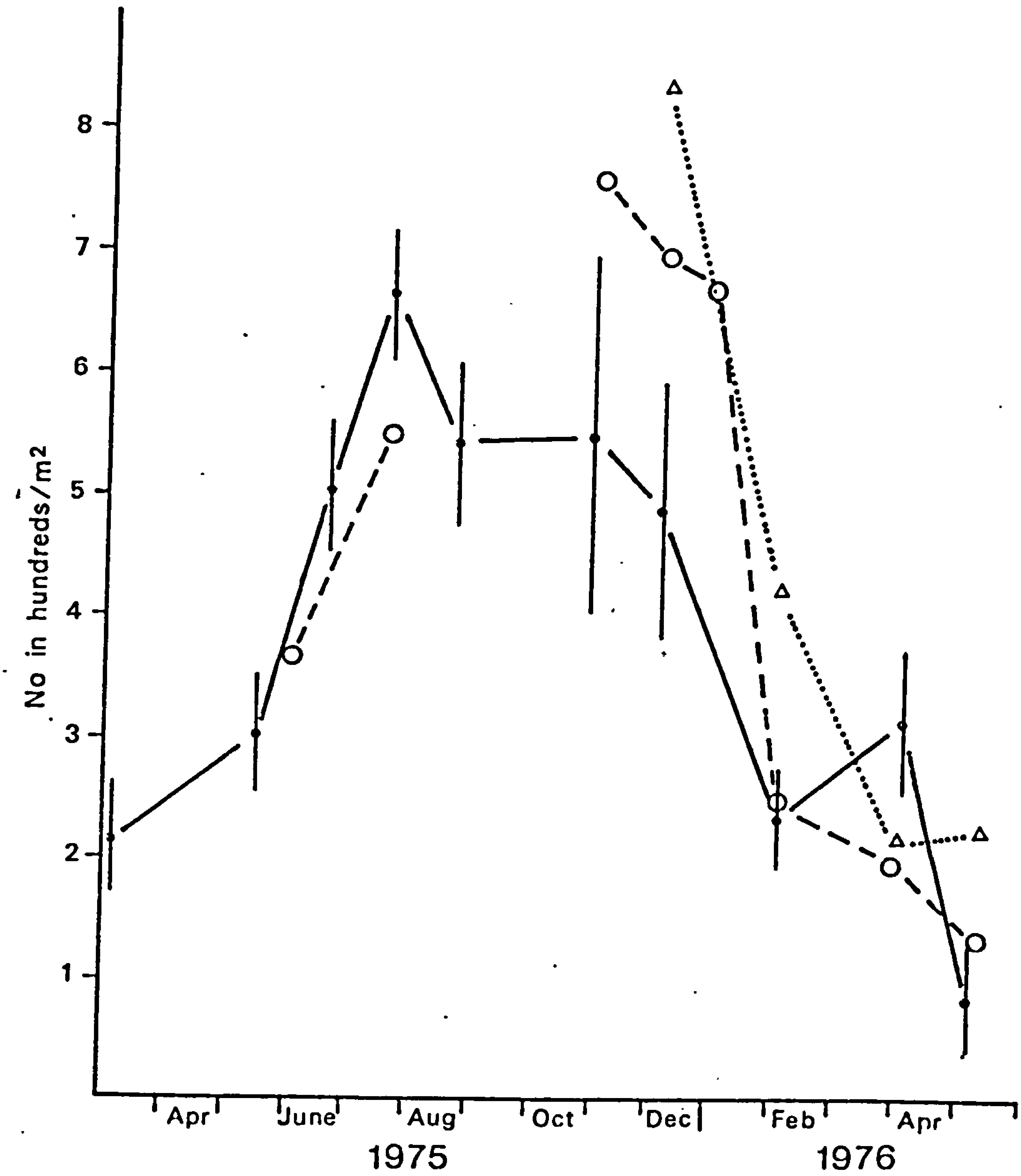


Figure 101. Variation in density of Macoma balthica more than 10 mm in length at Station 29 experimental area, Gayton.
—•— Control (± 1 S.E.); ·····Δ····· Bird exclosure II; – – O – – Fish exclosure.

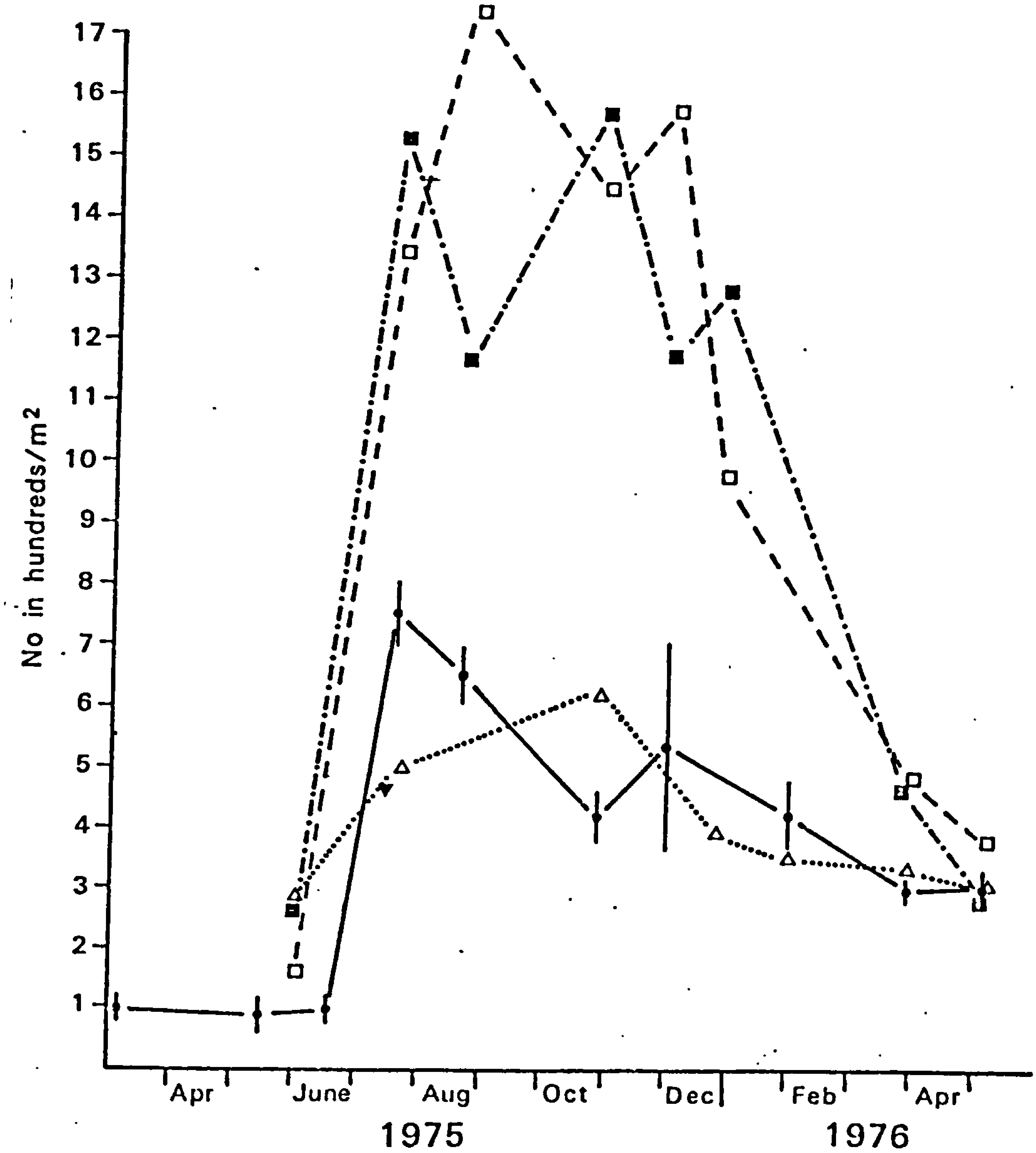


Figure 102. Variation in density of Nereis diversicolor at Station 22 experimental area, Gayton. —•— Control (± 1 S.E.); - - □ - - Total exclosure I; ·—■·— Total exclosure II; ·····△····· Bird exclosure I.

of the net there was an increased loss from the Total Exclosure areas until May when no significant difference could be found from the control.

Station 29

From the data available after the net was removed the densities in the fish exclosure did not differ significantly from the control. The densities in the bird exclosure were significantly lower (P<0.01) before net removal. However, densities at the three stations became remarkably similar by May 1976.

(iv) Conclusions

The N.diversicolor results at Station 22 substantiated the hypothesis. The total exclosures prevented predation and net removal was followed by increased predation. Under the bird exclosure fish predation closely followed the predation rate of the control.

These results were closely paralleled by M.balthica Station 22 results but in this species there was an unfortunate drop in density two months before the net was removed. A possible late migration of M.balthica from under the net may have been involved and the difficulties of maintaining the net prevented the 100% exclusion of birds. Fortunately, however, before the net was removed there was still a density significantly higher than the control.

At Station 29 N.diversicolor and M.balthica were not sampled as intensively as Station 22 and on the records obtained did not support the hypothesis, significant differences between the exclosures and the control were still present before the net was removed.

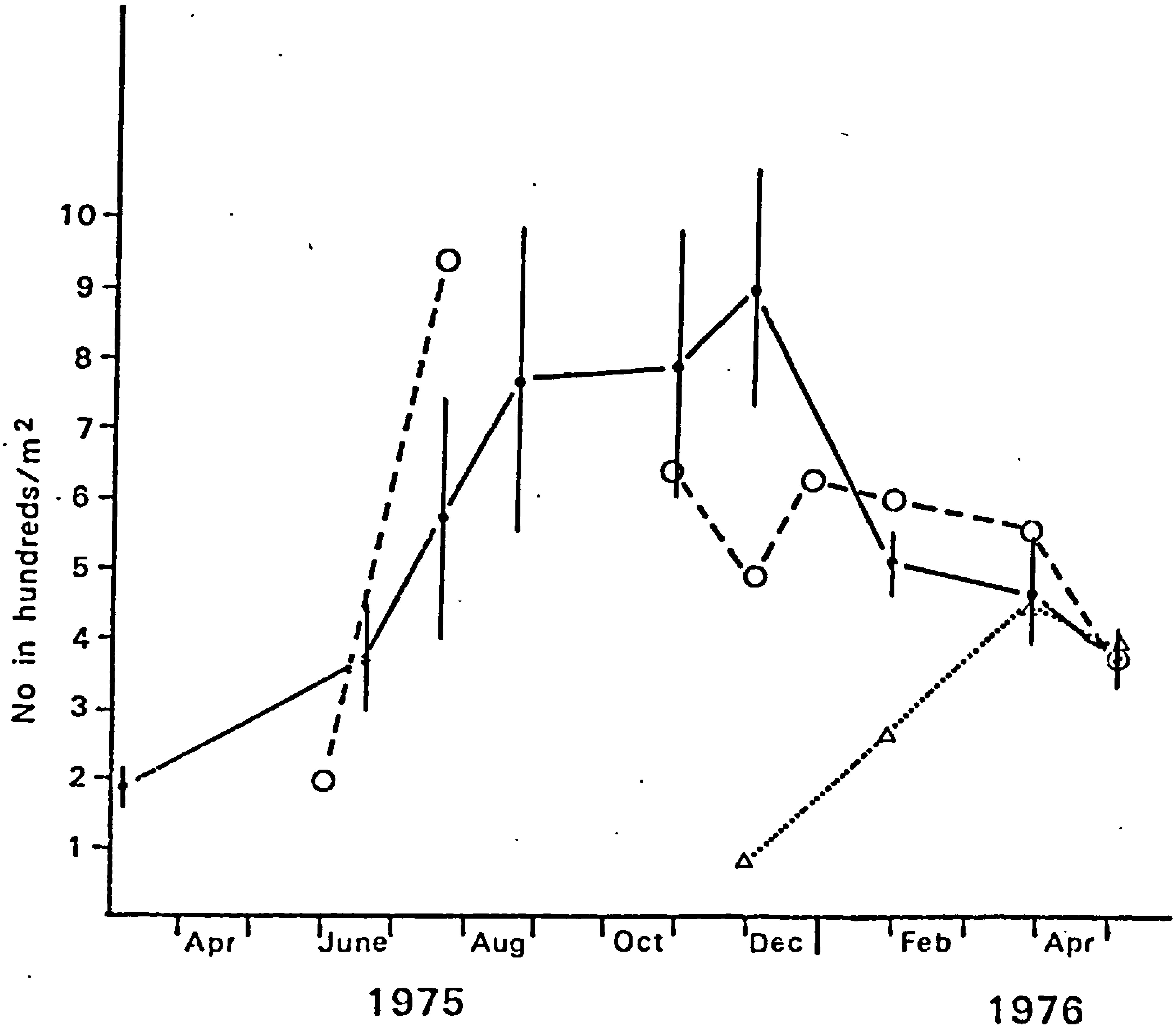


Figure 103. Variation in density of <u>Nereis diversicolor</u> at Station 29 experimental area, Gayton. ——•—— Control (± 1 S.E.); -----Δ------ Bird exclosure II; – – O – – Fish exclosure.

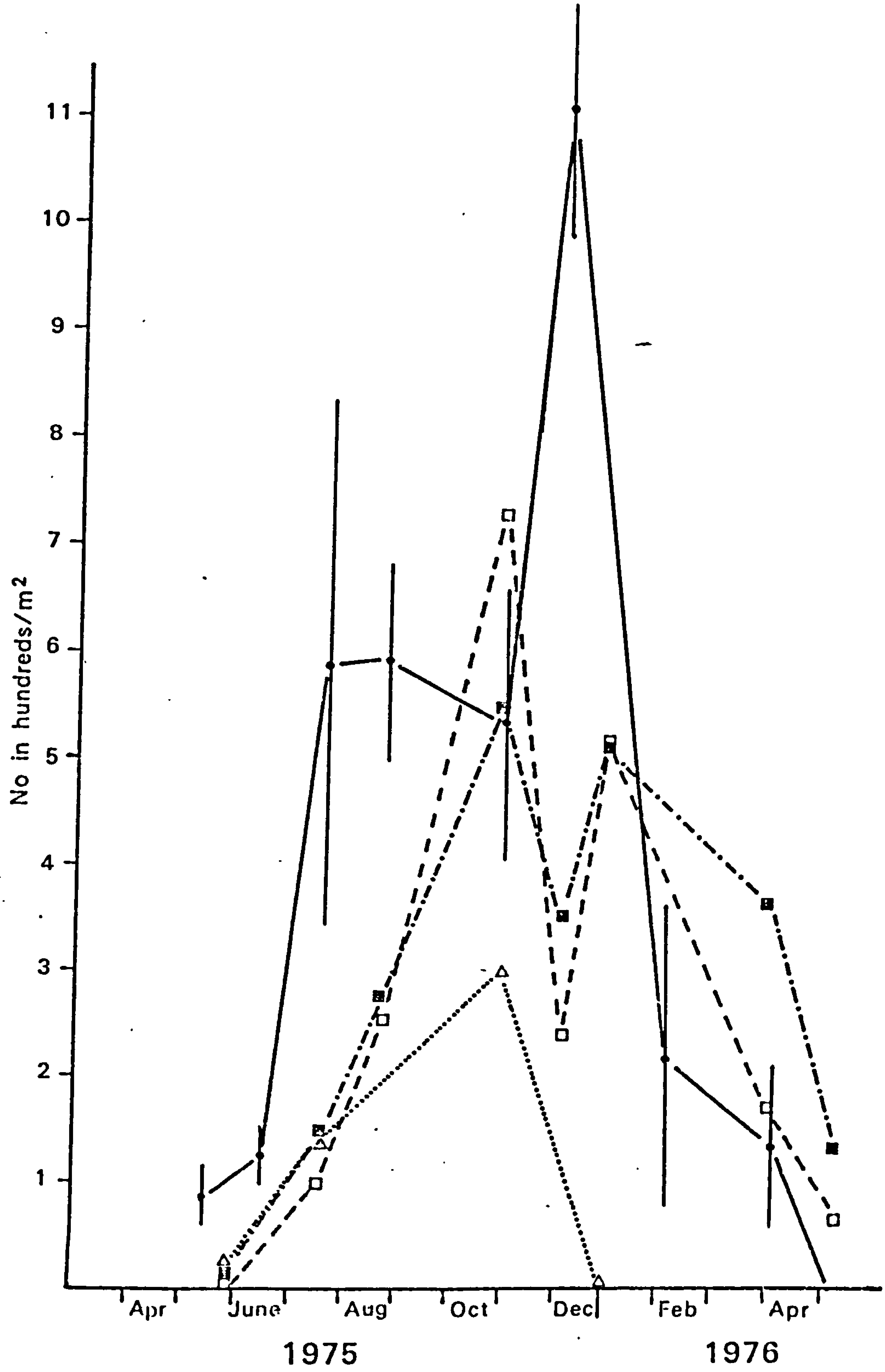


Figure 104. Variation in density of Scrobicularia plana at Station 22 experimental area, Gayton. —•— Control (± 1 S.E.); --□-- Total exclosure I; ·—■·— Total exclosure II; ·····Δ····· Bird exclosure I.

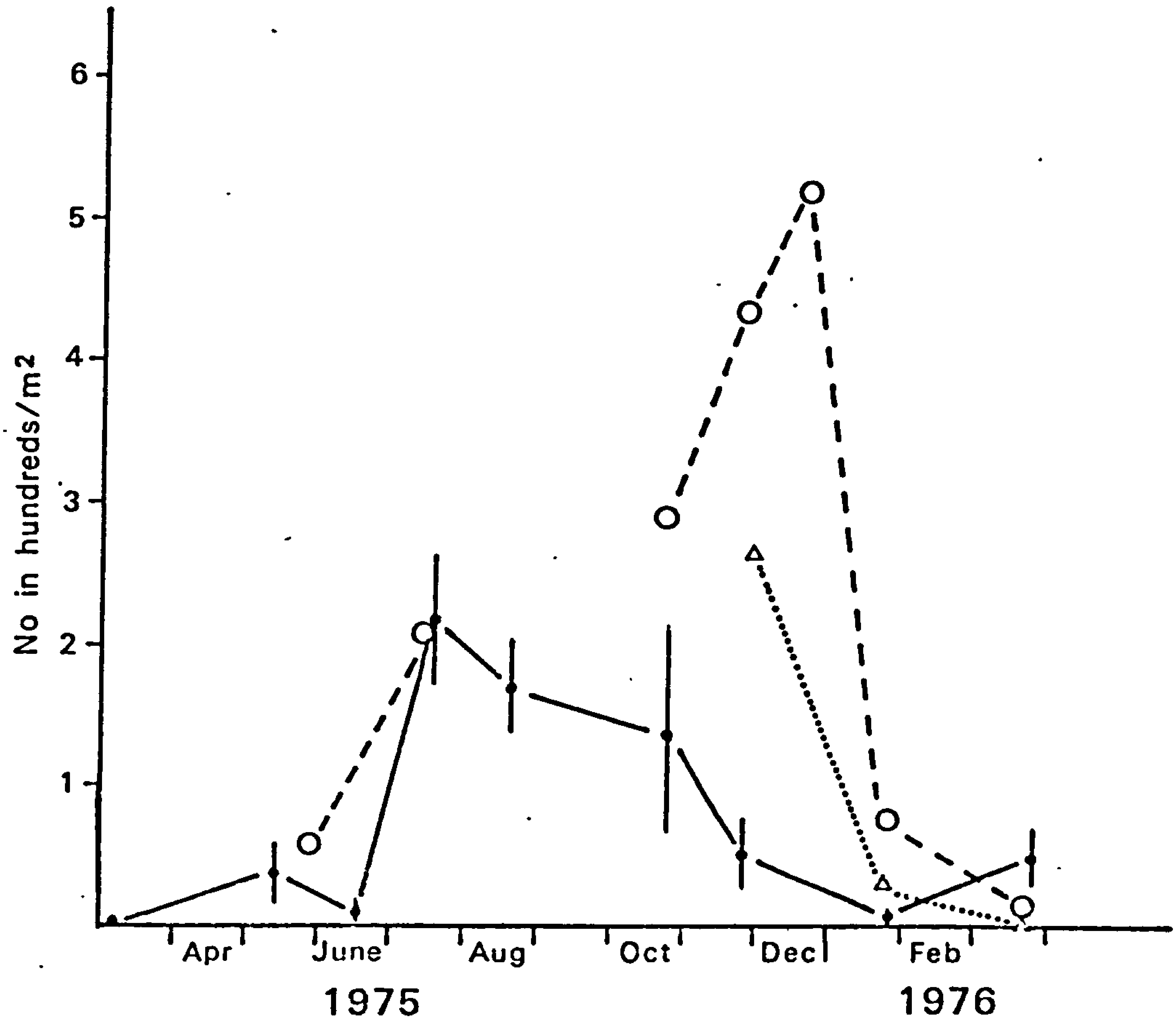


Figure 105. Variation in density of Scrobicularia plana at Station 29 experimental area, Gayton. ——•—— Control (± 1 S.E.); ·······Δ······· Bird exclosure II; – – O – – Fish exclosure.

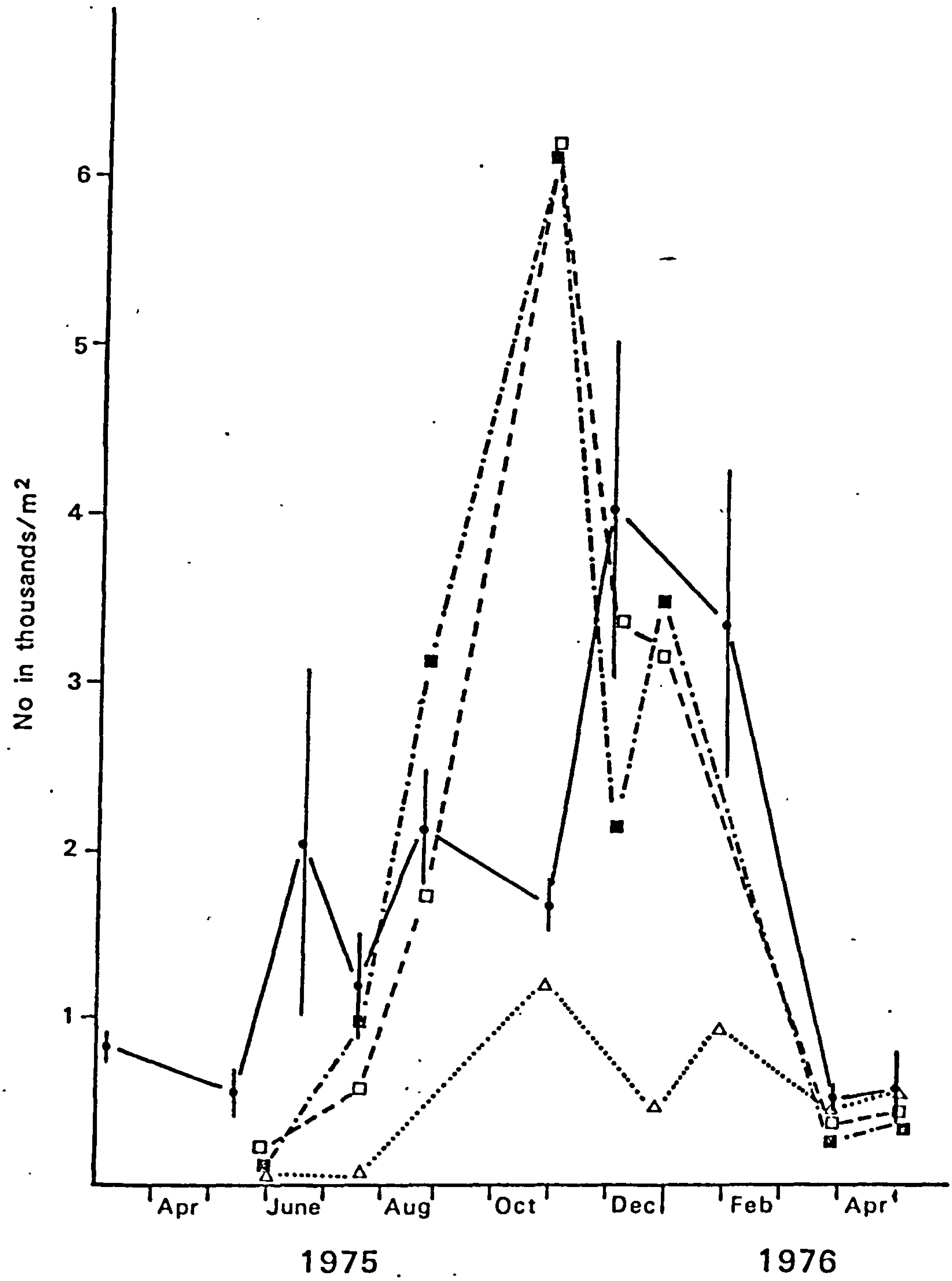


Figure 106. Variation in density of Hydrobia ulvae at Station 22 experimental area, Gayton. —•— Control (± 1 S.E.); --□-- Total exclosure I; -·■·- Total exclosure II; ······Δ······ Bird exclosure I.

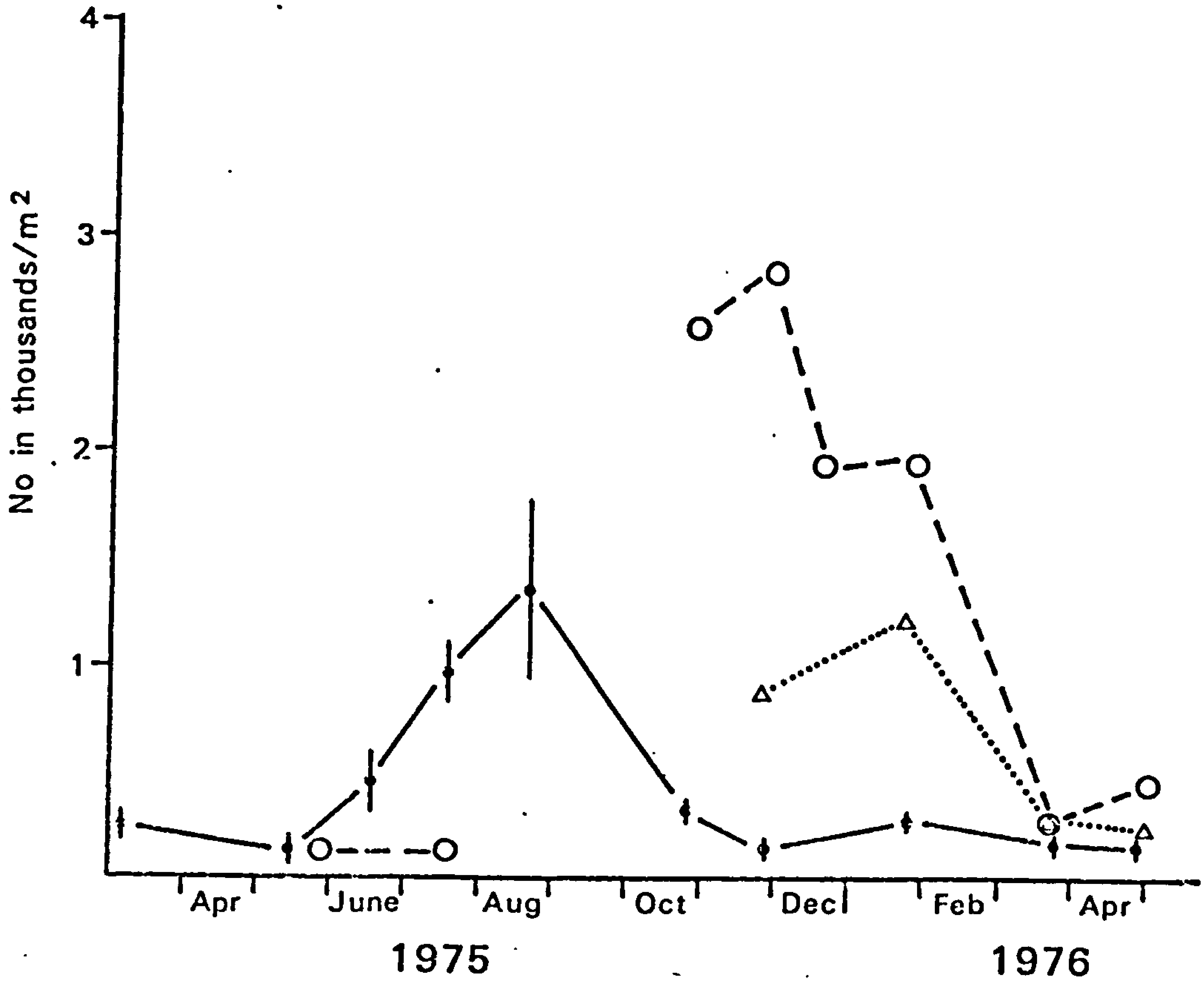


Figure 107. Variation in density of Hydrobia ulvae at Station 29 experimental area, Gayton. —•— Control (± 1 S.E.); ·····Δ····· Bird exclosure II; – – O – – Fish exclosure.

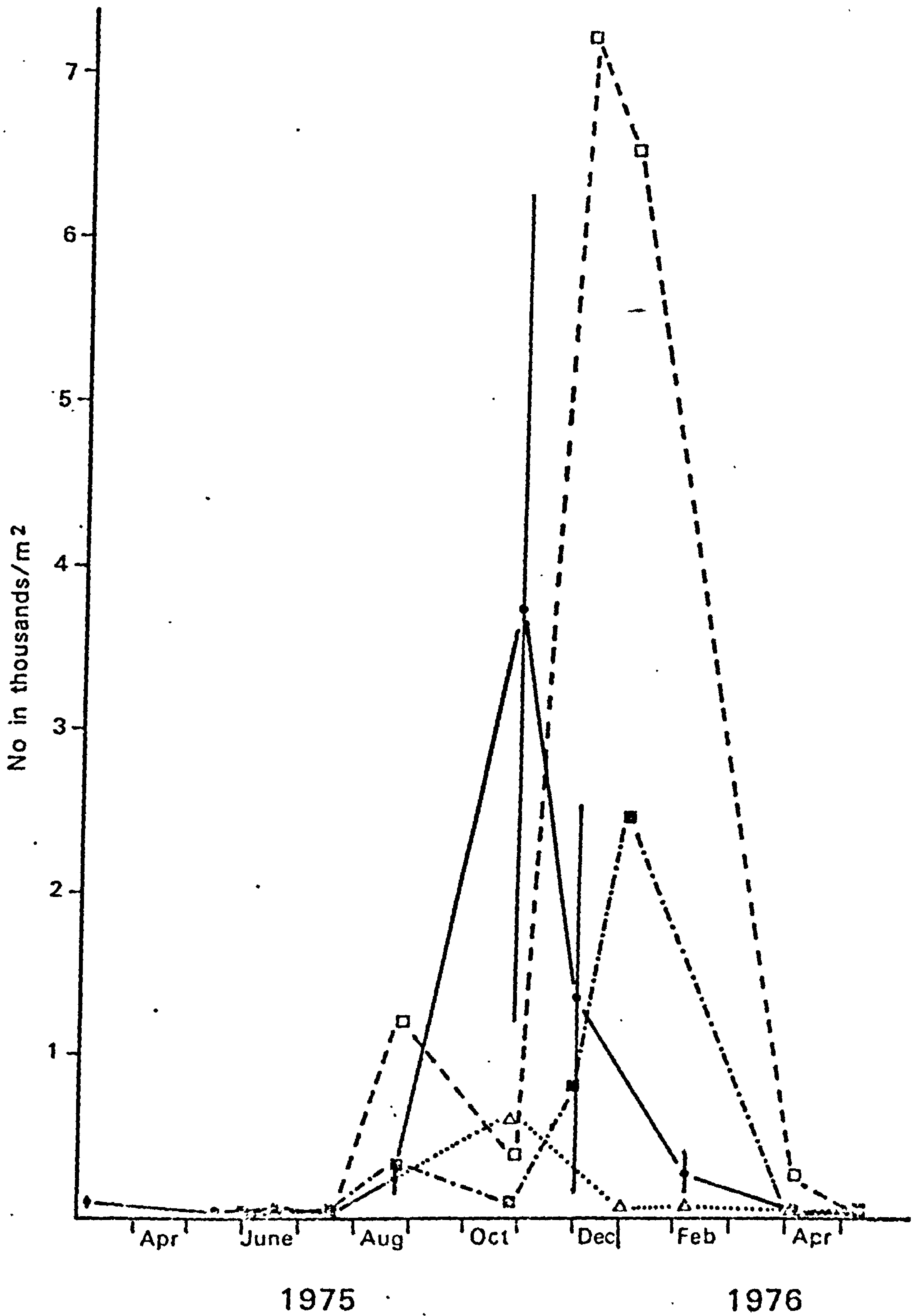


Figure 108. Variation in density of *Corophium* sp. at Station 22 experimental area, Gayton. —•— Control (± 1 S.E.); --□-- Total exclosure I; -·■-· Total exclosure II; ···△··· Bird exclosure I.

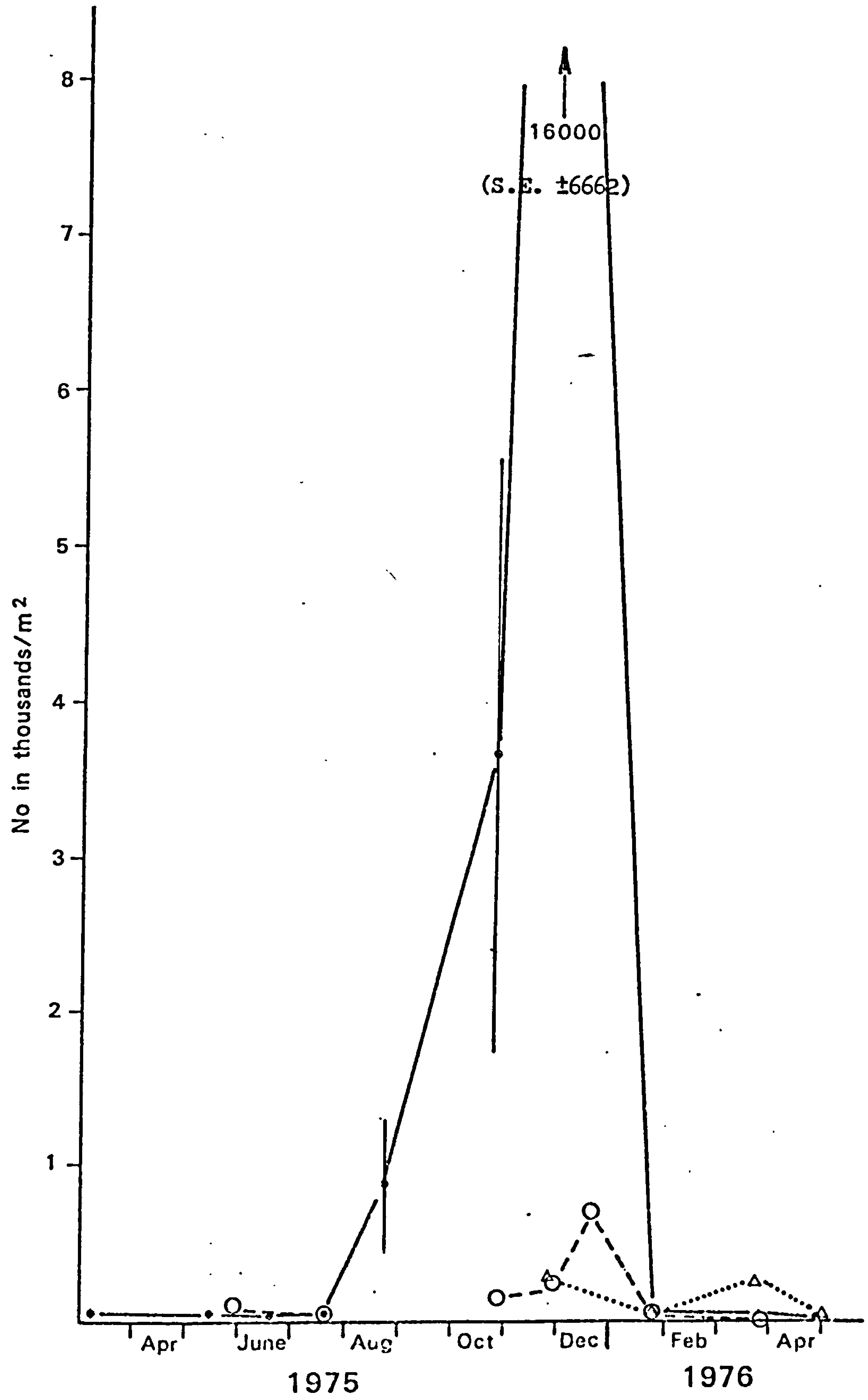


Figure 109. Variation in density of Corophium sp. at Station 29 experimental area, Gayton. —•— Control (± 1 S.E.); ······Δ······ Bird exclosure II; – – o – – Fish exclosure.

4 DISCUSSION

The distribution of macroinvertebrate species during the six year study revealed the variability generally associated with the estuarine environment.

The numerical analysis technique adopted supported the biological concept of the stability of the community. Although there was variation in position of the boundary between the communities, this could be considered as inevitable when an artificial boundary is imposed, on what is basically a continuum of changing species associations.

The increase in C.edule and S.plana in 1975 provided additional support to the concept and the analysis techniques, there being no major change in the species composition or distribution of the groups.

Each of the five main Association Analysis groups proved to be clearly defined and together with the physical chemical factors, capable of ecological interpretation as distinct habitats in the Estuary.

The multivariate approach in the analysis of the physical chemical factors emphasised that no single factor could distinguish between each of the five Association Analysis groups, but in combination each group had its own unique environmental parameters. This implied that although the study had to limit the environmental variables investigated, due to practical considerations, the variables which were selected proved adequate for the level of community analysis used.

The knowledge of these unique parameters for each association now has a practical application. The Estuary is under considerable pressure at the present time both as a result of man's past activities and future plans for the Estuary. It should be possible, provided the relevant physical/chemical information is available from hydrologists and engineers to predict the future distributions of the macroinvertebrates in the Estuary.

Although it is possible to compare the AA map groupings derived from the surveys with more subjective interpretations of communities in other earlier estuarine surveys, objective numerical classification techniques as used in this study enabled the recognition of communities which would have been extremely difficult using subjective methods. Comparisons with previous published work on other estuaries becomes subjective but a growing number of intertidal surveys are now adopting various objective classification techniques similar to AA (Eagle et al 1974; Kay and Knights 1975).

Comparisons between the similarity analysis groupings on the Lavan Sands 50 miles west of the Dee revealed parellels (Eagle et al 1974), even though the Lavan Sands could not be considered as estuarine.

The Dee Estuary Group 1 was not represented on the Lavan Sands, this group being found in very protected conditions on the Estuary which would not be found on the more exposed Lavan Sands. However, Group 2 on the Dee closely parelleled Groups B and C on the Lavan Sands but the presence of S.plana in these groups indicated affinities with Group 1 on the Dee. Group 3, the marine community on the Dee, containing such species as S.armiger, Corophium sp., A.marina and C.edule was closely paralleled by Groups D and E over much of the Lavan Sands reflecting the more marine conditions. Group 4 on the Dee appears to correspond with Group E on the Lavan Sands but the distinctive presence of H.arenarius witnessed in this

Group on the Dee was not particularly prominent on the Lavan Sands. The low shore marine component found on the Lavan Sands was not distinguished as a group on the Dee analysis.

The transect results indicated a large temporal variation in the macroinvertebrates. A number of factors were involved. In certain more mobile species, e.g. H.ulvae and Corophium sp. much of the variability could be accounted for by migration. Study of these species on the basis of a few sample sites, presents major problems, an extensive survey would be more appropriate.

Less mobile species were more suitable for analysis. In these species the variability was seasonal, associated with recruitment, but the variability of the annual recruitment emphasised one of the limitations of the present study.

Many estuarine species have a planktonic larval stage. Although allowing dispersal of the population, both physical/chemical and biological factors are operating which can have a large effect on the relative success or failure of a recruitment.

The study indicated, however, that the settlement and early distribution of the macroinvertebrates could be defined principally on the basis of the physical/chemical environment, but locally this could be modified by biological competition, e.g. S.plana inhibiting settlement of its own newly metamorphosed larvae (Green 1957), and probably other species such as M.balthica. Clearly in many species settlement occurred around a particular physical/chemical optimum, e.g. MHWN.

The possible factors involved in post-settlement variability was investigated in M.balthica. This indicated that following recruitment the general loss in variability throughout the remainder of the year was due mainly to predation. Three main categories were identified - invertebrates, fish and birds.

In a predation situation the regulation of the prey, depends on three main factors, the relative vulnerability of the prey, the density and the energy represented. The present study deals with the first two components but the relation of energy to the equation is still under investigation.

Although C.maenas was probably important in the early stages the results indicated that the mortality curve was mainly due to vertebrate predation operating via a density dependant mechanism. The evidence of a density dependant mechanism operating on M.balthica was obtained from a number of sources :

(1) The highly variable densities recorded at recruitment on the transect were reduced at a rate, determined by the size of the settlement, in a density dependant logistic curve (Solomon 1949) to a uniform minimum density before the next year's settlement.

(2) The extensive surveys indicated that the process was not limited to the transect alone but occurred over the Estuary. High 'peak' densities in the optimum areas by the following Spring had been removed but the overall distribution remained, indicating predation was concentrated where there was optimum return.

(3) The Coefficient of Dispersion values indicated a similar process on a smaller scale. At settlement densities were highly aggregated but reduced gradually over the year to random prior to the next recruitment.

(4) The netted area experiments indicated that if populations kept artificially high by the nets were exposed, increased predation occurred on the high density. The nets also indicated that

physical/chemical factors were not significantly influencing the mortality curve.

(5) Ornithological investigations on both the Dee and elsewhere indicated that waders concentrate their predation on the optimum areas of prey (Goss-Custard 1977), although predator interaction interference can occur at high densities.

The bird and fish exclosure experiments urgently need repeating but they did show that if the bird component was removed, the fish component compensated via the density dependant mechanism, the prey mortality rate remaining commensurate with the surrounding area, i.e. the control.

The results suggested a dynamic balance between the fish and birds. This could have a practical application, for example, in the barrage proposal for the Dee, there would be an unstable transition period when the redistribution of invertebrates occurred and if, due to developments there was a net loss of energy to the system, which is by no means certain, the impact this could have on the waders could be spread by the removal of the fish component

The minimum density for M.balthica which was recorded in all years and on other estuaries (Matchett 1957; Chambers and Milne 1975b) indicated ecologically the stability of the relationship between this invertebrate and its predators. Predation throughout the year acting as a homeostasis factor dampening much of the variability seen in the invertebrate at settlement.

Although the threshold minimum density was apparently constant from year to year the energy relationships need further investigation and this is being undertaken at the present time.

The dynamics of the relationship between the invertebrates was illustrated by the return of C.edule and S.plana to the Estuary.

If the increase in these two species represented a net energy input to the system the impact of predation on M.balthica could be expected to be less. While it was not possible to detect a major change in the mortality curve from the transect there was a rise in total numbers of M.balthica recorded in the 1976 extensive Spring survey (the extra area covered outside the Estuary was not used in this calculation). There was also a substantial drop in the numbers of M.balthica recorded in the following Autumn survey with the possibility of C.edule and S.plana interfering with the settlement of M.balthica and competing for space.

The results outlined for M.balthica represents just one of the invertebrates on the Estuary and its density dependant mortality curve. M.balthica illustrated a relatively simple one year predation cycle and a possible reason for the simplicity of this curve was the vulnerability of the 'O' group M.balthica near the surface of the sediment. This probability making them a first choice prey item. However, in N.diversicolor and many other invertebrates there is evidence of a two year predation cycle. In S.plana the dominance of one year's settlement can be present for several years, so that the time scale used on the Thurstaston and Mostyn sampling areas to investigate the dominant N.diversicolor and S.plana was inadequate.

The extensive nature of the study over a number of years emphasises the very great synchronization of the component parts of the system. Temporal variations were closely linked and these had an ecological significance, e.g. M.balthica settlement coincided with the settlement of young C.maenas and the experimental evidence indicated that C.maenas could be predating M.balthica at the same time C.maenas provided an easy prey for fish, and the occurrence of young P.flesus coincided with the settlement. Also at M.balthica settlement there was the arrival on the Estuary of the smaller waders, e.g. Dunlin and Knot. In the Autumn and early Winter both the fish and birds are present, but due possible to temperature or a lower predation threshold relatively few fish were present in late Winter and Spring. Prior to recruitment, when M.balthica densities were at their minimum, very few birds and fish were present in the Estuary.

General conclusions from the study were that the initial seasonal distribution of the young intertidal macroinvertebrate populations was controlled principally by the physical environment but subsequent change throughout the remainder of the year on these populations was by predation under the relatively mild and stable meteorological conditions of the study.

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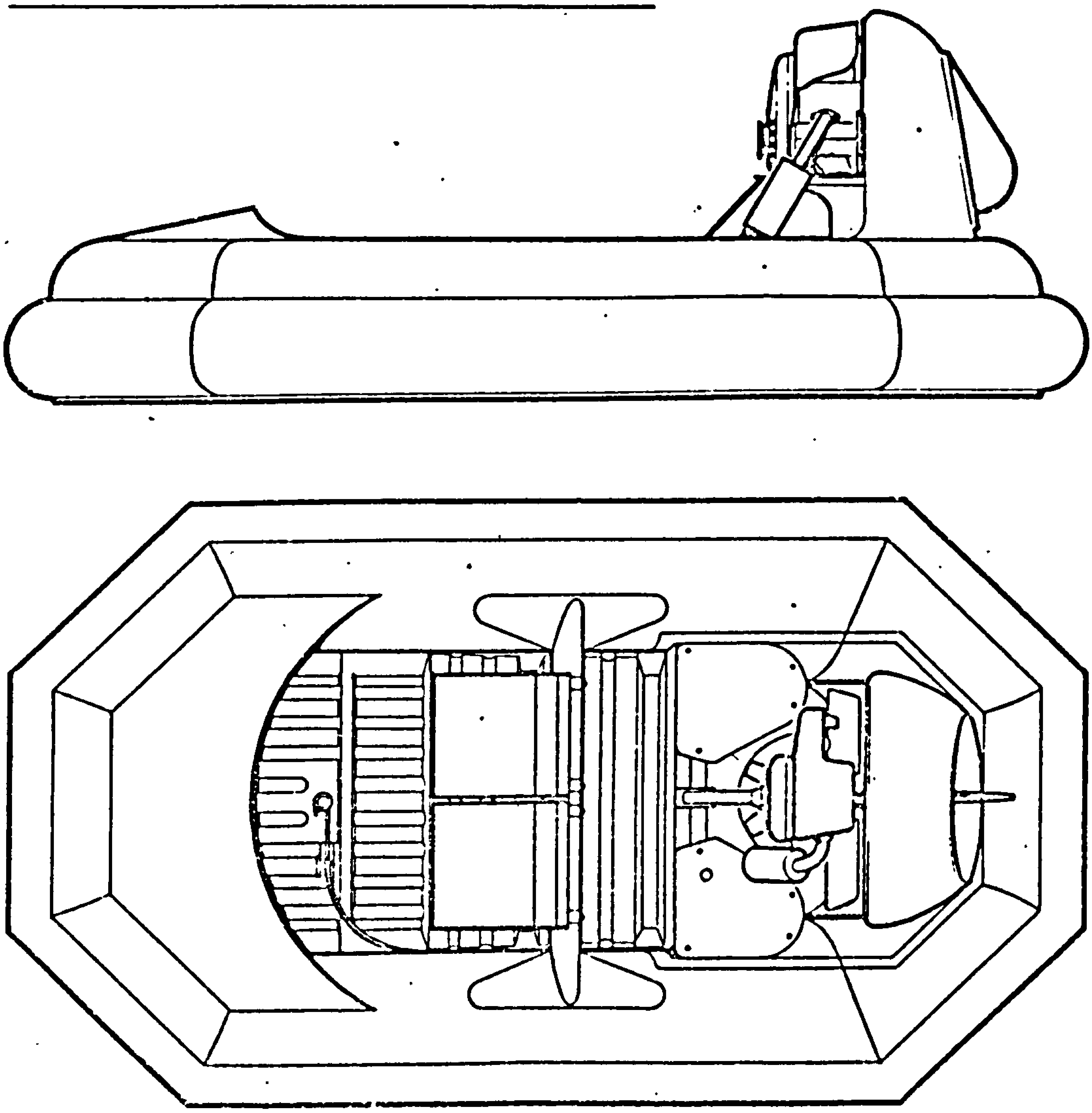
Yonge, C.M. 1953. Aspects of life in muddy shores. In: Essays in marine biology. The Richard Elmhirst Memorial lectures, 29-49.

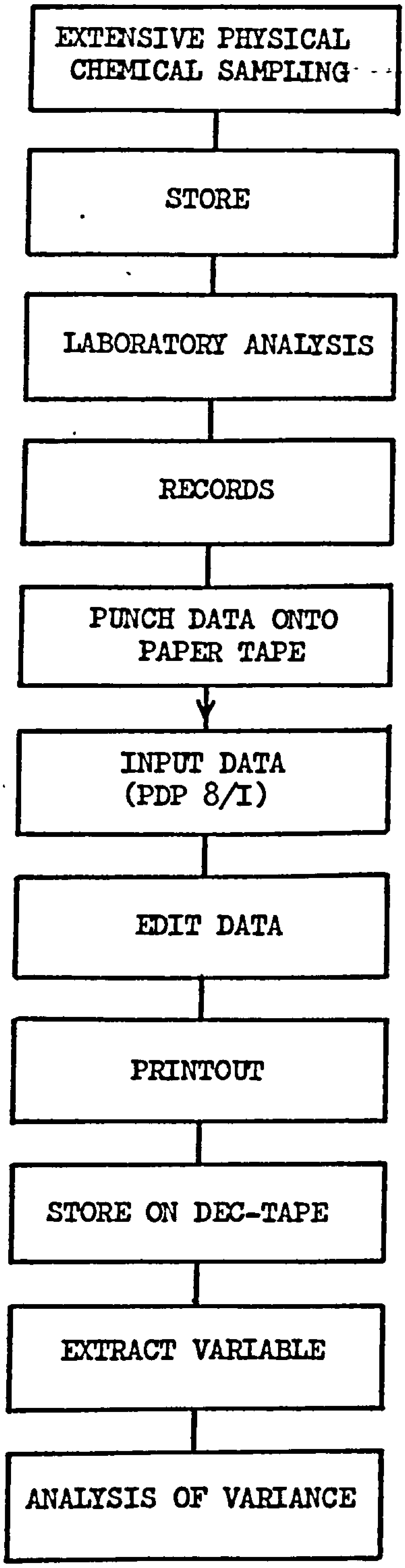
		ins	mm
Dimensions	Overall length (hovering)	131	3327
	width "	77	1956
	height "	47	1194
Packed Dimensions	length	56	1422
	width	48	1219
	height	40	1016
Weight (ready to operate)		220 lb	99.79 kg
Performance	land	35 mph	56 km/hr
	water	25 mph	40 km/hr
Structure	hull	Neoprene coated nylon inflatable tube	
	duct and floor	Glass reinforced polyster	
	skirt	bag type with peripheral seal strip	
Controls	One joystick control usable by either occupant. operates rudder in propellor slipstream. throttle combined, one handed operation.		
Engine	Lloyd LS 400 22 bhp 2 cylinder 2 stroke running on 40:1 petrol/oil mixture.		
Fans	Replaceable plastic blade propellor thrust 23".5 30° 3L 600mm lift 16".5 30° 3L 419mm		
Belt drive	Size, Alpha section 55"		



Appendix 1 General specifications of Hovercraft used in the surveys from Spring 1974.

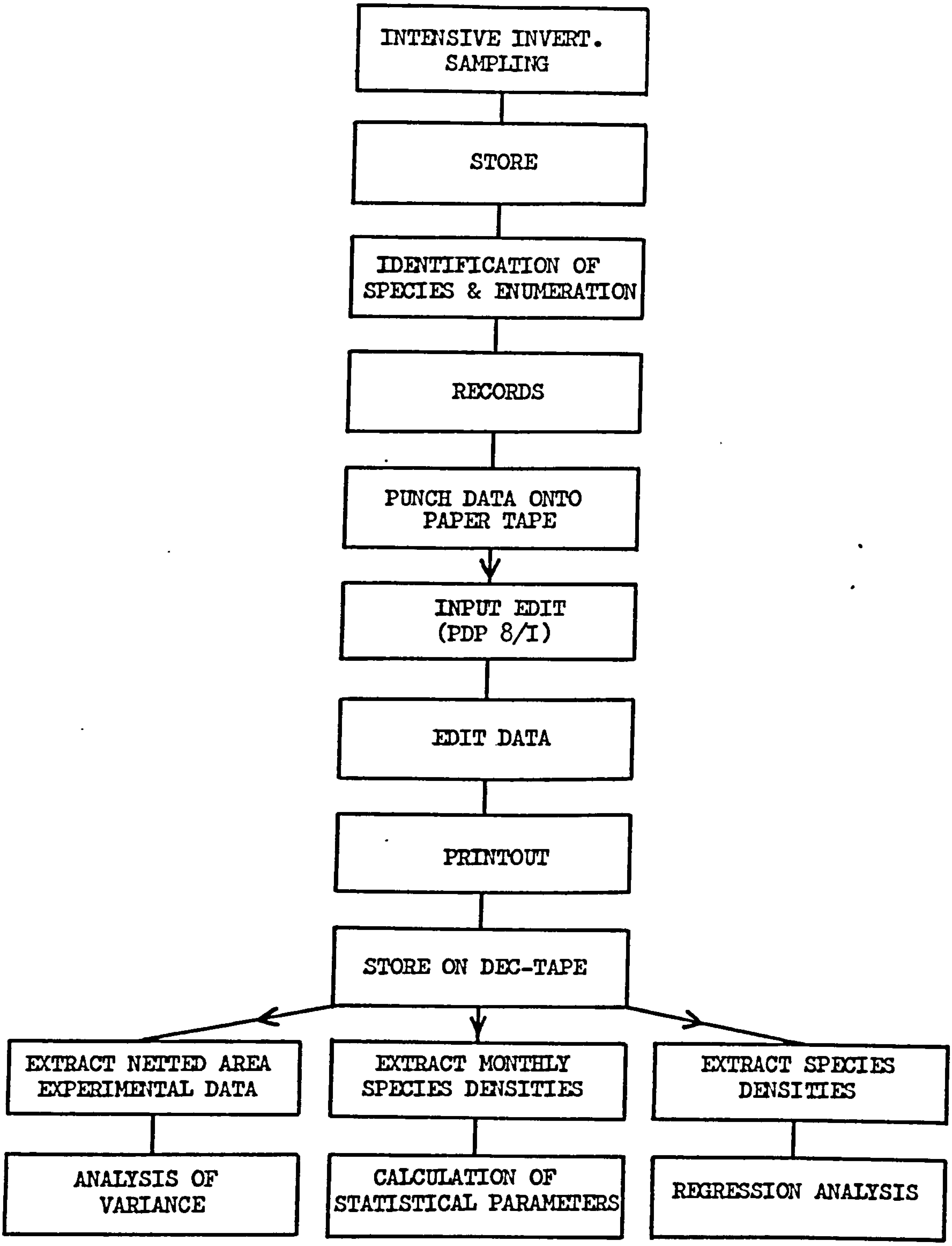
Appendix 2.

Flow chart indicating general procedure followed during the analysis of the extensive invertebrate sampling for each of the grid surveys, Autumn 1971 to Autumn 1976.



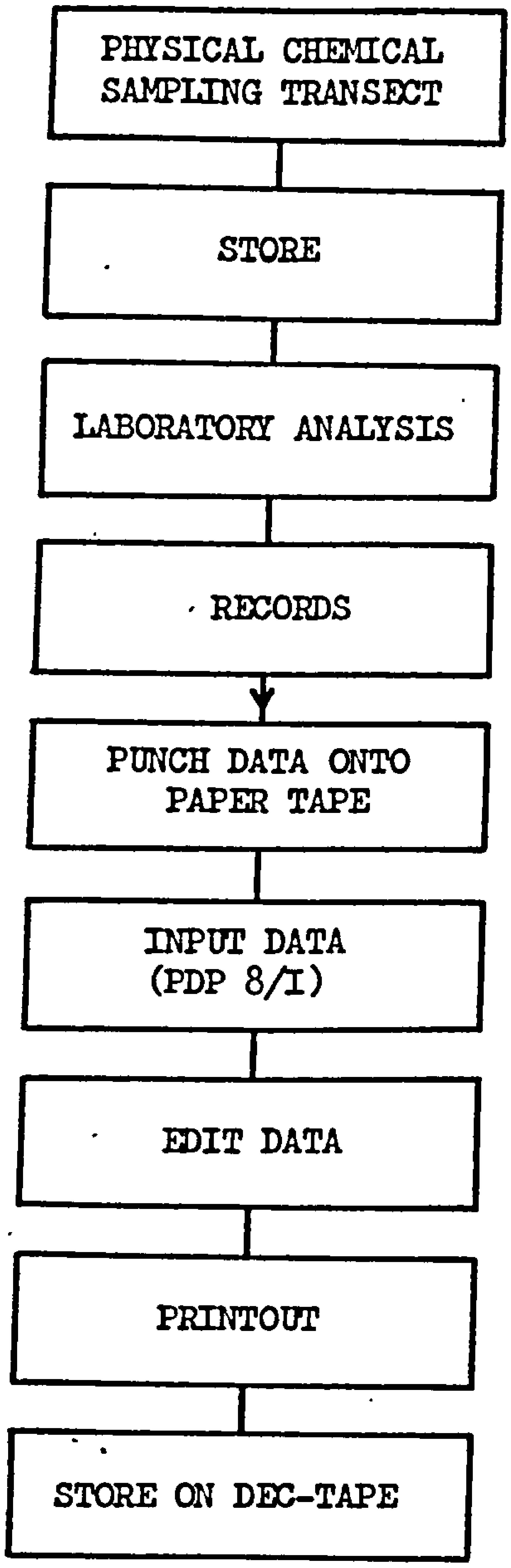
Appendix 3

Flow chart indicating general procedure followed during the analysis of the extensive physical chemical data for Autumn 1971, Spring 1974 and Spring 1976.



Appendix 4

Flow chart indicating general procedure followed during the analysis of the transect monthly invertebrate data.



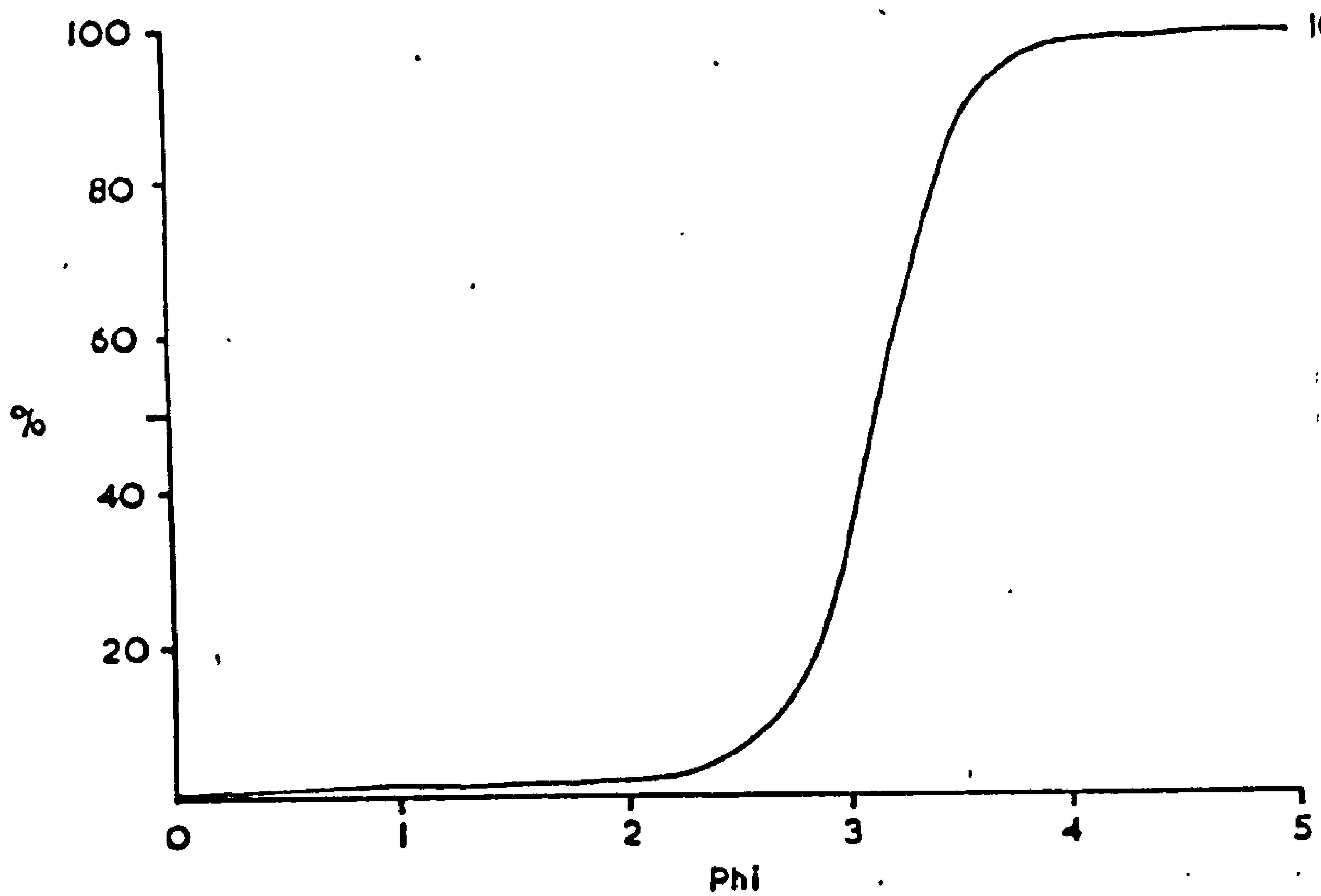
Appendix 5—

Flow chart indicating the general procedure followed during the analysis of the transect monthly physical/chemical data.

SITE No. 27-9
DATE 1-4-74
DEPTH 0-2.5 cms

Aperture (Micron)	Phi Scale	%Wt. Fract.	%Wt. Cum.
1000	0	0.2	0.2
500	1	1.1	1.3
250	2	1.3	2.6
125	3	30.6	33.2
63	4	64.9	98.1
>63		1.9	100

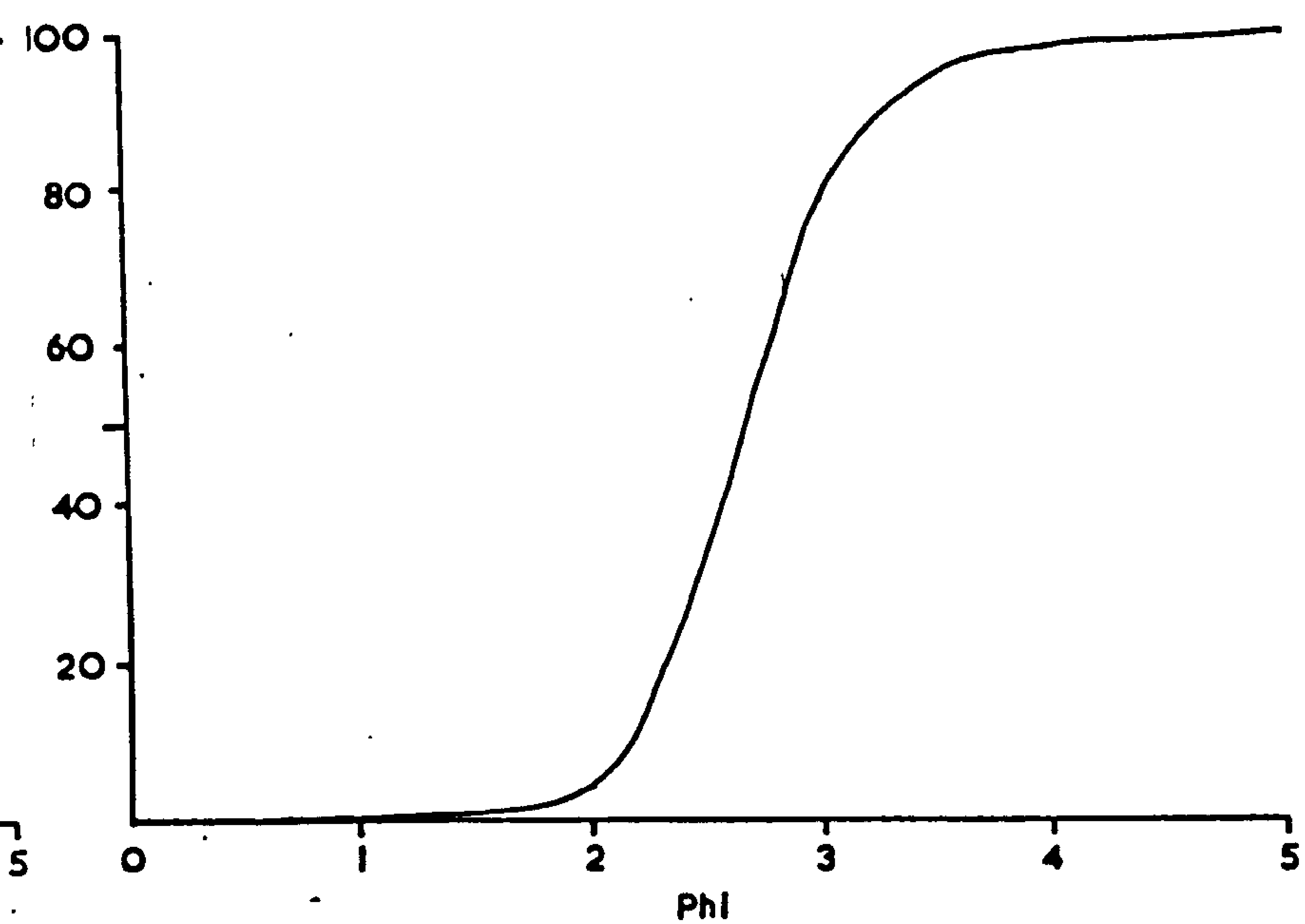
Md	[illegible]
Q_1	3.5
Q_2	2.85
$\bar{X}$	3.18



SITE No. 33-14
DATE 27-3-76
DEPTH 0-2.5 cms

Aperture (Micron)	Phi Scale	%Wt. Fract.	%Wt. Cum.
1000	0	0	0
500	1	0.09	0.09
250	2	3.46	3.55
125	3	75.2	78.75
63	4	19.64	98.38
>63		1.62	100

Md	2.675
Q_1	3.1
Q_2	2.25
$\bar{X}$	2.68

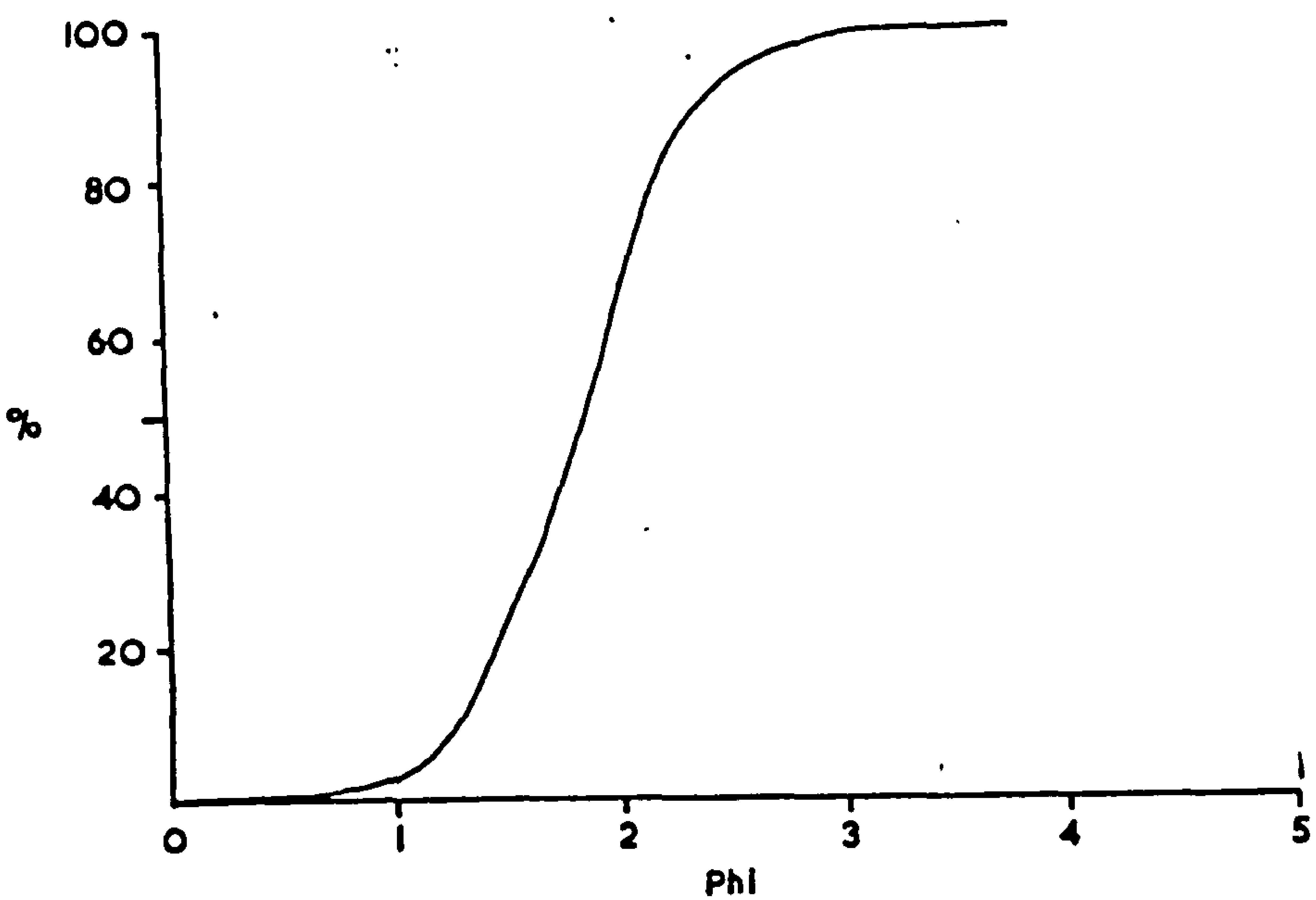


Appendix 6 Sediment particle size, specimen cumulative percentage curves plotted against Phi scale.
Md - Median; Q_1 - 84%; Q_2 - 16%; $\bar{X}$ - Mean.

SITE No. 51-17
DATE 28-4-76
DEPTH 0-2.5 cms

Aperture (Micron)	Phi Scale	%Wt. Fract.	%Wt. Cum.
1000	0	0	0
500	1	2.66	2.66
250	2	63.3	65.96
125	3	33.4	99.36
63	4	0.08	99.44
>63		0.56	100

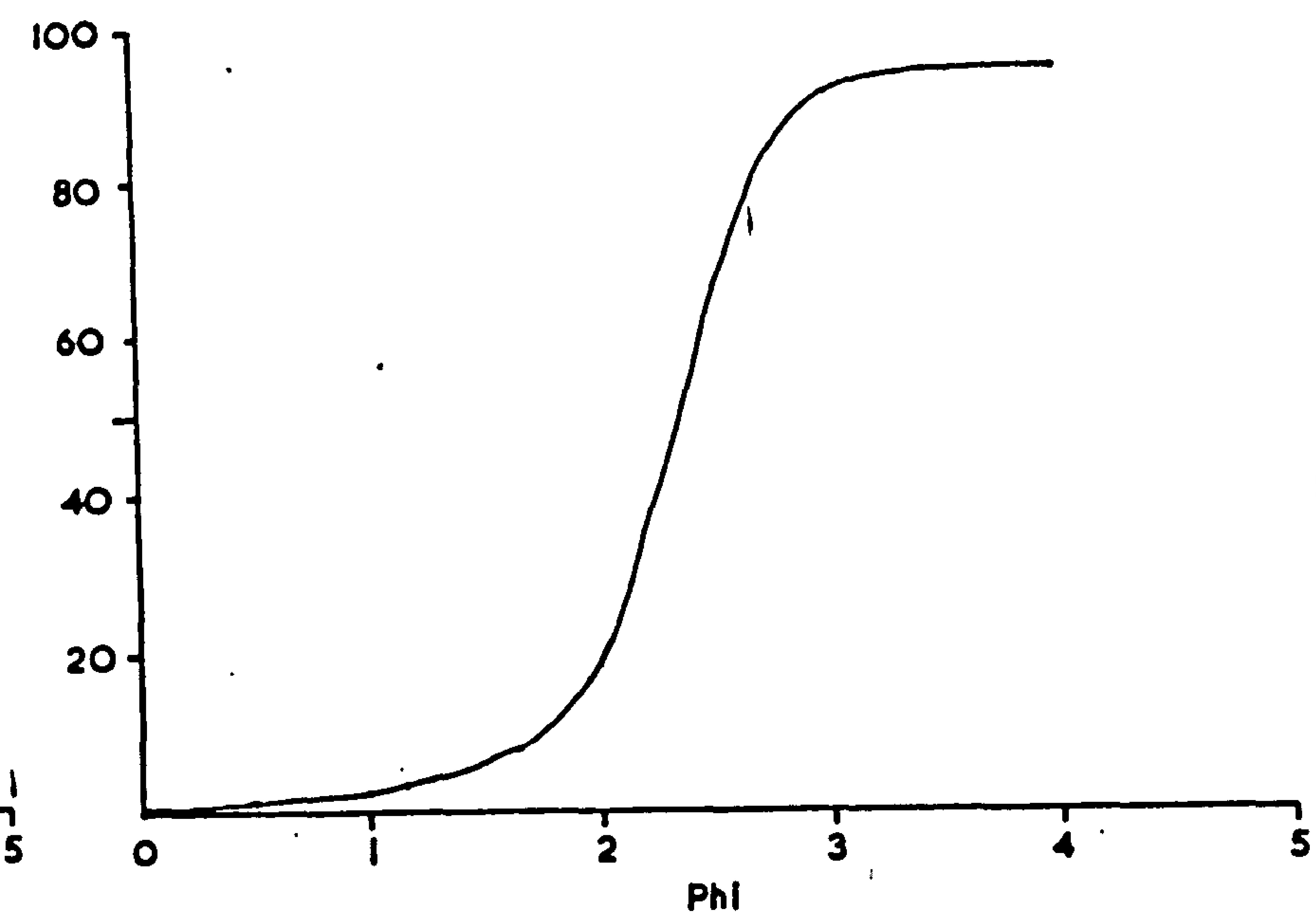
Md	1.85
Q_1	2.2
Q_2	1.4
$\bar{X}$	1.82



SITE No. 52-20
DATE 28-4-76
DEPTH 0-2.5 cms

Aperture (Micron)	Phi Scale	%Wt. Fract.	%Wt. Cum.
1000	0	0.57	0.57
500	1	2.2	2.77
250	2	16.0	18.77
125	3	72.3	91.07
63	4	2.98	94.05
>63		5.95	100

Md	2.35
Q_1	2.75
Q_2	1.95
$\bar{X}$	2.35



Appendix 7 Sediment particle size, specimen cumulative percentage weight curves plotted against Phi scale. Md - Median; Q_1 - 84%; Q_2 - 16%; $\bar{X}$ - Mean.

Appendix 8

S P E C I E S L I S T *

BENTHIC FAUNA

COELENTERATA	
Cnidaria	*Obelia gelatinosa* Pallas *Aurelia aurita* L.
Ctenophora	*Pleurobrachia pileus* O.F. Müller
PLATYHELMINTHES	
Turbellaria	*Polycelis nigra* O.F. Müller *Turbellaria* sp.
NEMERTEA	*Prostoma* sp. *Cerebratulus* sp. *Lineus longissimus* Gunnerus
NEMATODA	*Nematode* sp.
ANNELIDA	
Polychaeta	*Eteone longa* Fabricius *Nereis diversicolor* O.F. Müller *Nereis pelagica* L. *Nereis virens* Sars *Nephthys hombergi* Fabricius *Nephthys caeca* Fabricius *Nephthys* sp. *Phyllodoce macrophthalma* Schmarda *Phyllodoce laminosa* Gmelin *Phyllodoce maculata* L. *Scoloplos armiger* O.F. Müller *Amphiglena mediterranea* *Pygospio elegans* Claparède *Ophelia bicornis* Savigny *Polydora ciliata* Johnston *Lanice conchilega* Pallas *Arenicola marina* L. *Pectinaria koreni* Malmgren
Oligochaeta	*Clitellio arenarius* O.F. Müller *Tubifex costatus* Claparède
ECHINODERMATA	
Echinoidea	*Echinocardium cordatum* Pennant

* The following list was constructed from a combination of the present work and earlier works by Perkins (1956) and Stopford (1951). A detailed species list of species on and around Hilbre Island has been compiled by McMillan (1942).

ARTHROPODA

Crustacea	Tigriopus fulvus Fischer
	Balanus balanoides L.
	Balanus crenatus Bruguiere
	Eurydice pulchra Leach
	Sphaeroma rugicauda Leach
	Gnathia maxillaris Montagu
	Orchestia gammarella Pallas
	Corophium volutator Pallas
	Corophium arenarium Crawford
	Hyperia galba Montagu
	Haustorius arenarius Slabber
	Bathyporeia pelagica Bate
	Bathyporeia sarsi Watkin
	Janira maculosa Leach
	Schistomysis spiritus Norman
	Hemimysis sp.
	Carcinus maenas Pennant
	Leander squilla L.
	Crangon vulgaris L.
	Portunus marmoreus Leach
	Neomysis vulgaris Thompson
	Cancer pagurus L.
Insecta	Archistoma besselsi Packard
	Diptera larvae sp.
	Psychodid larvae
	Aphid sp.

MOLLUSCA

Gastropoda	Hydrobia ulvae Pennant
	Littorina littorea L.
	Littorina rudis Maton
Lamellibranchiata	Mytilus edulis L.
	Tellina tenuis da Costa
	Macoma balthica L.
	Scrobicularia plana da Costa
	Cerastoderma edule L.
	Mya arenaria L.
	Abra Alba Wood

CHORDATA

Osteichthyes	Gobius minutus Pallas
	Pleuronectes platessa L.
	Platichthys flesus L.
	Ammodytes lanceolatus
	Anguilla anguilla L.
	Solea vulgaris Quensel

Key

- `.` Land
- `-` Water (low tide)
- `"` Saltmarsh
- `+` Bank

Frequency group /m^2

- `*` 0
- 1 $10 - 10^2$
- 2 $10^2 - 10^3$
- 3 $10^3 - 10^4$
- 4 $10^4 - 10^5$
- 5 $10^5 - 10^6$

Appendix 9

Computer printout of invertebrate distributions.

```
3 NEREIS DIVERS.   AUT71

52 ....++-------++++++++++++----
51 ....***--------******++------
50 ...12**----++---*****------++
49 ..11****----*++---*----++++++
48 ..***1*+---*+*****---*+***+++
47 ..*****-++--****+---**+*121..
46 ..****-+++--++++----**21*1...
45 ..31*-+**++-+++-----+**12....
44 ....--****+-+-------***2.....
43 ...-*+****+----+++---*12.....
42 ....+****++---+*+*+--+*2.....
41 .....-**++---+++**+*+-1......
40 ....-++++--+--+***2*+-2......
39 .....-++--**+***+21**122.....
38 .....-++-******+*2221222.....
37 .....+--*******+1213212......
36 .....+--***1****2233213......
35 .....+*++******12223321"......
34 ....."*++**1**222222*"""......
33 ....."****1**22221"""""""......
32 ....."11***+**1232"""""""".......
31 ....."*2******122*2+"""".......
30 ......"2*+****23*"""""""""".......
29 ......2******121"""""""........
28 ......**211*231**1""""..........
27 ....."2*1*12""""1*""""""".........
26 ......"2*3+1""""""""""""""..........
25 .....""""31""""""""""""""""""..........
24 .......""++""""""""""""""""..........
23 .........+""""""""""""""""""...........
22 .........+"+""""""""""".............
21 ........""""""....................

   00000000111111111122222222223
   23456789012345678901234567890
```

```
6 ETEONE LONGA   AUT71

52 ....++---------+++++++++++----
51 ....**1---------******++------
50 ...22*1----++---*****-------++
49 ..121***----*++---*----++++++
48 ..1111*+---*+*****---*+*2*+++
47 ..2****-++--****+---*1+1112..
46 ..*1**-+++--++++----*21***...
45 ..11*-+**++-+++------1*21*....
44 ....--*1**+-+-------*122.....
43 ...-*+1*1*+----+++---*22.....
42 ....+1**+++---+*+*+--+21.....
41 .....12*++---+++**+*+-1......
40 ....-++++--+--+***1*+-1......
39 .....-++--**++**+*****2*.....
38 .....-++-**1**+*2112**1......
37 .....+--*******+2*21111......
36 .....+--**12*1*112*111*......
35 .....+*++*****22221***"......
34 ....."1++1***222*31**"""......
33 ....."**1***123222*"""""""......
32 ....."*11**+***121"""""""".......
31 ....."******12221*1+"""".......
30 ......"""*+***131*""""""""".......
29 ......11*1121212*"""""""........
28 ......**21213222**""""..........
27 ....."1*2*23""""1*""""""".........
26 ......"1*2+*""""""""""""""..........
25 .....""""**""""""""""""""""""..........
24 .......""++""""""""""""""""..........
23 .........+""""""""""""""""""...........
22 .........+"+""""""""""".............
21 .........""""""....................

   00000000111111111122222222223
   23456789012345678901234567890
```

Key

- `.` Land
- `-` Water (low tide)
- `"` Saltmarsh
- `+` Bank

Frequency group /m²

*	0
1	$10 - 10^2$
2	$10^2 - 10^3$
3	$10^3 - 10^4$
4	$10^4 - 10^5$
5	$10^5 - 10^6$

Appendix 10

Computer printout of invertebrate distributions.

```
    11 PYGOSPIO ELEGANS   AUT71

52  ....++-------++++++++++++----
51  ....***--------******+++-----
50  ...13**----++---*****------++
49  ..*32***----*++---*----++++++
48  ..3**1*+---*+******---*+***++
47  ..4***-++--****+---*1+*22*..
46  ..***-+++--++++-----*1132*...
45  ..*2*-+***+-+++------+1221....
44  ....--****+-+-------*12*.....
43  ...-*+****+----+++---*32.....
42  ....+1****+---+*+*+--+**.....
41  .....-1*++---+++***+*+-*......
40  ....-++++--+--+1***1+-*......
39  .....-++--**+++**+5****3*.....
38  .....-++-******+*43*1***......
37  .....+--***1***+22233**......
36  .....+--**35*1**34*343*......
35  .....+1++**1*24443331"......
34  ....."2++1***3*23534*"""......
33  ....."33*1*1*343443""""""......
32  ....."211**+1111*2"""""".......
31  ....."242*1**3422*3+"""........
30  ......"31+1**1543""""""""........
29  ......3**214*315*"""""""........
28  ......**5132443213"""..........
27  ....."4***23"""**"""""".........
26  ......"4*4+2""""""""""""".........
25  ....."""4*"""""""""""""""..........
24  ......."++"""""""""""""""..........
23  ........+""""""""""""""...........
22  ........+"+""""""""..............
21  ........"""""................

    00000000111111111122222222223
    23456789012345678901234567890
```

```
    23 SCROBICULARIA PL.   AUT71

52  ....++-------++++++++++++----
51  ....***--------******+++-----
50  ...*3**----++---*****------++
49  ..******----*++---*----++++++
48  ..*****+---*+******---*+****++
47  ..*****-++--****+---*******..
46  ..****-+++--++++-----******...
45  ..1**-+***+-+++------+***1....
44  ....--****+-+-------***1.....
43  ...-*+****+----+++---*11.....
42  ....+****+---+*+*+--+2*.....
41  .....-**+---+++***+*+-2......
40  ....-++++--+--+******+-*......
39  .....-++--**+++**+1***223.....
38  .....-++-******+*111**12......
37  .....+--*******+*1*1**2......
36  .....+--*********1*1**2......
35  .....+*++*******1*111*"......
34  ....."*++*************"""......
33  ....."********2****""""""......
32  ....."****+*******""""""".......
31  ....."**************+"""........
30  ......"""*+********""""""""........
29  ......**********""""""".........
28  ......*******2****"""..........
27  ....."******"""**""""""..........
26  ......"**2+*""""""""""""".........
25  ....."""**"""""""""""""""""..........
24  ......."++""""""""""""""""..........
23  ........+""""""""""""""""...........
22  ........+"+"""""""""...............
21  ........"""""................

    00000000111111111122222222223
    23456789012345678901234567890
```

Key

- • Land
- \- Water (low tide)
- " Saltmarsh
- \+ Bank

Frequency /m²

*	0
1	$10 - 10^2$
2	$10^2 - 10^3$
3	$10^3 - 10^4$
4	$10^4 - 10^5$
5	$10^5 - 10^6$

Appendix 11

Computer printout of invertebrate distributions.

```
      24 MAC BALTH TOTAL    AUT71

52  •••++--------+++++++++++----
51  ••••***---------********+------
50  •••2432----++---*****-------++
49  ••23331*----**+---*----++++++
48  ••3222*+---**+111**---2+2*1+++
47  ••3****-++--***1+---23+2232••
46  ••**1*-+++--++++----23223*•••
45  ••231-+1*++-+++-----33232••••
44  ••••--21**+-+-------*433•••••
43  •••-**1**+----+++---342•••••
42  ••••+**1+++---+*+*+--+42•••••
41  •••••-21++---+++21+2+-3••••••
40  ••••-++++--+--+22332+-3••••••
39  •••••-++--1*++22+32*1343•••••
38  •••••-++-122**+23333233••••••
37  •••••+--*121222+3333333••••••
36  •••••+--*1231222333334333••••••
35  •••••+1++*12223*334332"••••••
34  •••••"2++212*33333321""••••••
33  •••••"*1*1*22333332"""""••••••
32  •••••"12111+233333""""""•••••••
31  •••••"12*11122332*2+""•••••••
30  ••••••"11+2*22341""""""""•••••••
29  ••••••21111223232""""""••••••••
28  ••••••**22223422*1""•••••••••
27  •••••"2*2*33"""11""""""•••••••••
26  ••••••"2*4+2"""""""""""""•••••••••
25  •••••""""21"""""""""""""""•••••••••
24  •••••••"++""""""""""""""•••••••••
23  ••••••••+"""""""""""""""•••••••••
22  ••••••••+"+""""""""•••••••••••••
21  ••••••••"""""•••••••••••••••••

    0000000011111111112222222223
    23456789012345678901234567890
```

```
      25 MAC. BALTH. >10MM    SPR 73

52  •••++--------++++++*+++++----
51  ••••*++---------********++-----
50  •••+21*----++---++++**-------++
49  ••1222*+----+++---*----++++++
48  ••11*2++---*+++***---*+12*2++
47  ••*++++-++--++++*+---*2+1121++
46  ••1**+-+**--+++++----11112*•••
45  ••1++-+***+-+++------11111••••
44  ••••--+*++*-+-------1222•••••
43  •••-++*+++*----+++---+2+•••••
42  ••••+*1****---+++++--+3+•••••
41  •••••+1+++---++++++++-2••••••
40  ••••-+1++--+-+++*1122+-2••••••
39  •••••-1+--**++212212++12•••••
38  •••••-*+-++1++**2111222••••••
37  •••••+--+++1++*2222122•••••••
36  •••••+--+++2++112222112••••••
35  •••••++++11+++2222221"••••••
34  •••••"+++++++22221++""••••••
33  •••••"+++++*22221**""""""••••••
32  •••••"+++++++++++""""""•••••••
31  •••••"++++++222*11+""•••••••
30  ••••••""""+++112122""""""""•••••••
29  ••••••1+**2112*11""""""••••••••
28  ••••••++111221***+""•••••••••
27  •••••"+**211""""++""""""•••••••••
26  ••••••"*1*+1""""""""""""•••••••••
25  •••••""""1+"""""""""""""""•••••••••
24  •••••••"++""""""""""""""•••••••••
23  ••••••••+"""""""""""""""•••••••••
22  ••••••••+"+""""""""•••••••••••••
21  ••••••••"""""•••••••••••••••••

    0000000011111111112222222223
    23456789012345678901234567890
```

Key

.	Land
-	Water (low tide)
"	Saltmarsh
+	Bank
	Frequency /m^2
*	0
1	10 - 10^2
2	10^2 - 10^3
3	10^3 - 10^4
4	10^4 - 10^5
5	10^5 - 10^6

Appendix 12

Computer printout of invertebrate distributions.

```
         29 HYDROBIA ULVAE    AUT71

52   ....++-------++++++++++++----
51   ....**2--------******+++-----
50   ...1342----++---*****------++
49   ..3321**----*++---*----++++++
48   ..311**+---*+*****---*+*11+++
47   ..2****-++--****+---*1+2322..
46   ..****-+++--++++----131231...
45   ..11*-+**++-+++-----13232....
44   ....--****+-+-------*233.....
43   ...-*+****+----+++---222.....
42   ....+***+++---+*+*+--+32.....
41   .....-**++---+++**+*+-2......
40   ....-++++--+--+***2*+-2......
39   .....-++--**++**+1***133.....
38   .....-++-*****+**111122......
37   .....+--*******+1222233......
36   .....+--*******123231*3......
35   .....+*++******2232321"......
34   ....."*++*****12232**""......
33   ....."*******2*232"""""......
32   ....."*****+****21"""".......
31   ....."*1*******11**+"".......
30   ......""*+*****1*""""".......
29   ......*********1*""""........
28   ......*******1****"".........
27   ....."******""**"""".........
26   ......"***+*"""""""".........
25   ....."""**""""""""""..........
24   ......."++""""""""""..........
23   ........+"""""""""...........
22   .........+"+""""".............
21   ........""".................

     00000000111111111122222222223
     23456789012345678901234567890
```

```
         37 HAUSTORIUS AREN.    AUT71

52   ....++-------++++++++++++----
51   ....***--------1*1221+++-----
50   ...***2----++---1222*------++
49   ..****2*----1++---*----++++++
48   ..****1+---1+*1*12---*+112+++
47   ..*****-++--**1*+---**+****..
46   ..****-+++--++++----******...
45   ..***-+*1++-+++-----+****....
44   ....--***1+-+-------****.....
43   ...-1+****+----+++---***.....
42   ....+***+++---+*+*+--+**.....
41   .....-**++---+++11+2+-*......
40   ....-++++--+--+*1***+-*......
39   .....-++--22++2*+*******.....
38   .....-++-21*1*+********......
37   .....+--1*12***+*******......
36   .....+--***************......
35   .....+*++1************"......
34   ....."*++************""......
33   ....."************""""".......
32   ....."****1+1*****"""".......
31   ....."*************+"".......
30   ......""*+********"""".......
29   ......***********""""........
28   ......************"".........
27   ....."******""**"""".........
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SET NO 22

DATE 17 6 75
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SPECIES	TOTAL	MEAN	VAR	S.D.	S.E.	S.E.%MEAN
2	20	4	2.5	1.58	.71	17.68
4	22	4.4	76.3	8.73	3.91	88.78
7	3500	700	20000	141.42	63.25	9.04
15	5	1	5	2.24	1	100
17	25	5	5	2.24	1	20
18	1048	209.6	25996.3	161.23	72.11	34.4
19	960	192	25949.5	161.09	72.04	37.52
20	88	17.6	11.8	3.44	1.54	8.73
21	3	.6	.8	.89	.4	66.67
22	412	82.4	9523.3	97.59	43.64	52.96
25	16	3.2	12.7	3.56	1.59	49.8
28	2	.4	.3	.55	.24	61.24
29	8	1.6	6.3	2.51	1.12	70.16

SET NO 22

DATE 18 7 75
REP= 5
SIZE= 400

SPECIES	TOTAL	MEAN	VAR	S.D.	S.E.	S.E.%MEAN
2	152	30.4	22.8	4.77	2.14	7.02
4	56	11.2	72.2	8.5	3.8	33.93
7	2400	480	47000	216.79	96.95	20.2
17	118	23.6	475.3	21.8	9.75	41.31
18	1020	204	9753	98.76	44.17	21.65
19	914	182.8	9247.7	96.16	43.01	23.53
20	106	21.2	15.2	3.9	1.74	8.22
21	1	.2	.2	.45	.2	100
22	238	47.6	843.8	29.05	12.99	27.29
25	5	1	1.5	1.22	.55	54.77
29	136	27.2	162.2	12.74	5.7	20.94

SET NO 22

DATE 21 8 75
REP= 5
SIZE= 400

SPECIES	TOTAL	MEAN	VAR	S.D.	S.E.	S.E.%MEAN
2	132	26.4	17.8	4.22	1.89	7.15
4	188	37.6	157.8	12.56	5.62	14.94
7	480	96	7280	85.32	38.16	39.75
17	119	23.8	74.2	8.61	3.85	16.19
18	1917	382.4	27905.3	167.05	74.71	19.49
19	1820	364	26149.5	161.71	72.32	19.87
20	96	19.2	60.7	7.79	3.48	18.15
22	429	85.8	1160.7	34.07	15.24	17.76
23	1	.2	.2	.45	.2	100
25	49	9.8	170.7	13.07	5.84	59.62
29	36	7.2	13.7	3.7	1.66	22.99

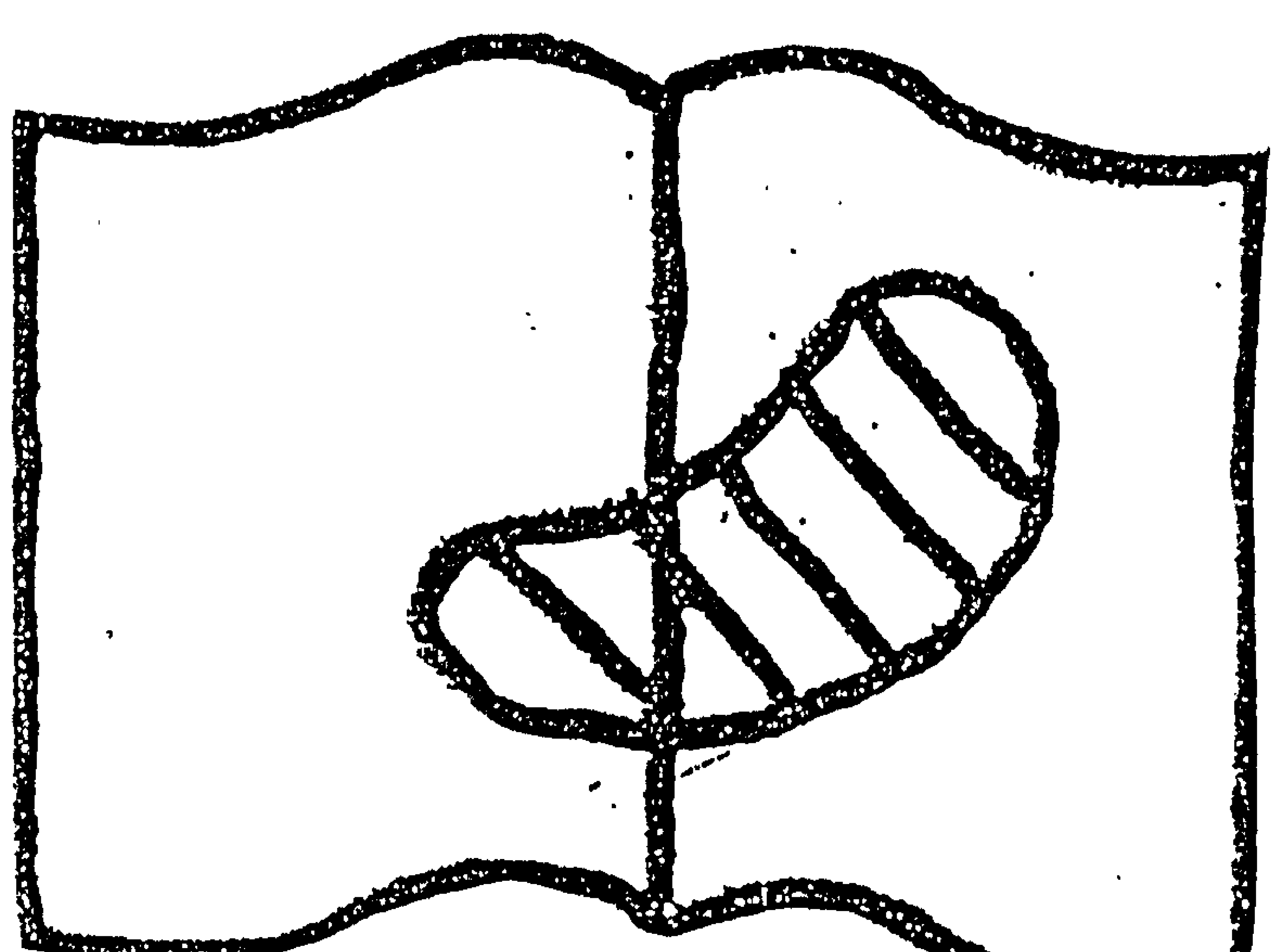
Example of Gayton transect invertebrate data printout.

	Areas km2	
	Springs	Neaps
Estuary - total area	125.32	125.32
Mud & Sand	81.8 (65.27)	70.64 (56.37)
Northern Shore	50.52	45.84
Heswall Bank	41.56	37.96
Neston Bank	14.72	14.72
Gayton Bank	13.88	13.72
Greenfield Bank	7.36	6.28
Dawpool Bank	5.6	3.24
West Kirby Bank	8.96	7.88
Southern Shore	14.16	13.28
Flint Bank	1.2	1.2
Bagillt Bank	4.84	4.64
Mostyn Bank	8.12	7.44
Sandbanks	7.12	11.52
Salisbury Bank	10.92	8.08
Middle Salisbury	5.88	3.16
West Hoyle - incomplete	0.32	0.28
Saltmarsh	21.36 (17.04)	21.36 (17.04)
Northern Shore	18.6	18.6
Southern Shore	2.76	2.76
Area of water at low water	17.6 (14.04)	31.4 (35.06)
Main Dee Channel	4.56 (3.64)	1.92 (1.53)

Appendix 14 Areas of component parts of the present open Estuary in 1971, figures in brackets represent percentage area of the Estuary.

Best Copy Available

Variable Print Quality



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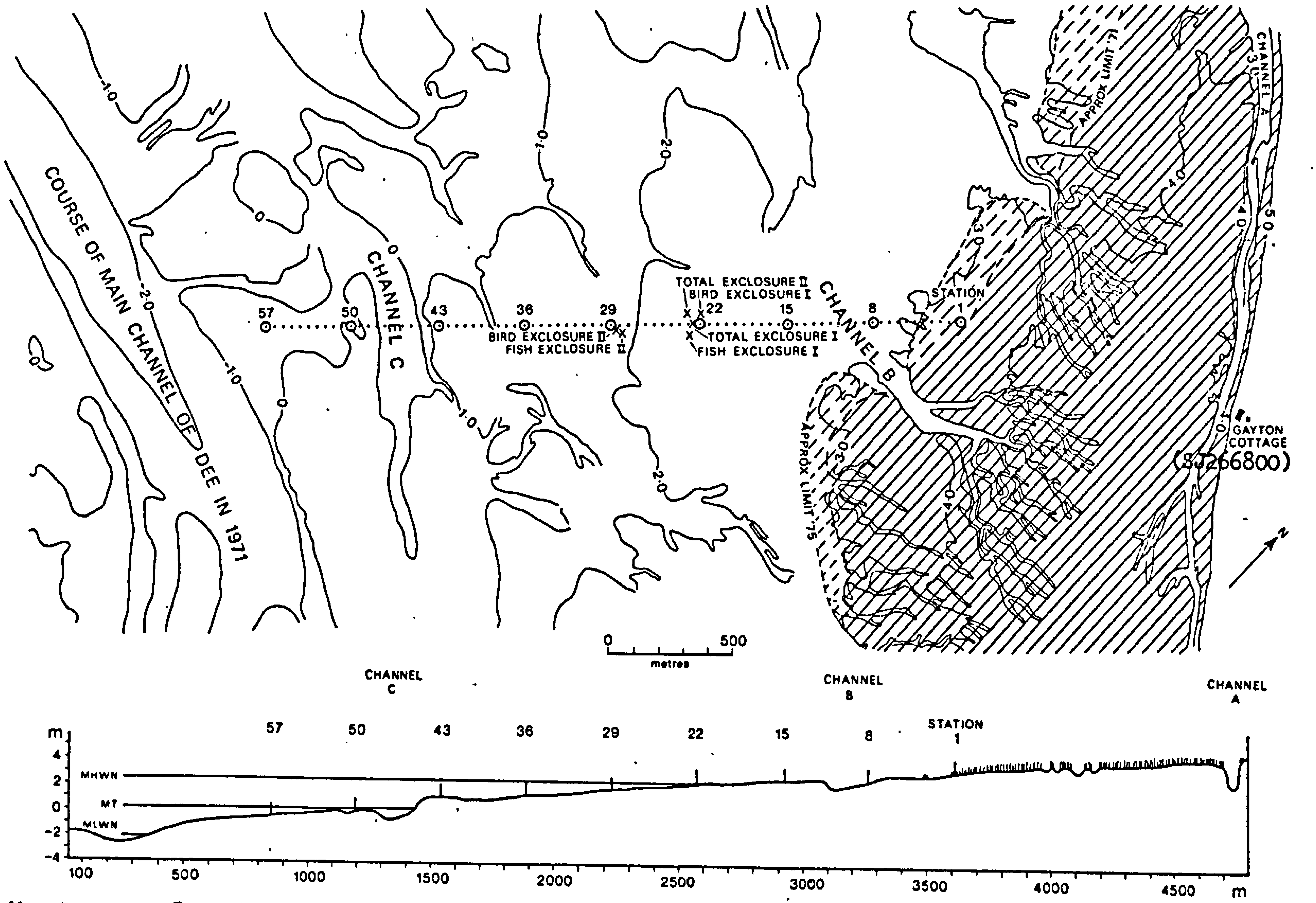
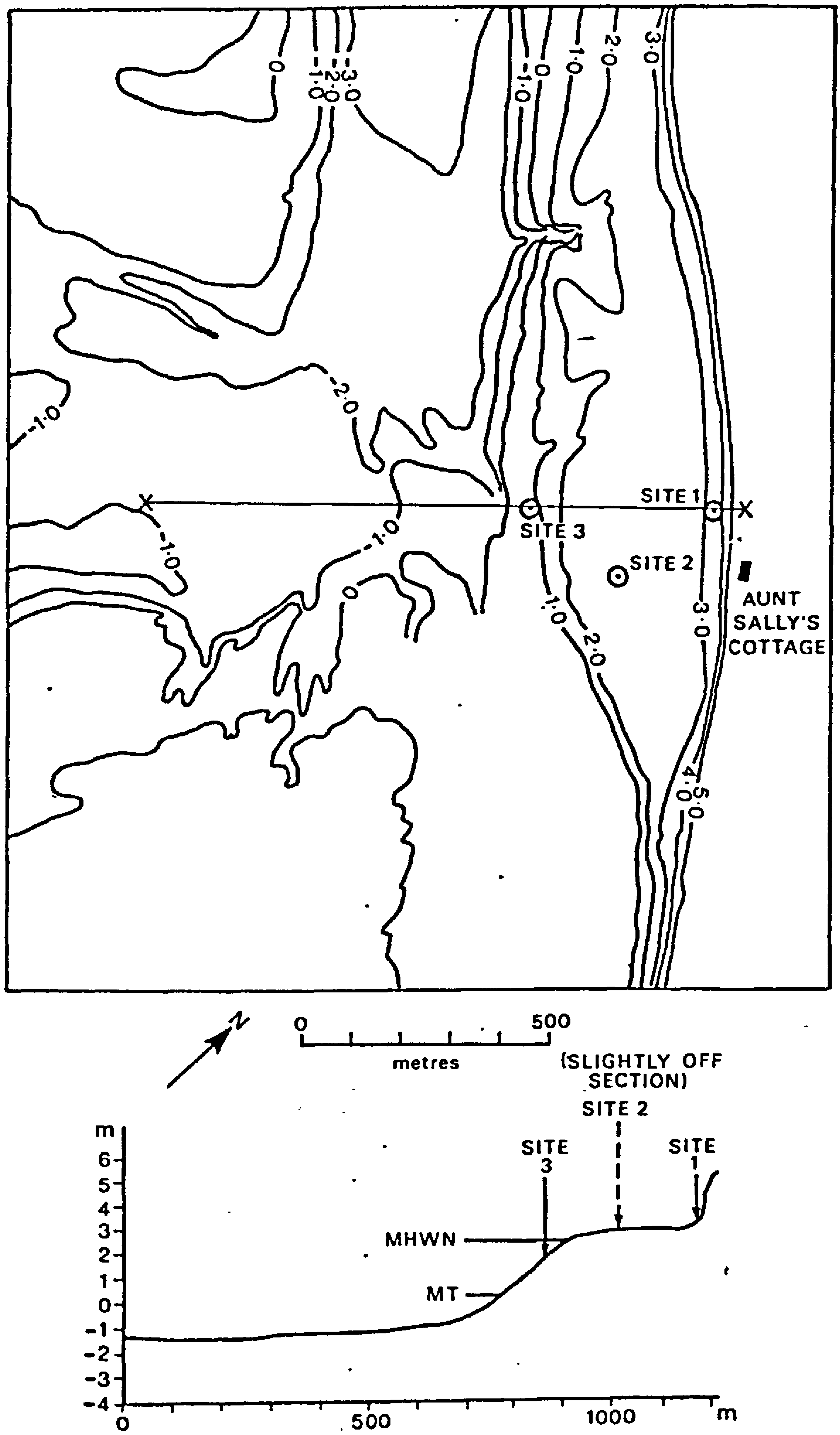
PRINT

Map 1 Physiographic regions of the Study Area.

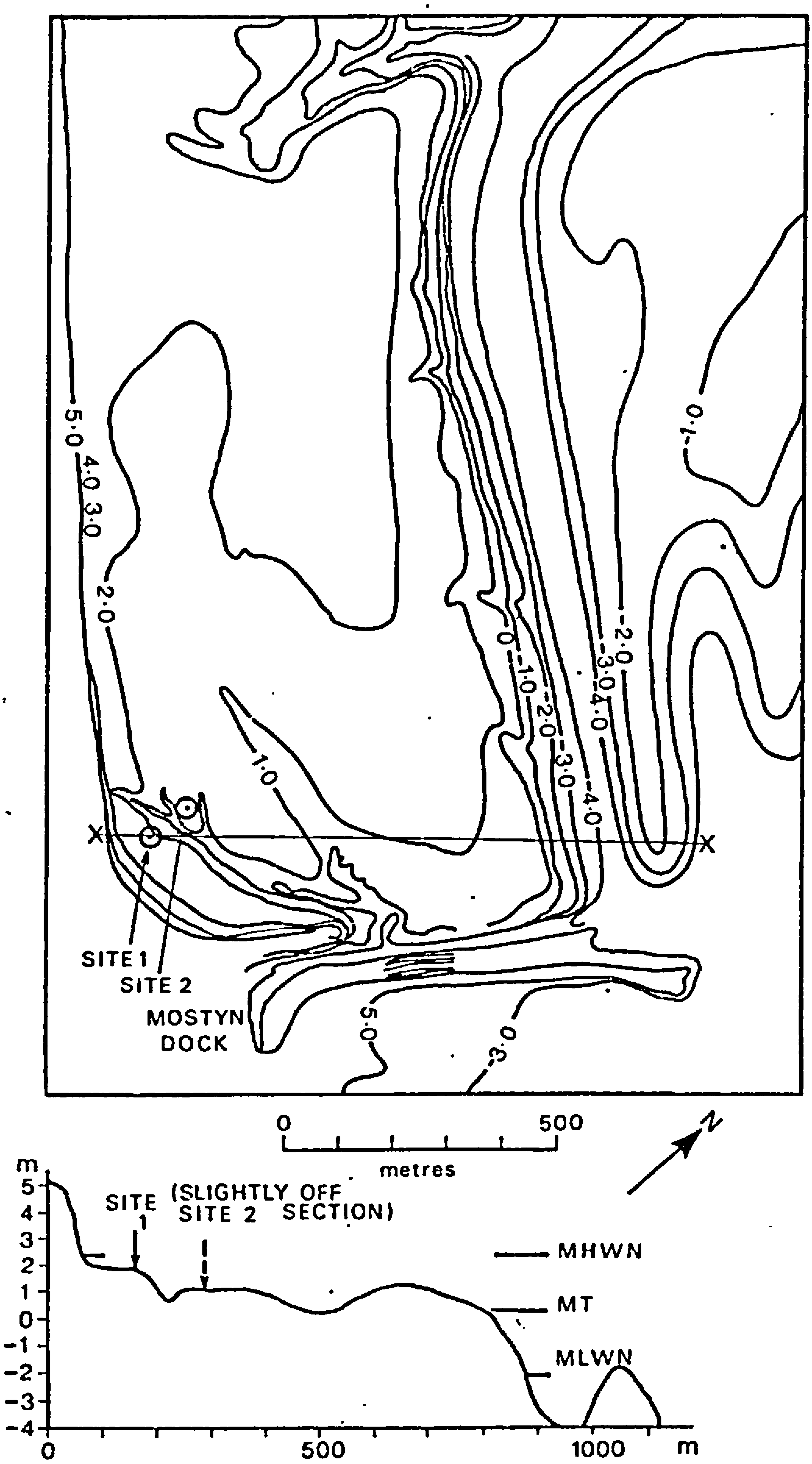
Map 2 Location grid used in the bi-annual extensive surveys.



Map 3. **Location of Gayton sampling stations** (hatched area denotes saltmarsh).
Station 1 = Grid survey site 33-21 (Map 2), Station 2 = 33-20, etc.



Map 4. Location of Thurstaston sampling area - Aunt Sally's Cottage (Grid Ref. SJ 236835).



Map 5. Location of Mostyn sampling area - Mostyn Dock (Grid Ref. SJ 155812).

Map 6. Dee Estuary in 1684 (figures in channels represent depth at low water).

Map 7. Dee Estuary in 1732.

Map 8. Dee Estuary in 1749.

Map 9. Dee Estuary in 1800.

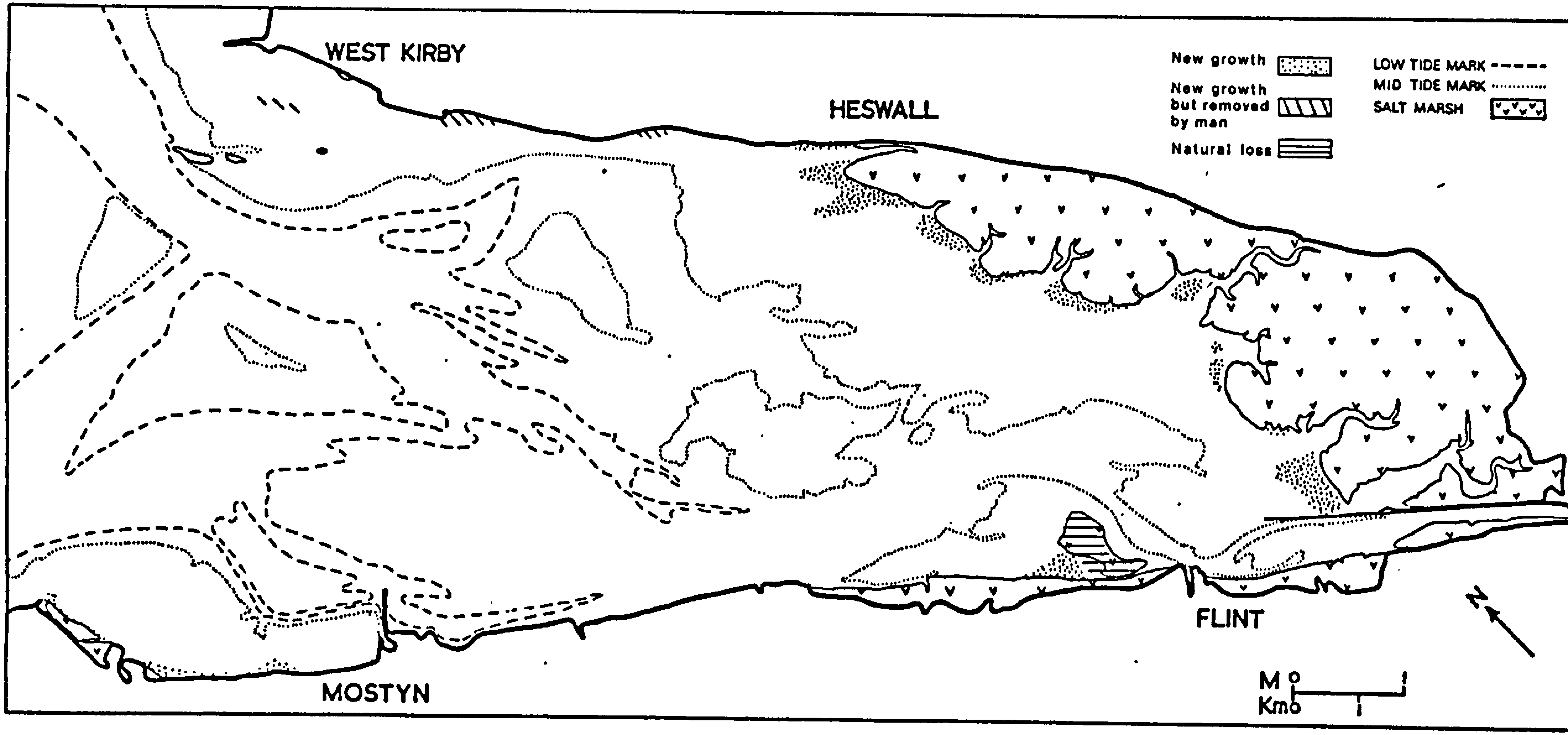
Map 10. Dee Estuary in 1849.

Map 11. Dee Estuary in 1910.

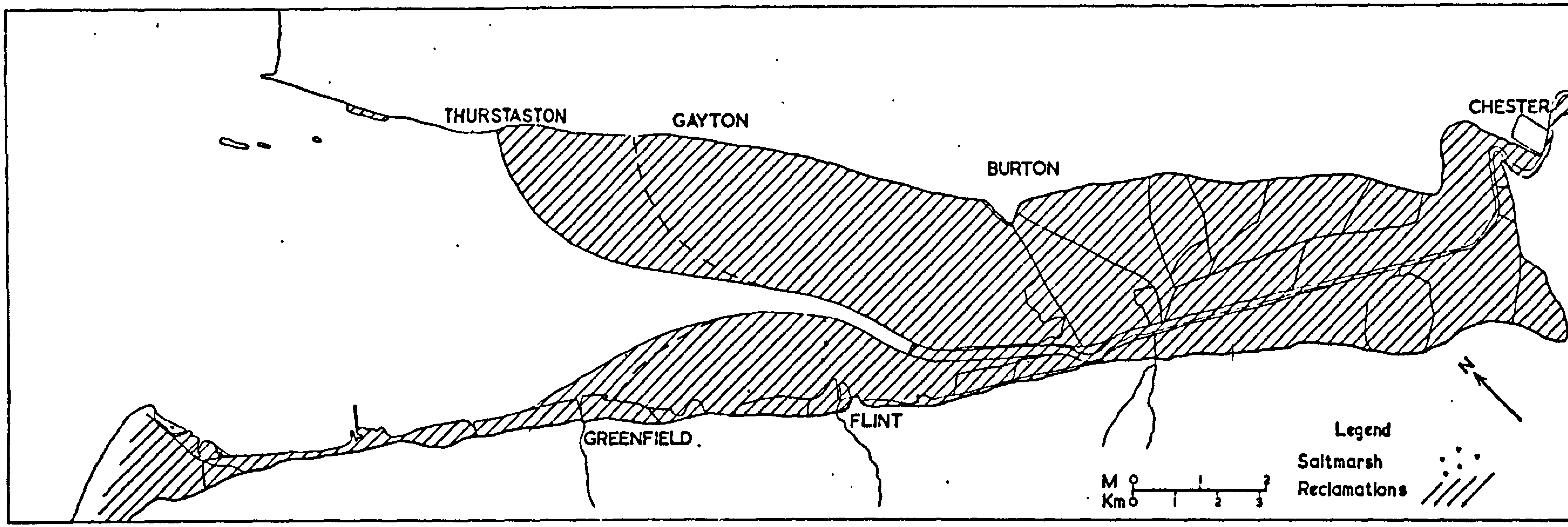
Map 12. Dee Estuary in 1932.

Map 13. Dee Estuary in 1956.

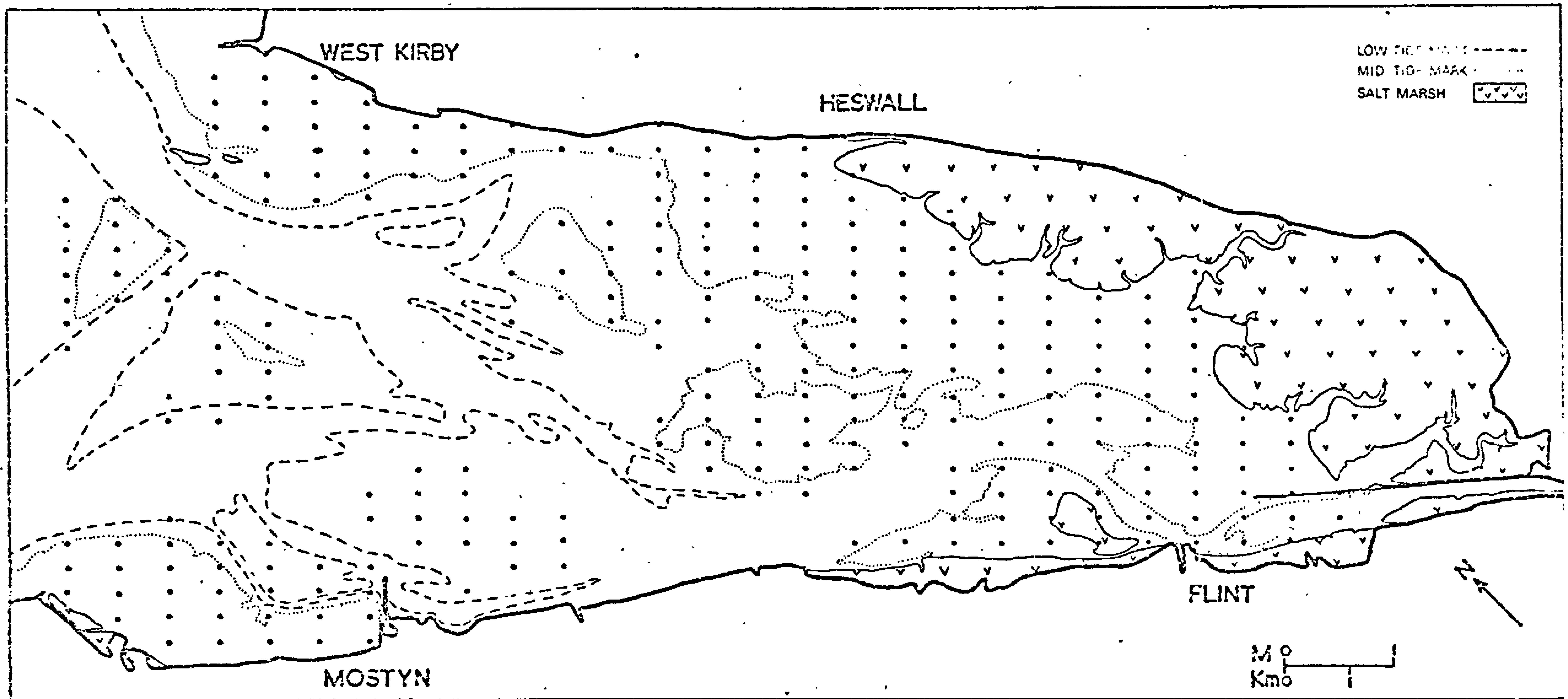
Map 14. Dee Estuary in 1971.



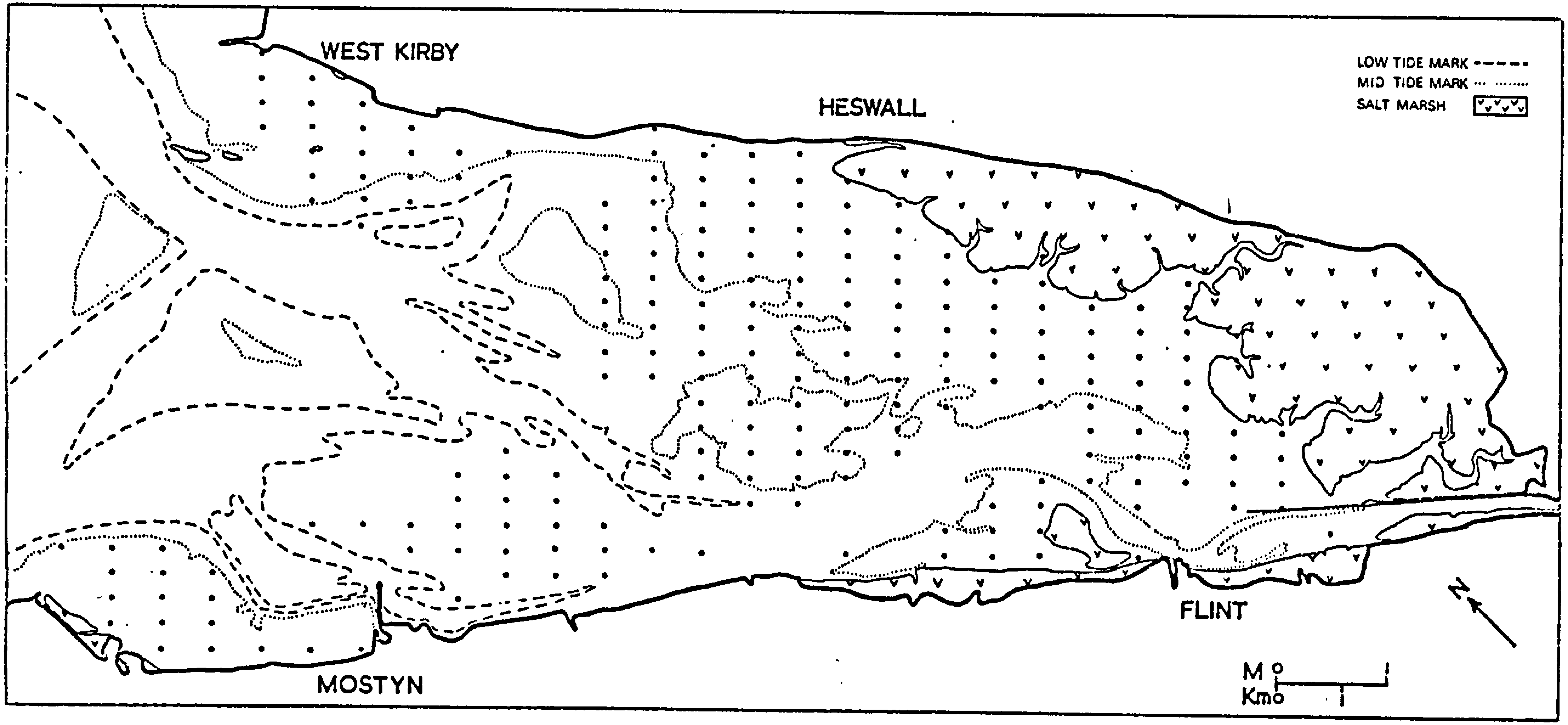
Map 15. Change in saltmarsh area between 1971 and 1976.



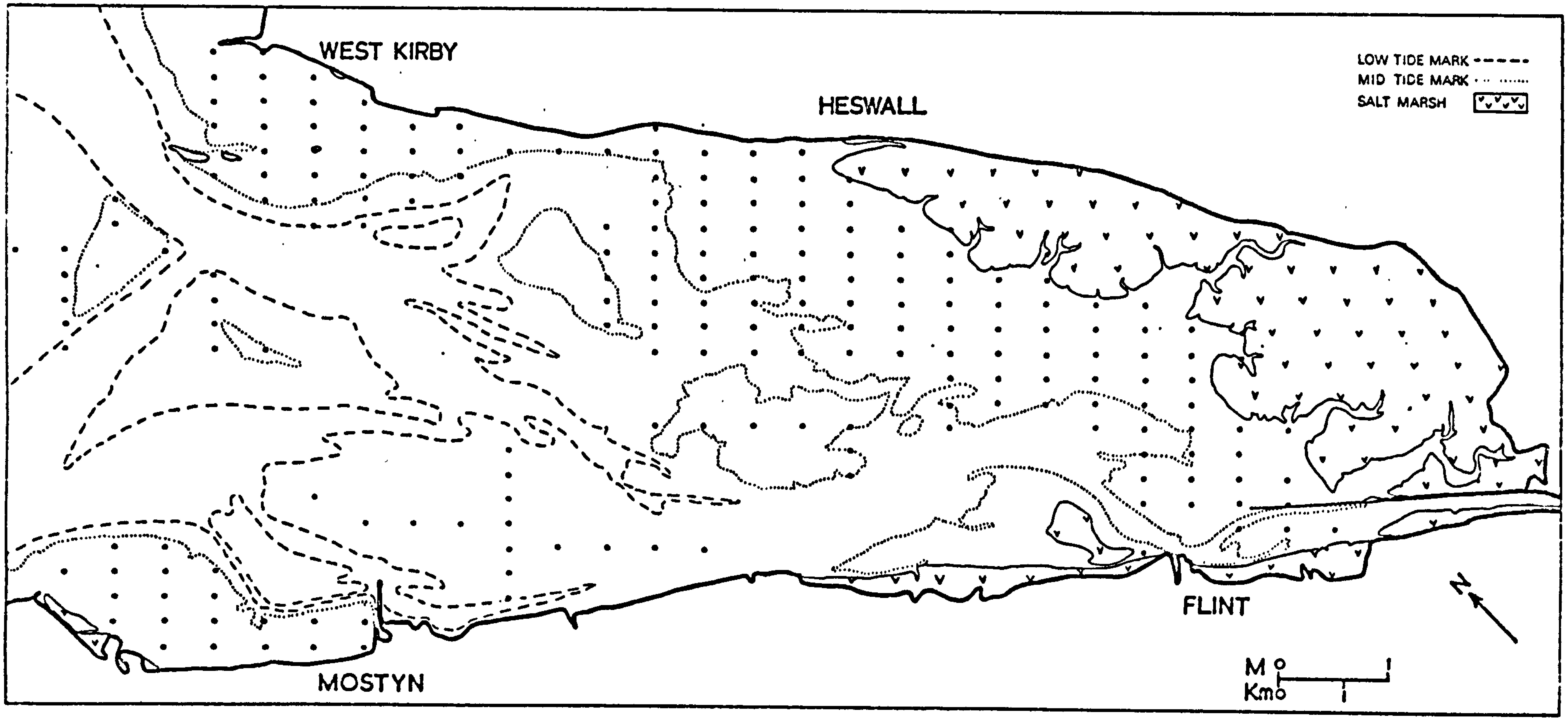
Map 16. Proposed developments in the Estuary - approximate shape of the extended barrage scheme, hatched line denotes contracted scheme.



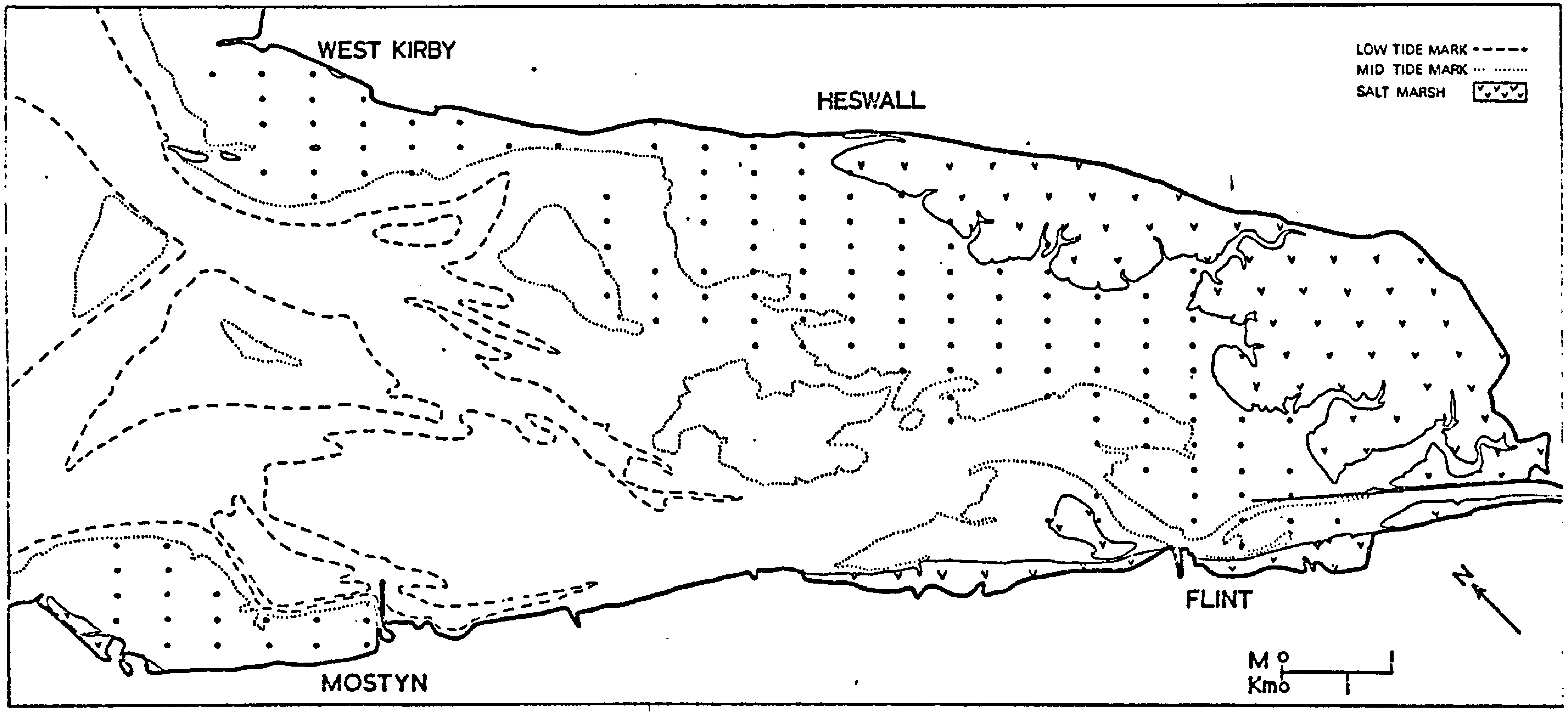
Map 17. Distribution of grid sampling sites in Autumn 1971.



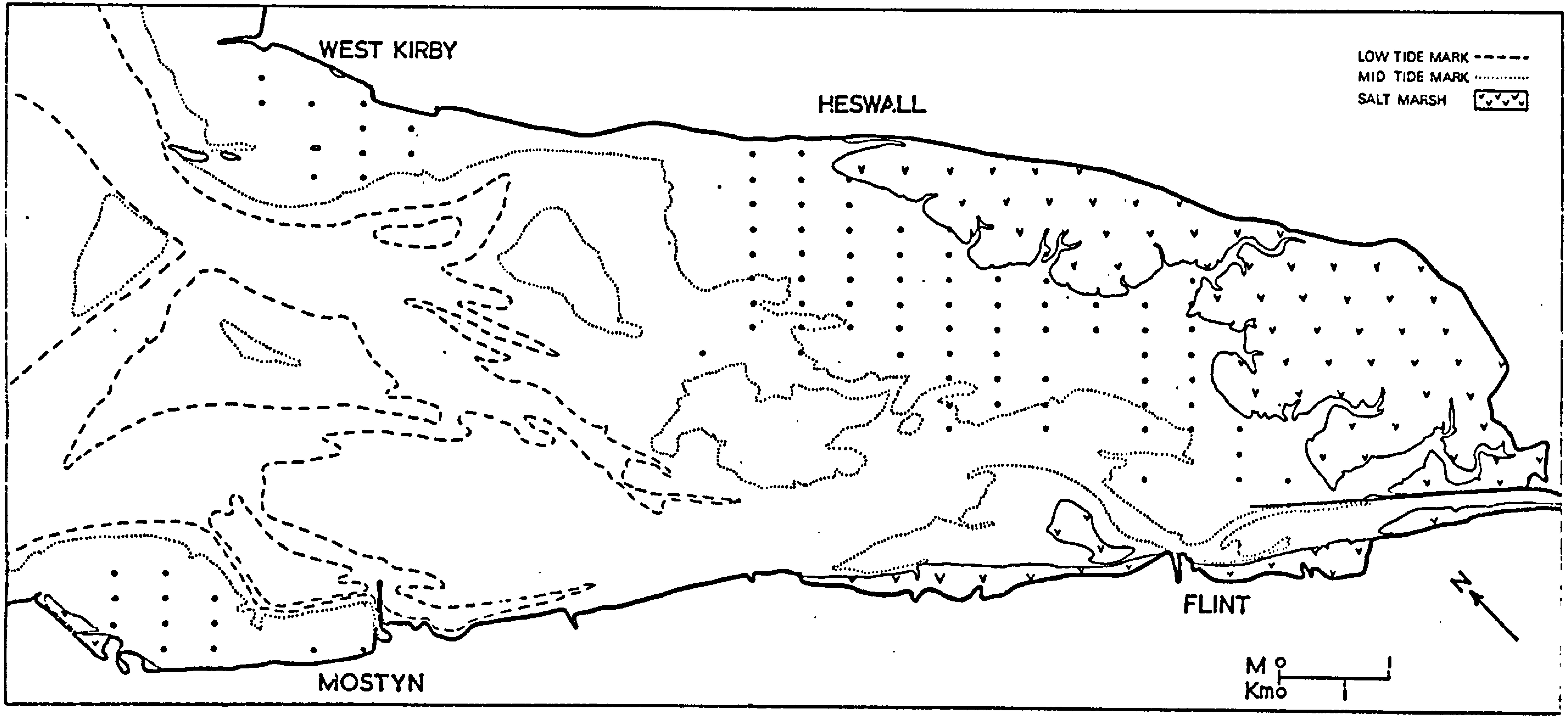
Map 18. Distribution of grid sampling sites in Spring 1972.



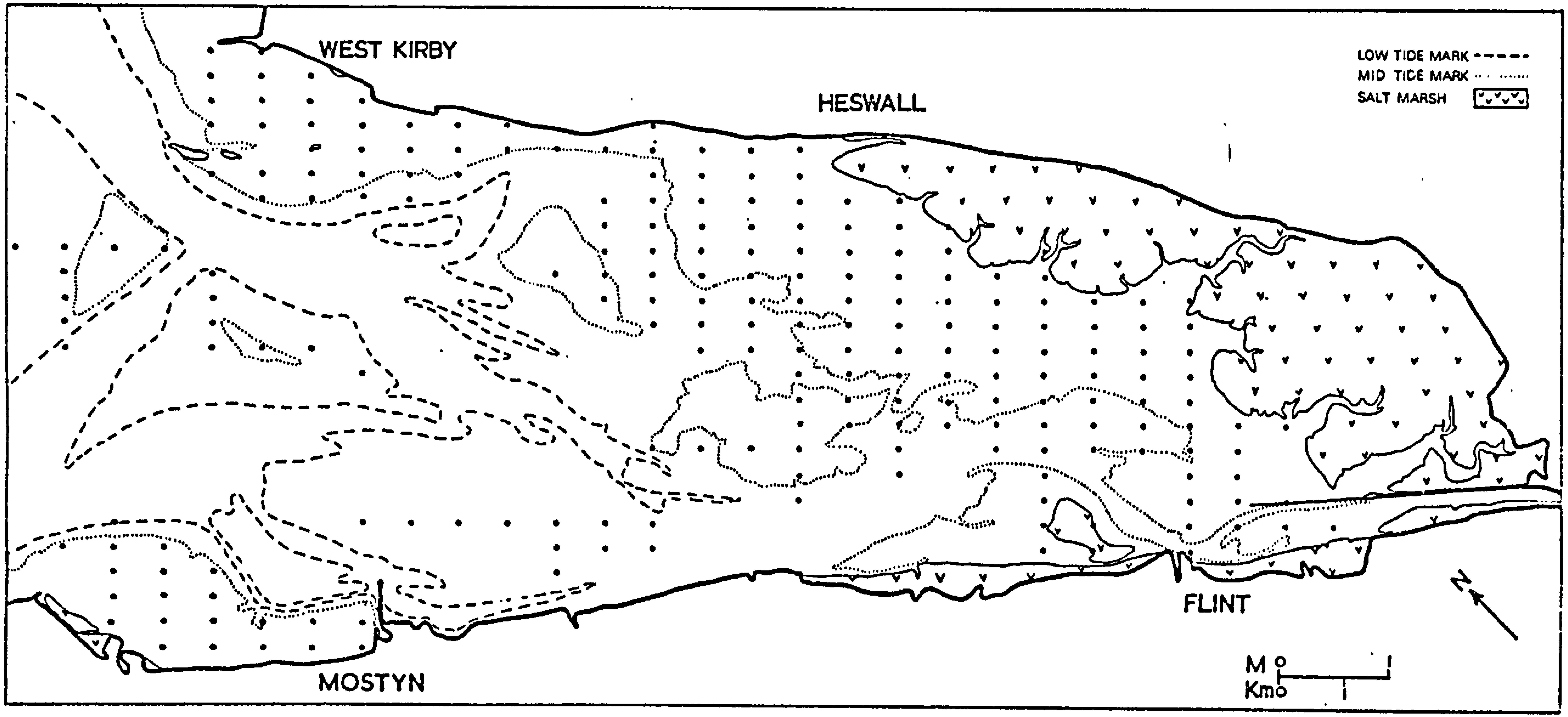
Map 19. Distribution of grid sampling sites in Spring 1973.



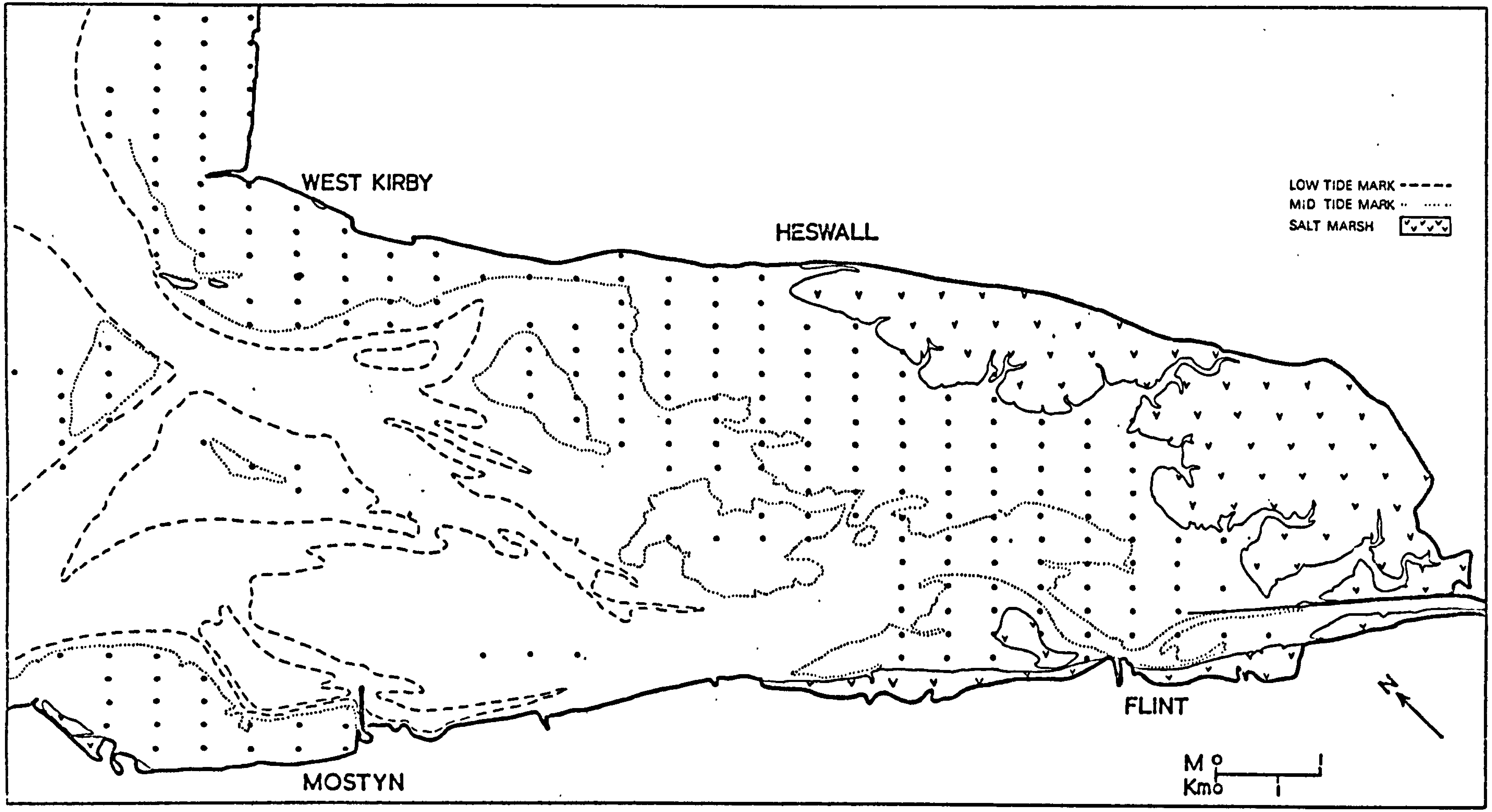
Map 20. Distribution of grid sampling sites in Spring 1974.



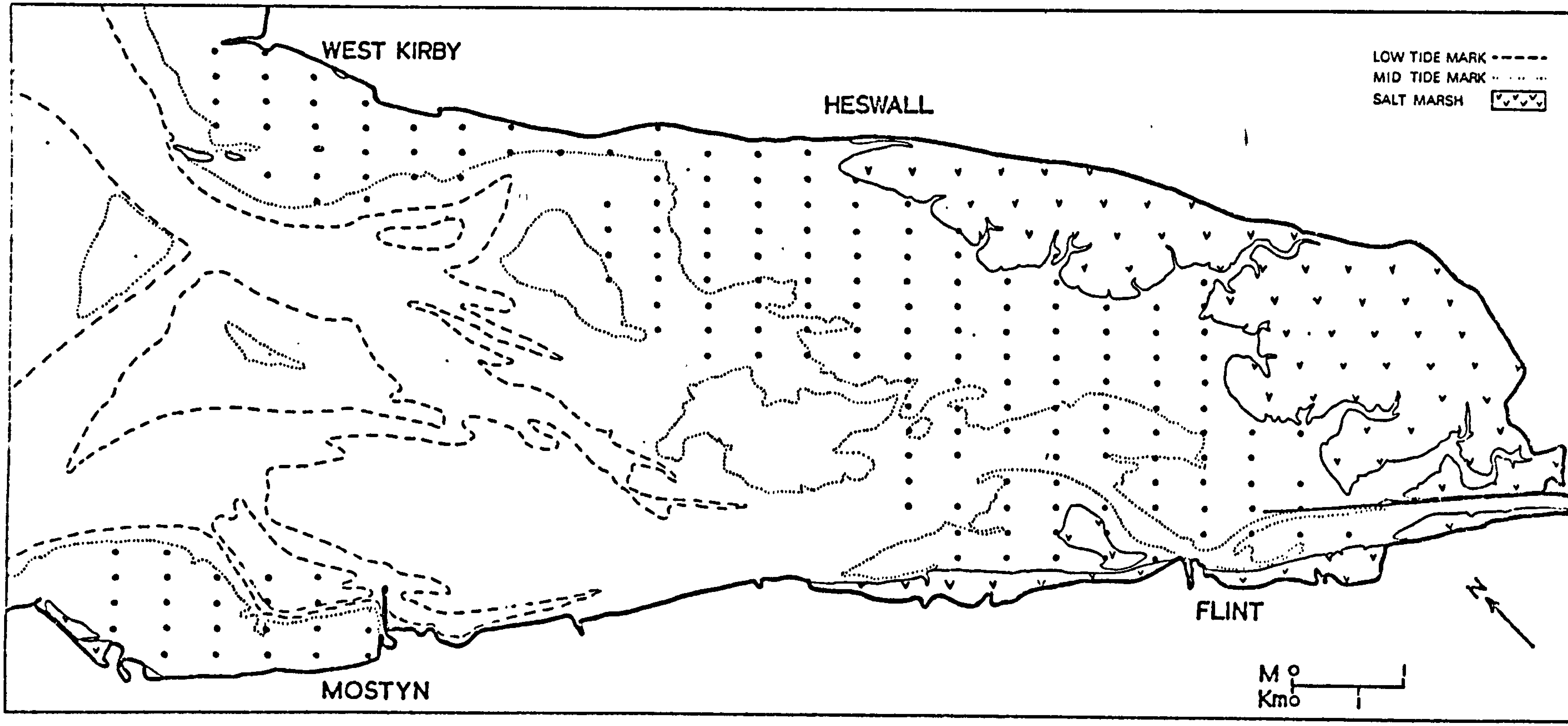
Map 21. Distribution of grid sampling sites in Spring 1975.



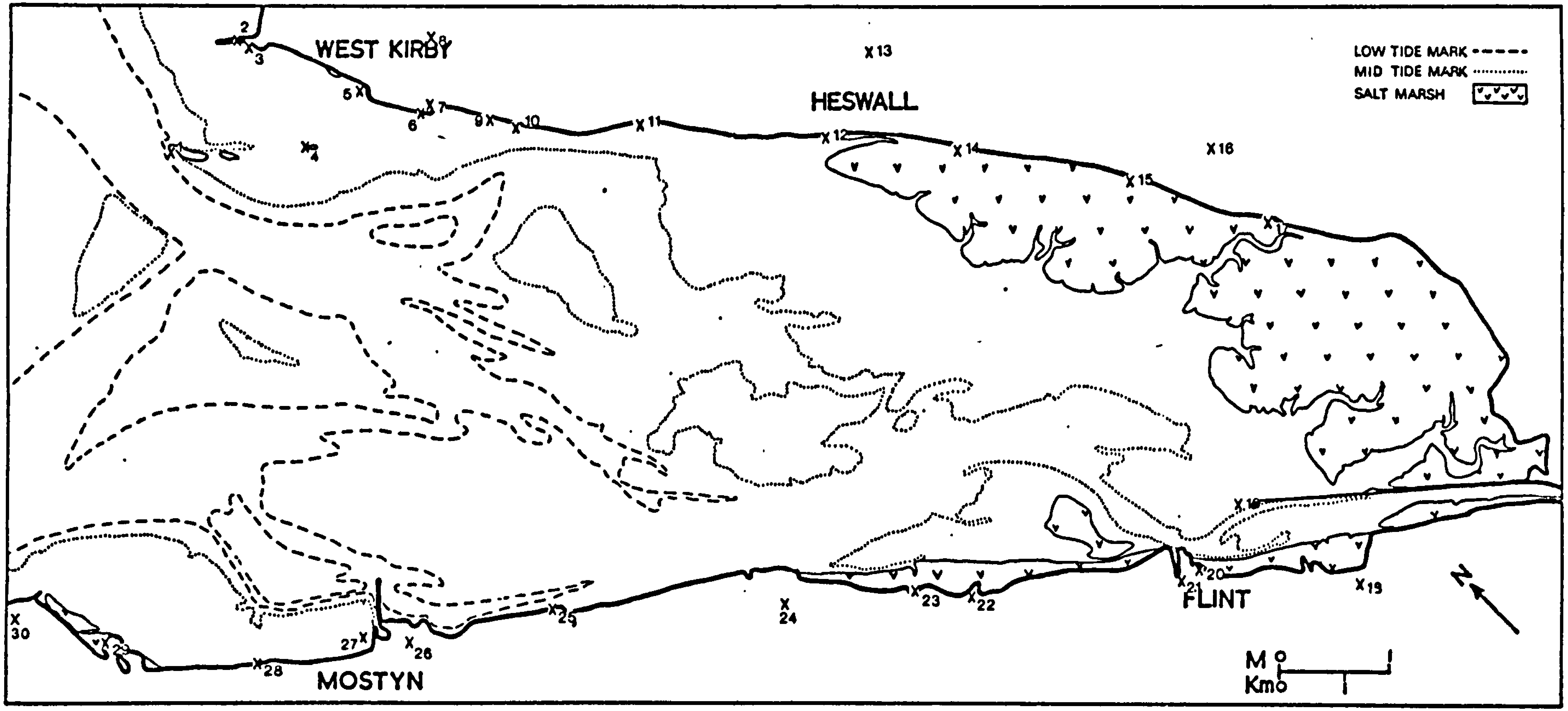
Map 22. Distribution of grid sampling sites in Autumn 1975.



Map 23. Distribution of grid sampling sites in Spring 1976.

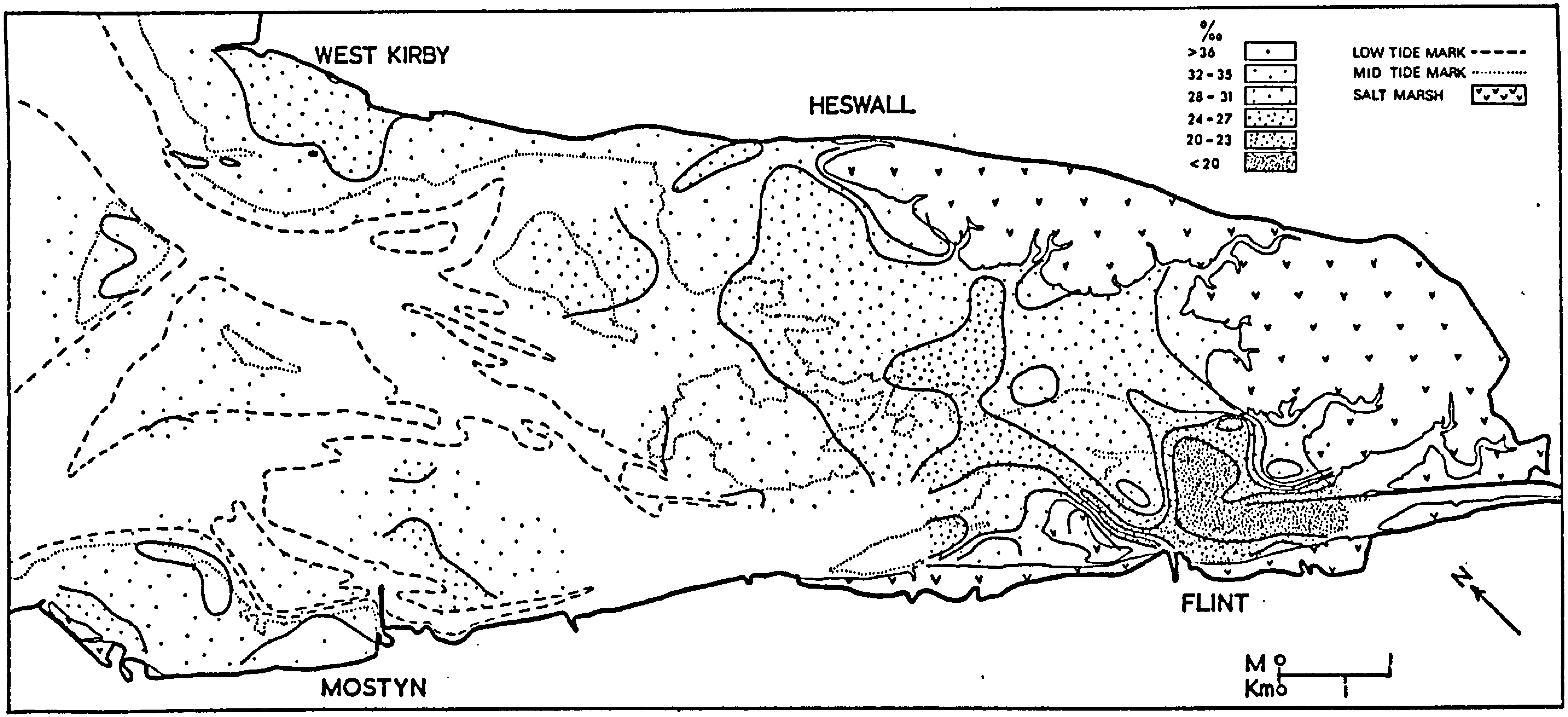


Map 24. Distribution of grid sampling sites in Autumn 1976.



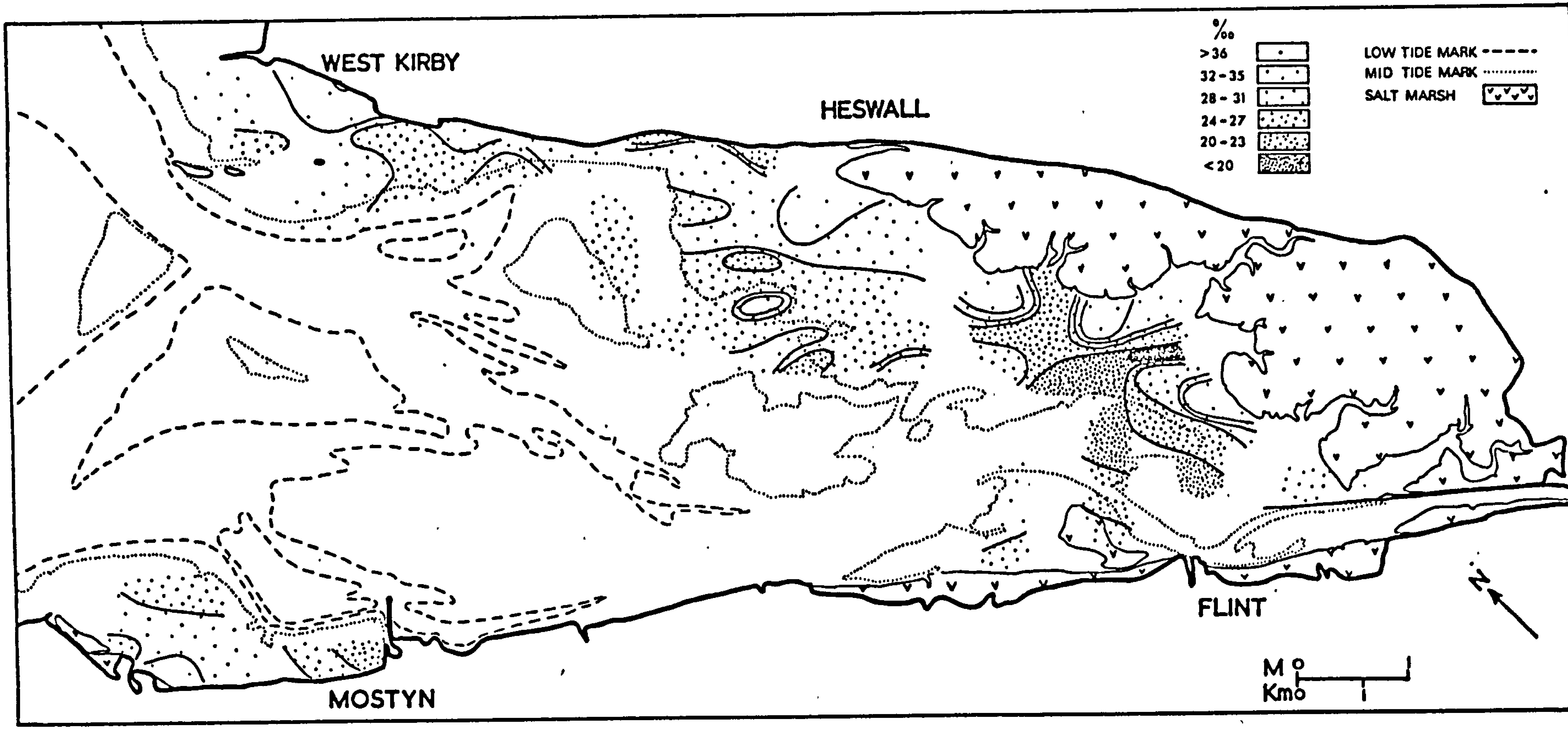
Map 25. Compass Bearing Reference Sites.

Map 26. Distribution of Tidal Heights in Spring 1971.

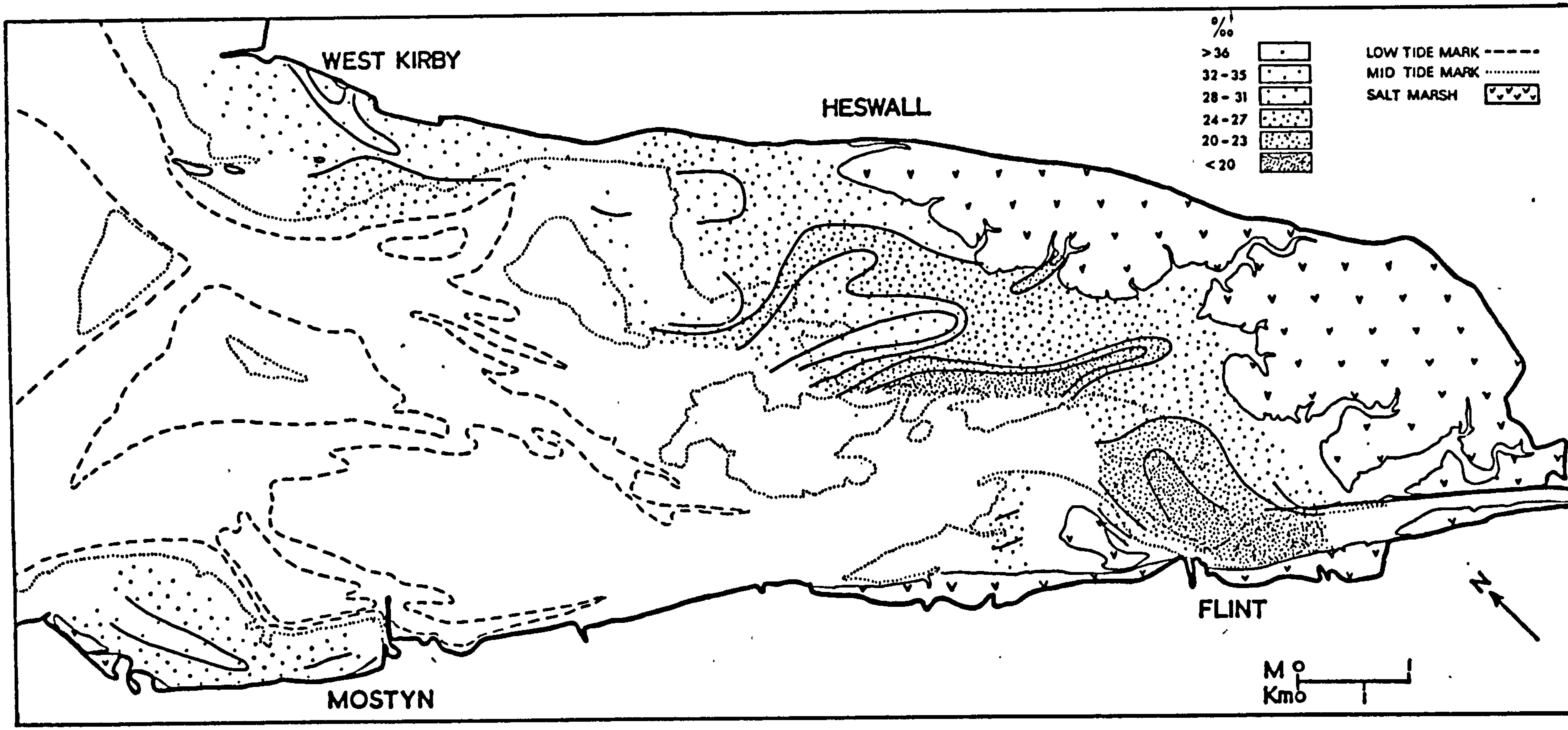


Map 27. Distribution of sediment Interstitial Salinity at 0-2.5 cms depth in Autumn 1971.

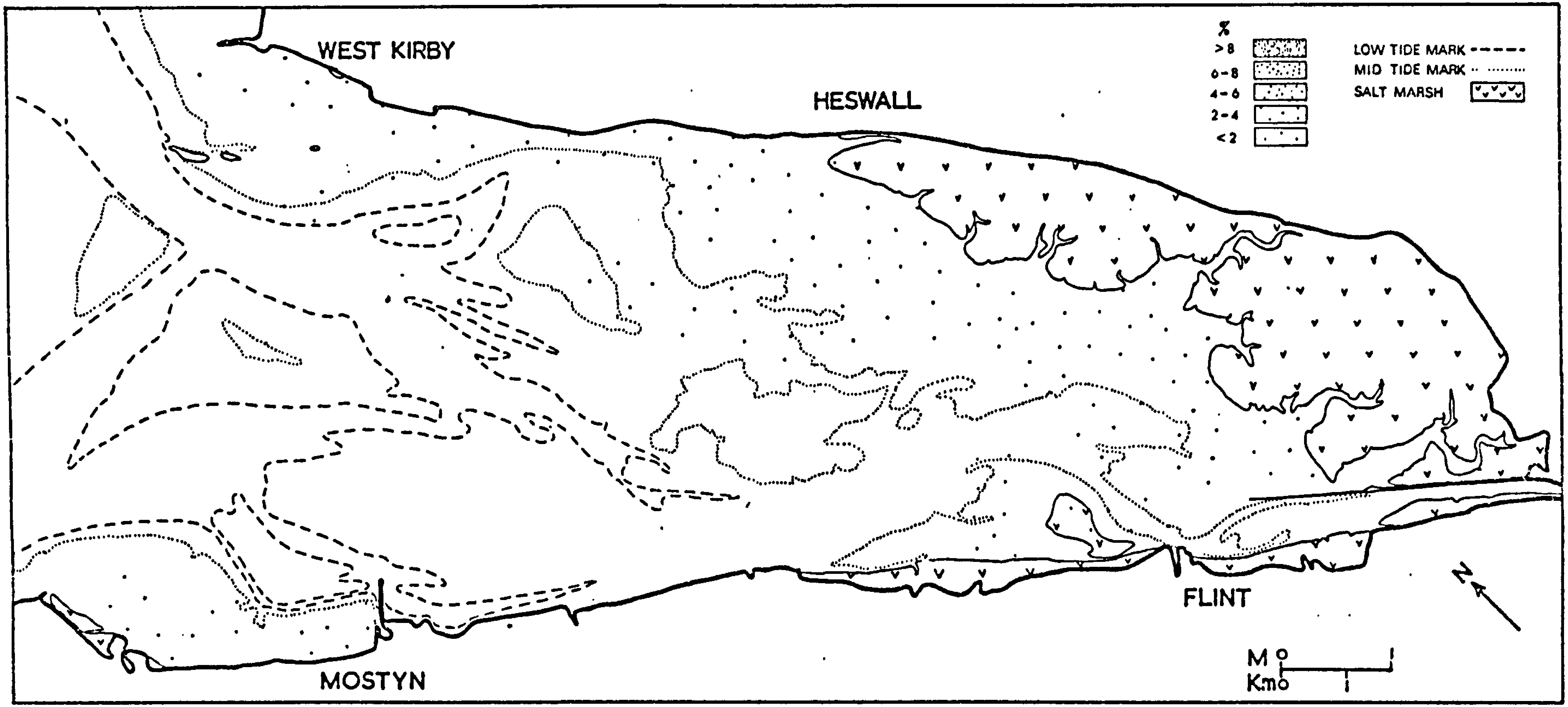
Map 28. Distribution of sediment Interstitial Salinity at 17.5-20 cms depth in Autumn 1971.



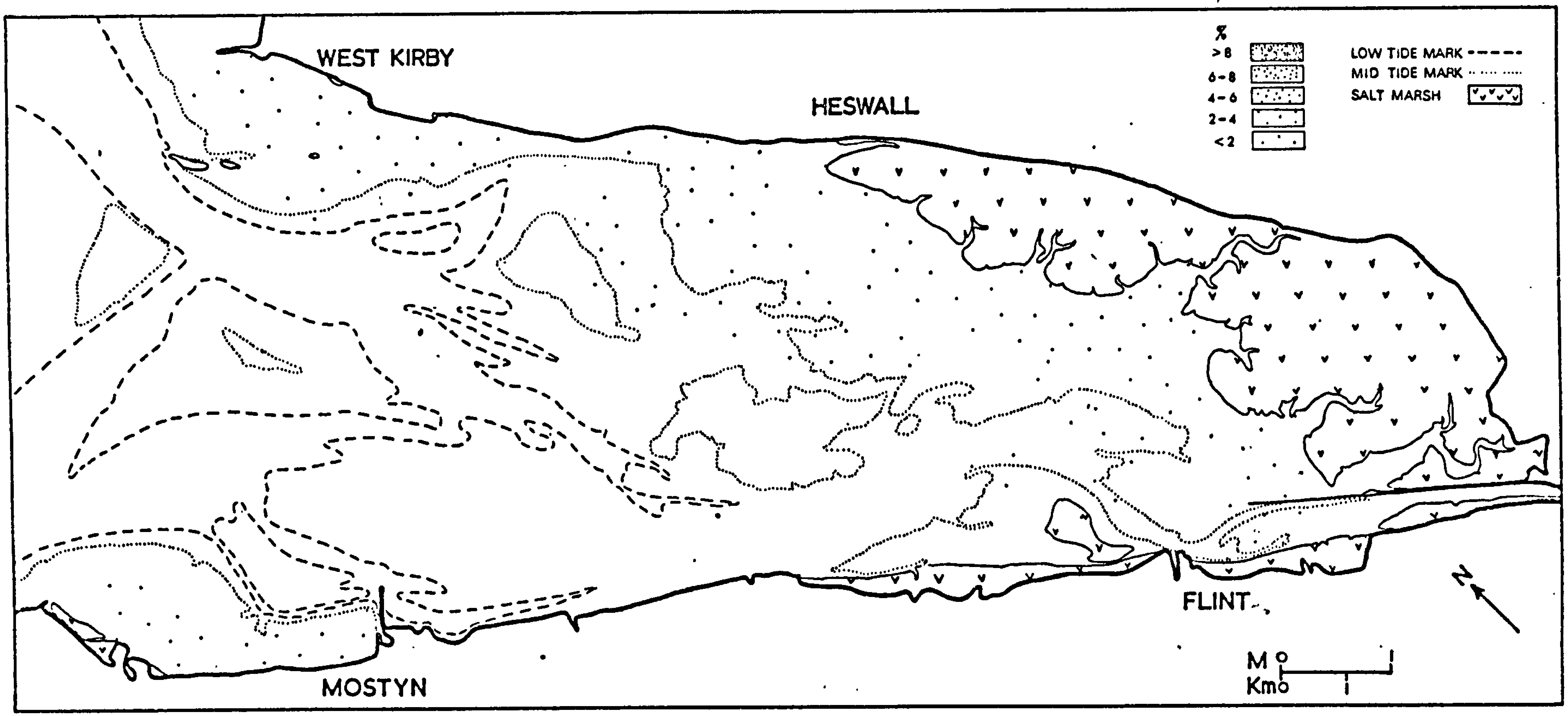
Map 29. Distribution of sediment Interstitial Salinity at 0-2.5 cms depth in Spring 1974.



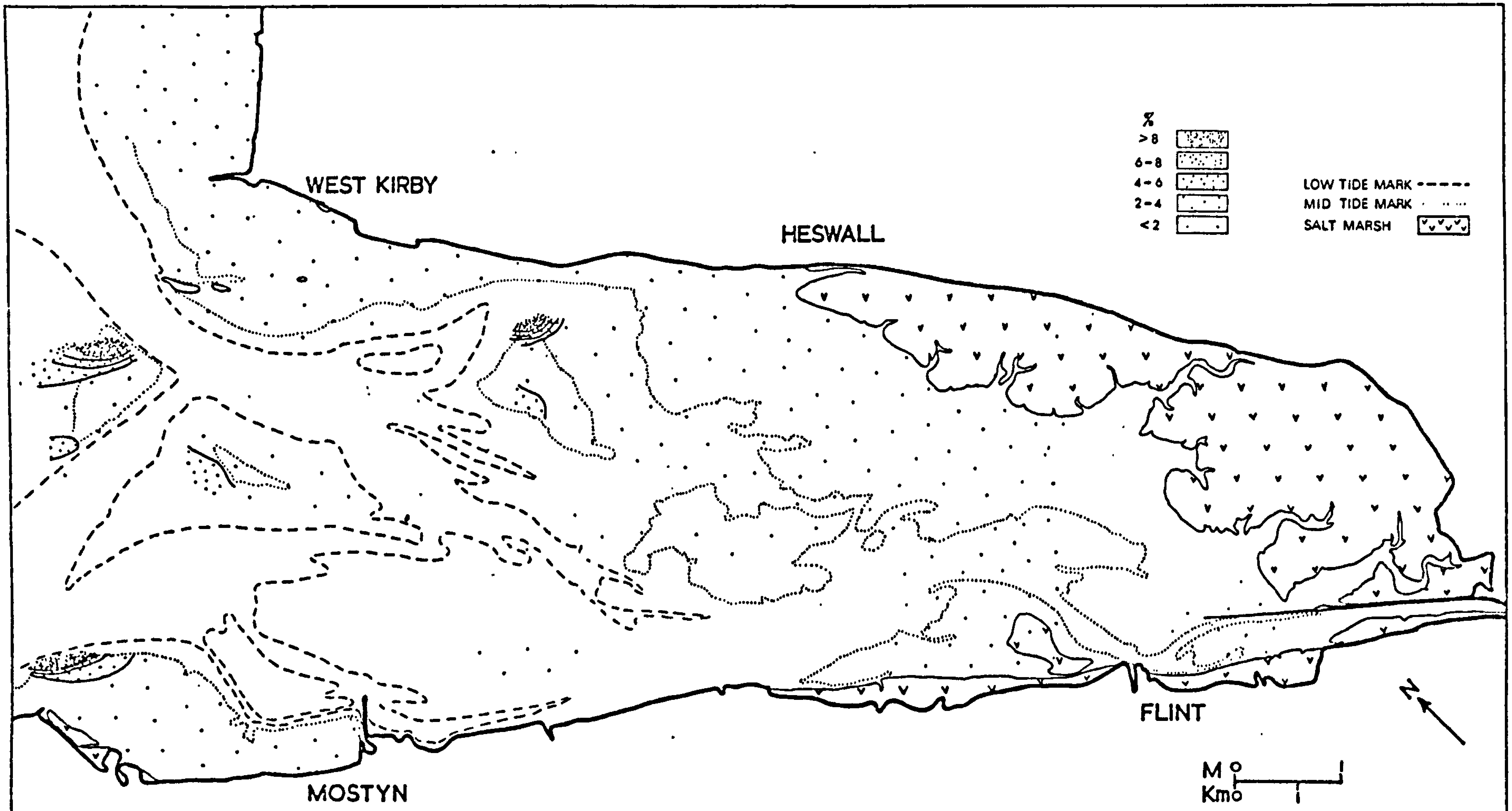
Map 30. Distribution of sediment Interstitial Salinity at 17.5-20 cms depth in Spring 1974.



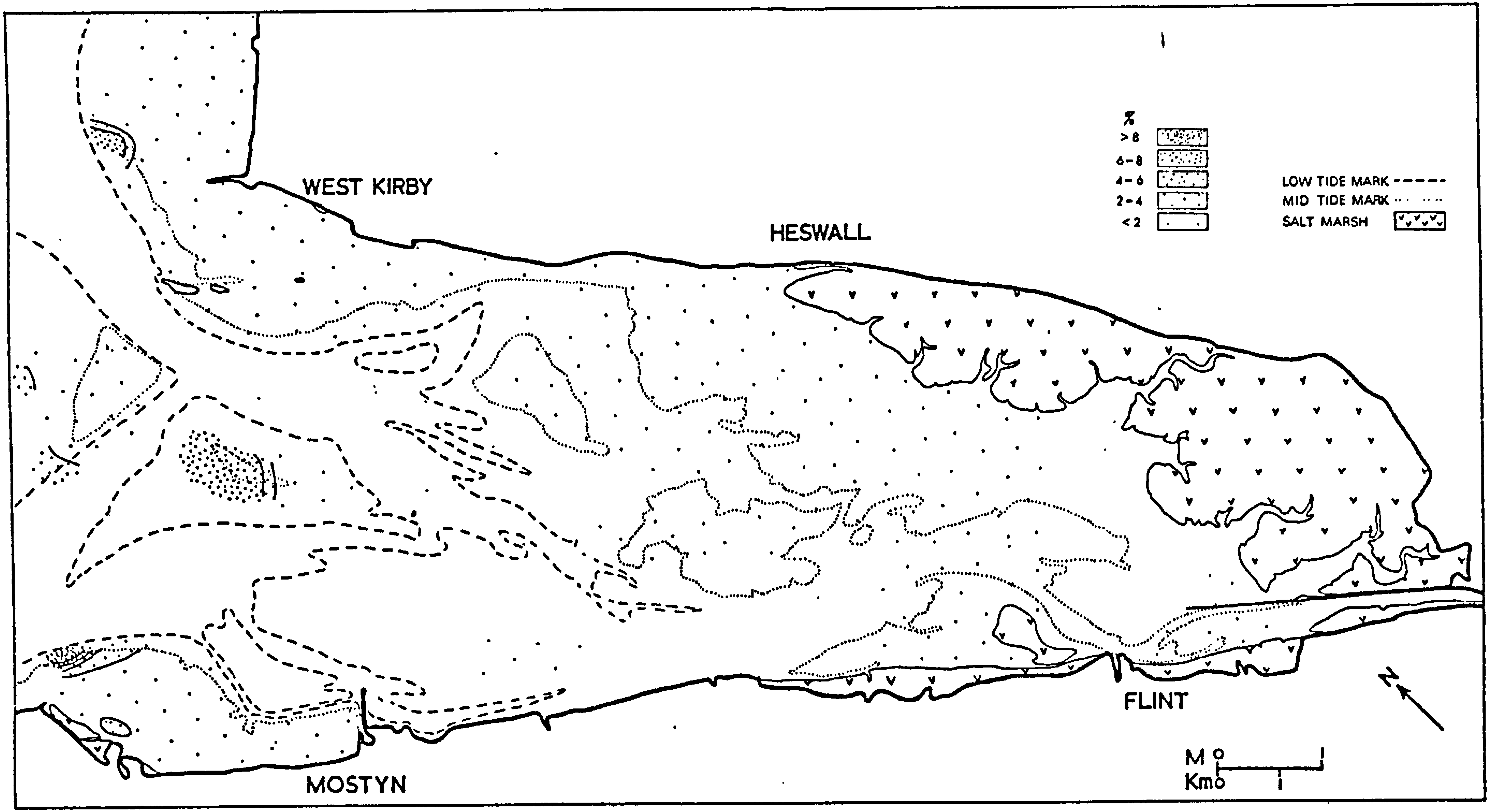
Map 31. Distribution of Coarse Sand (500-1000µ) at 0-2.5 cms depth in Spring 1974.



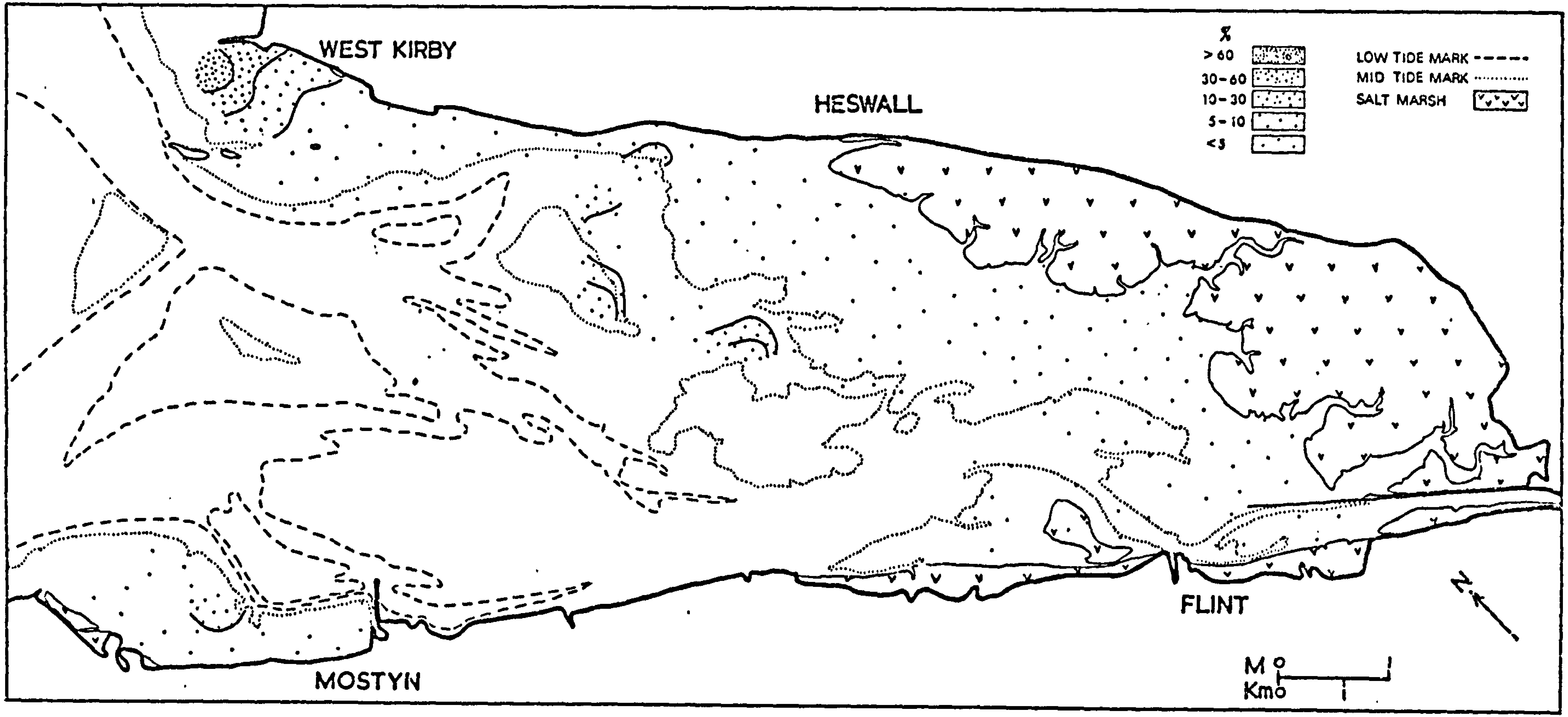
Map 32. Distribution of Coarse Sand (500-1000u) at 17.5-20 cms depth in Spring 1974.



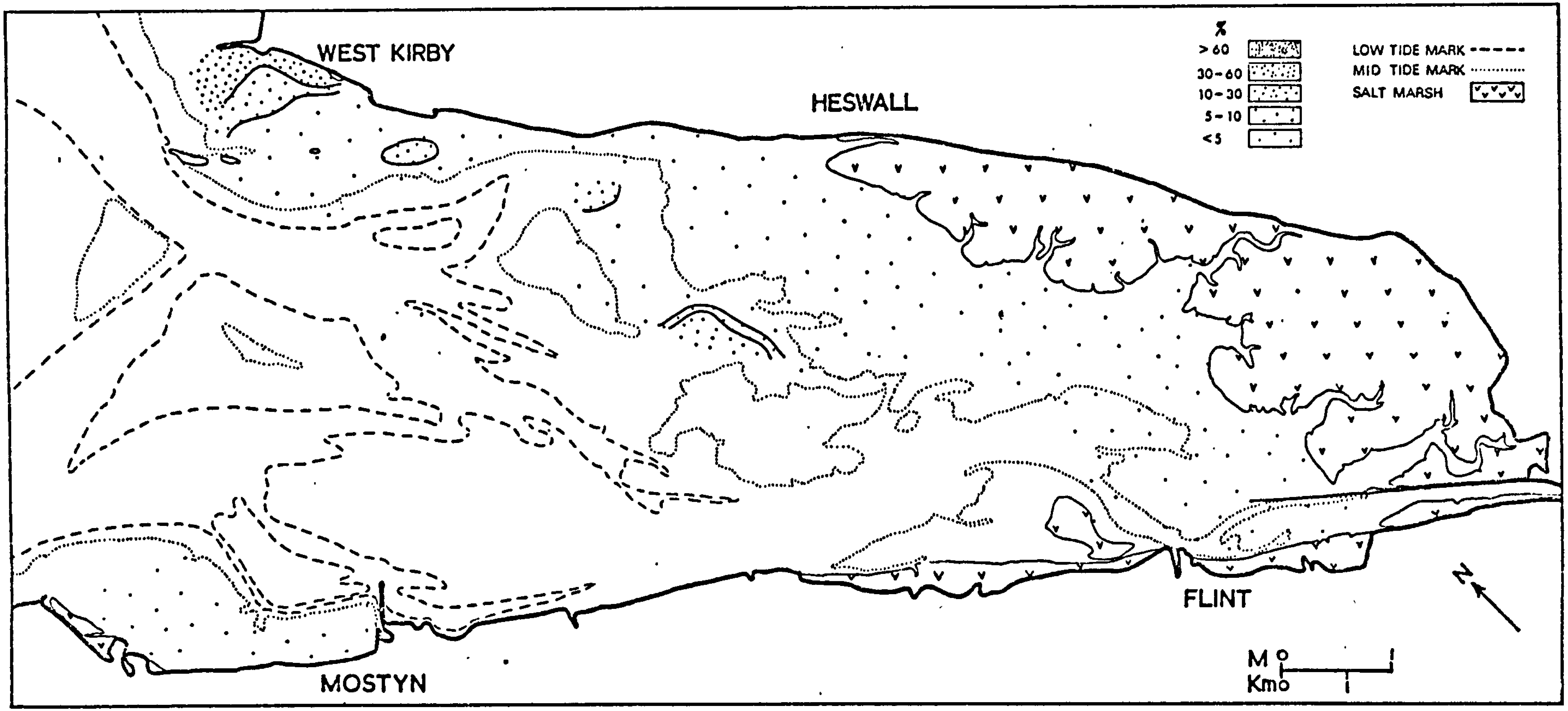
Map 33. Distribution of Coarse Sand (500-1000µ) at 0-2.5 cms depth in Spring 1976.



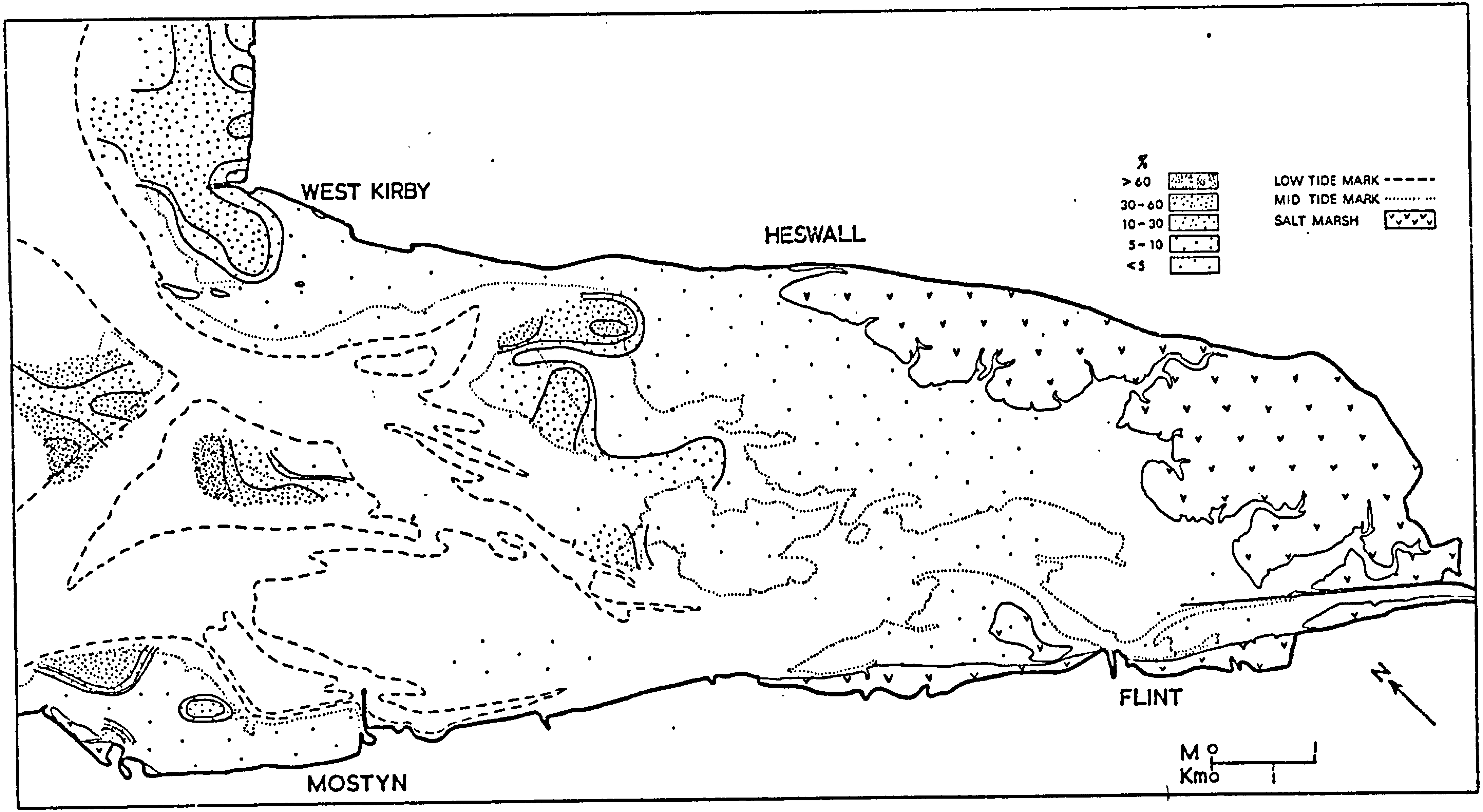
Map 34. Distribution of Coarse Sand (500-1000µ) at 17.5-20 cms depth in Spring 1976.



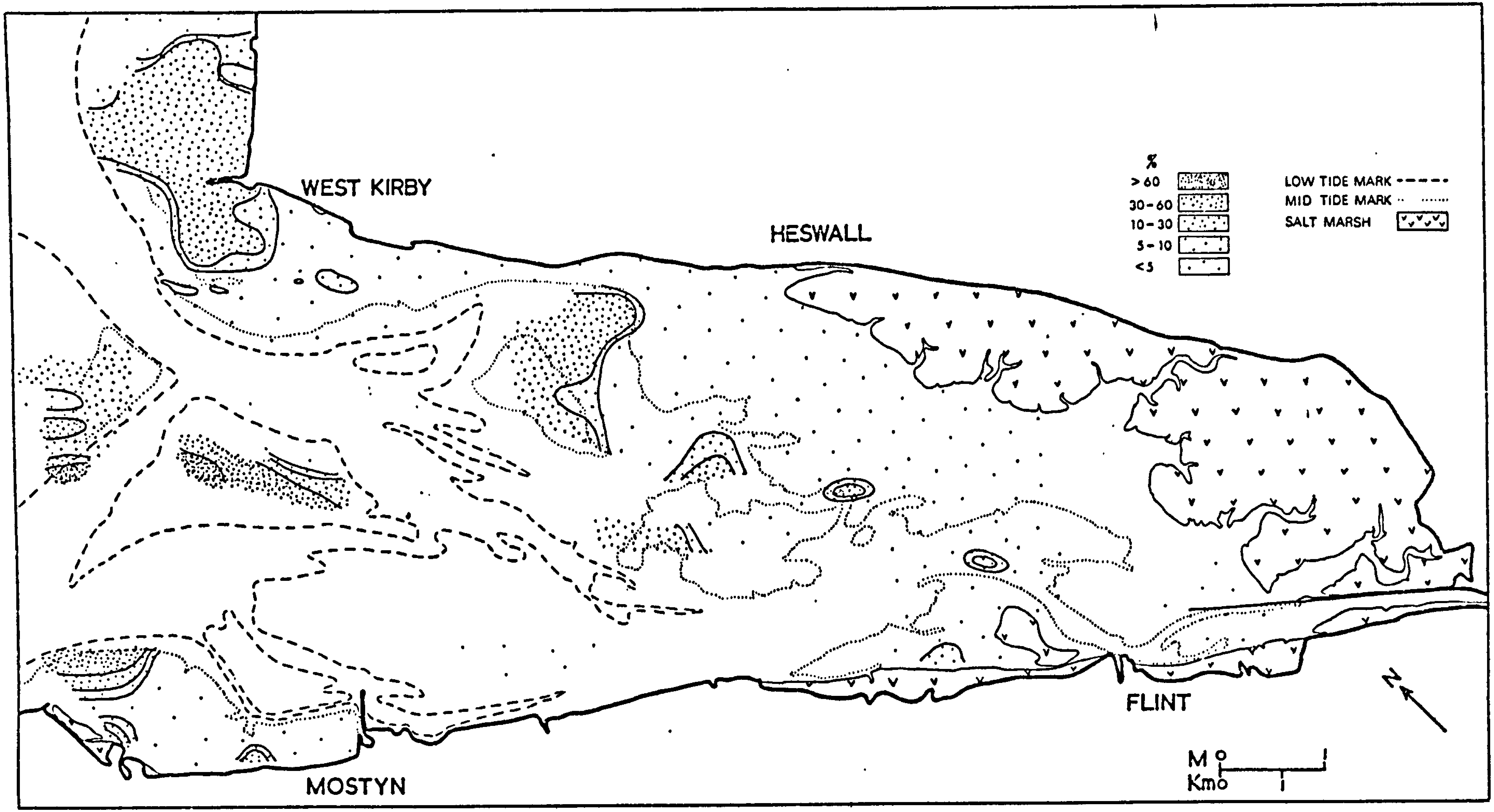
Map 35. Distribution of Medium Sand (250-500u) at 0-2.5 cms depth in Spring 1974.



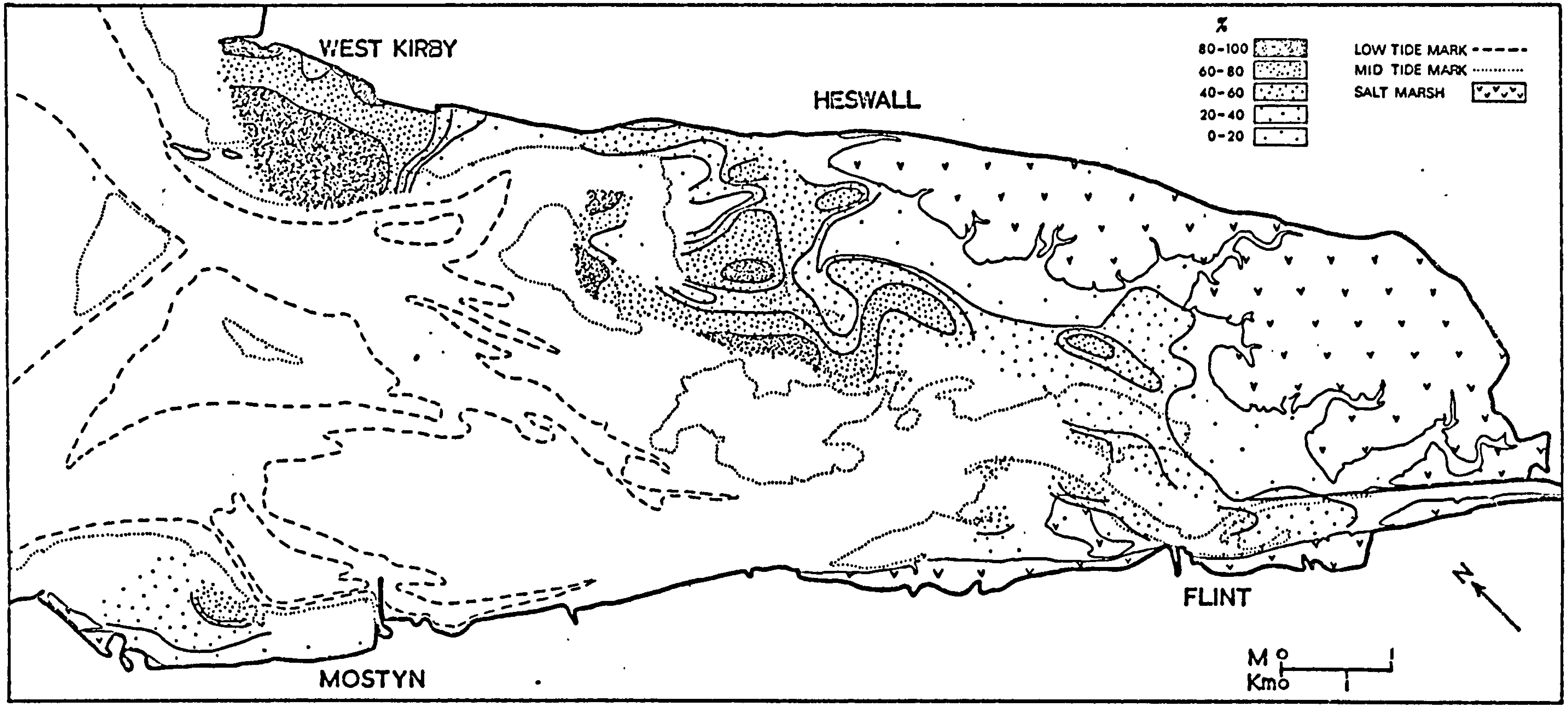
Map 36. Distribution of Medium Sand (250-500μ) at 17.5-20 cms depth in Spring 1974.



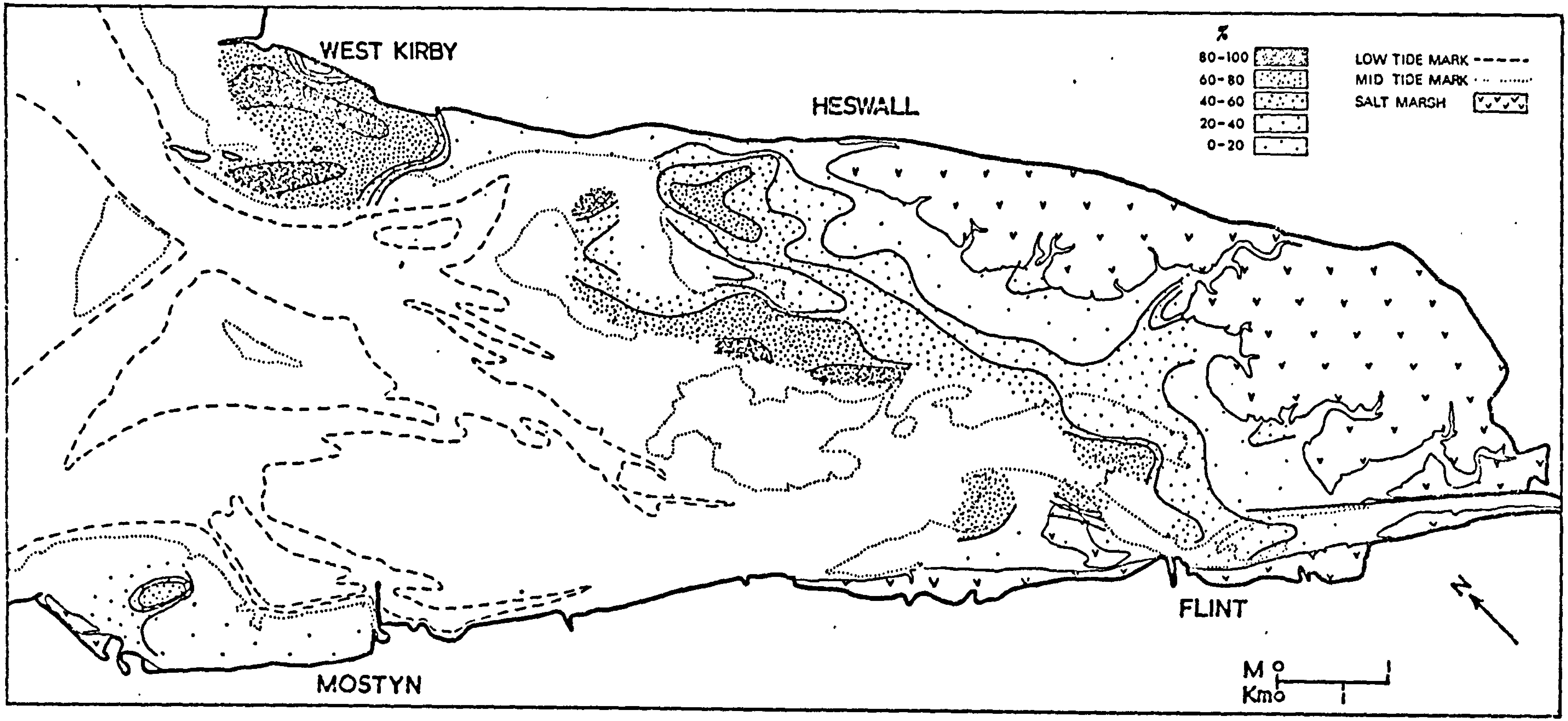
Map 37. Distribution of Medium Sand (250-500µ) at 0-2.5 cms depth in Spring 1976.



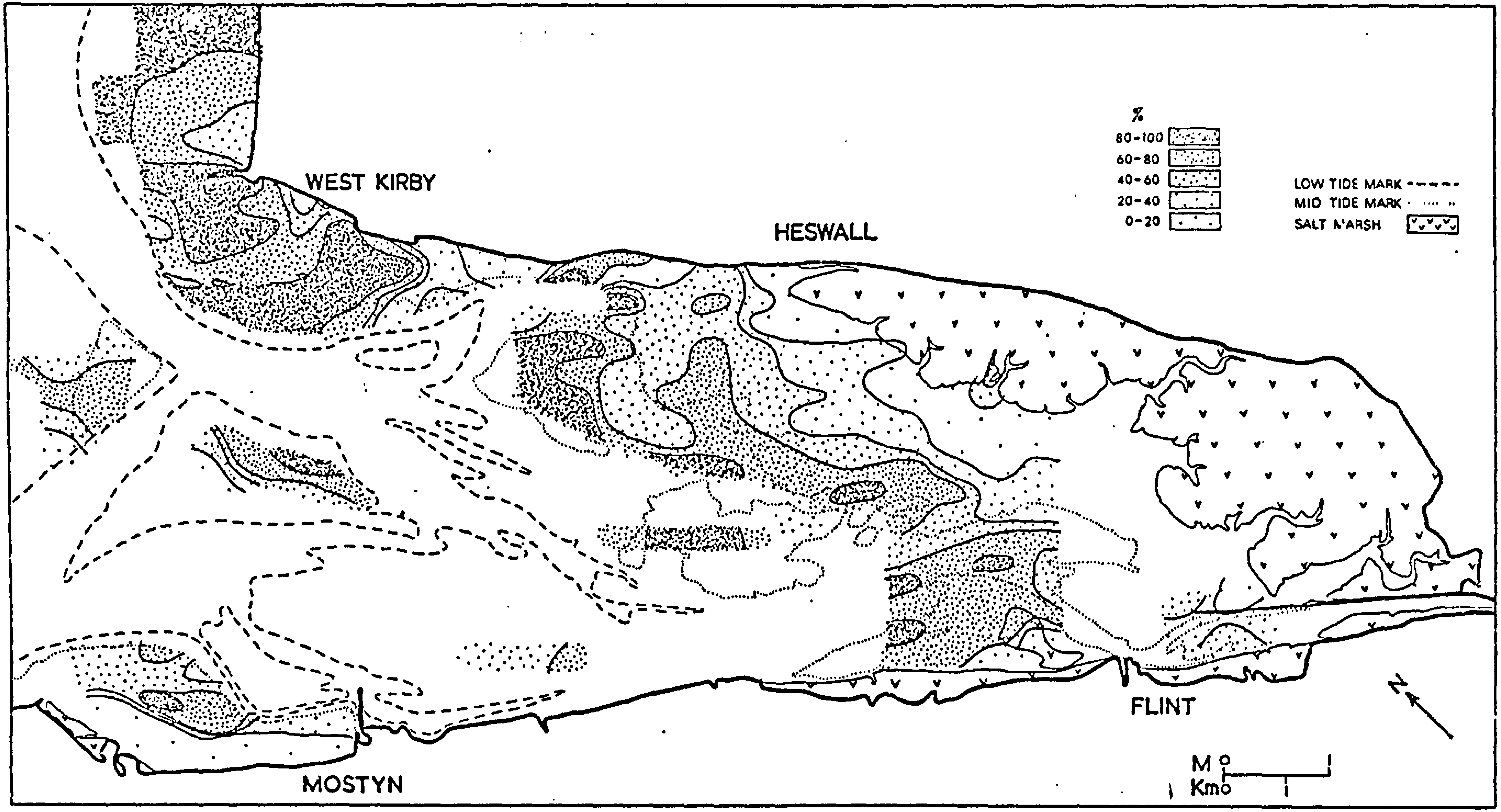
Map 38. Distribution of Medium Sand (250-500u) at 17.5-20 cms depth in Spring 1976.



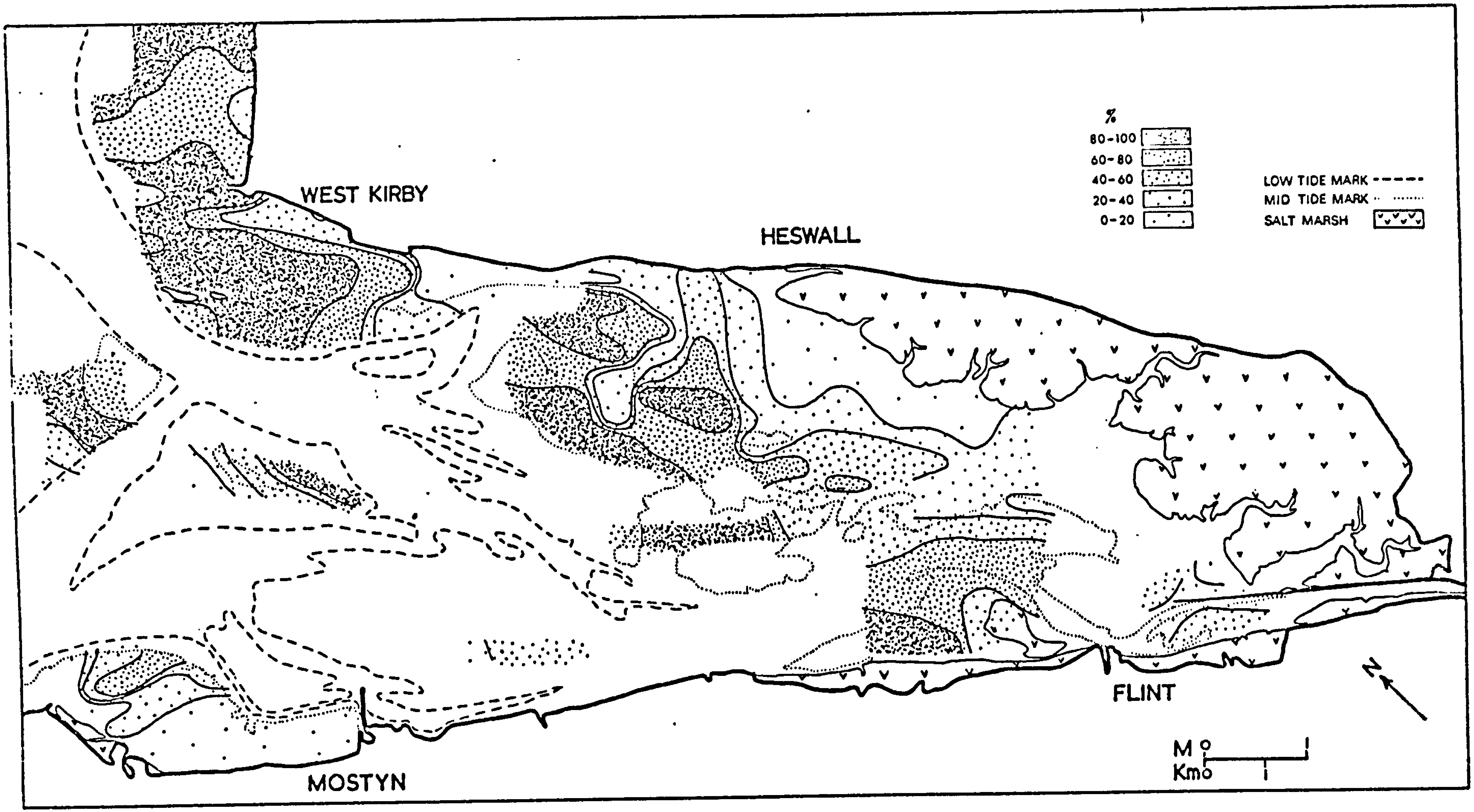
Map 39. Distribution of Fine Sand (125-250u) at 0-2.5 cms depth in Spring 1974.



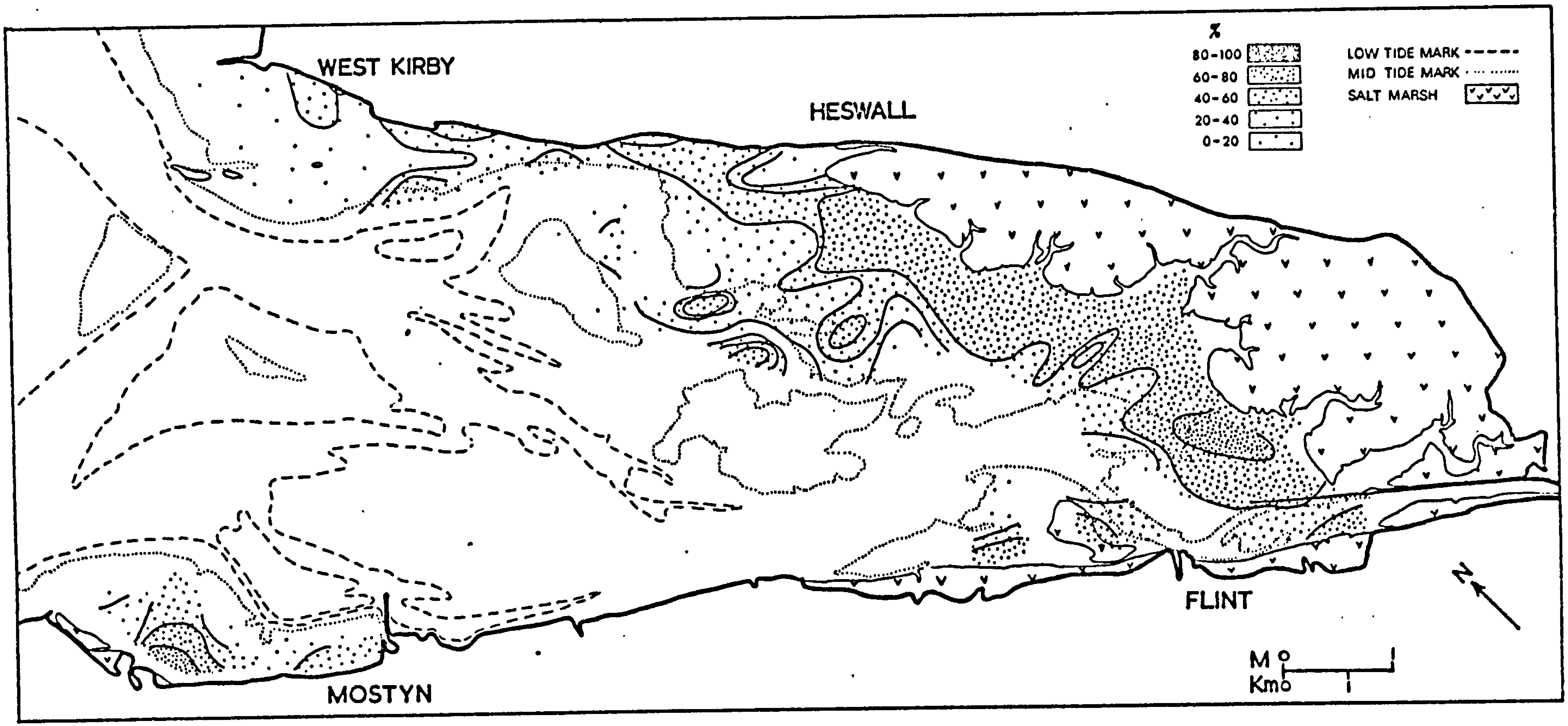
Map 40. Distribution of Fine Sand (125-250μ) at 17.5-20 cms depth in Spring 1974.



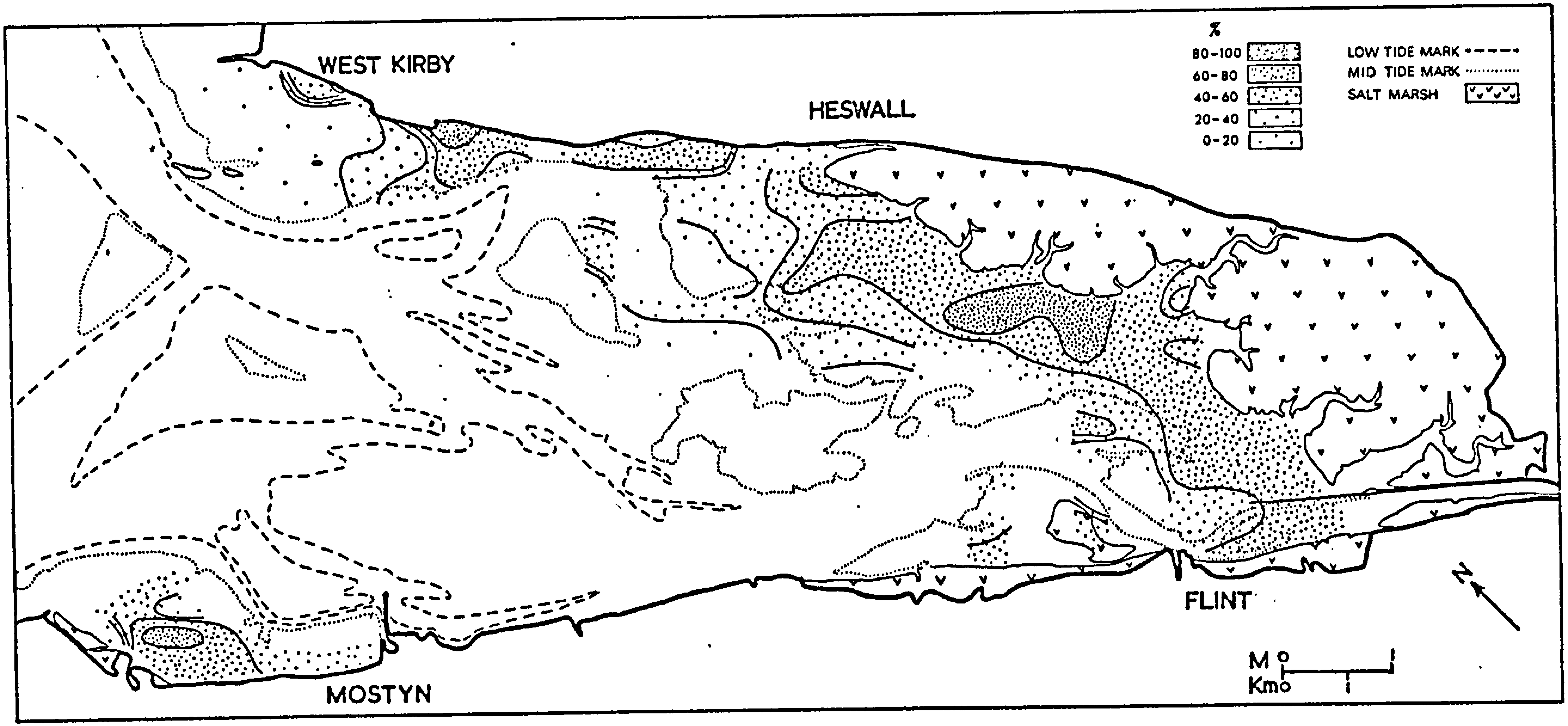
Map 41. Distribution of Fine Sand (125-250u) at 0-2.5 cms depth in Spring 1976.



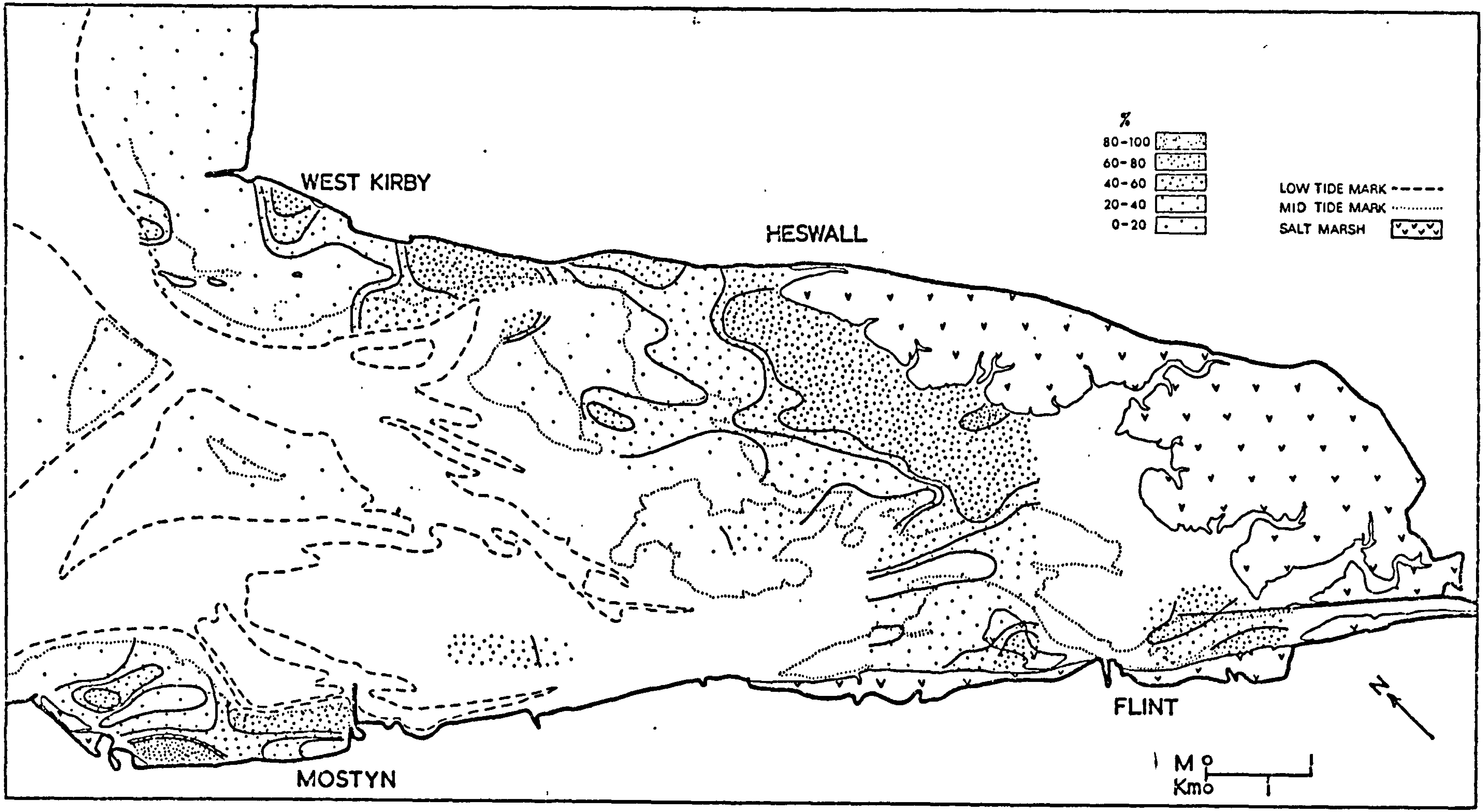
Map 42. Distribution of Fine Sand (125-250u) at 17.5-20 cms depth in Spring 1976.



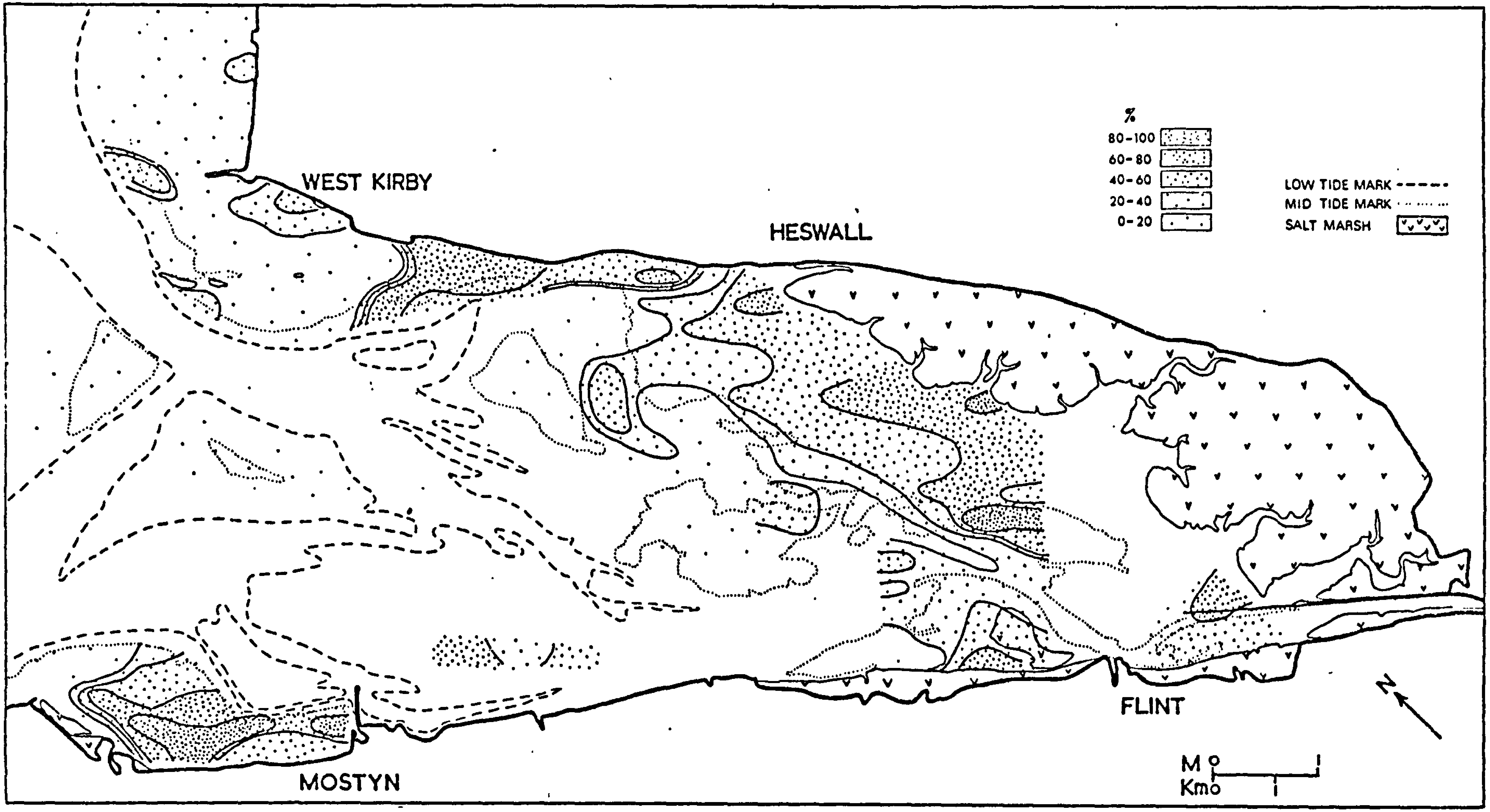
Map 43. Distribution of Very Fine Sand (63-125u) at 0-2.5 cms depth in Spring 1974.



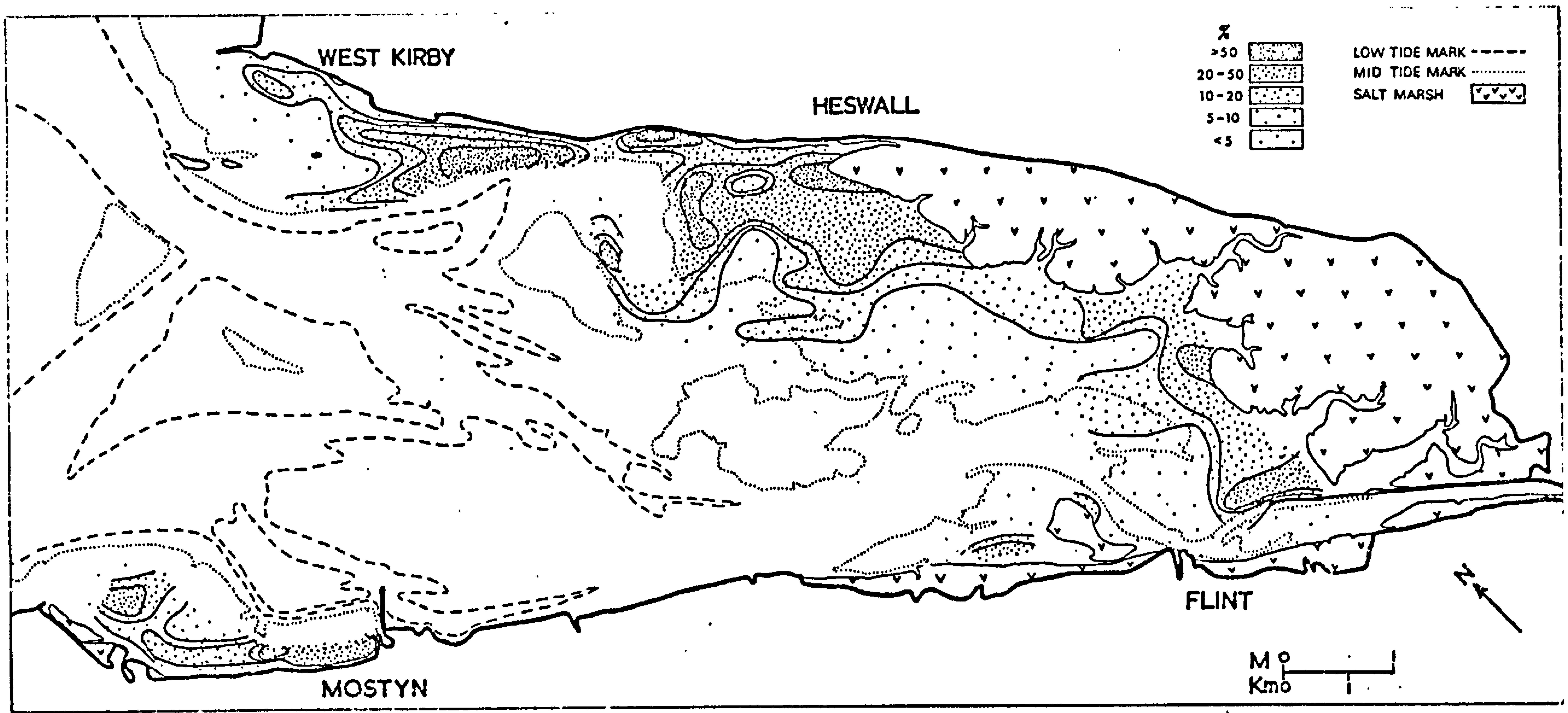
Map 44. Distribution of Very Fine Sand (63-125μ) at 17.5-20 cms depth in Spring 1974.



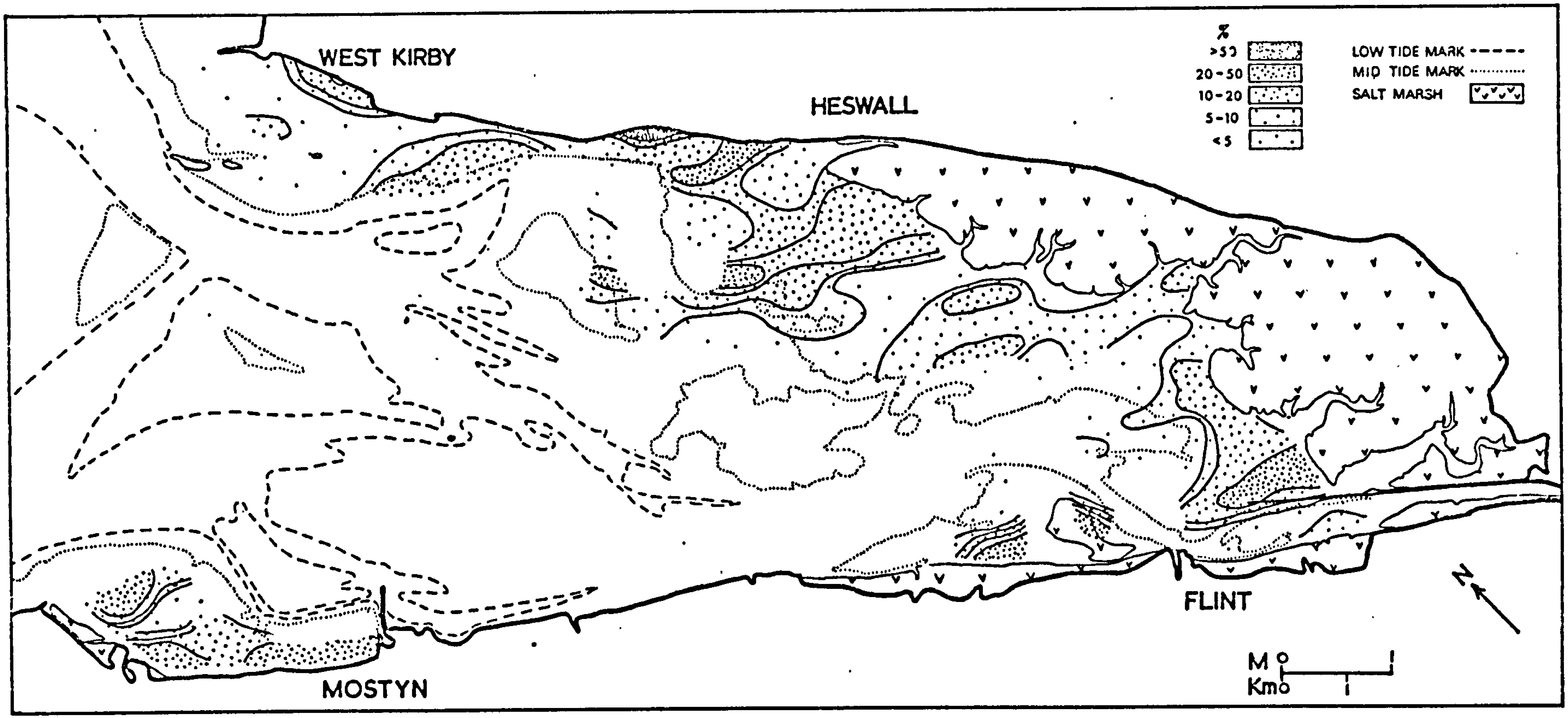
Map 45. Distribution of Very Fine Sand (63-125u) at 0-2.5 cms depth in Spring 1976.



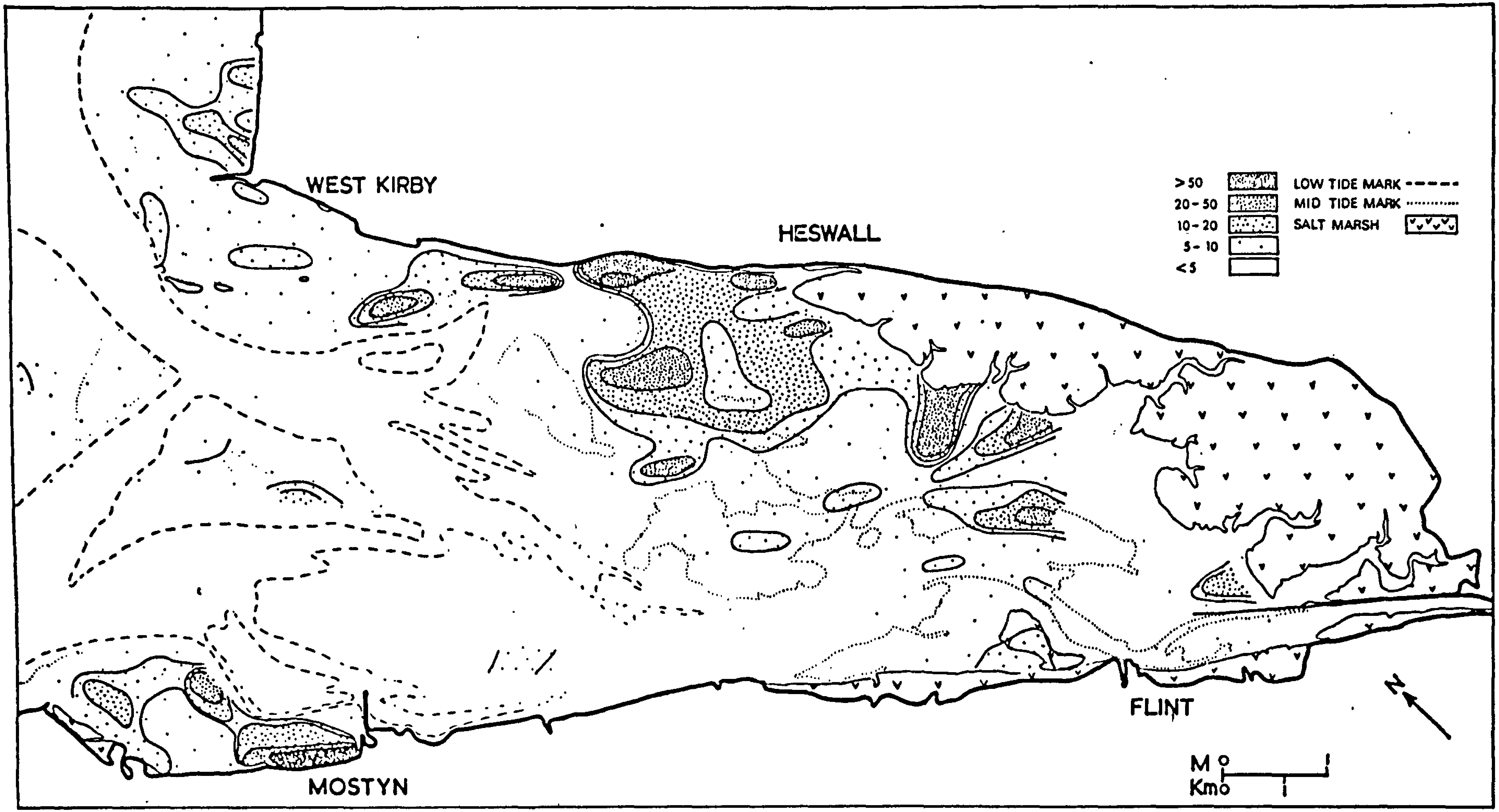
Map 46. Distribution of Very Fine Sand (63-125u) at 17.5-20 cms depth in Spring 1976.



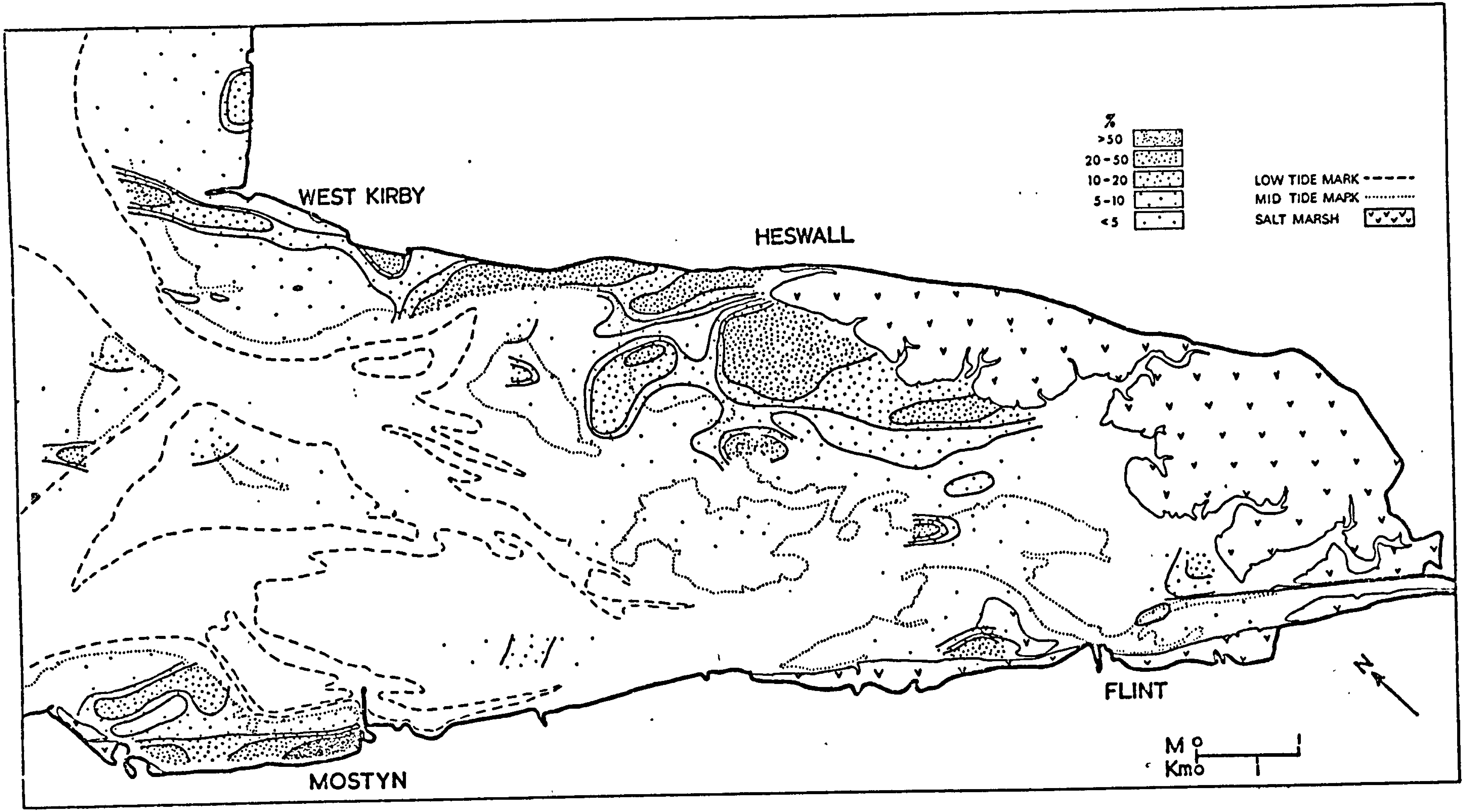
Map 47. Distribution of Silt and Clay (<63μ) at 0-2.5 cms depth in Spring 1974.



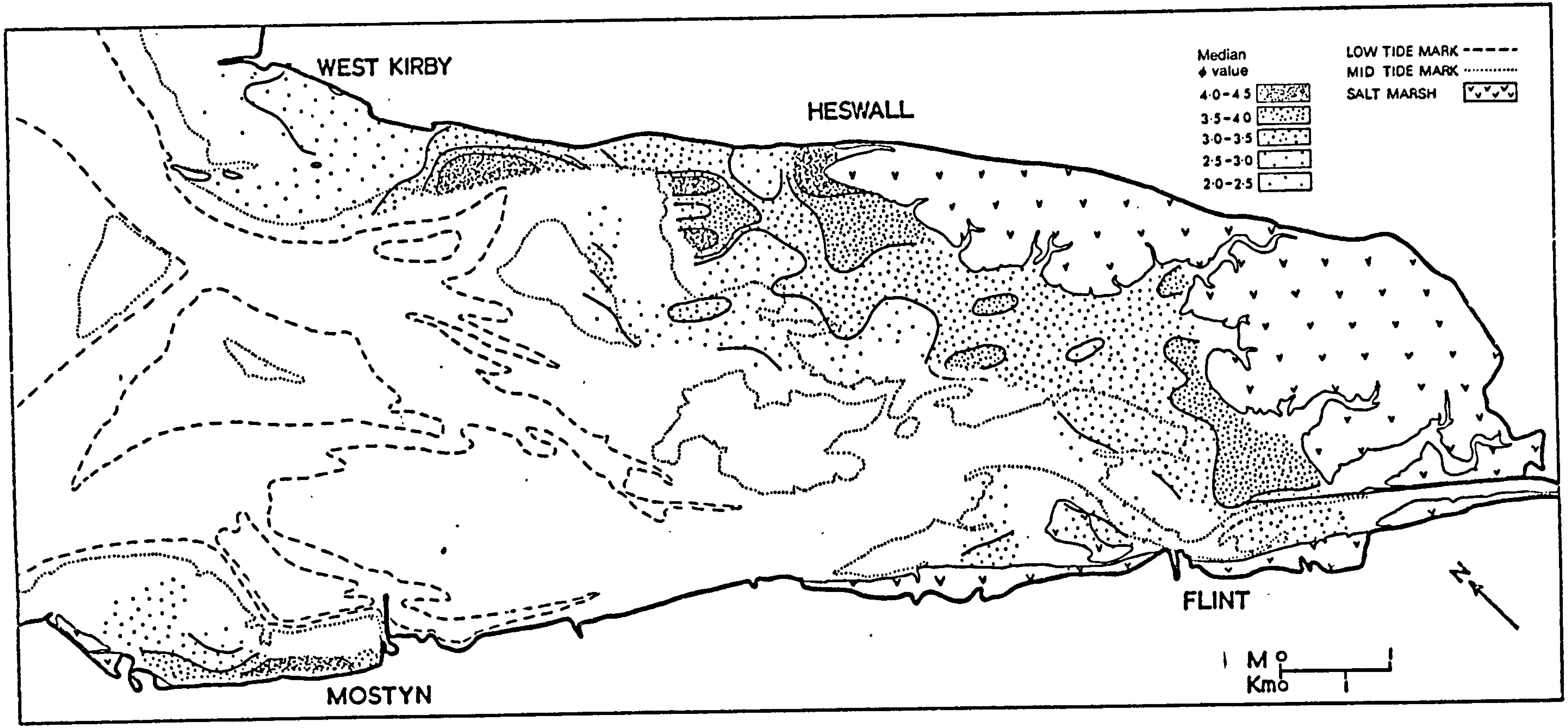
Map 48. Distribution of Silt and Clay (<63u) at 17.5-20 cms depth in Spring 1974.



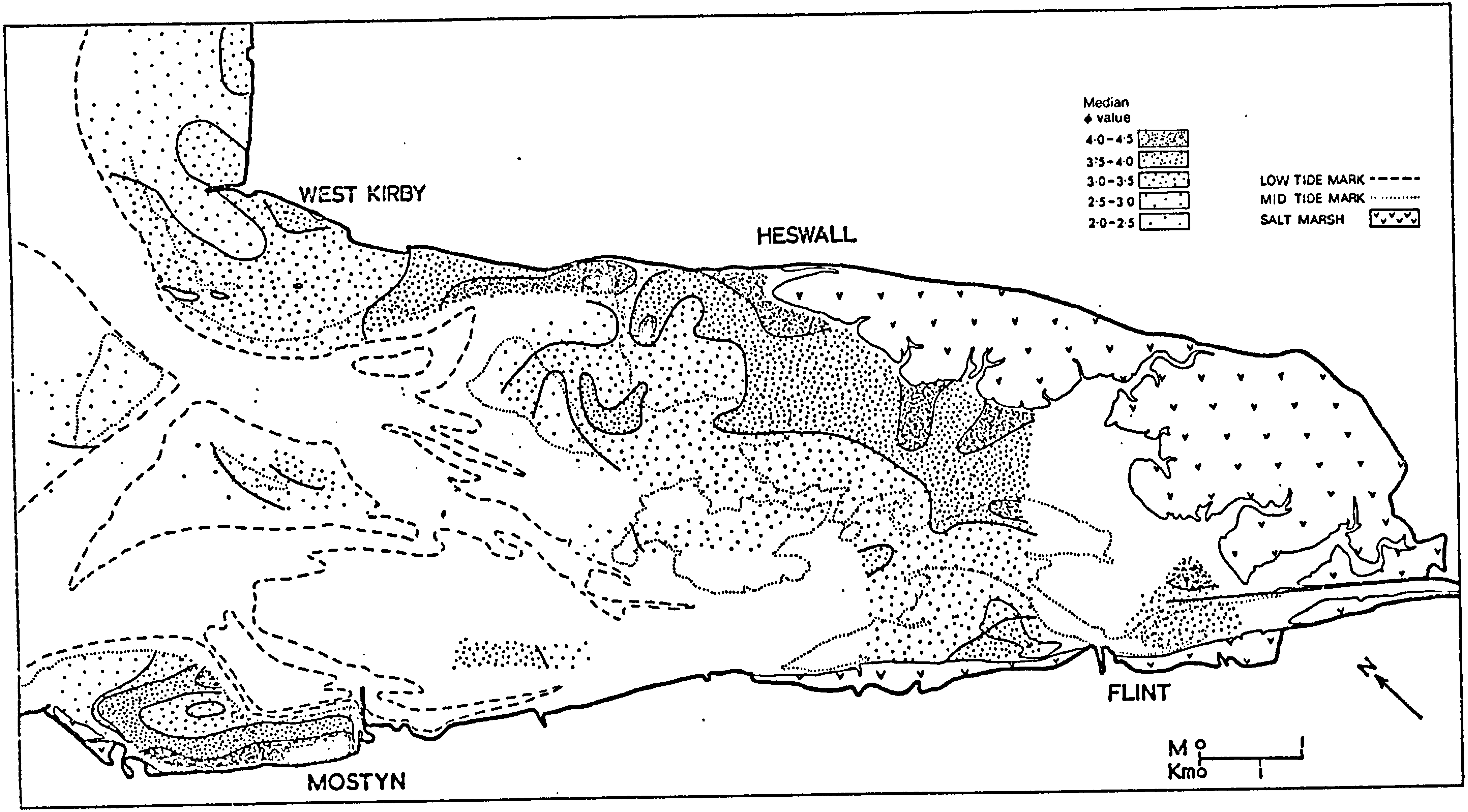
Map 49. Distribution of Silt & Clay (<63μ) at 0-2.5 cms depth in Spring 1976.



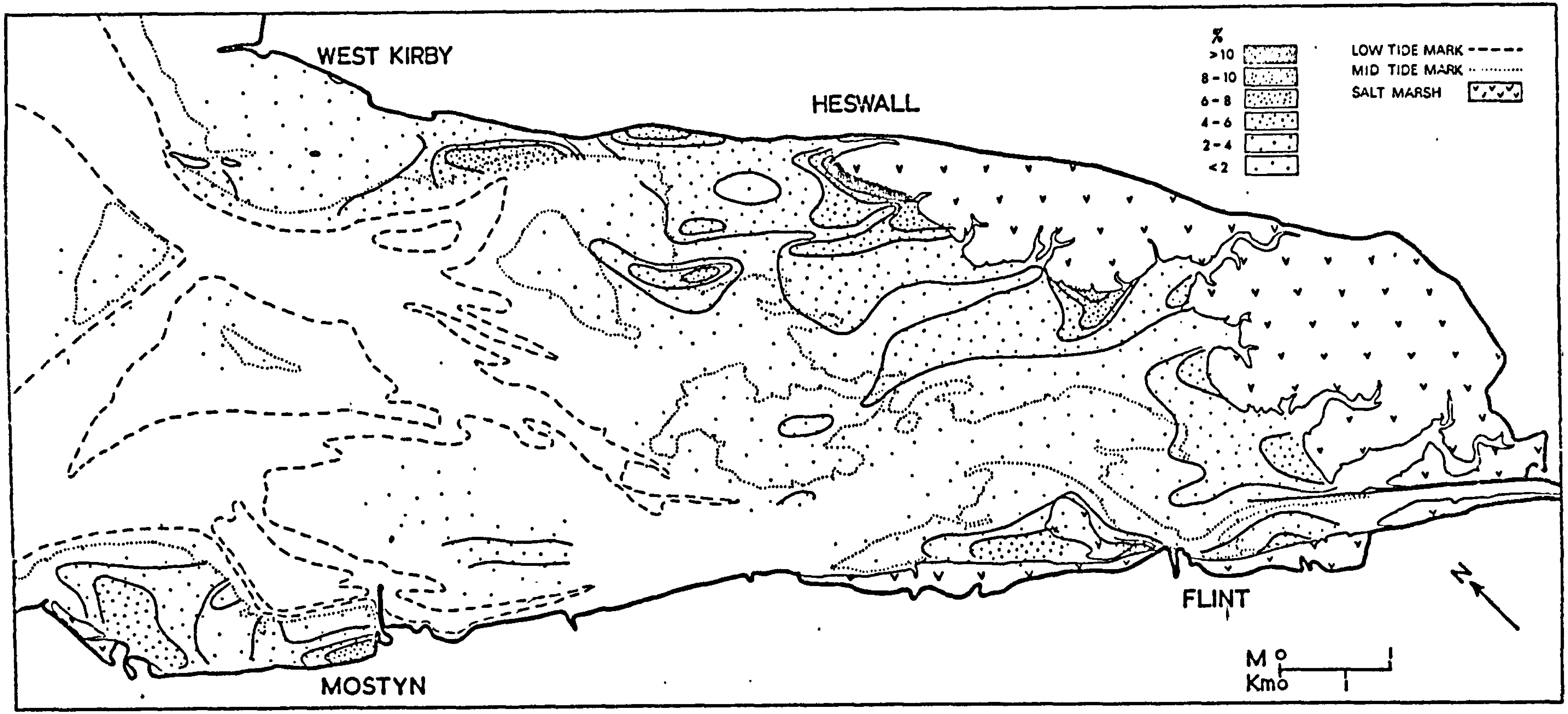
Map 50. Distribution of Silt & Clay (<63µ) at 17.5-20 cms depth in Spring 1976.



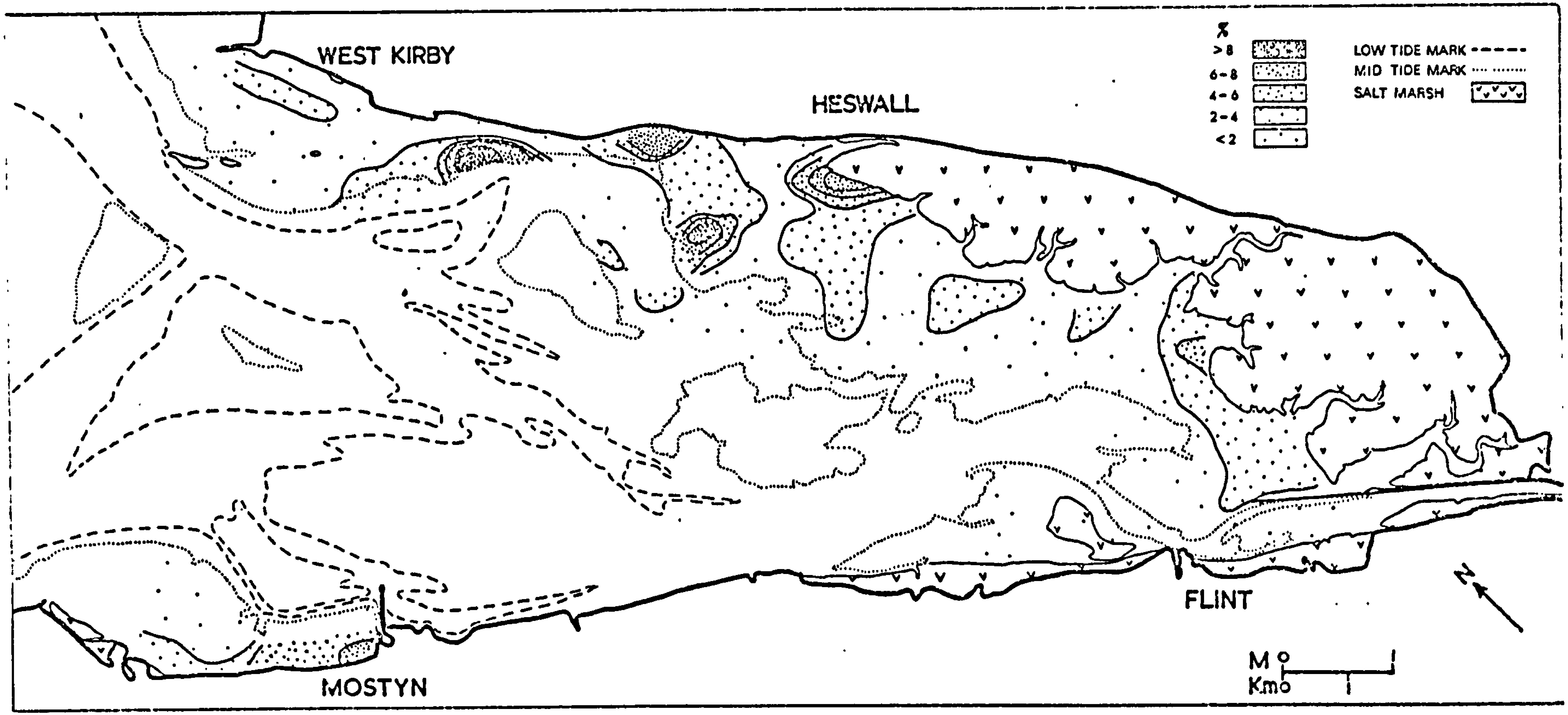
Map 51. Distribution of Median Ø value at 0-2.5 cms depth in Spring 1974.



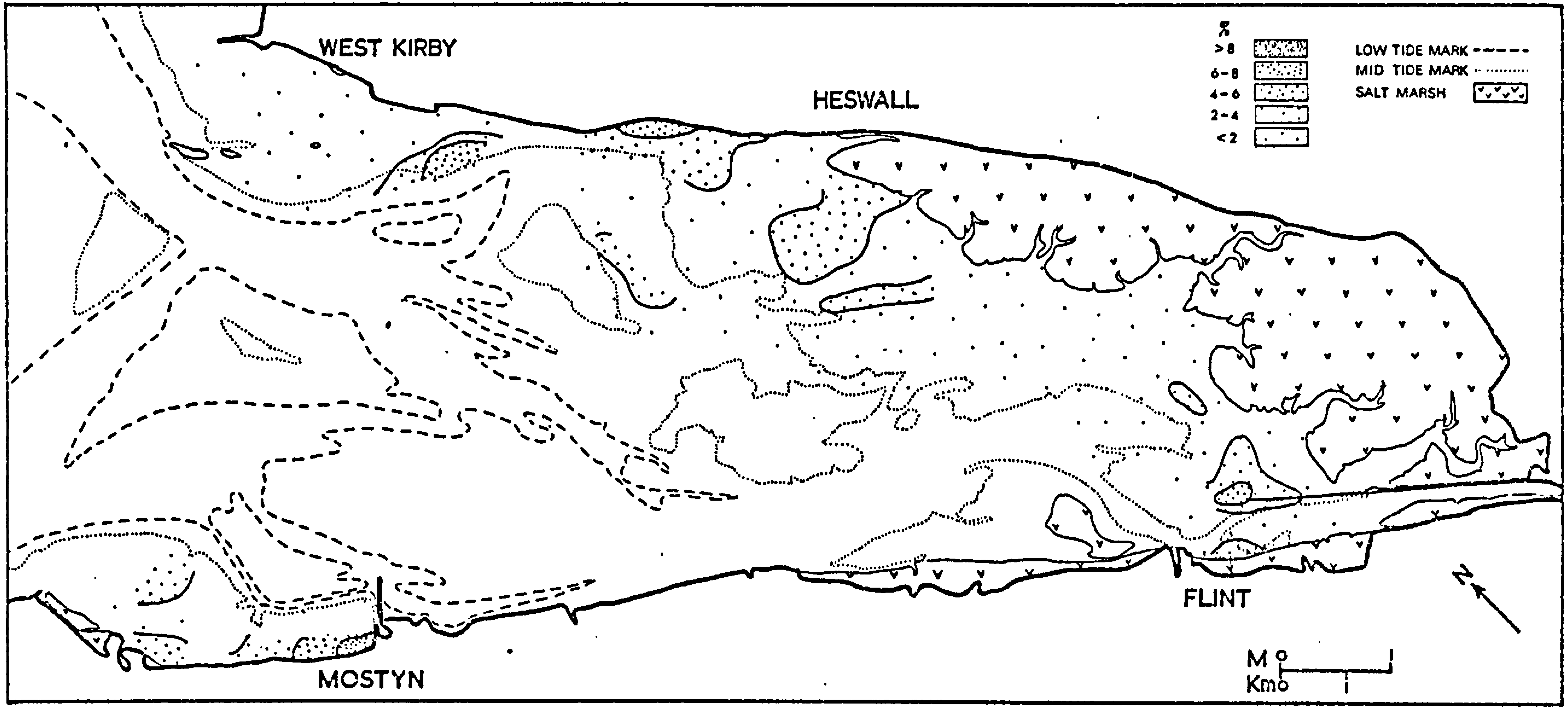
Map 52. Distribution of Median Ø value at 0–2.5 cms depth in Spring 1976.



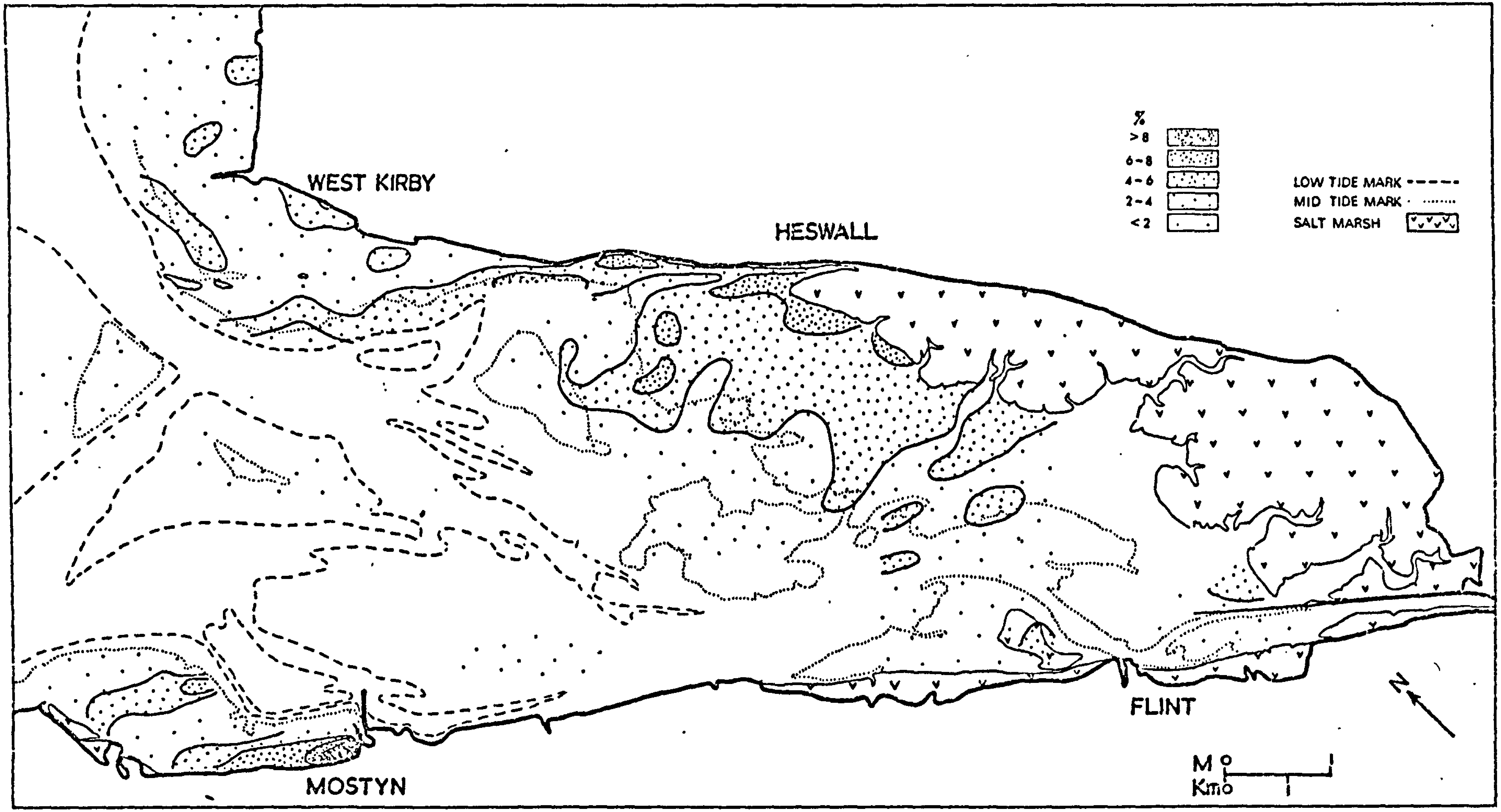
Map 53. Distribution of sediment Percentage Loss on Ignition at 0-2.5 cms depth in Autumn 1971.



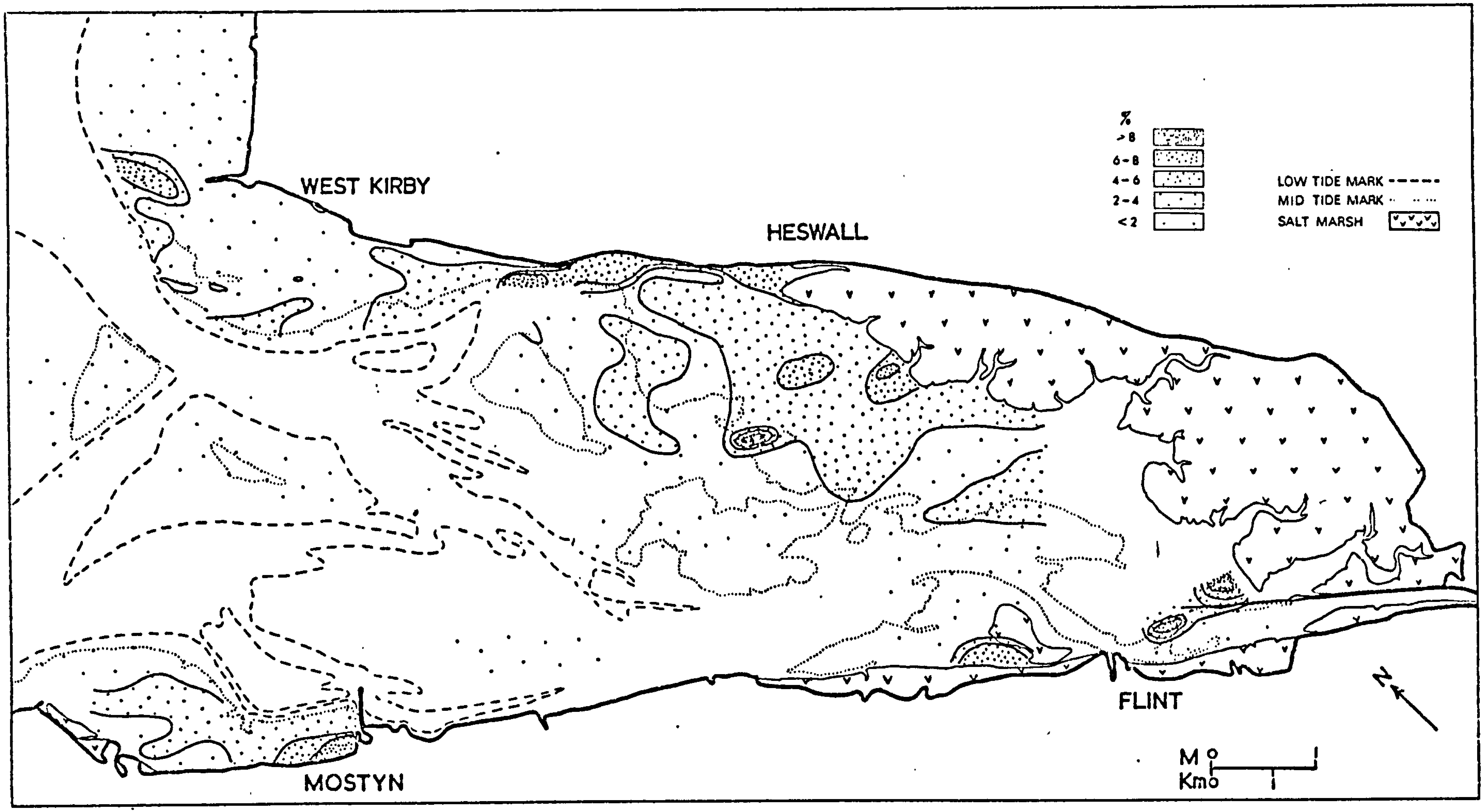
Map 54. Distribution of sediment Percentage Loss on Ignition at 0-2.5 cms depth in Spring 1974.



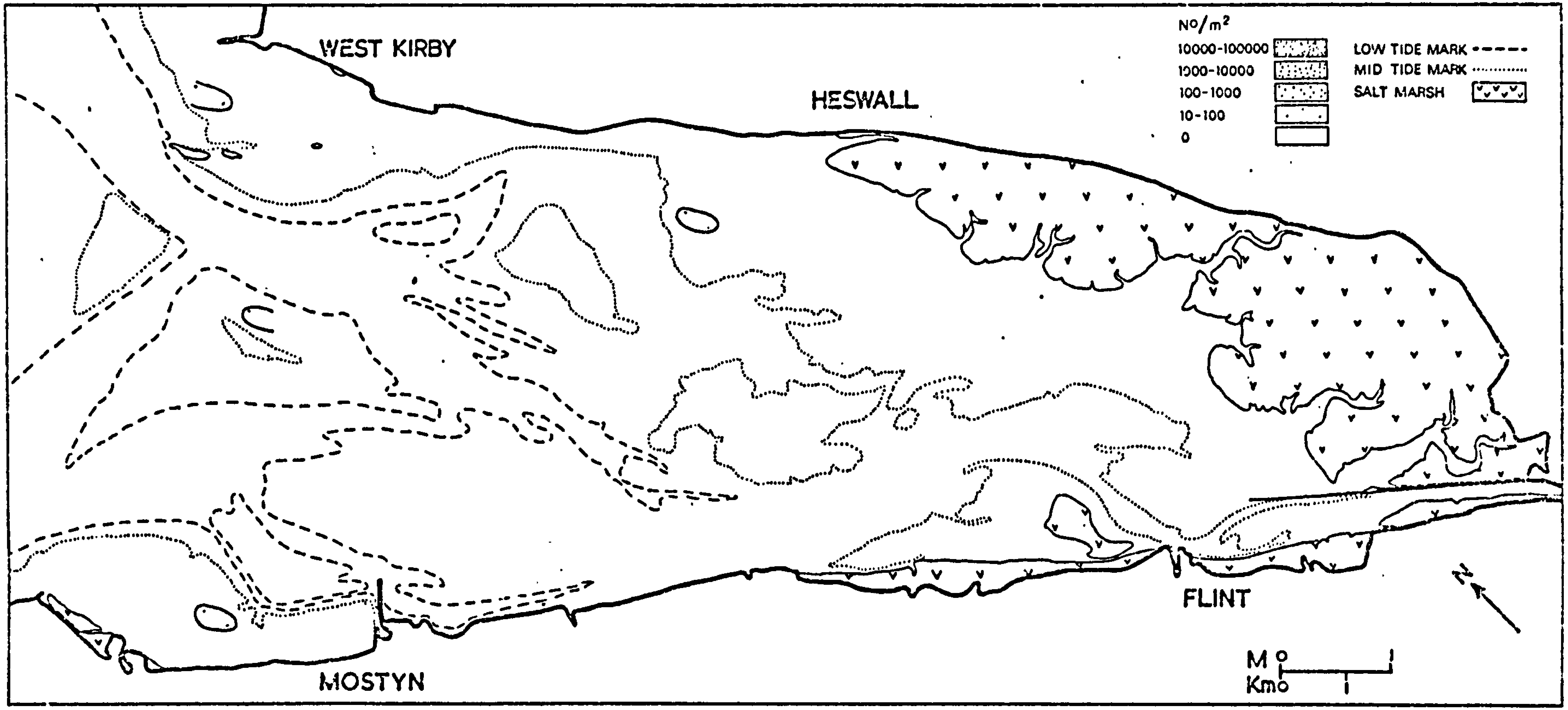
Map 55. Distribution of sediment Percentage Loss on Ignition at 17.5-20 cms depth in Spring 1974.



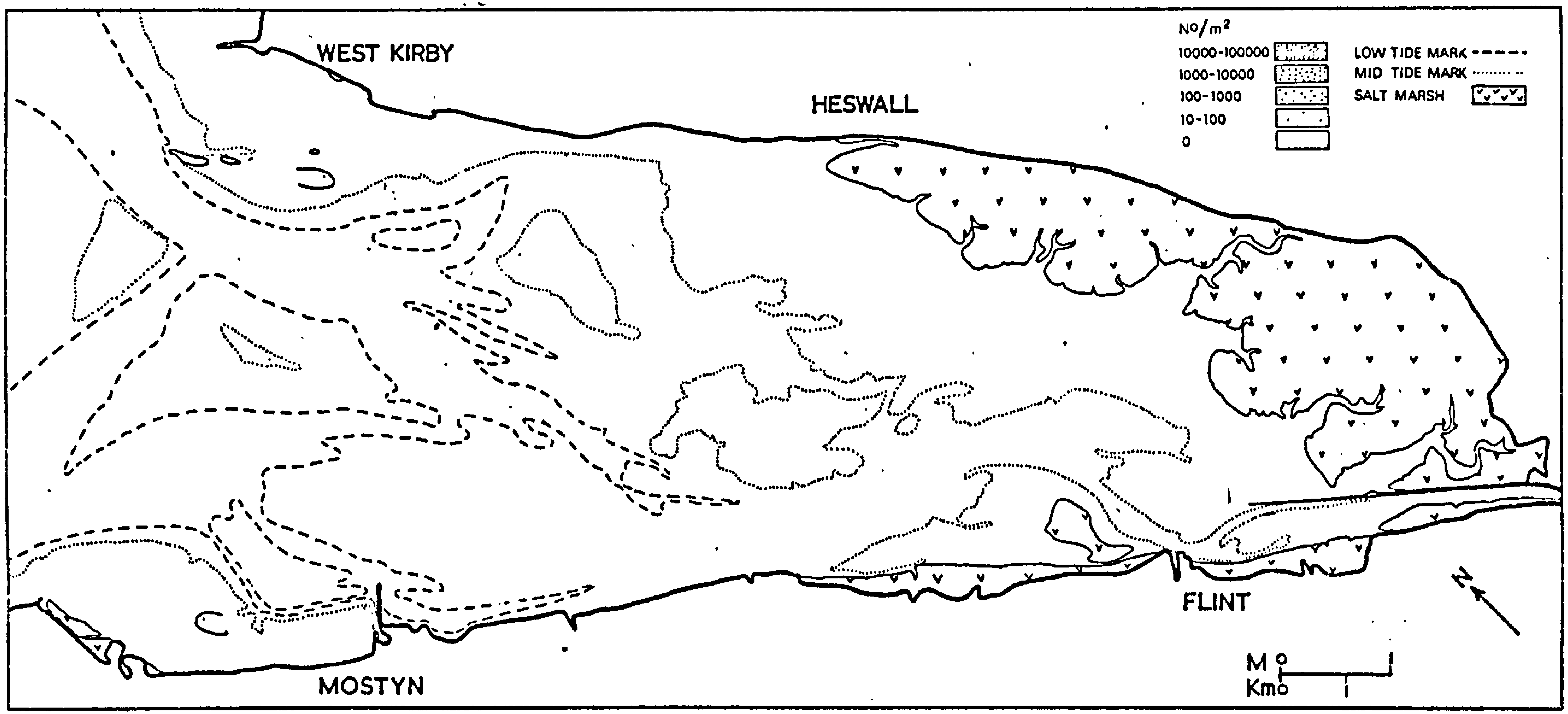
Map 56. Distribution of sediment Percentage Loss on Ignition at 0-2.5 cms depth in Spring 1976.



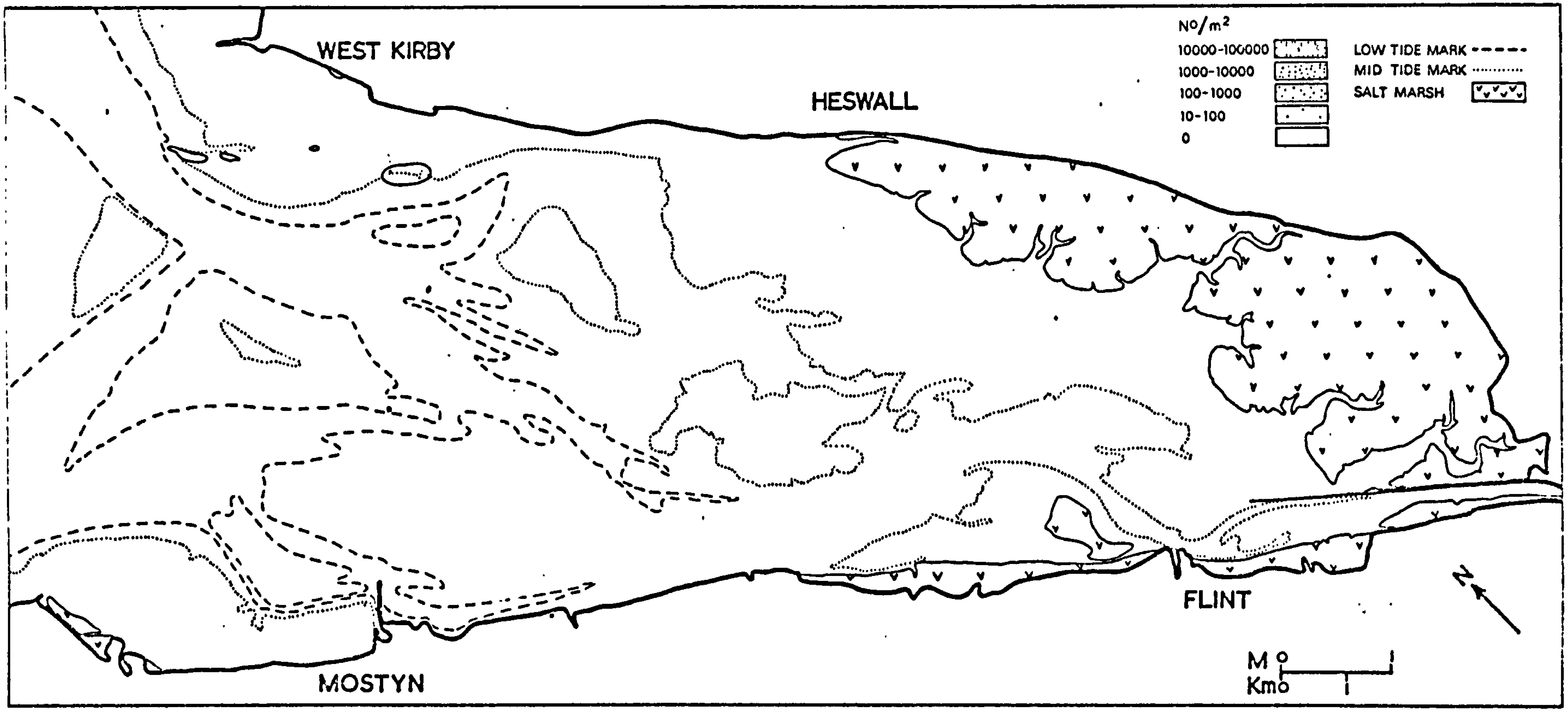
Map 57. Distribution of sediment Percentage Loss on Ignition at 17.5-20 cms depth in Spring 1976.



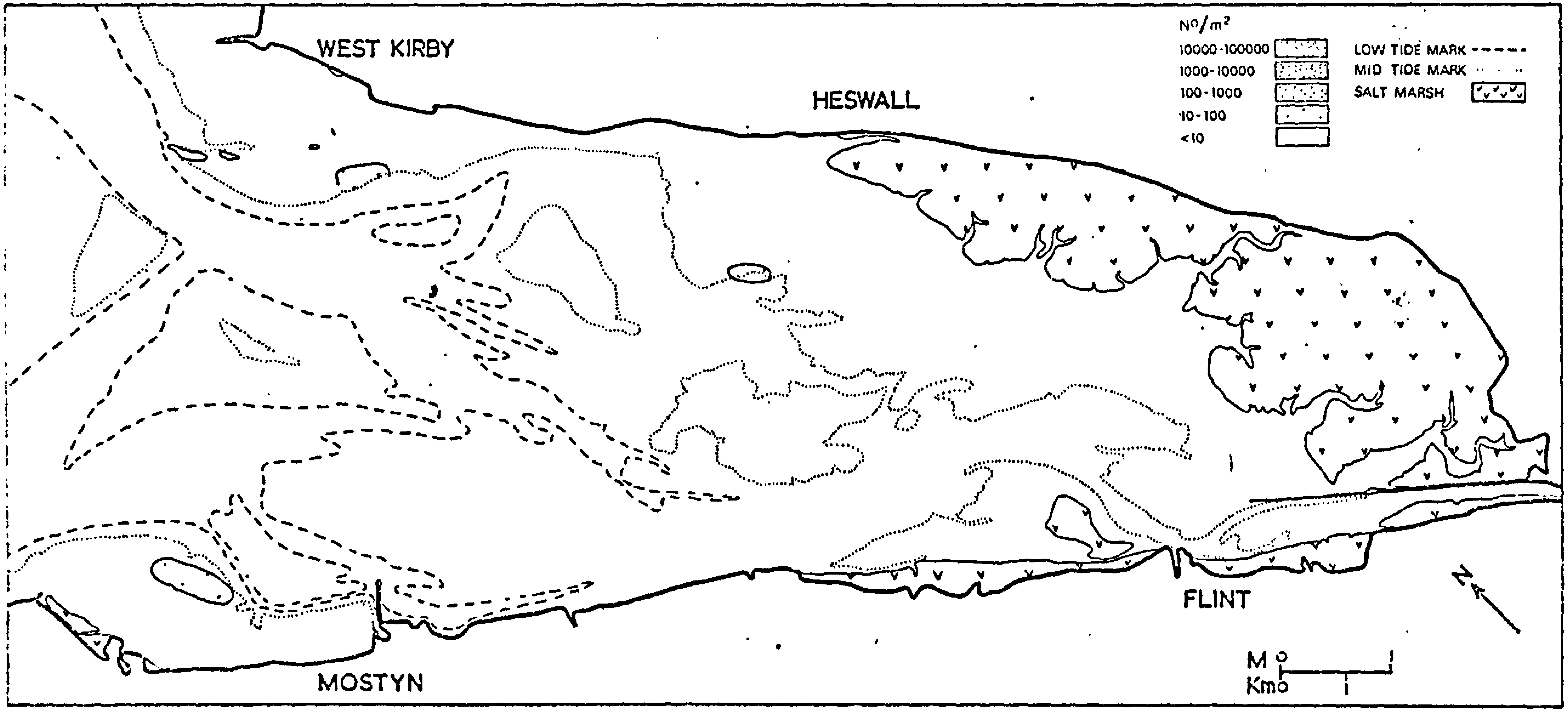
Map 58. Density distribution of <u>Phyllodoce</u> sp. in Autumn 1971



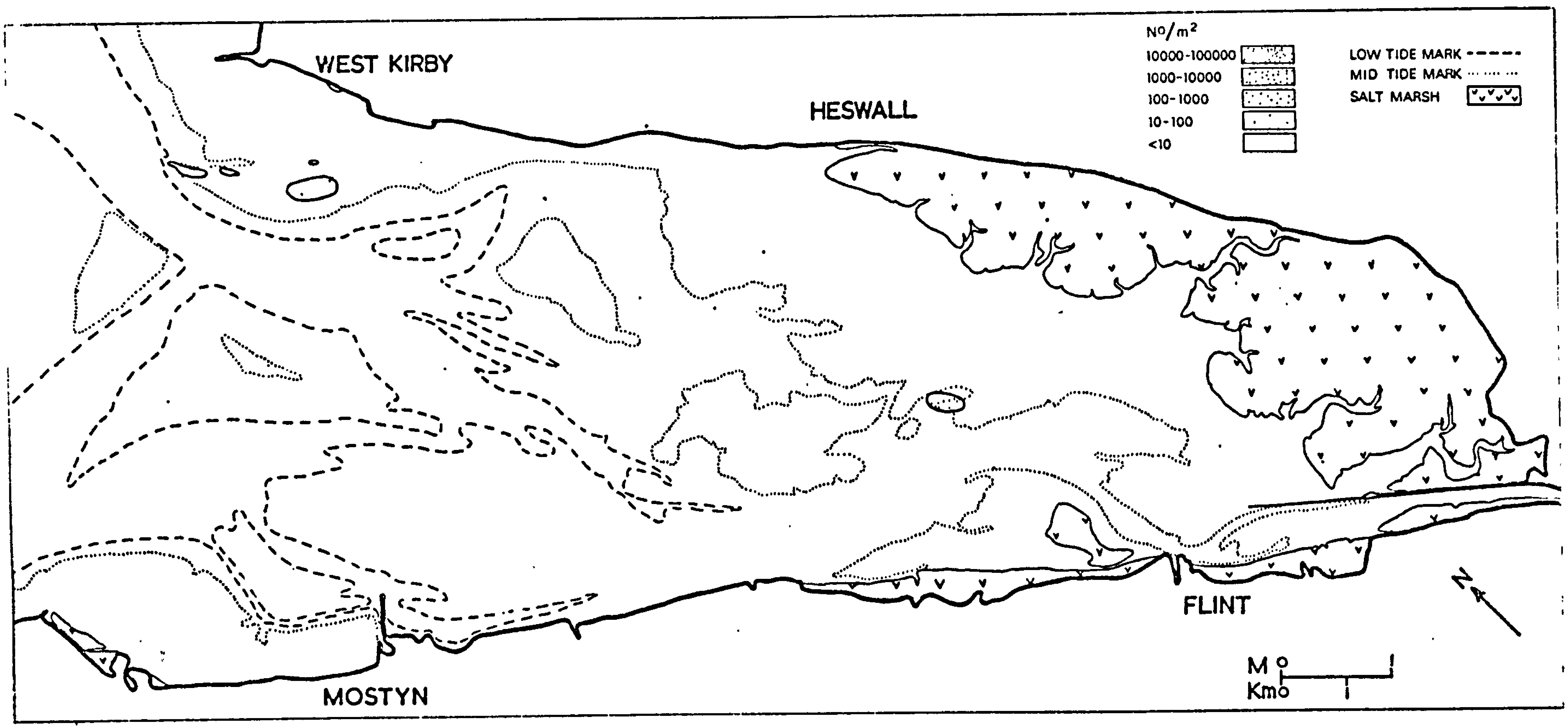
Map 59. Density distribution of Phyllodoce sp. in Spring 1972.



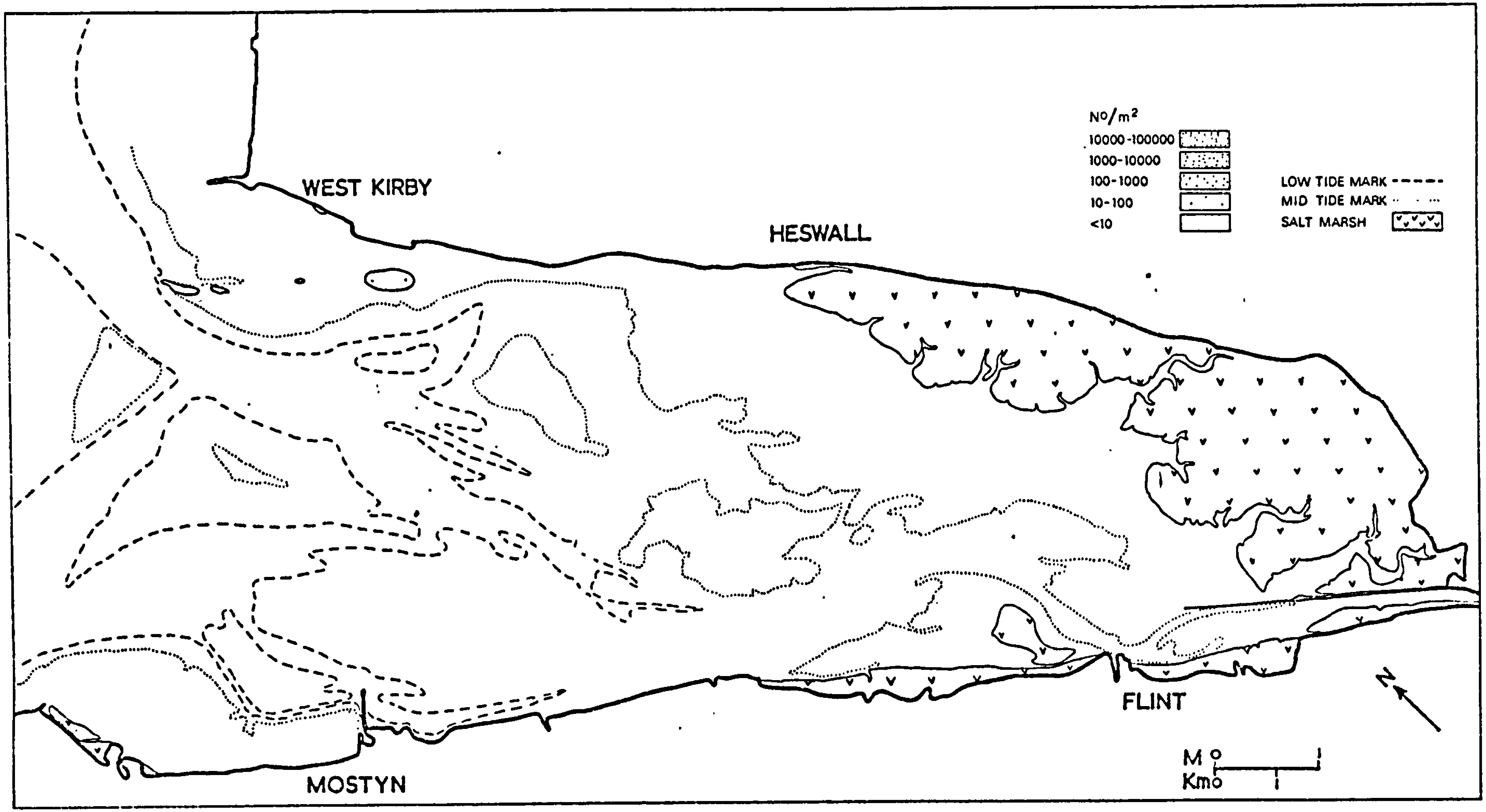
Map 60. Density distribution of Phyllodoce sp. in Spring 1973.



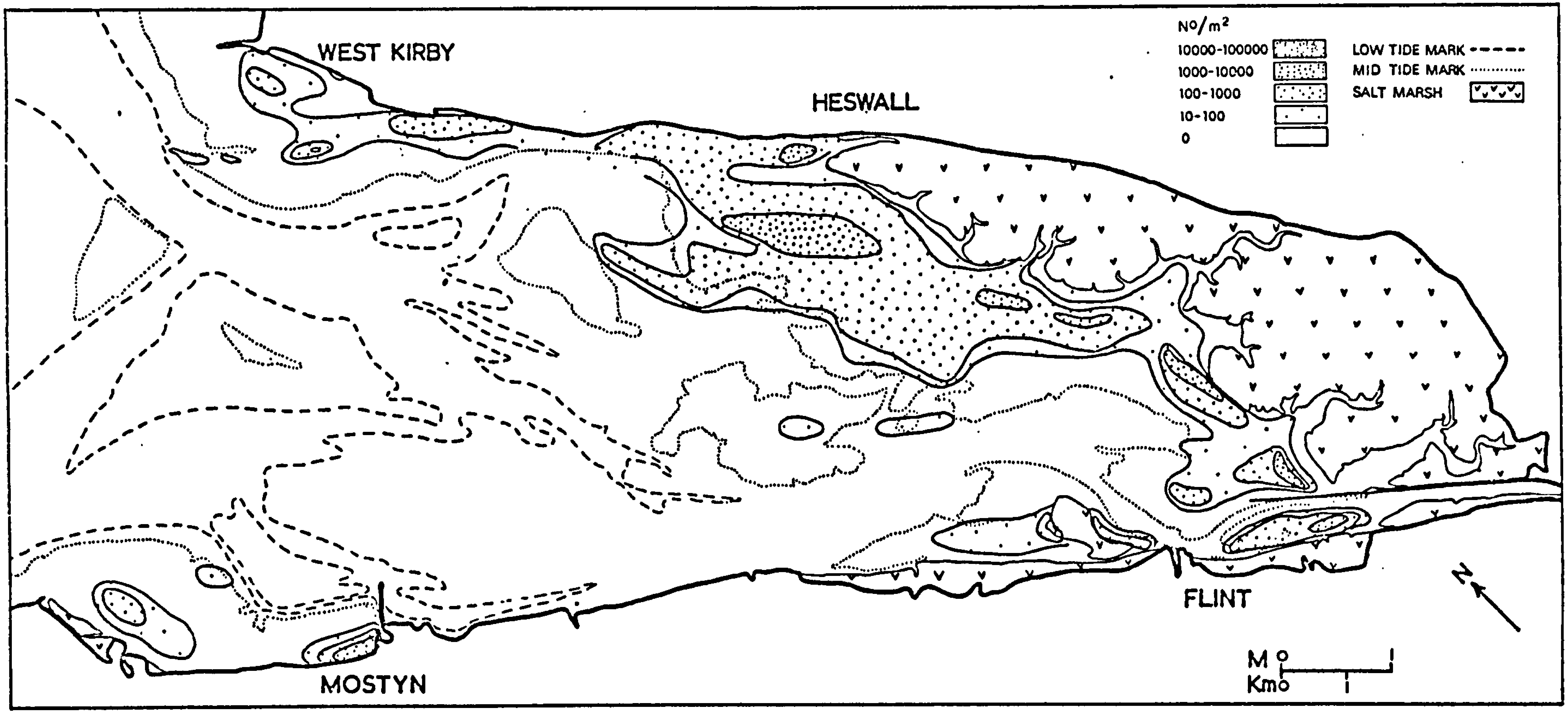
Map 61. Density distribution of <u>Phyllodoce</u> sp. in Spring 1975.



Map 62. Density distribution of Phyllodoce sp. in Autumn 1975.

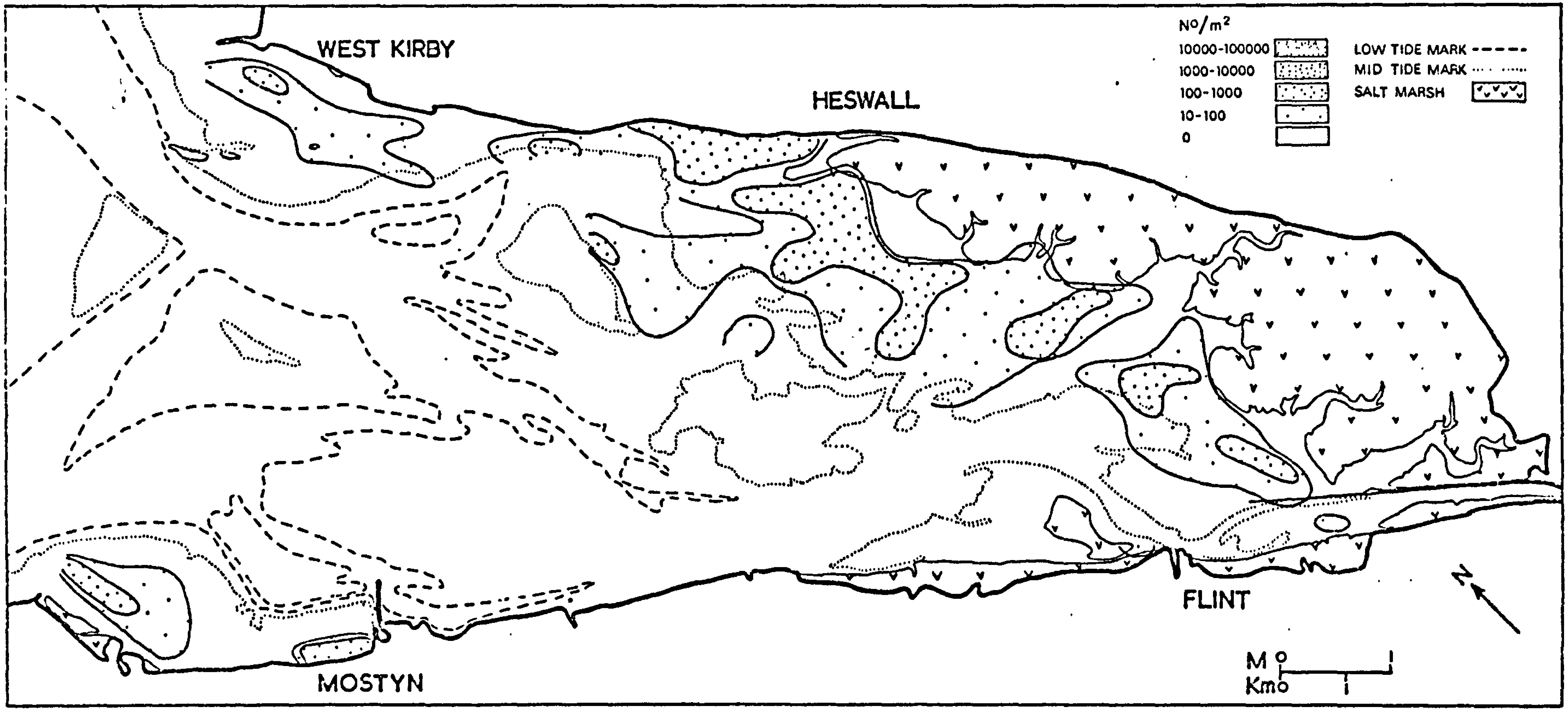


Map 63. Density distribution of Phyllodoce sp. in Spring 1976.

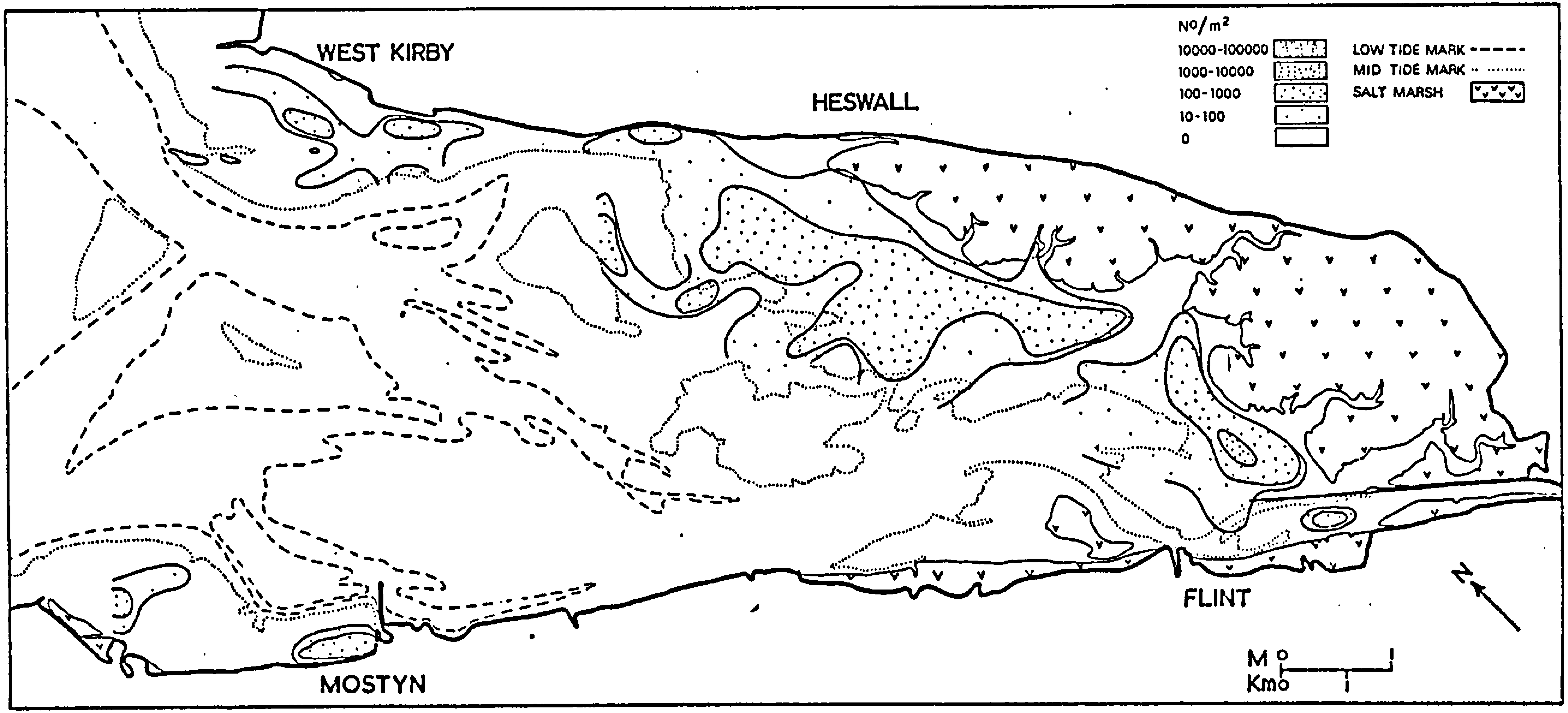


Map 64. Density distribution of Nereis diversicolor in Autumn 1971.

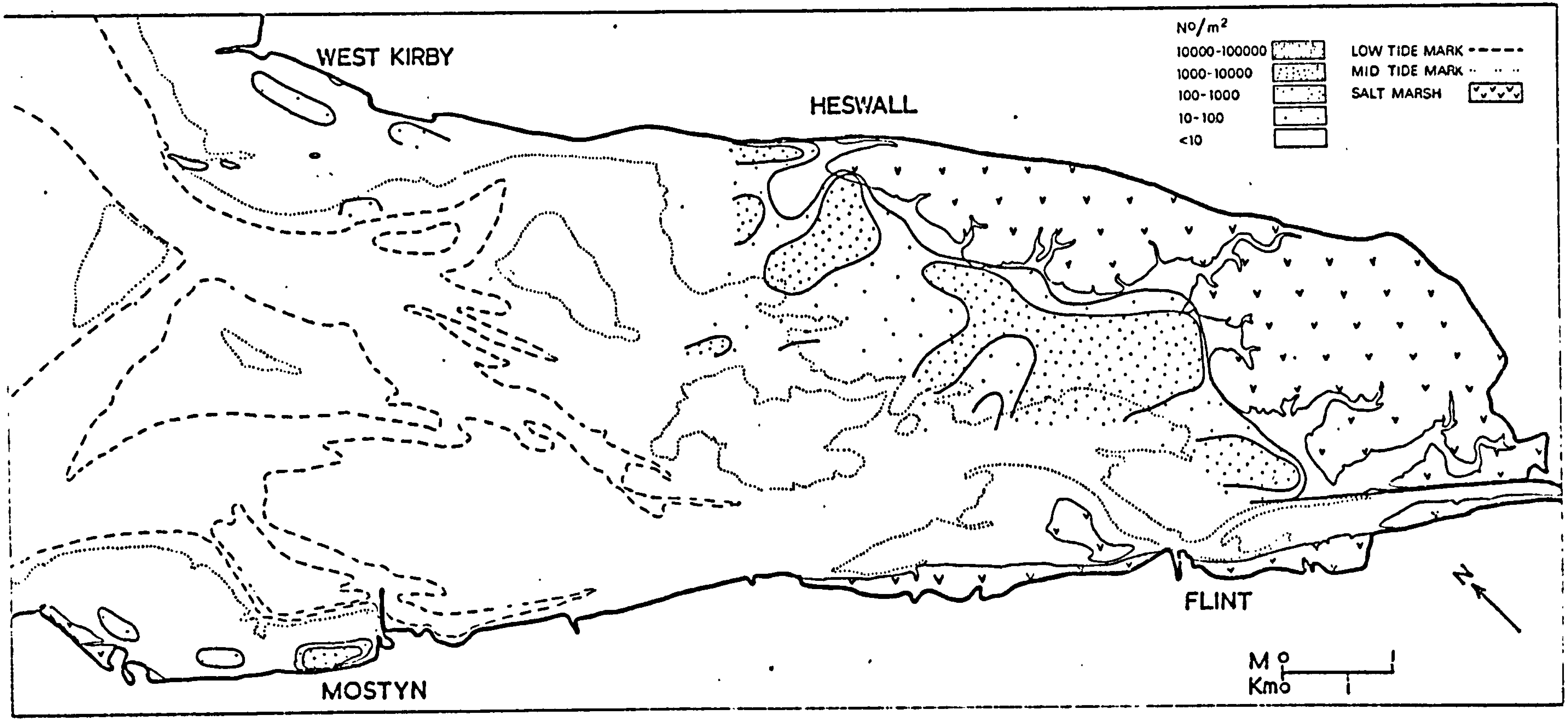
Map 65. Density distribution of Nereis diversicolor in Spring 1972.



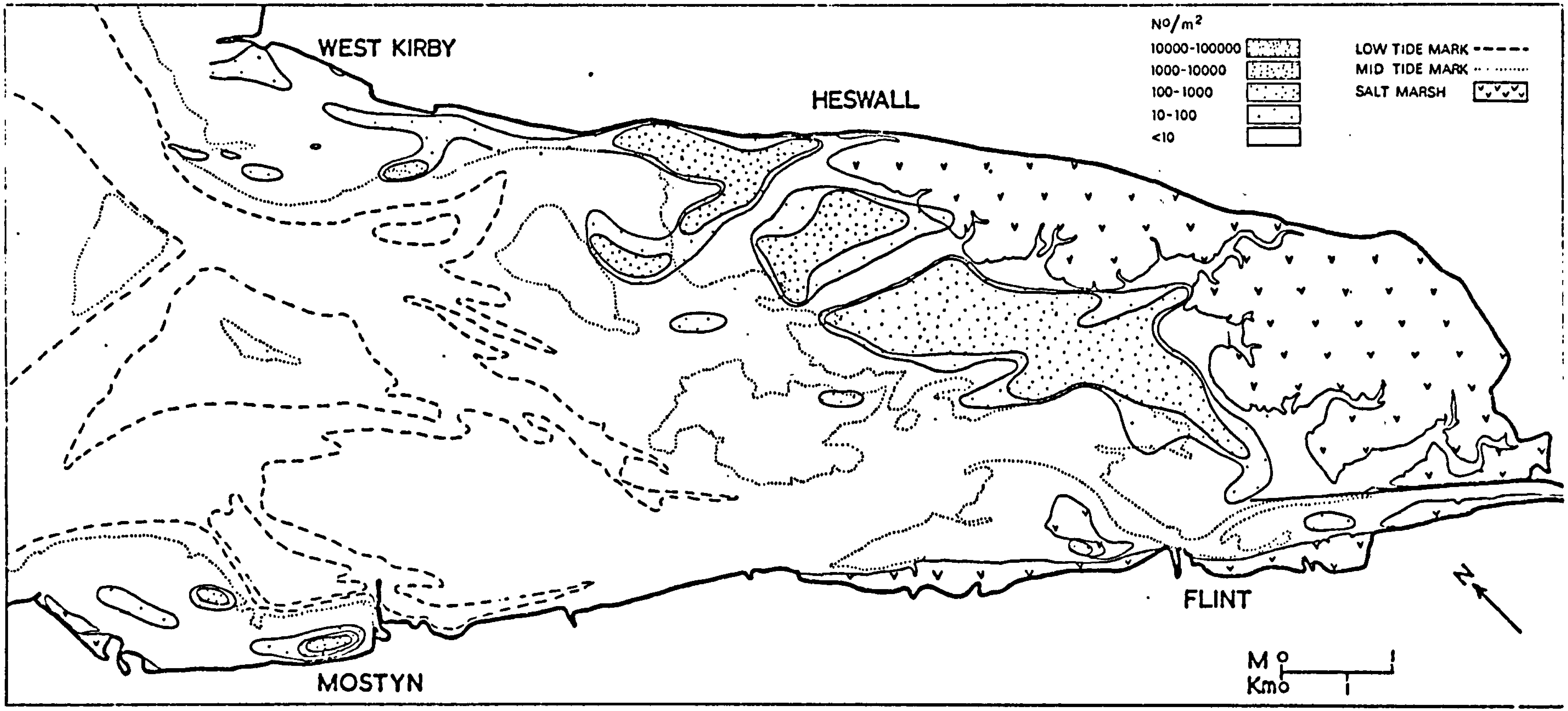
Map 66. Density distribution of Nereis diversicolor in Spring 1973.



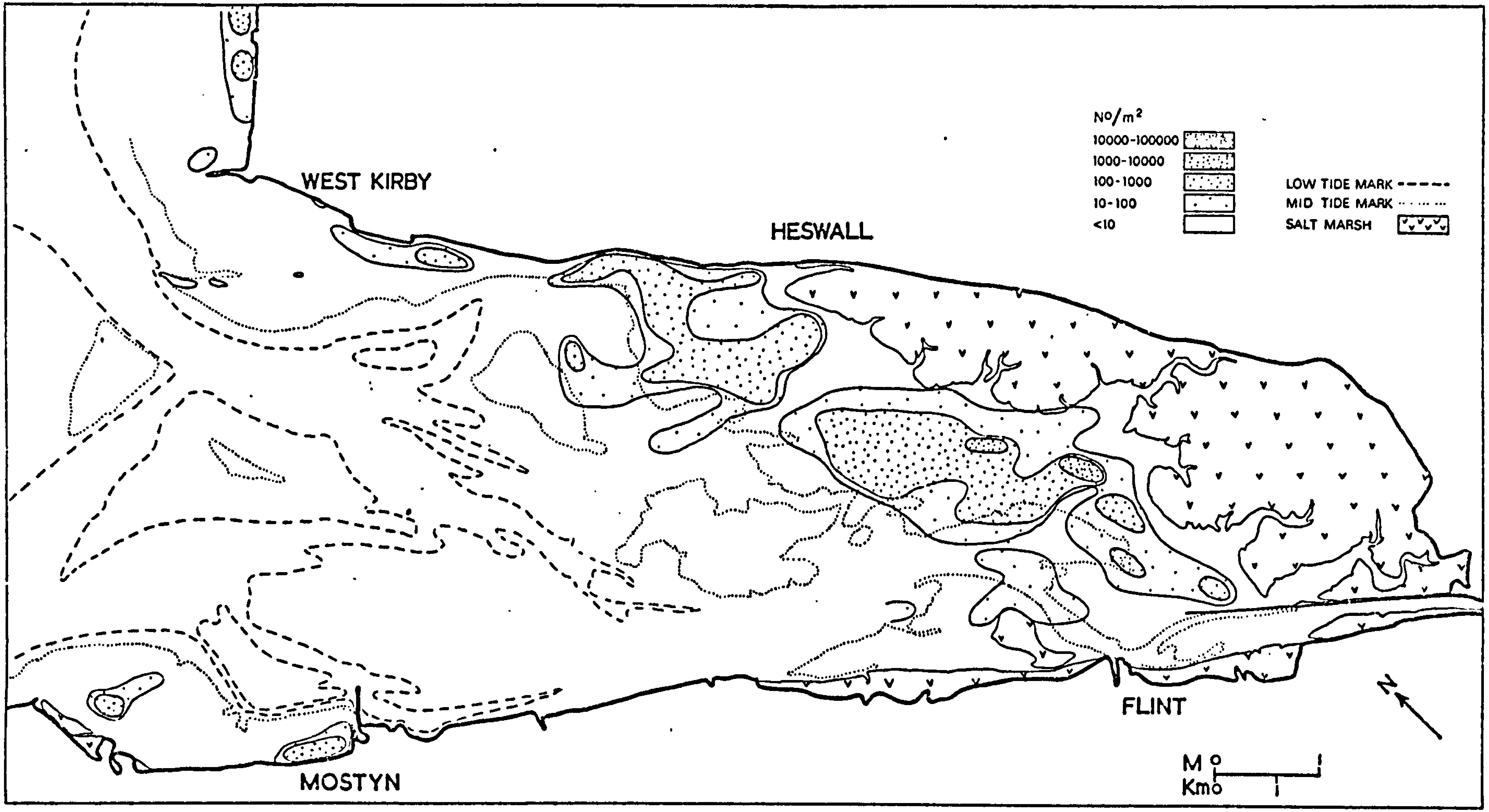
Map 67. Density distribution of <u>Nereis diversicolor</u> in Spring 1974.



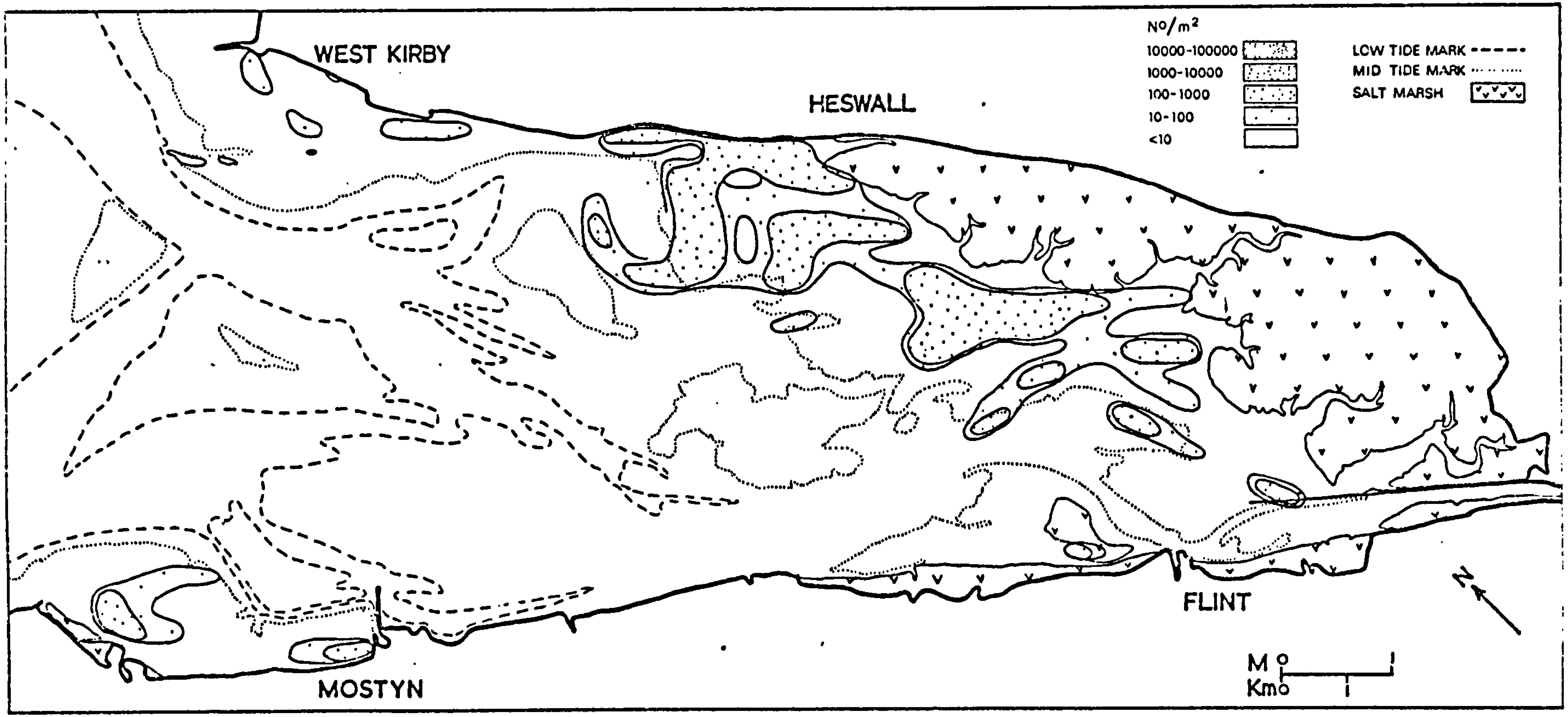
Map 68. Density distribution of <u>Nereis diversicolor</u> in Spring 1975.



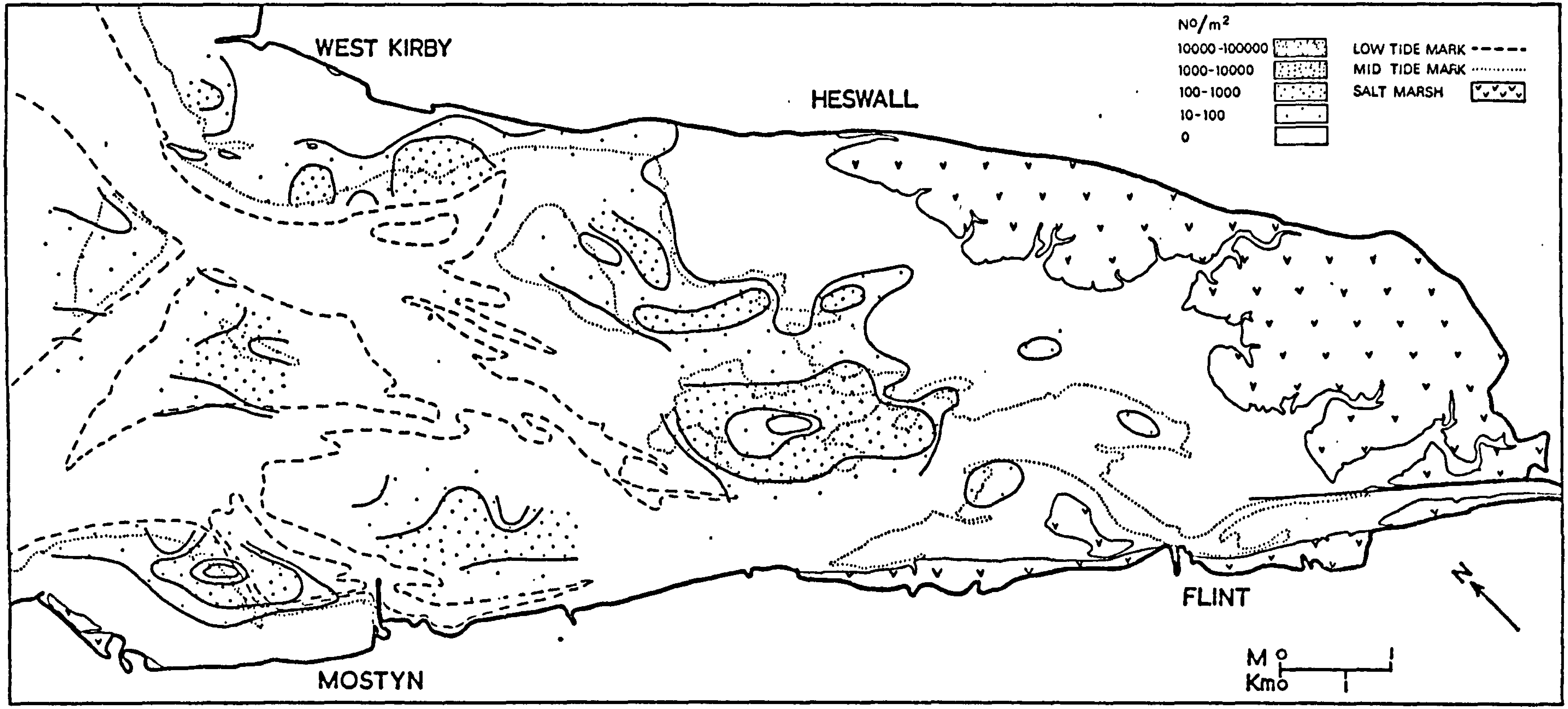
Map 69. Density distribution of <u>Nereis diversicolor</u> in Autumn 1975.



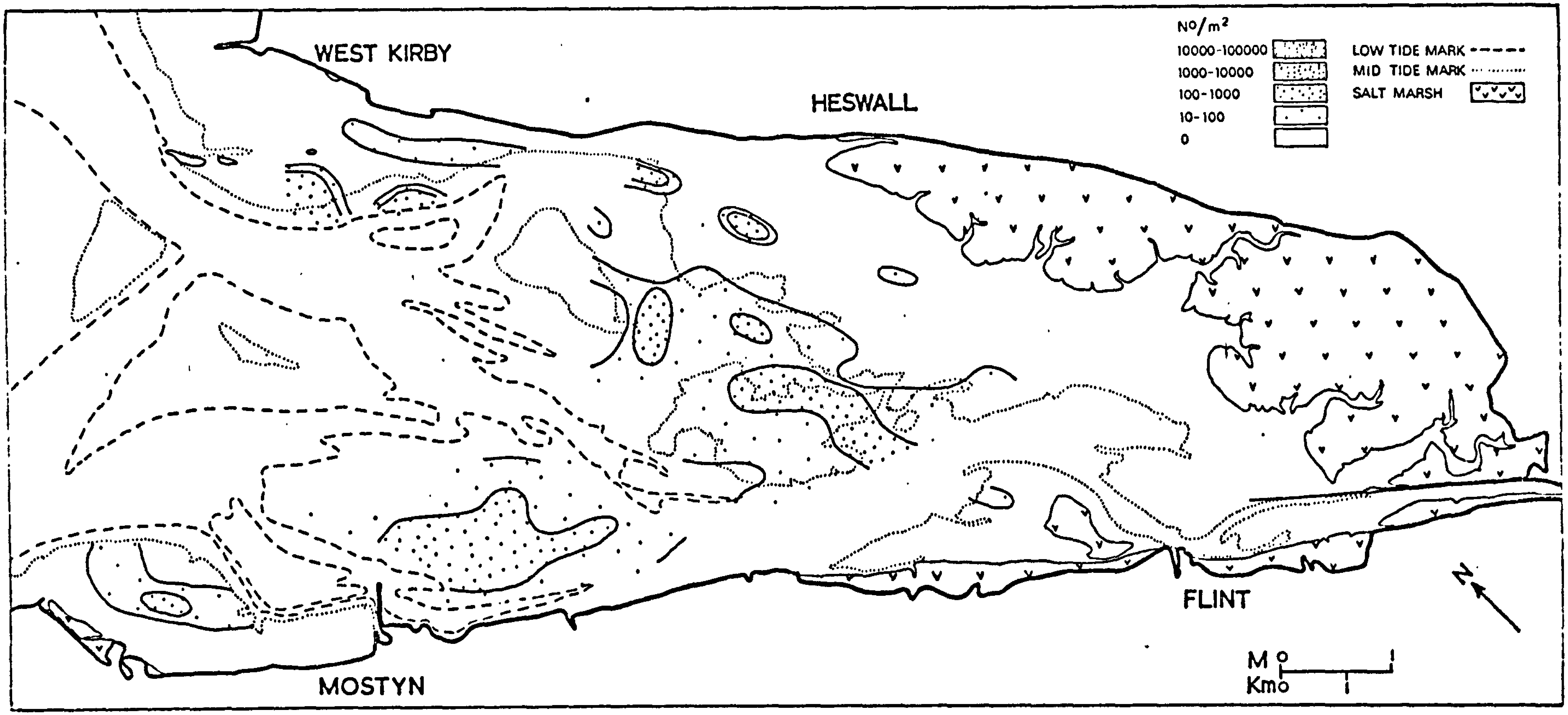
Map 70. Density distribution of <u>Nereis diversicolor</u> in Spring 1976.



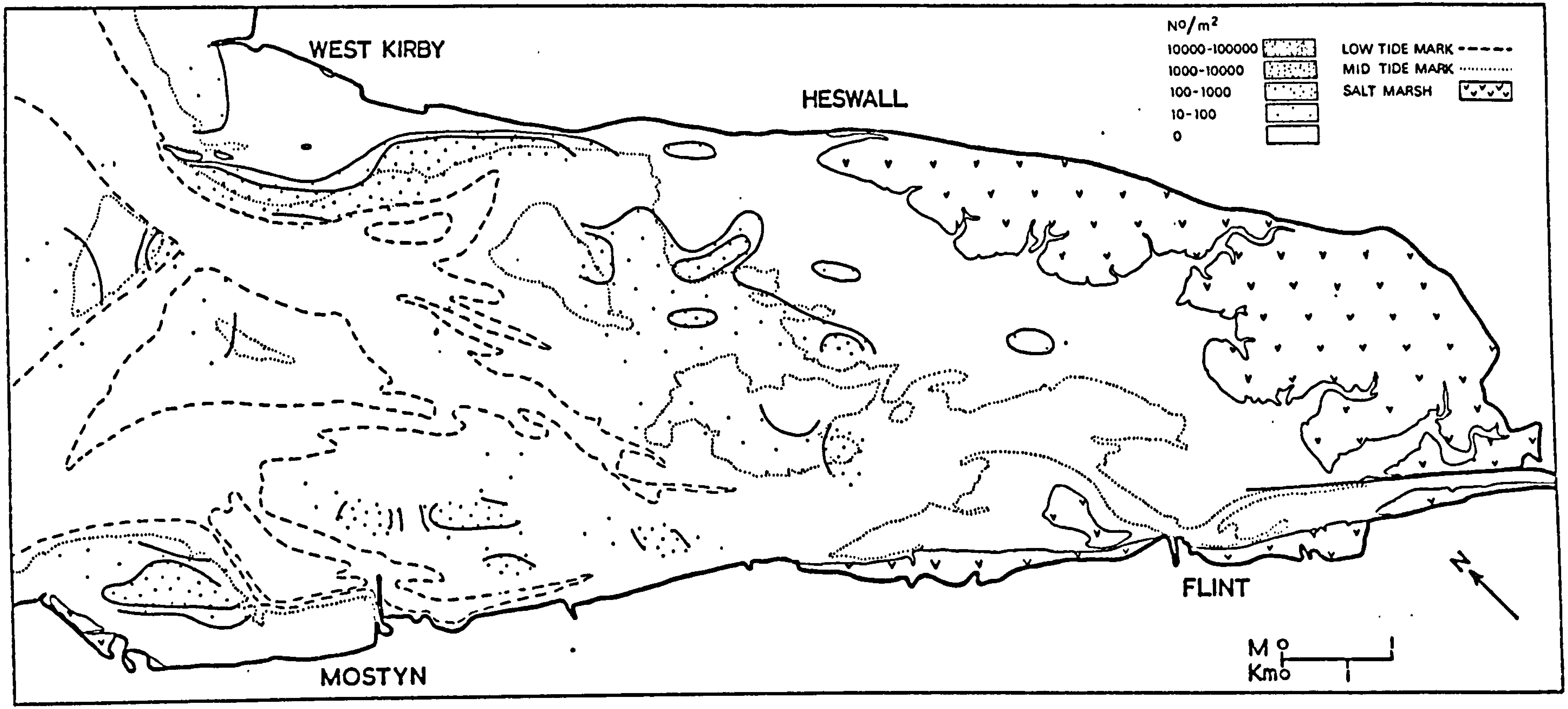
Map 71. Density distribution of <u>Nereis diversicolor</u> in Autumn 1976.



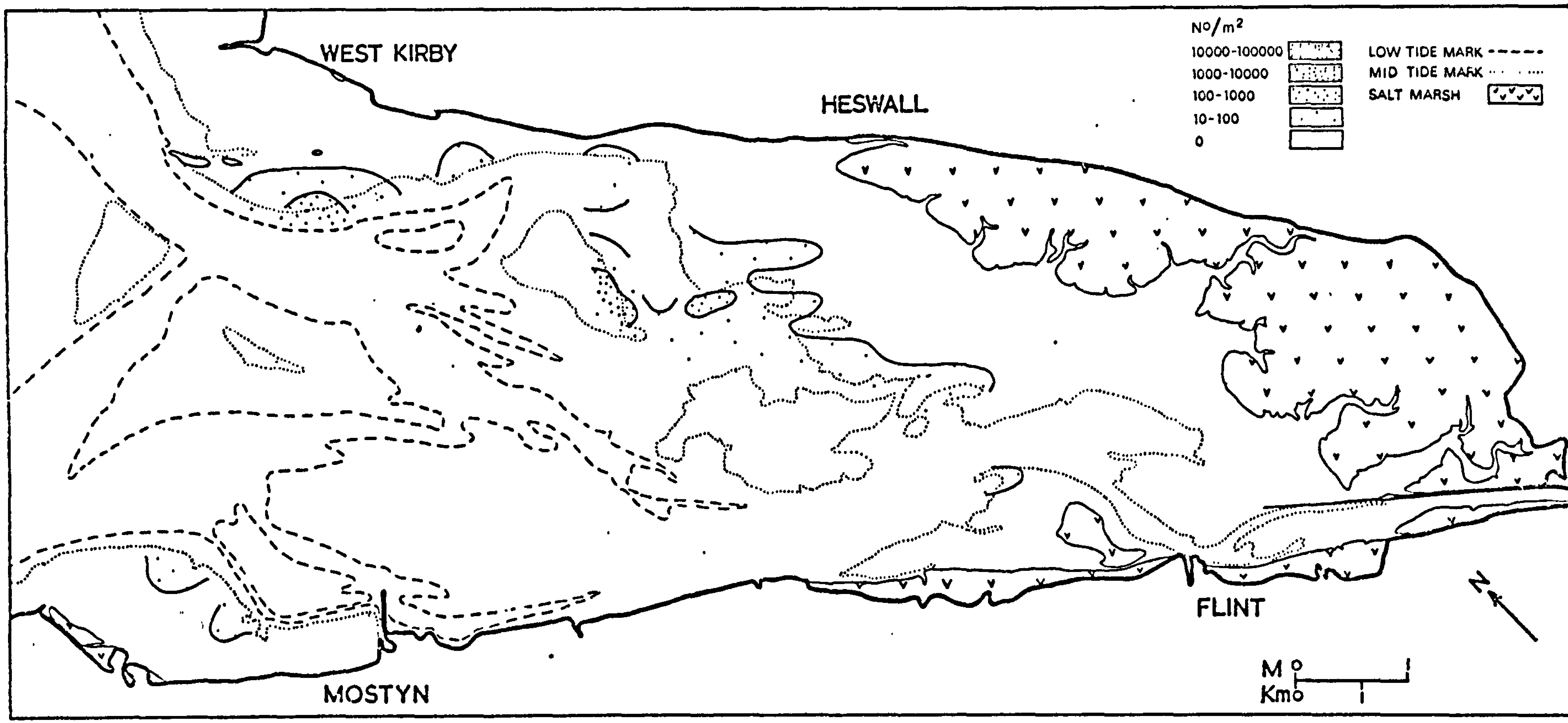
Map 72. Density distribution of Nephthys sp. in Autumn 1971.



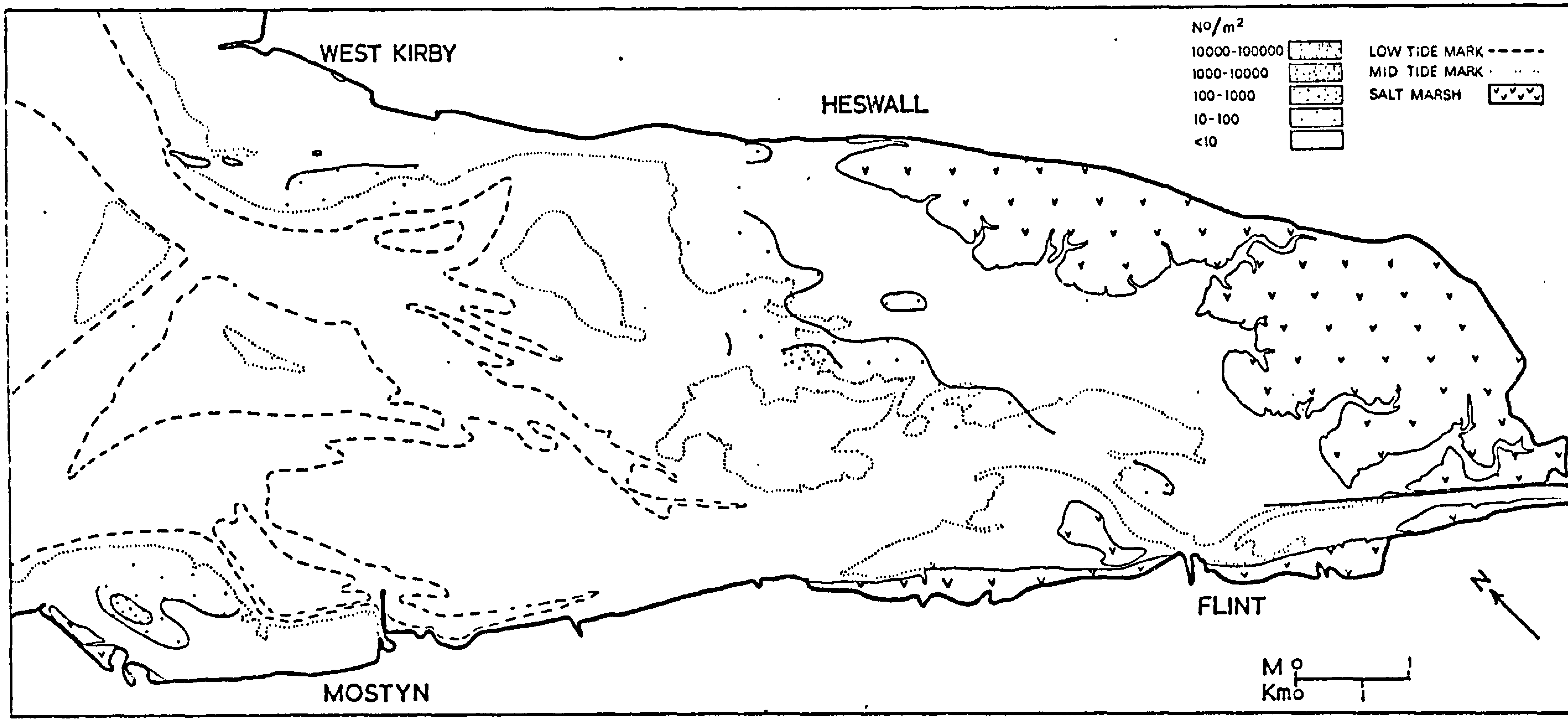
Map 73. Density distribution of Nephthys sp. in Spring 1972.



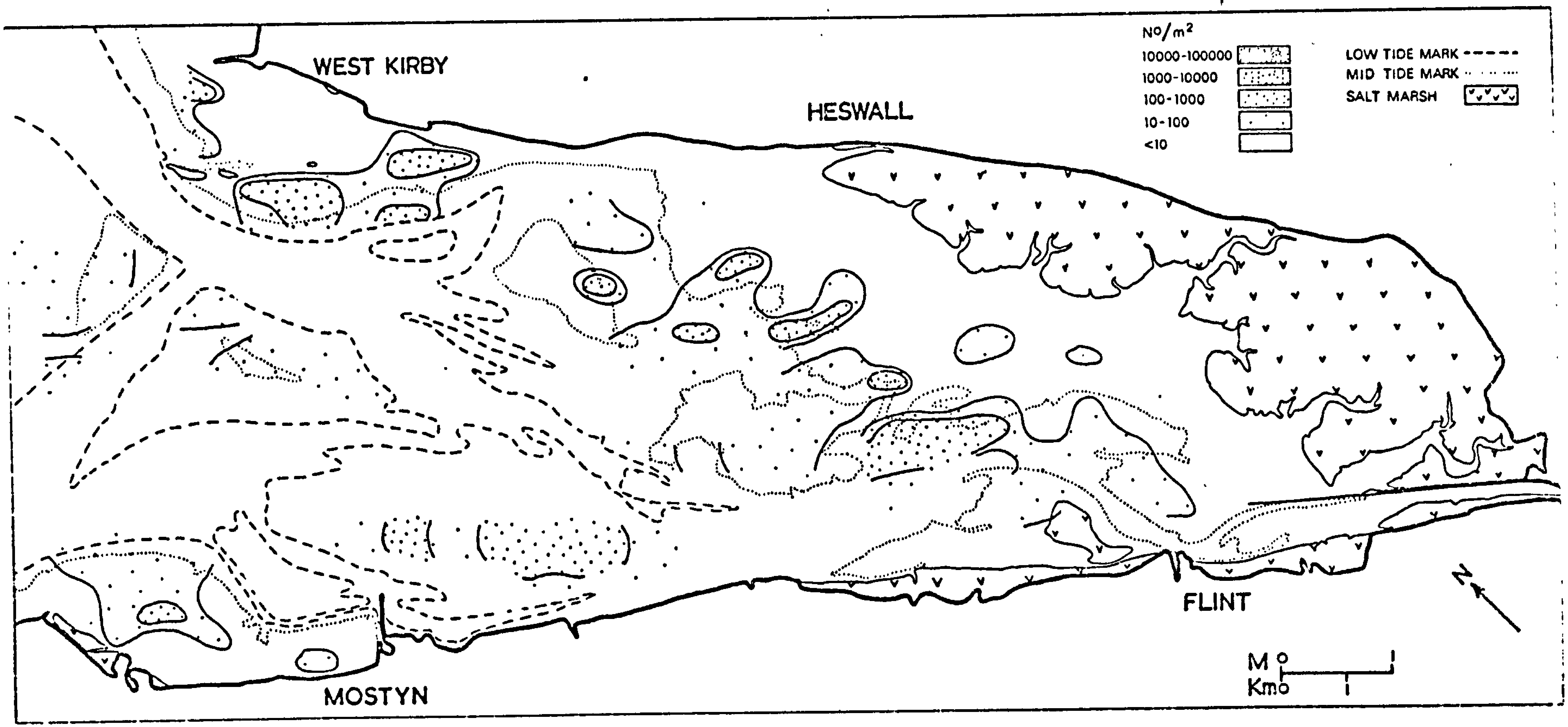
Map 74. Density distribution of Nephthys sp. in Spring 1973.



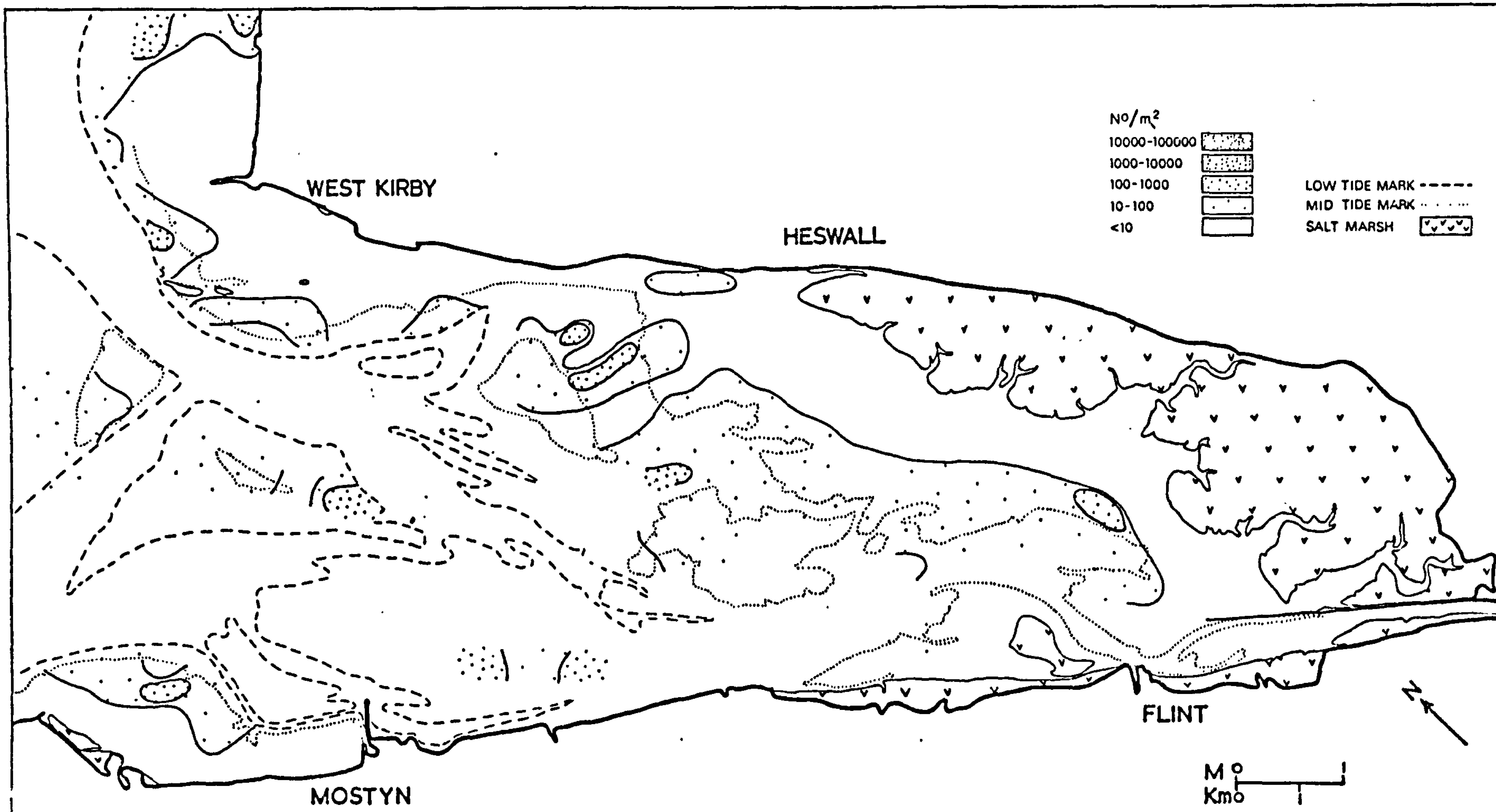
Map 75. Density distribution of Nephthys sp. in Spring 1974.



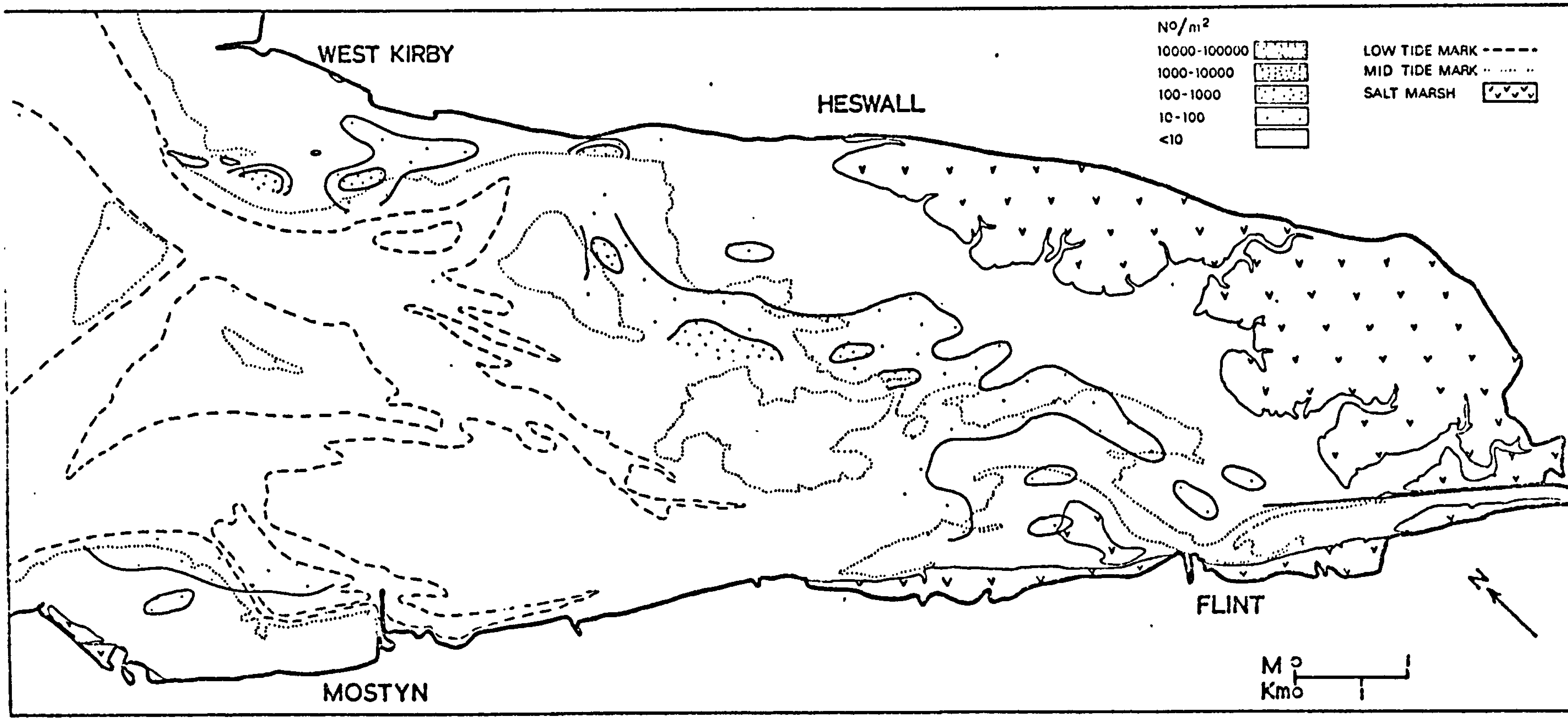
Map 76. Density distribution of <u>Nephthys</u> sp. in Spring 1975.



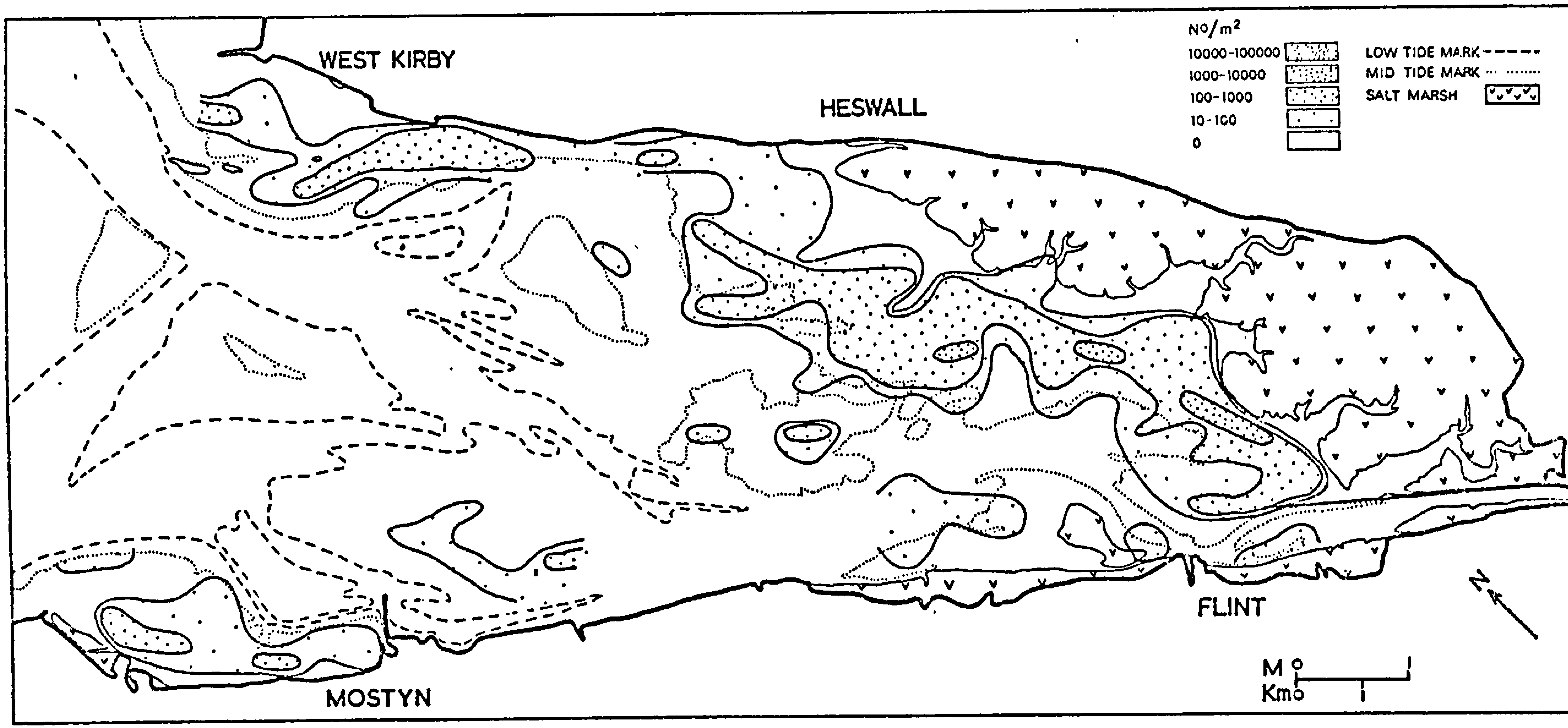
Map 77. Density distribution of Nephthys sp. in Autumn 1975.



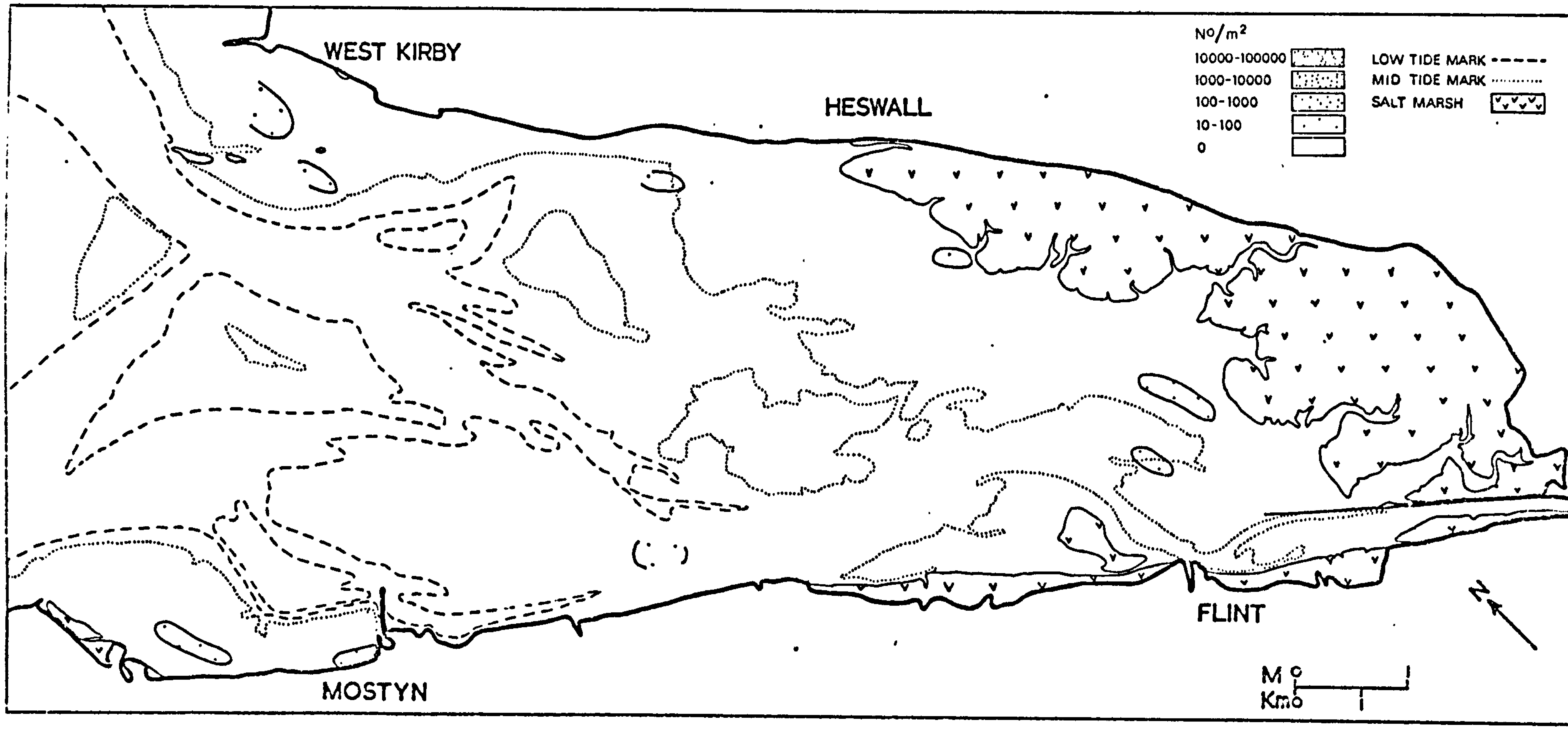
Map 78. Density distribution of <u>Nephthys</u> sp. in Spring 1976.



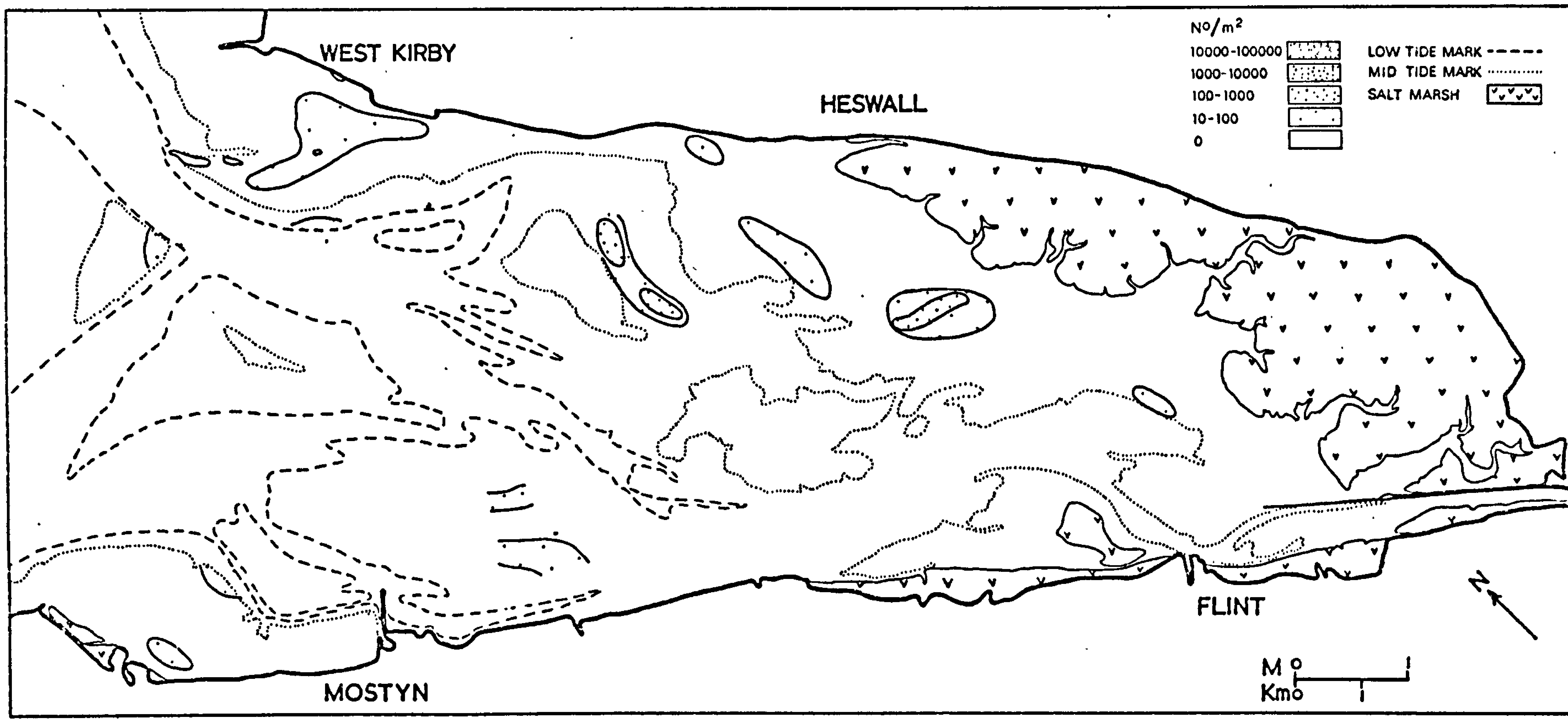
Map 79. Density distribution of Nephthys sp. in Autumn 1976.



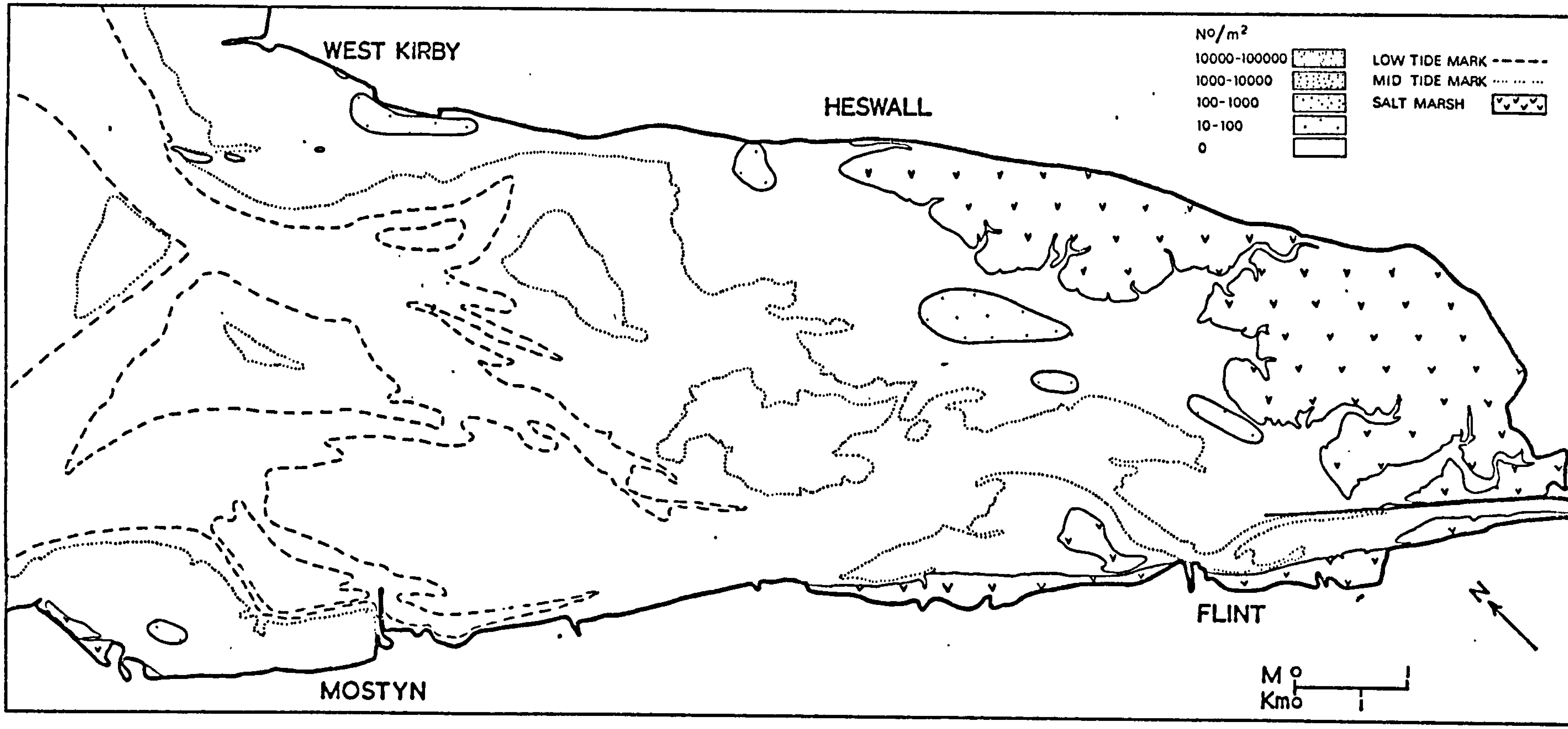
Map 80. Density distribution of <u>Eteone longa</u> in Autumn 1971.



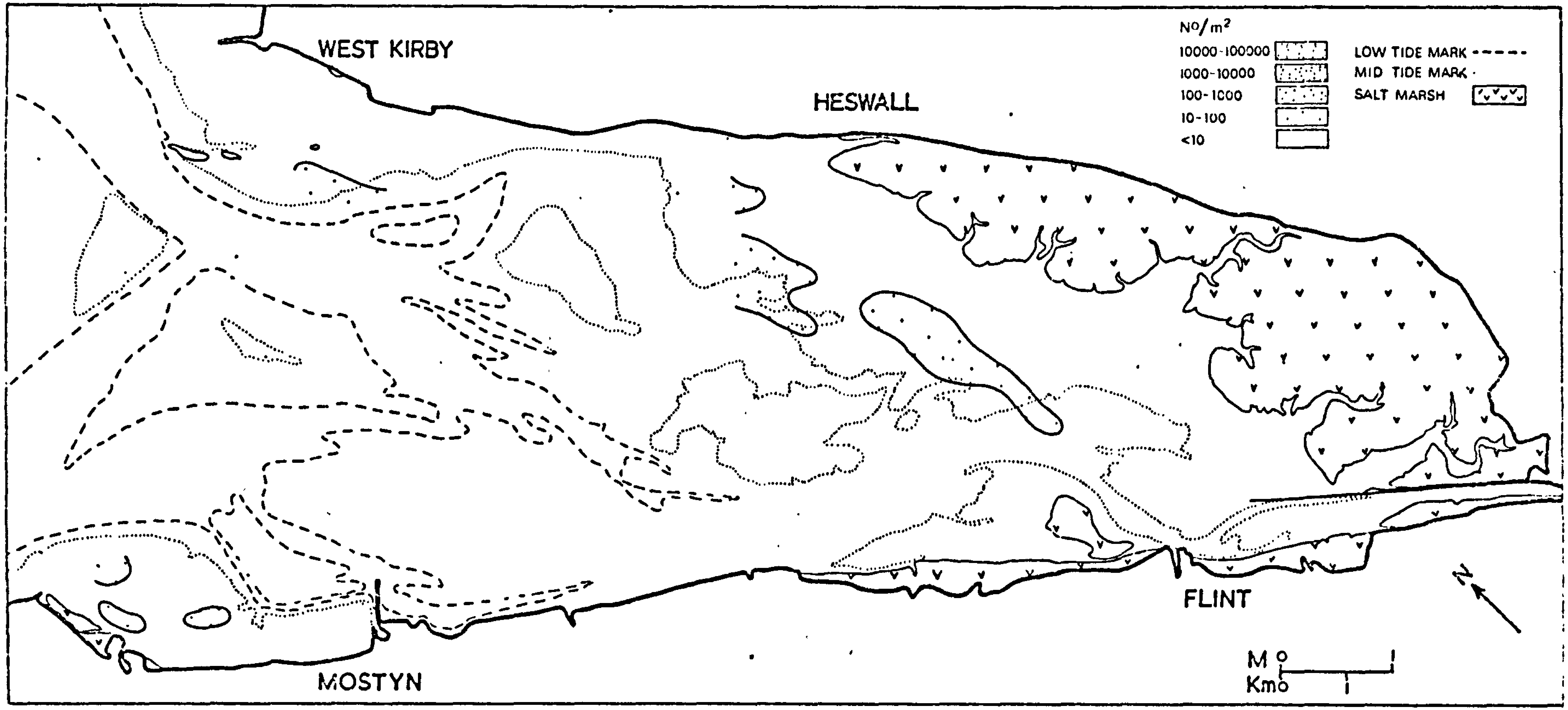
Map 81. Density distribution of Eteone longa in Spring 1972.



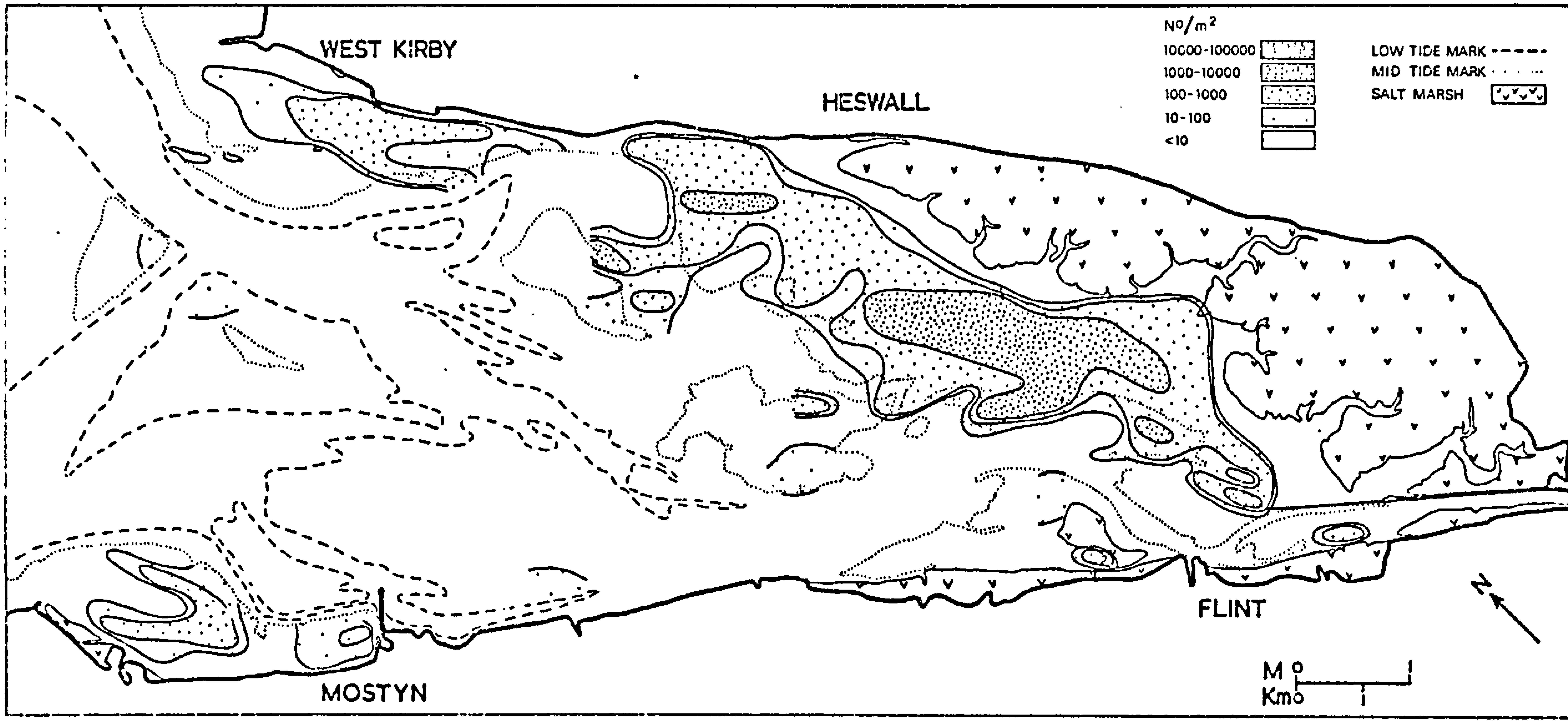
Map 82. Density distribution of <u>Eteone longa</u> in Spring 1973.



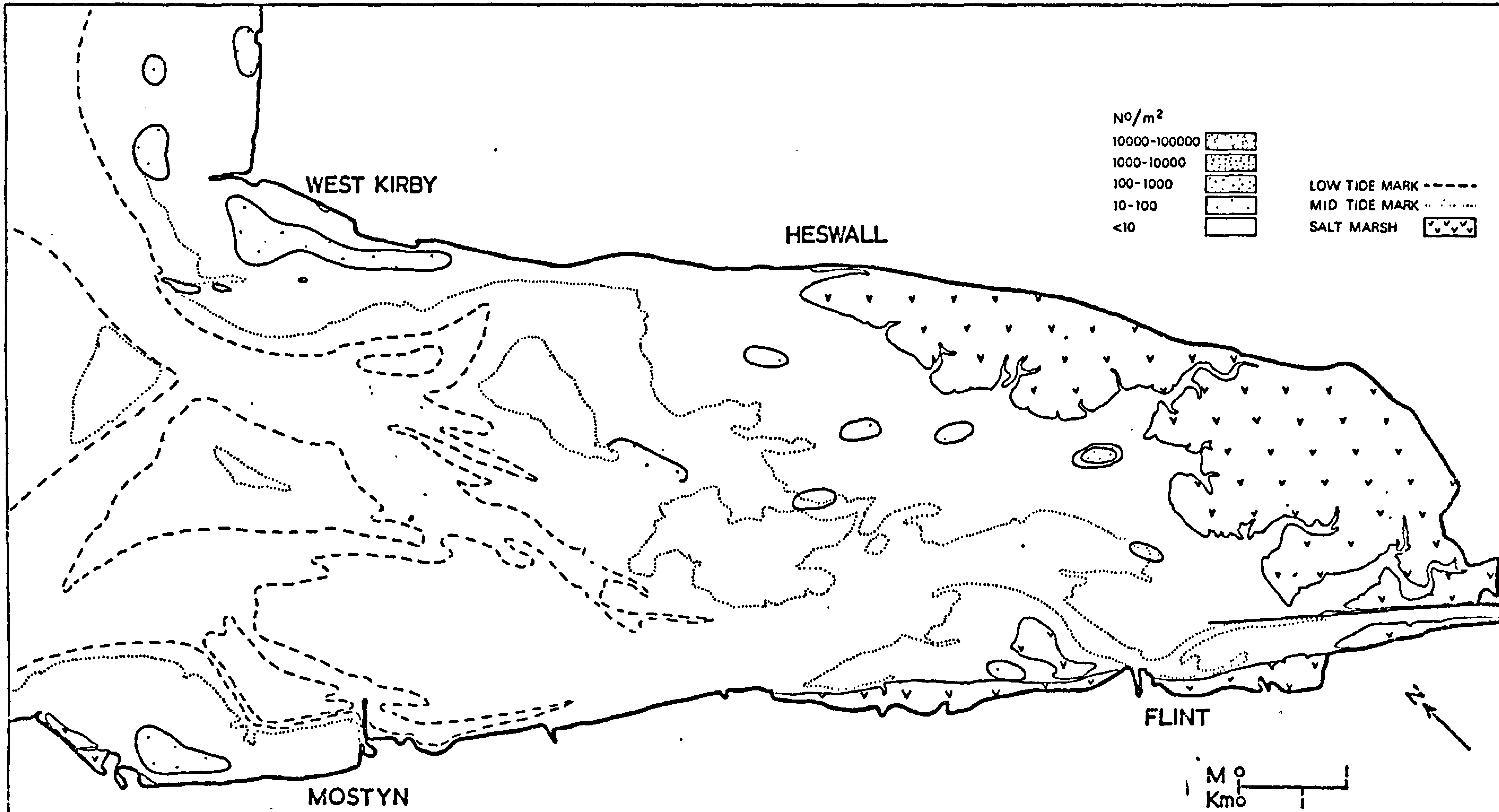
Map 83. Density distribution of Eteone longa in Spring 1974.



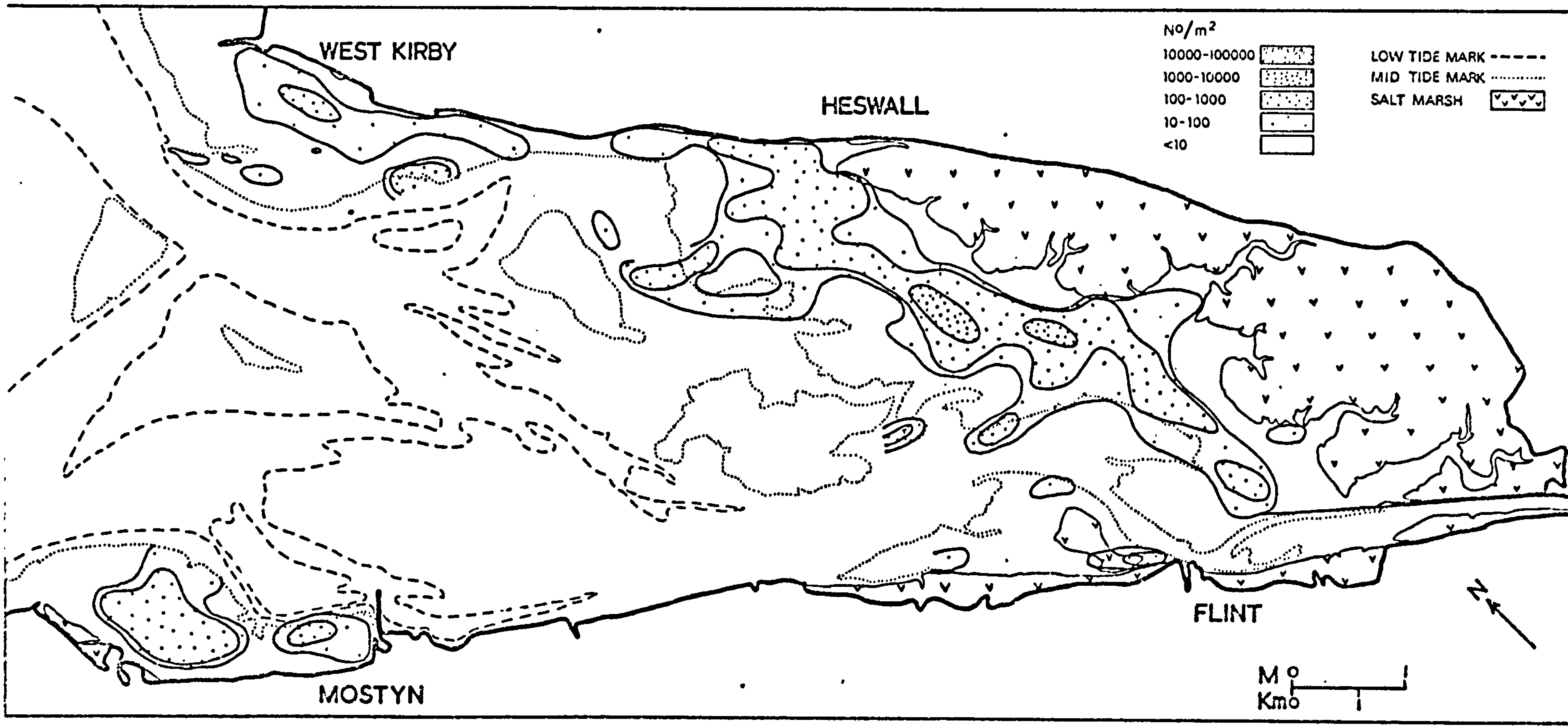
Map 84. Density distribution of Eteone longa in Spring 1975.



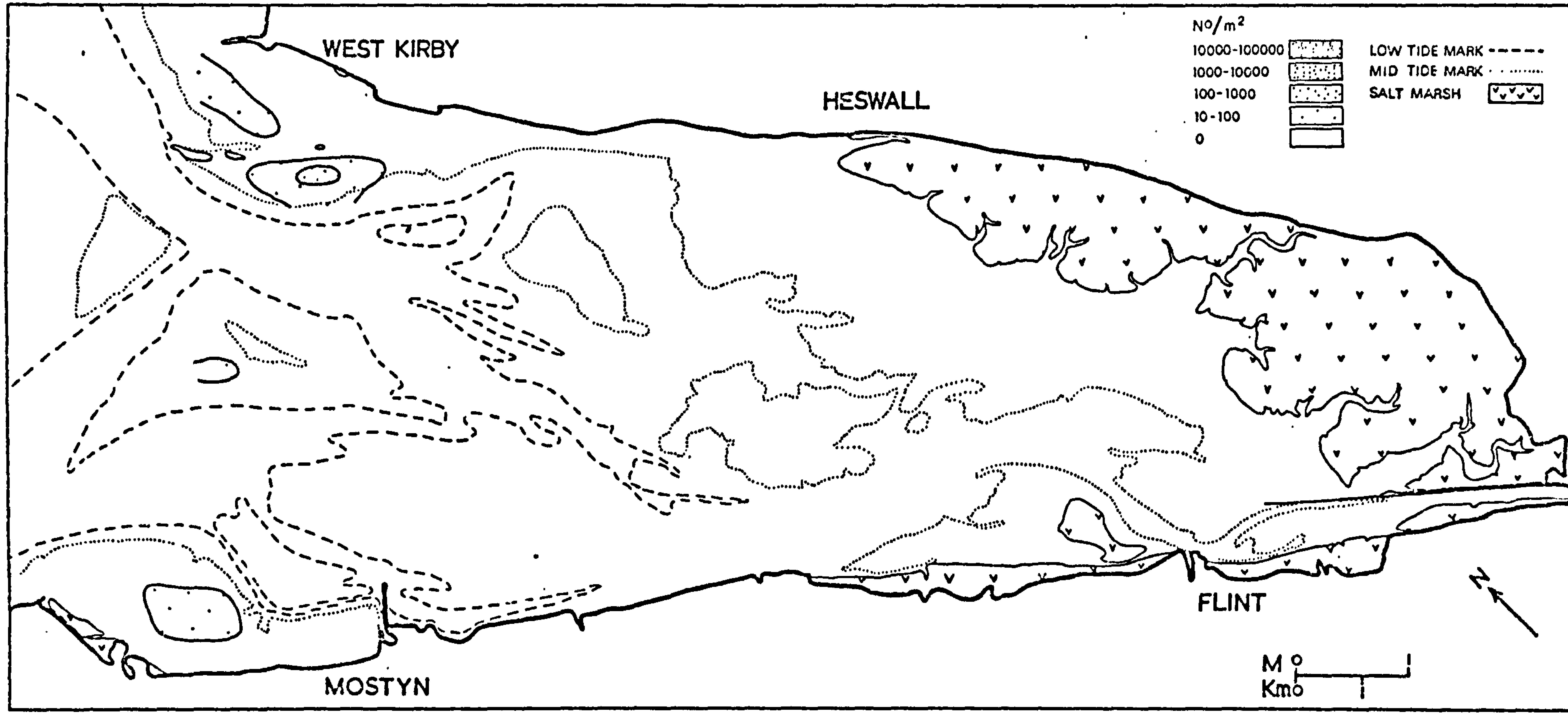
Map 85. Density distribution of Eteone longa in Autumn 1975.



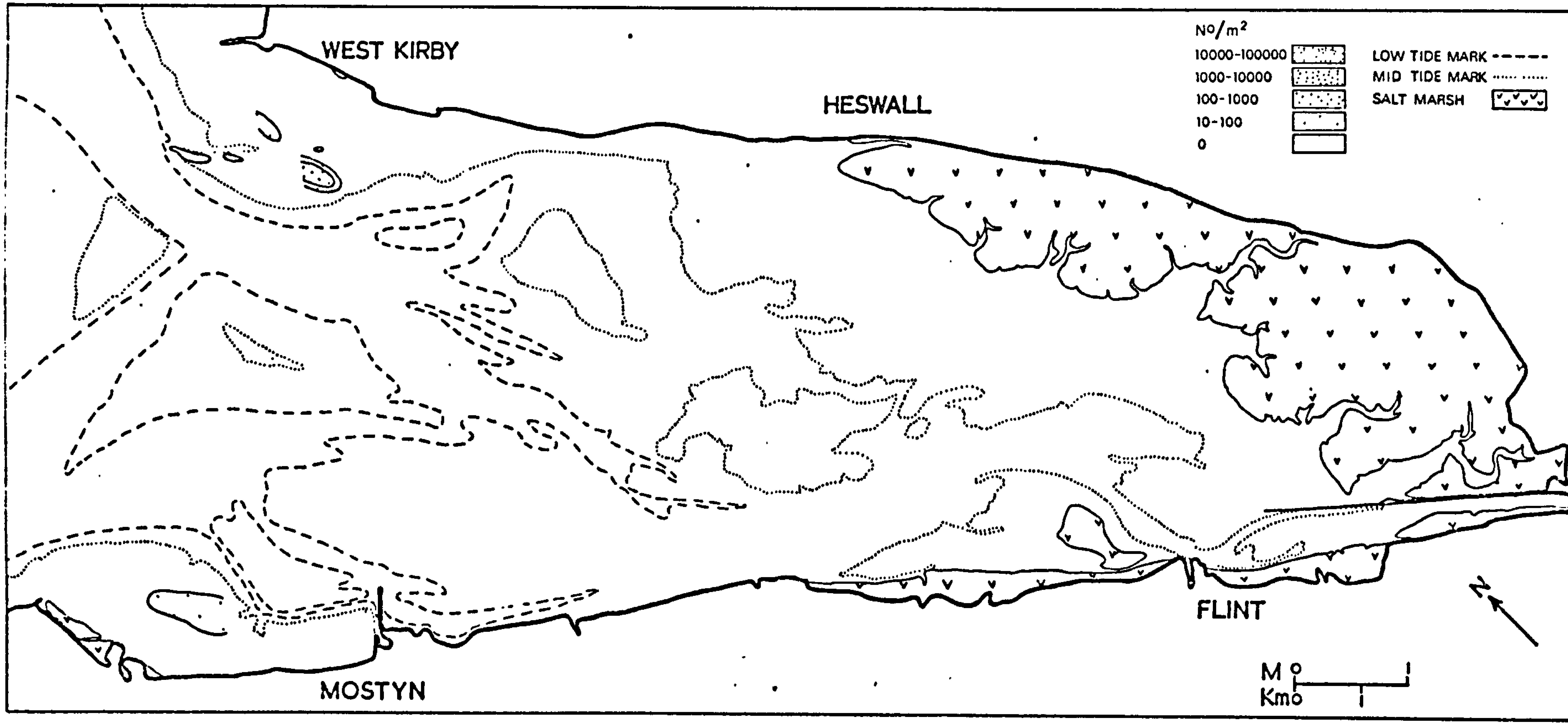
Map 86. Density distribution of Eteone longa in Spring 1976.



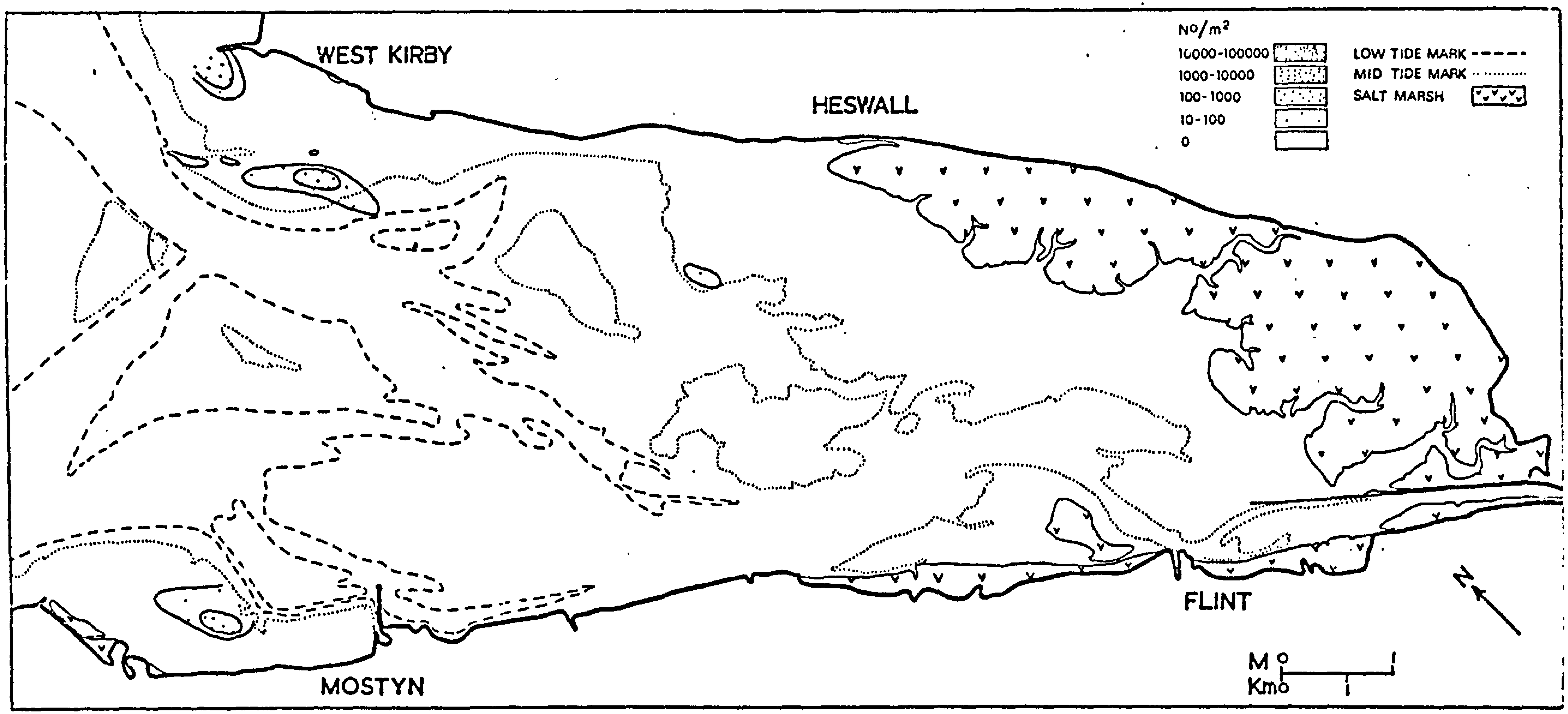
Map 87. Density distribution of Eteone longa in Autumn 1976.



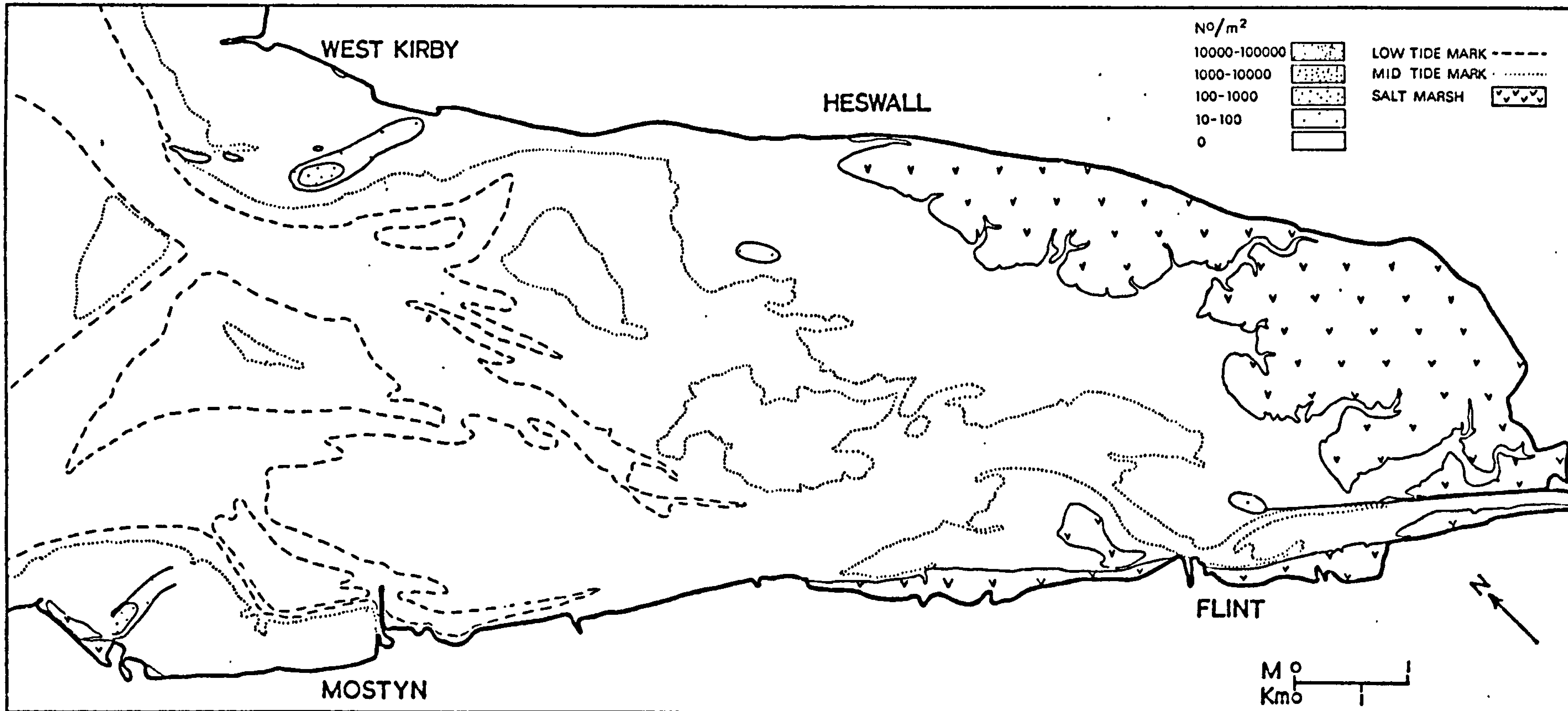
Map 88. Density distribution of Scoloplos armiger in Autumn 1971.



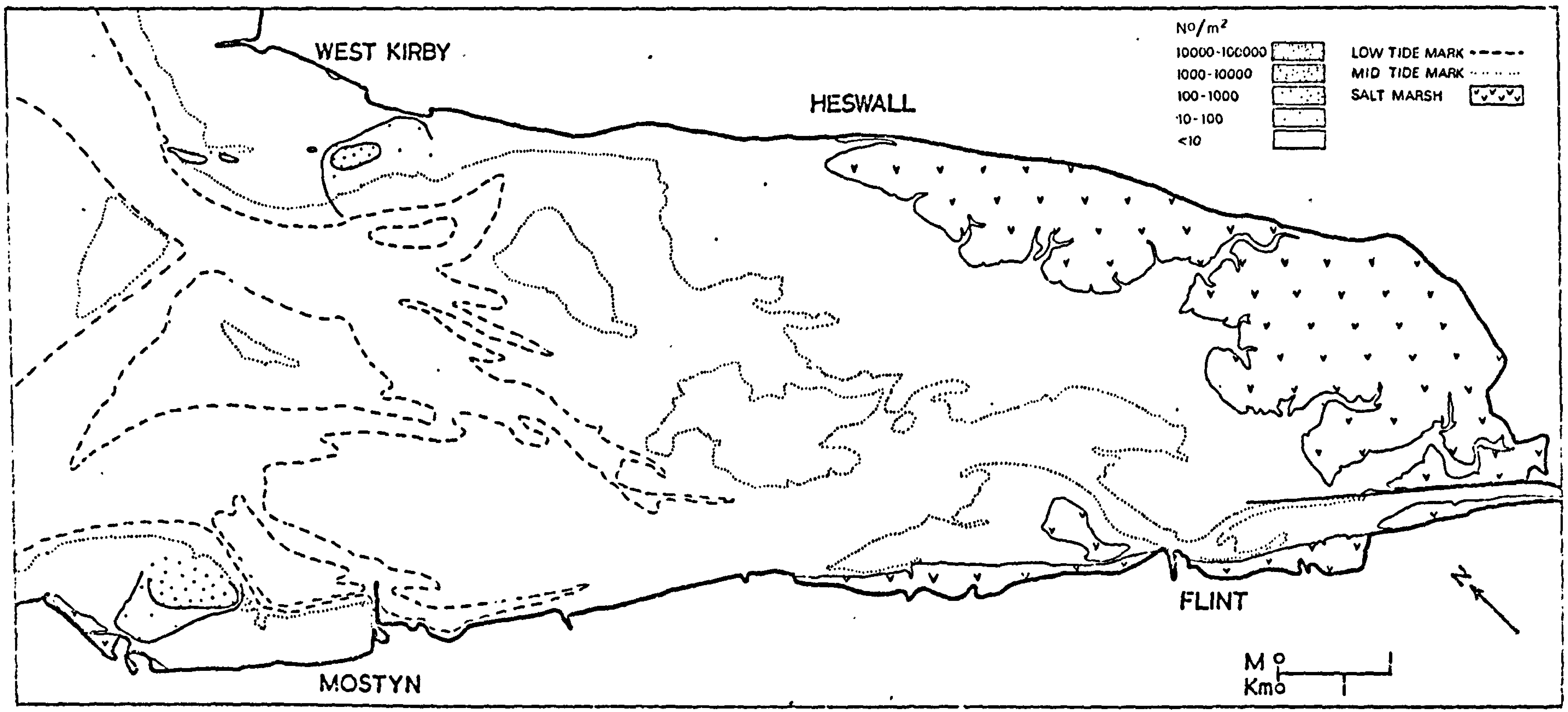
Map 89. Density distribution of *Scoloplos armiger* in Spring 1972.



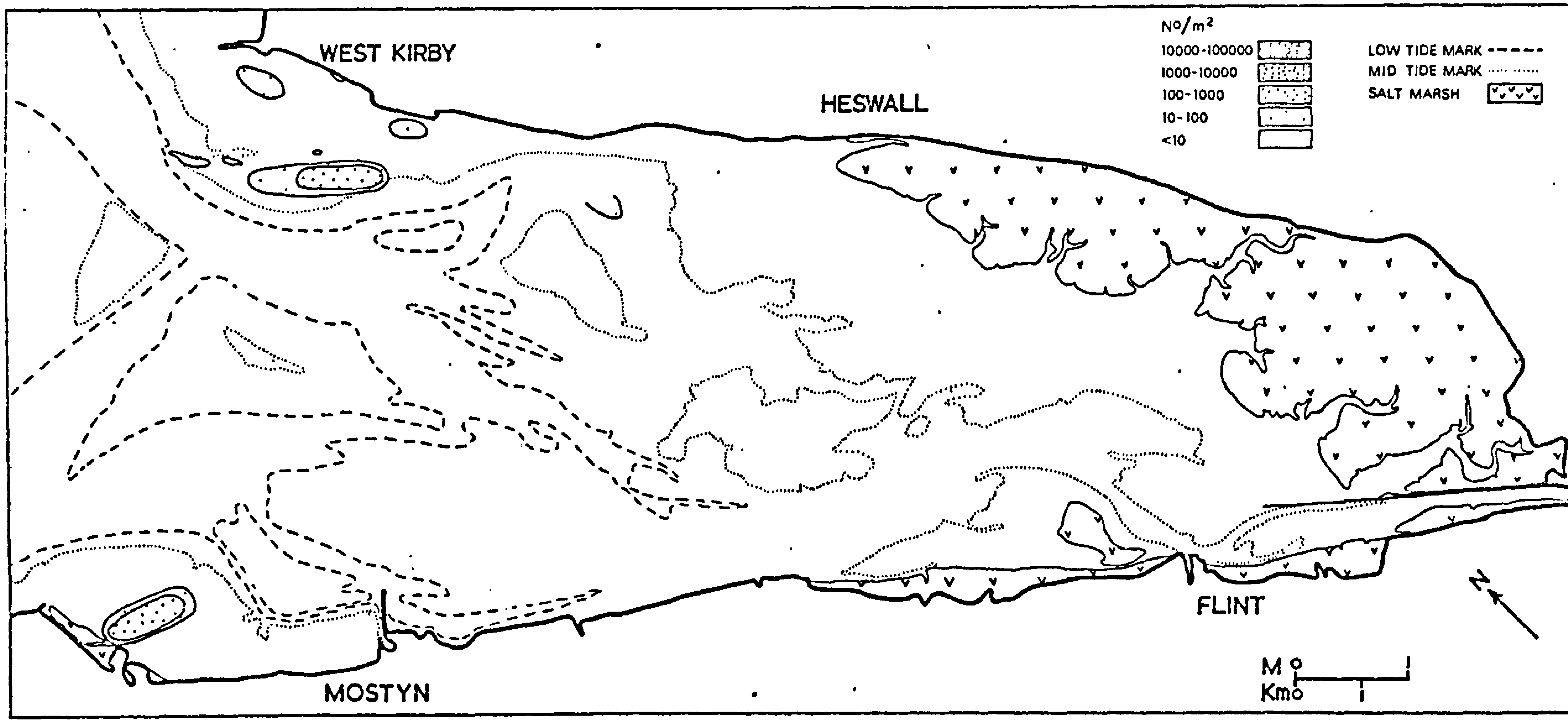
Map 90. Density distribution of Scoloplos armiger in Spring 1973.



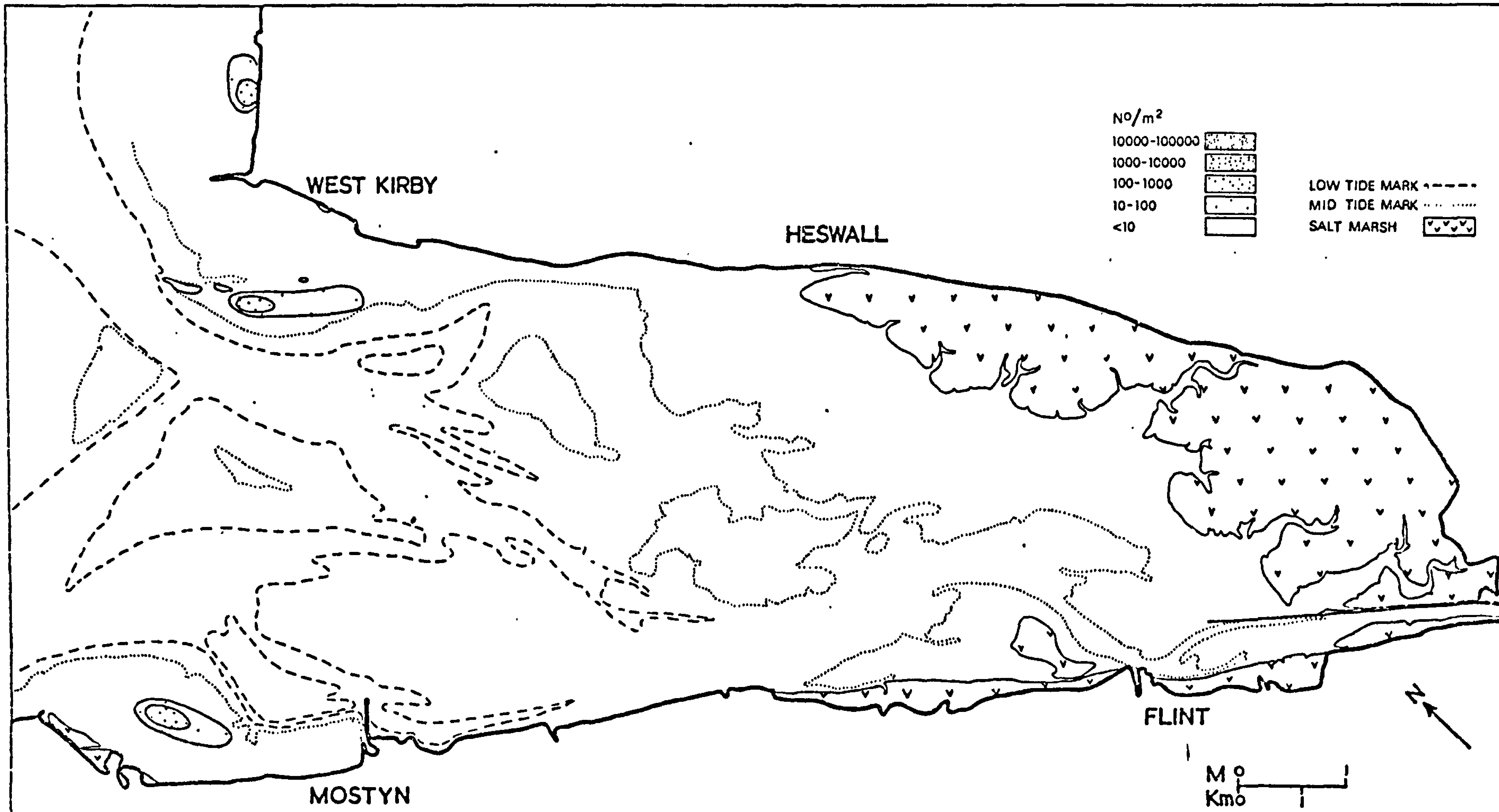
Map 91. Density distribution of Scoloplos armiger in Spring 1974.



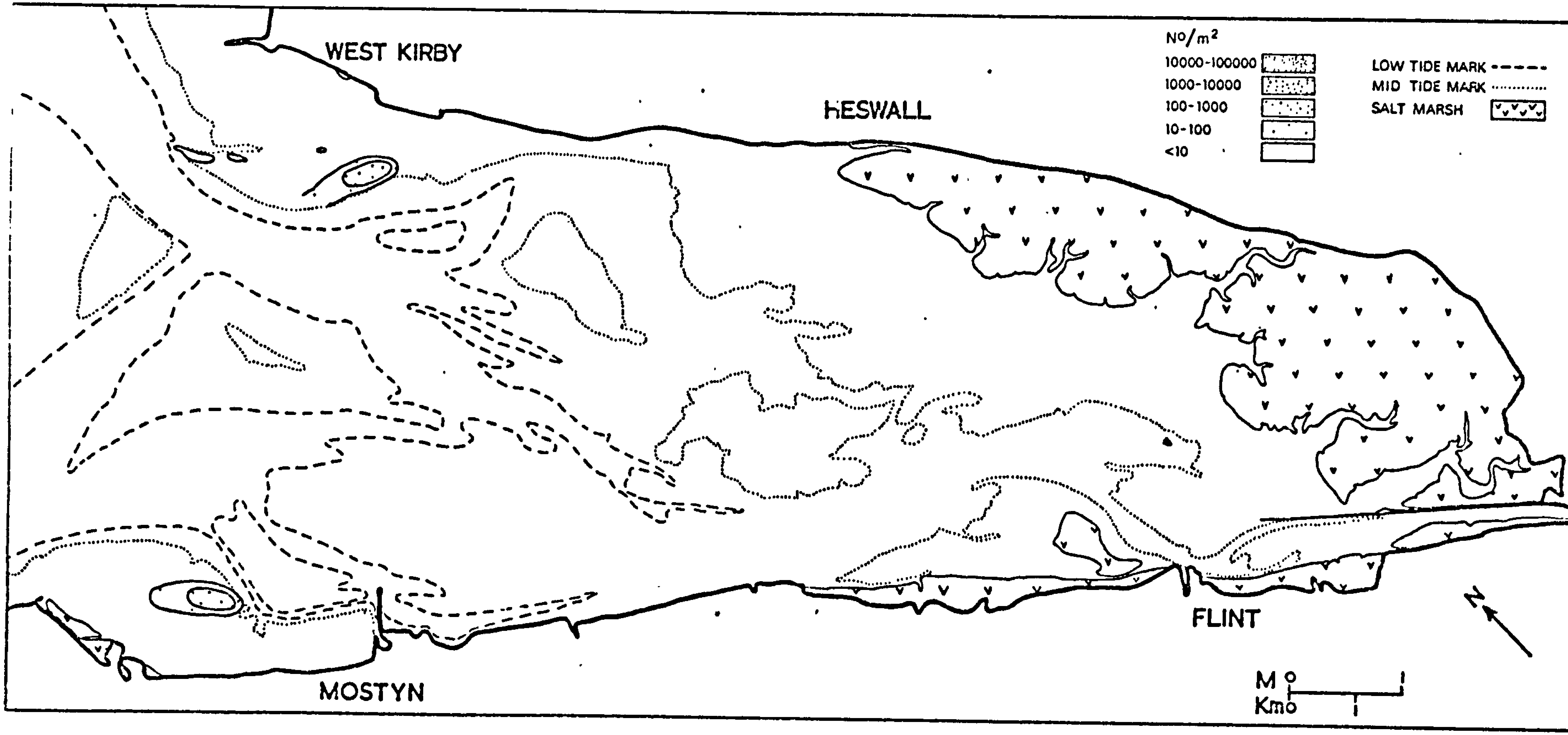
Map 92. Density distribution of <u>Scoloplos armiger</u> in Spring 1975.



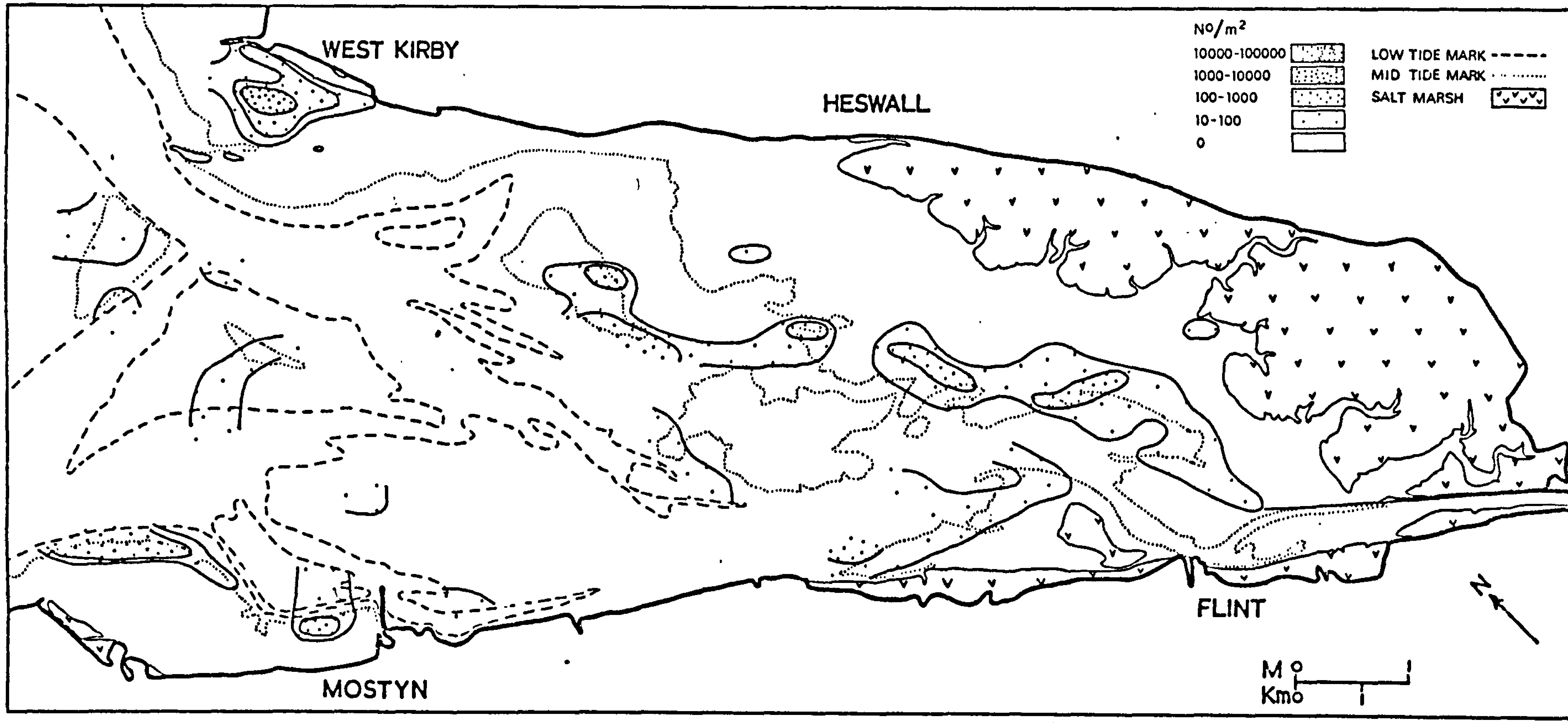
Map 93. Density distribution of <u>Scoloplos armiger</u> in Autumn 1975.



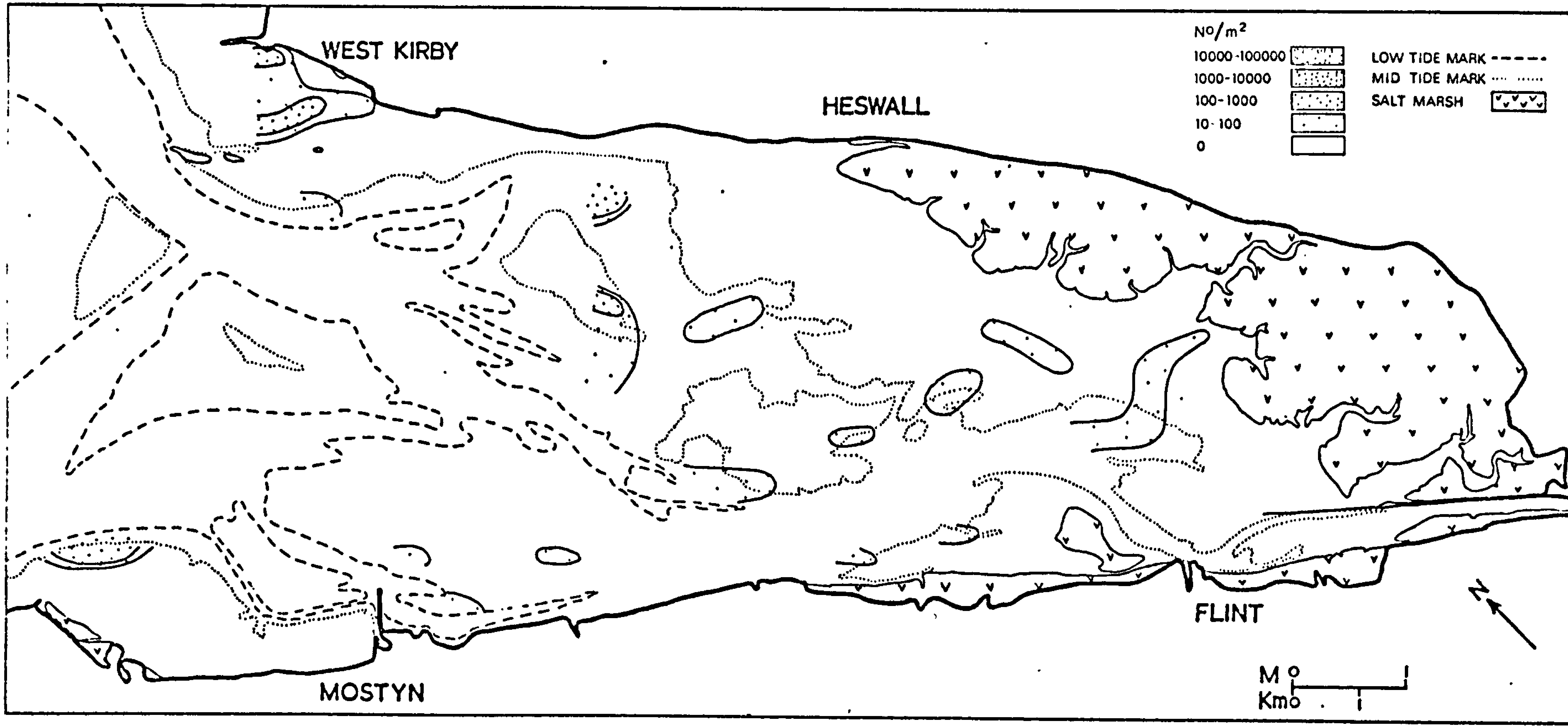
Map 94. Density distribution of Scoloplos armiger in Spring 1976.



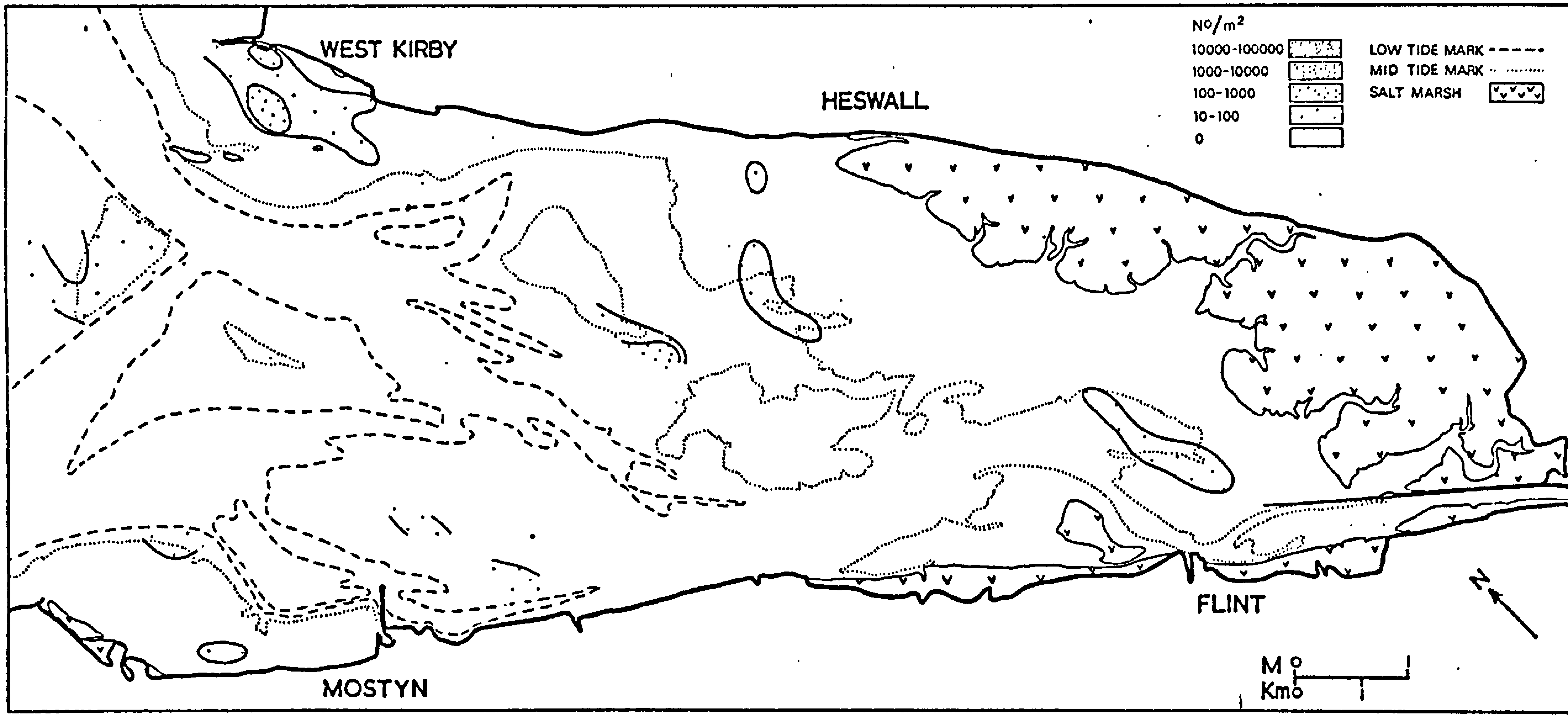
Map 95. Density distribution of <u>Scoloplos armiger</u> in Autumn 1976.



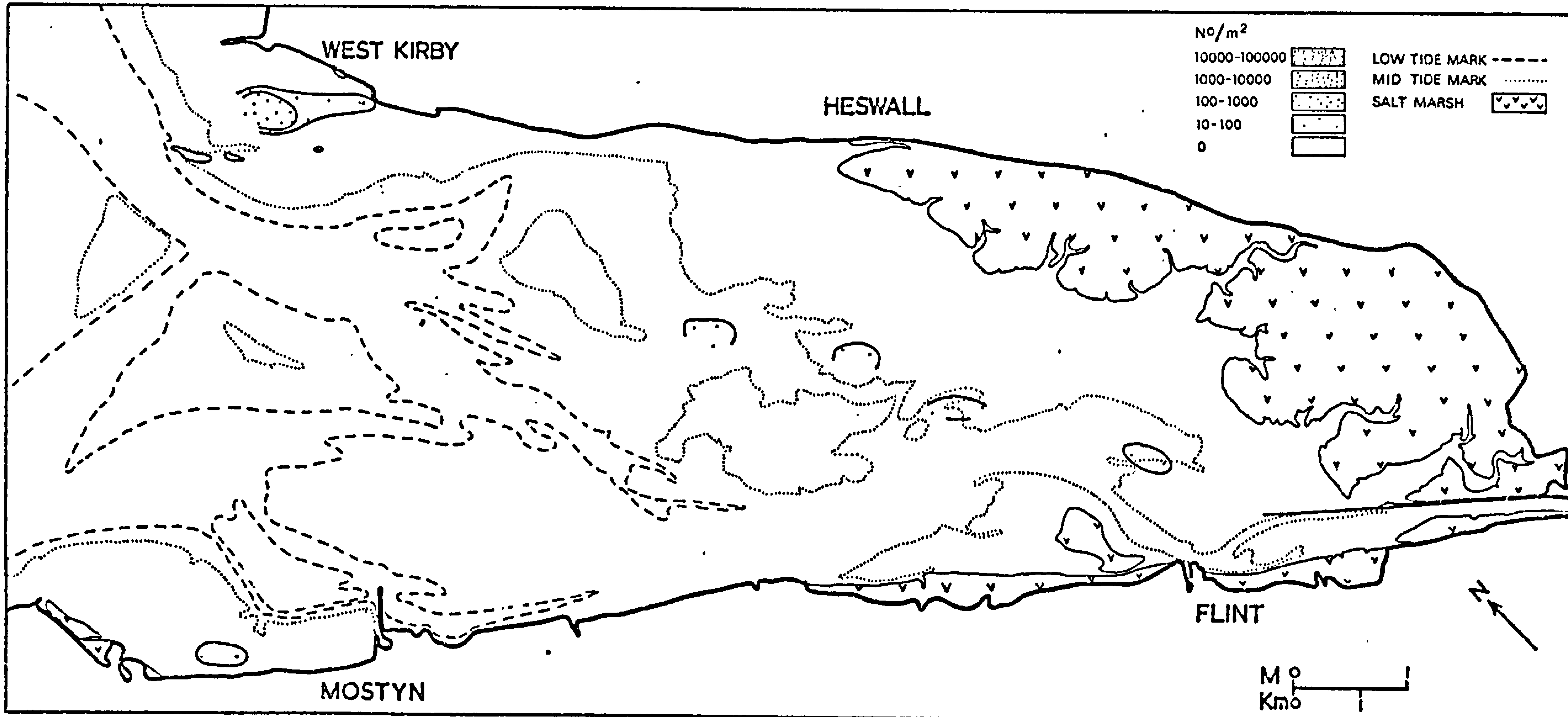
Map 96. Density distribution of <u>Nerine cirratulus</u> in Autumn 1971.



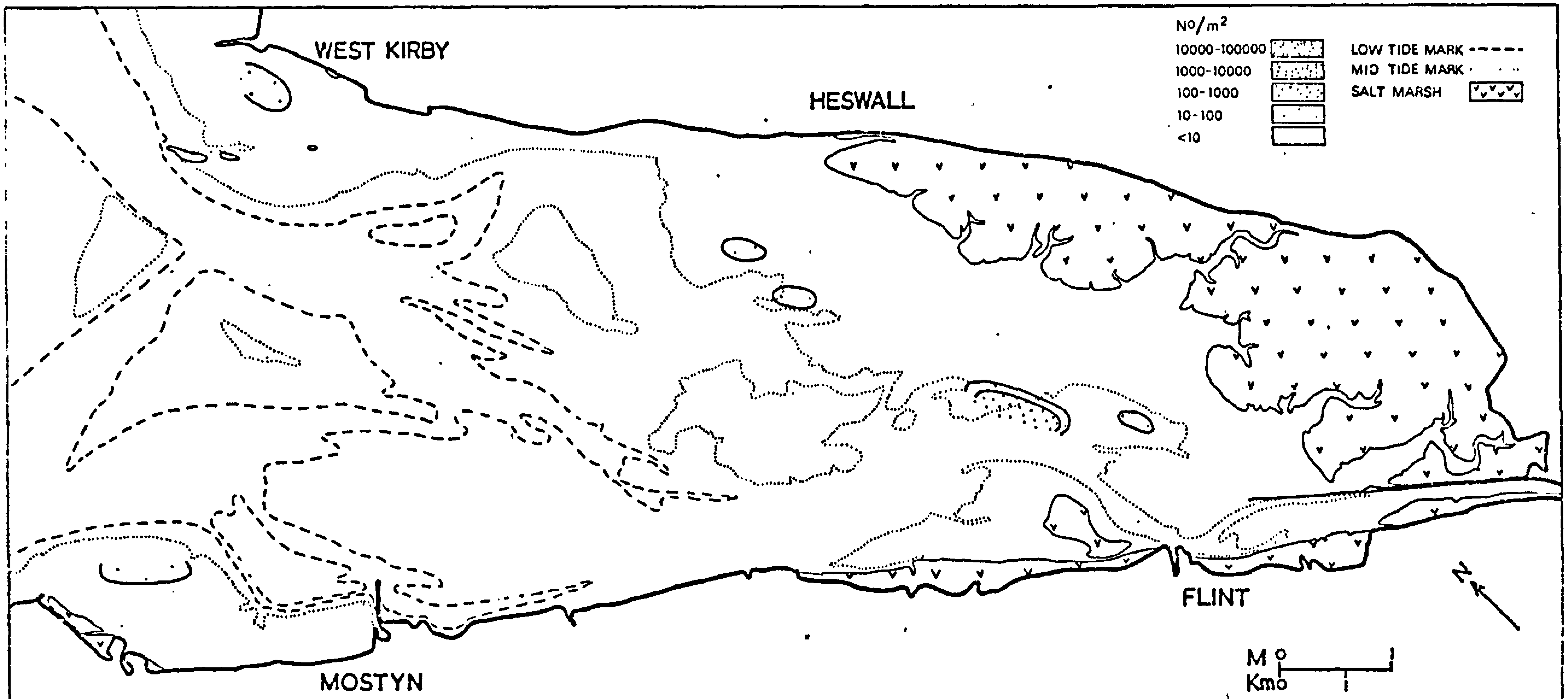
Map 97. Density distribution of Nerine cirratulus in Spring 1972.



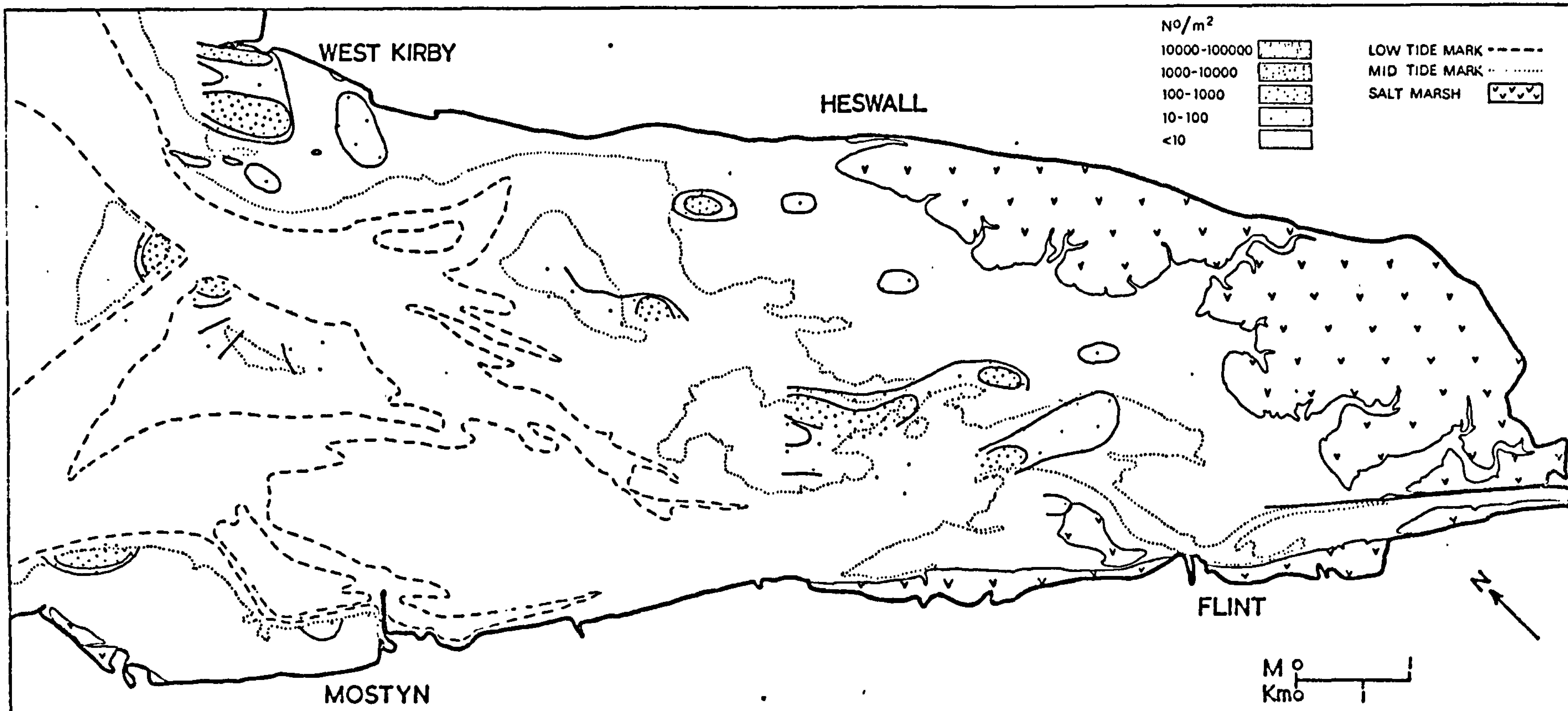
Map 98. Density distribution of <u>Nerine cirratulus</u> in Spring 1973.



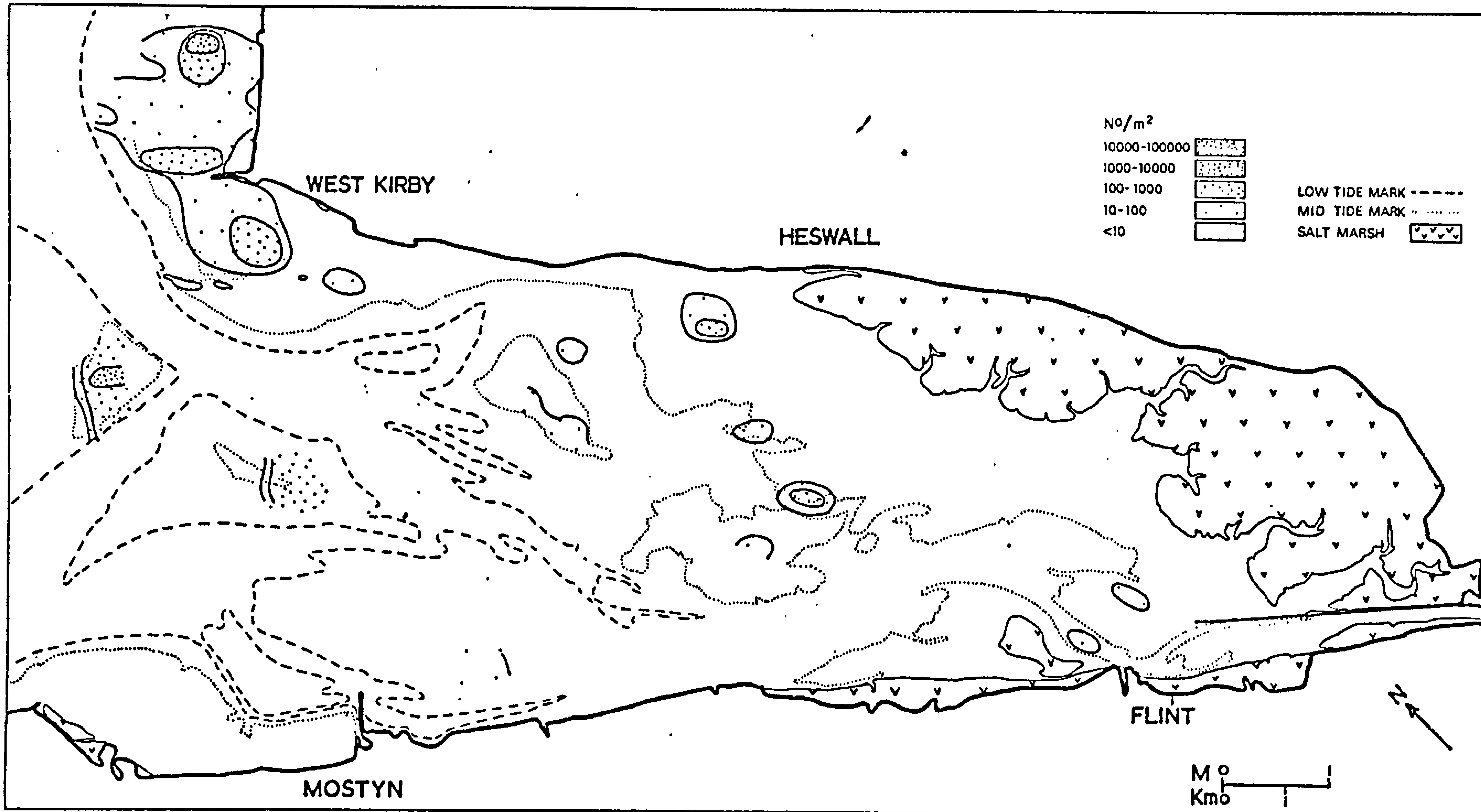
Map 99. Density distribution of Nerine cirratulus in Spring 1974.



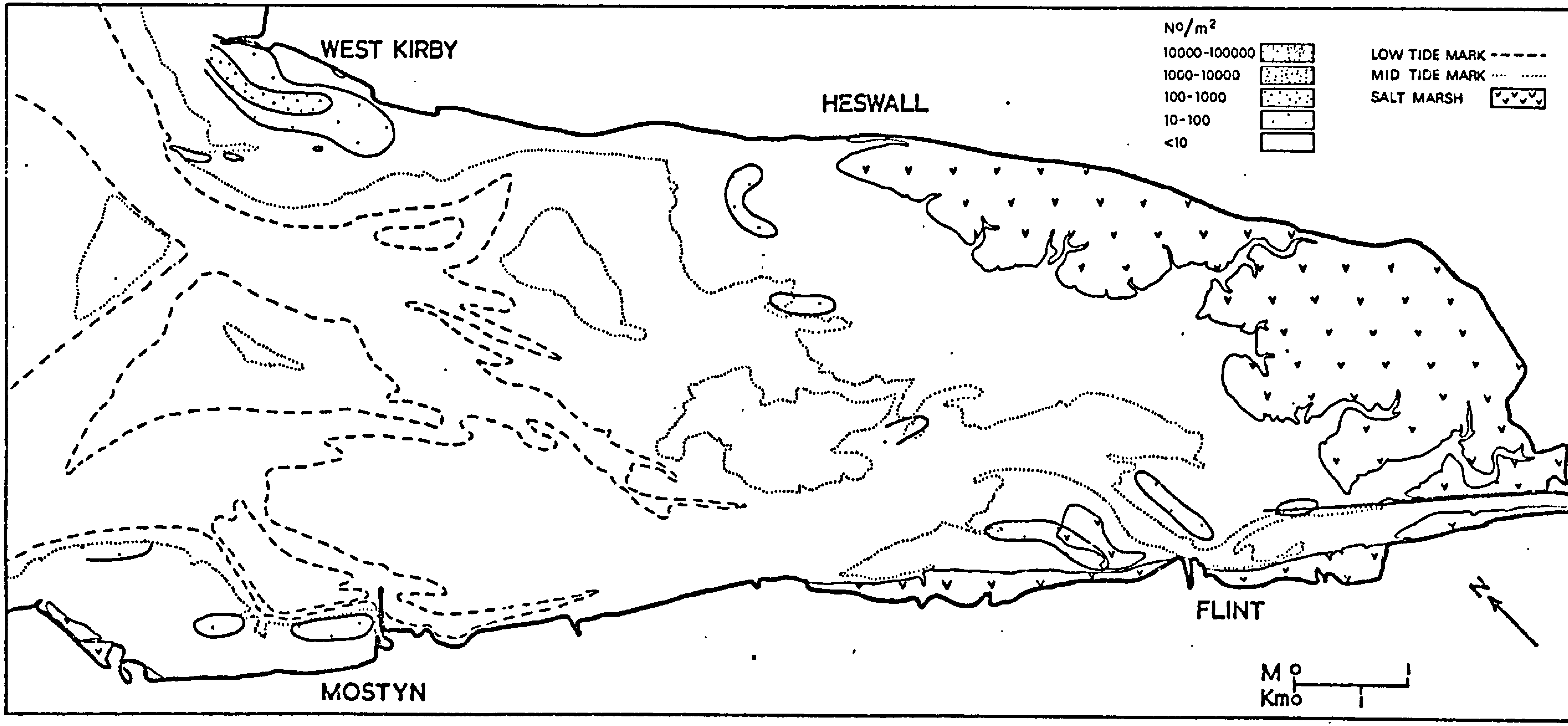
Map 100. Density distribution of Nerine cirratulus in Spring 1975.



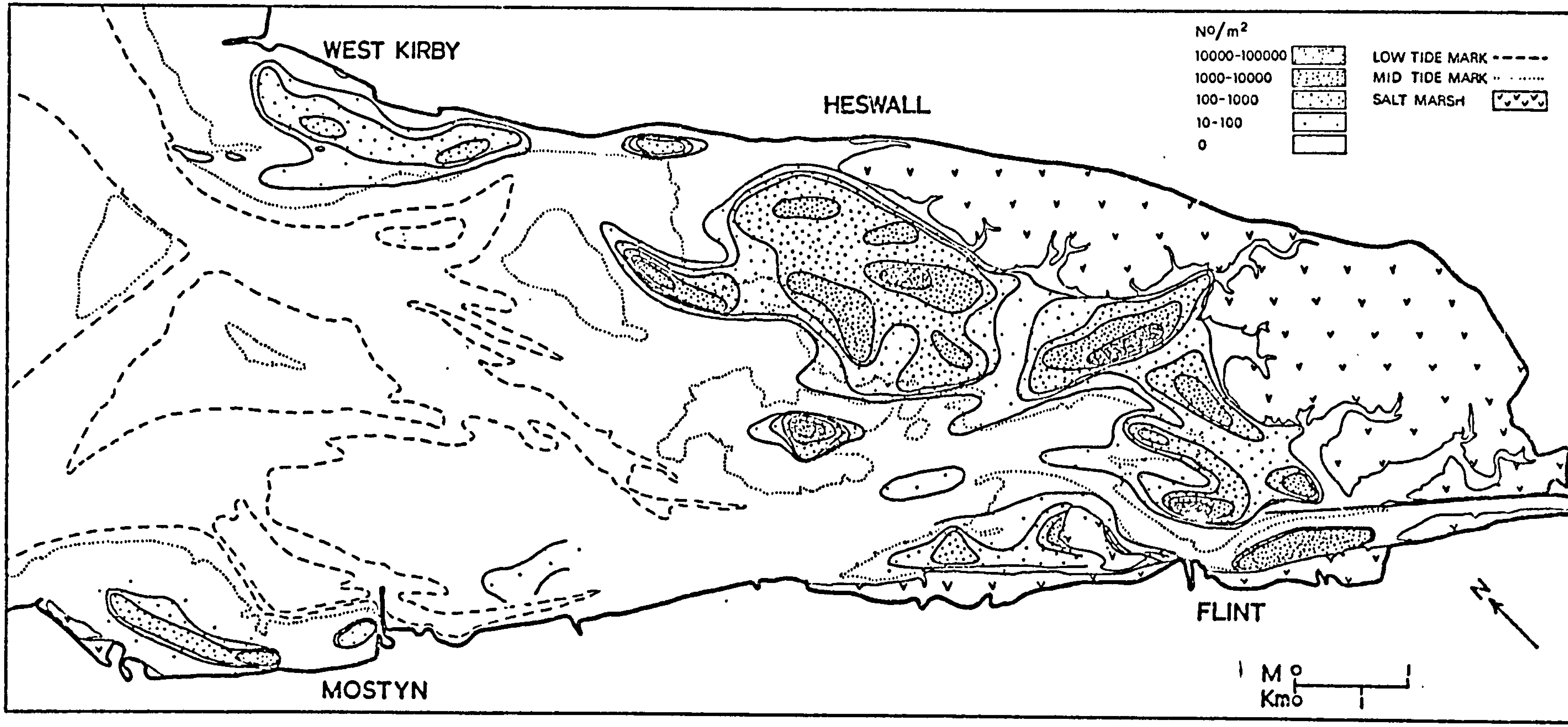
Map 101. Density distribution of <u>Nerine cirratulus</u> in Autumn 1975.



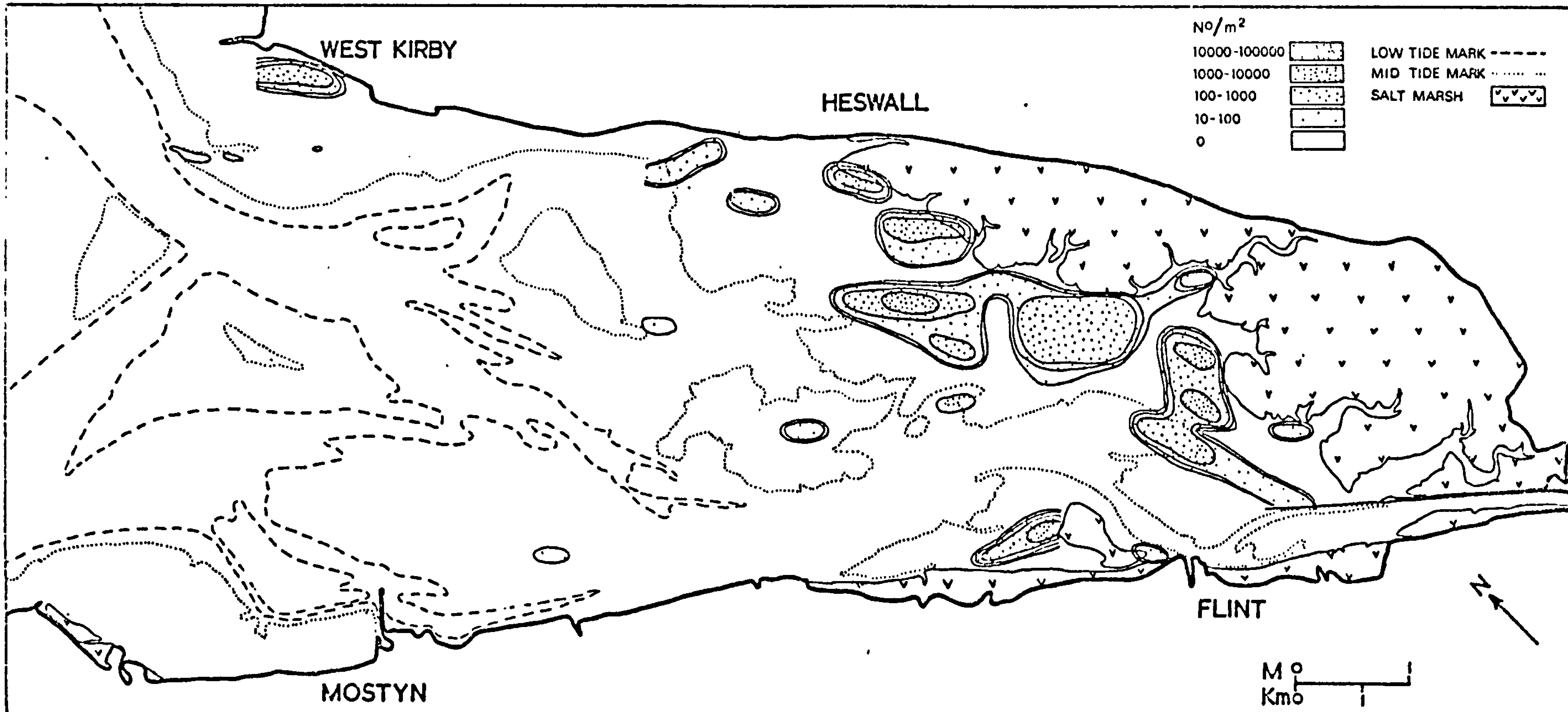
Map 102. Density distribution of <u>Nerine cirratulus</u> in Spring 1976.



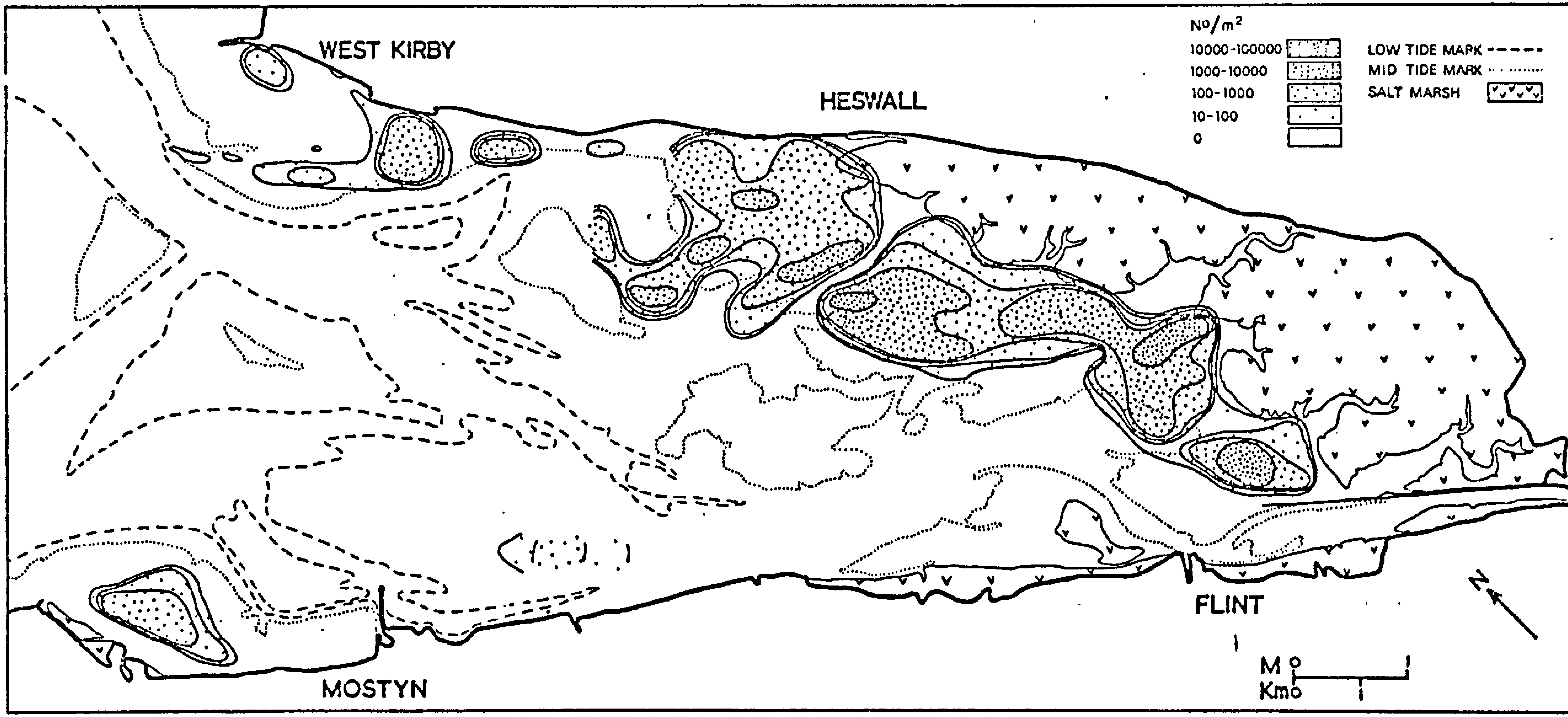
Map 103. Density distribution of <u>Nerine cirratulus</u> in Autumn 1976.



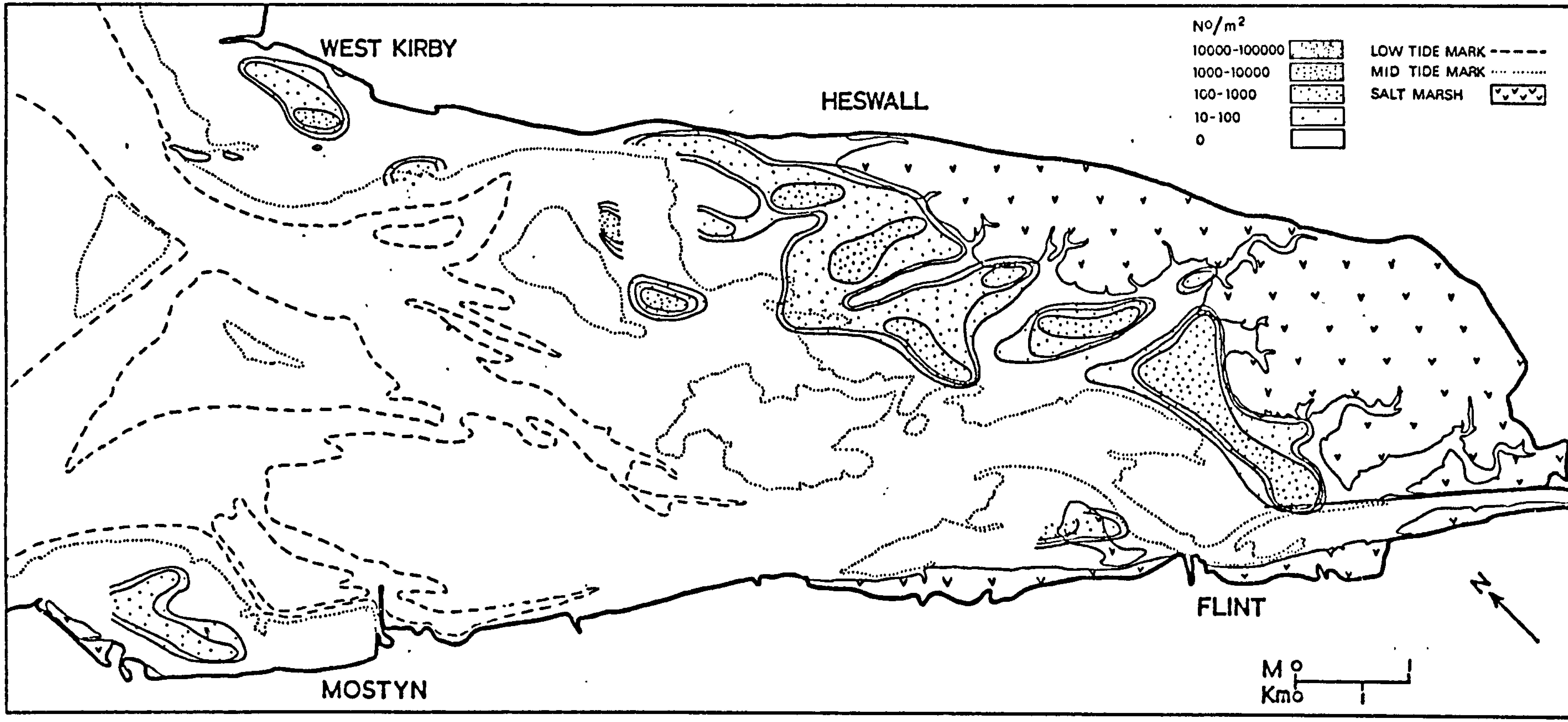
Map 104. Density distribution of Pygospio elegans in Autumn 1971.



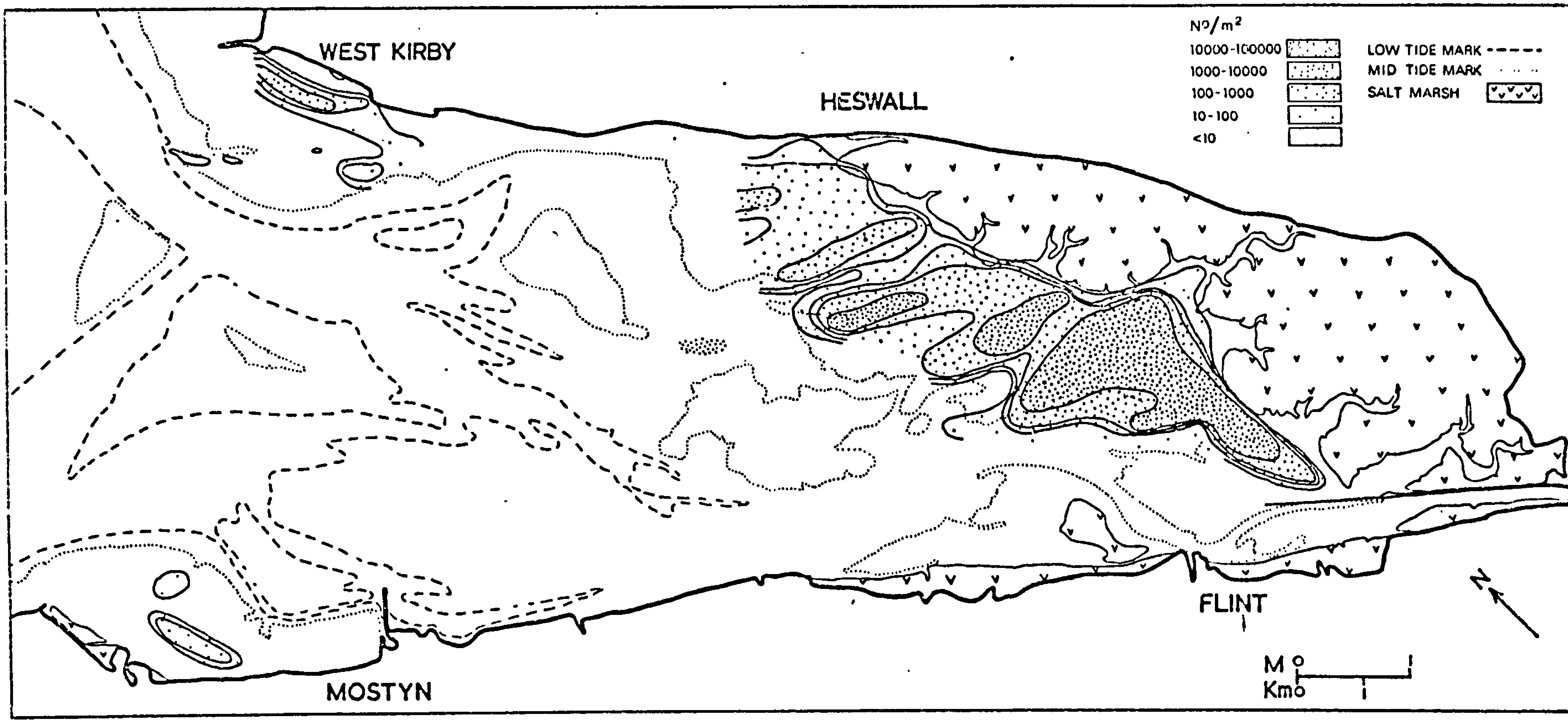
Map 105. Density distribution of Pygospio elegans in Spring 1972.



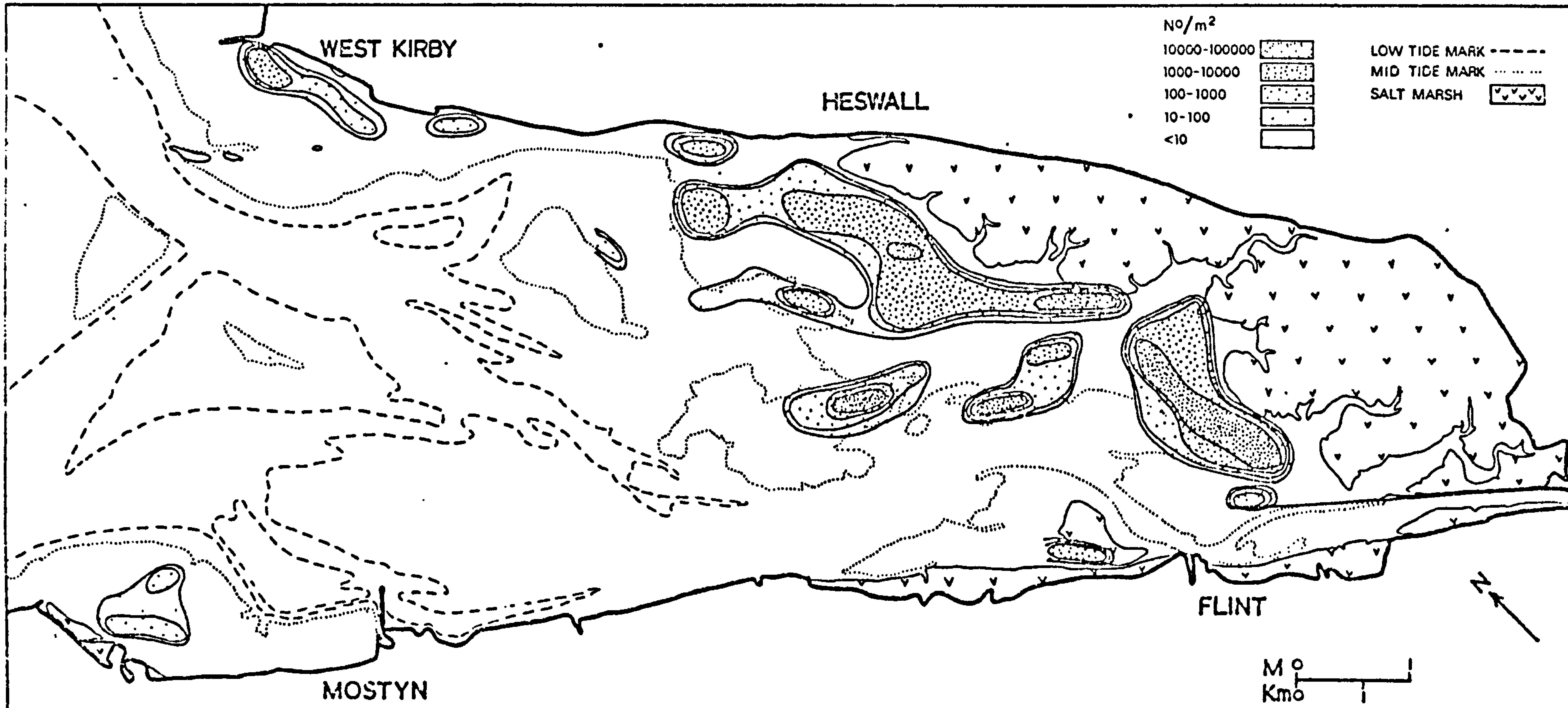
Map 106. Density distribution of Pygospio elegans in Spring 1973.



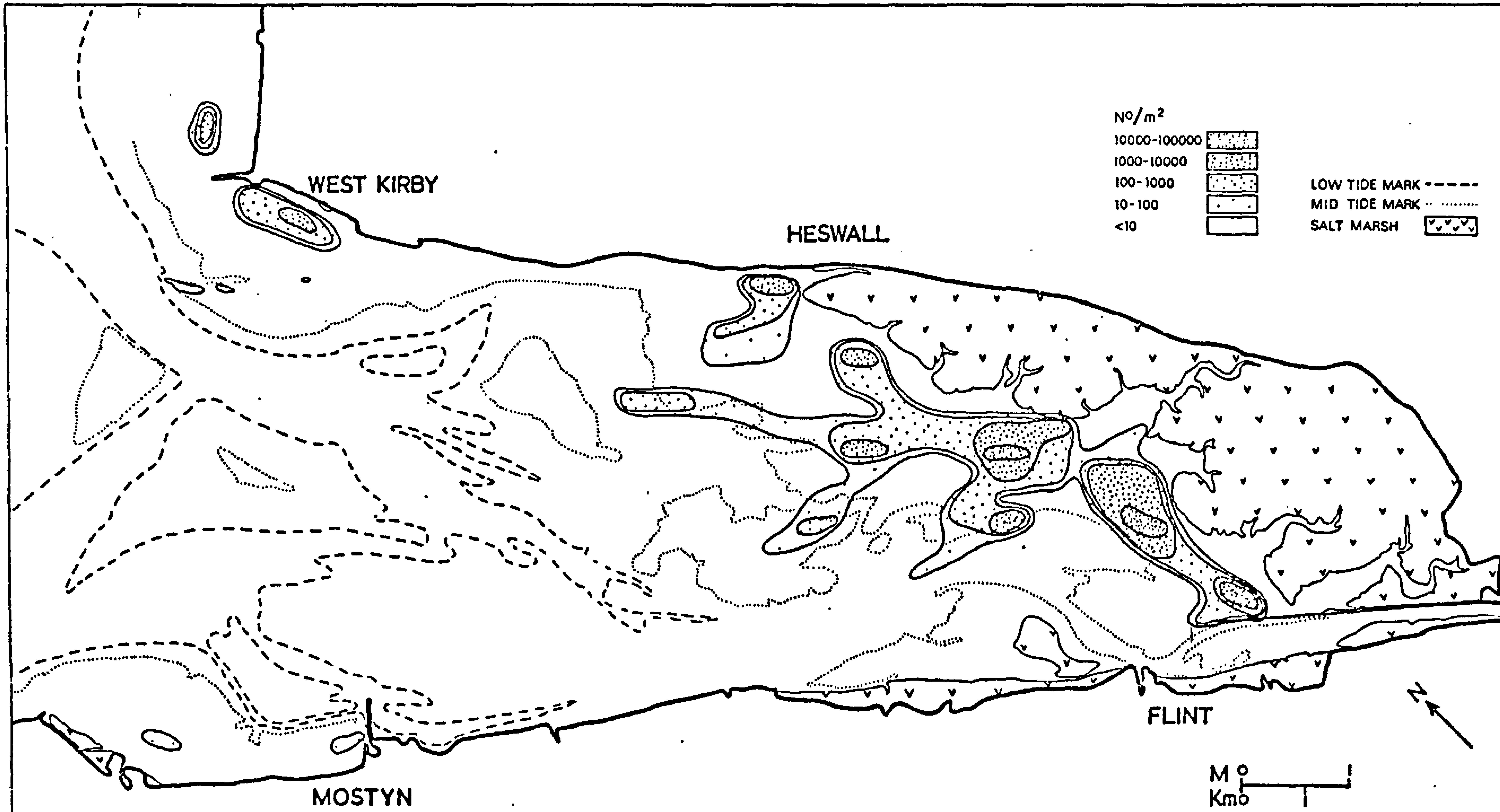
Map 107. Density distribution of Pygospio elegans in Spring 1974.



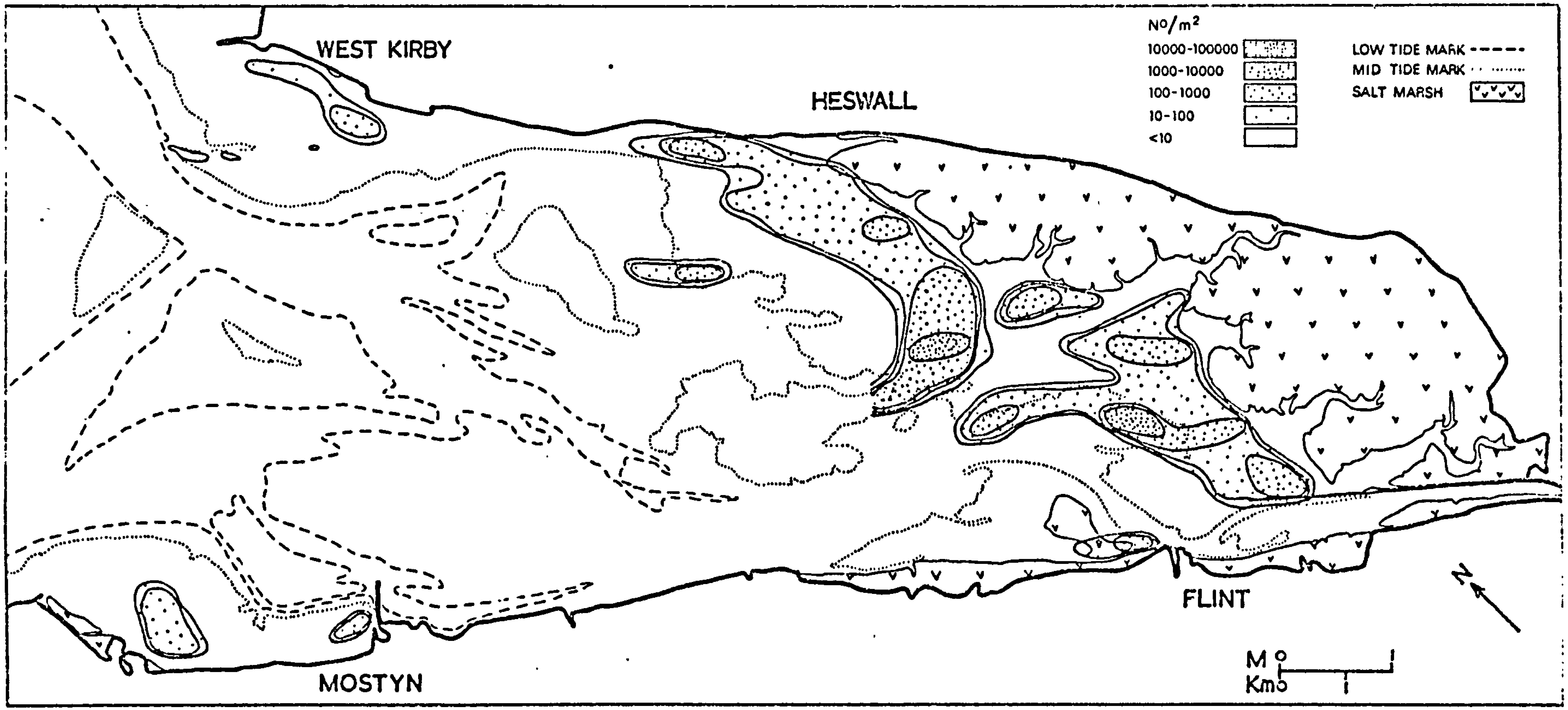
Map 108. Density distribution of Pygospio elegans in Spring 1975.



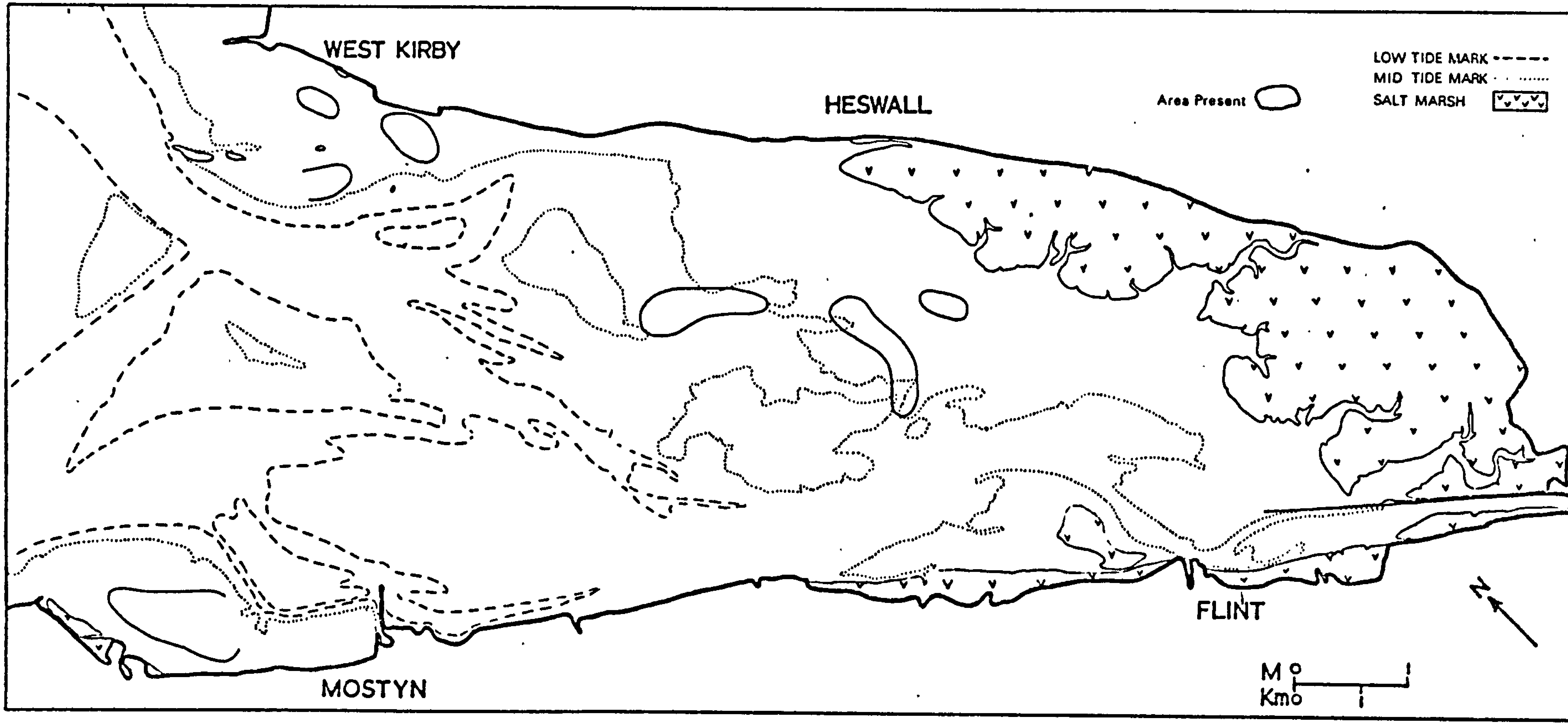
Map 109. Density distribution of Pygospio elegans in Autumn 1975.



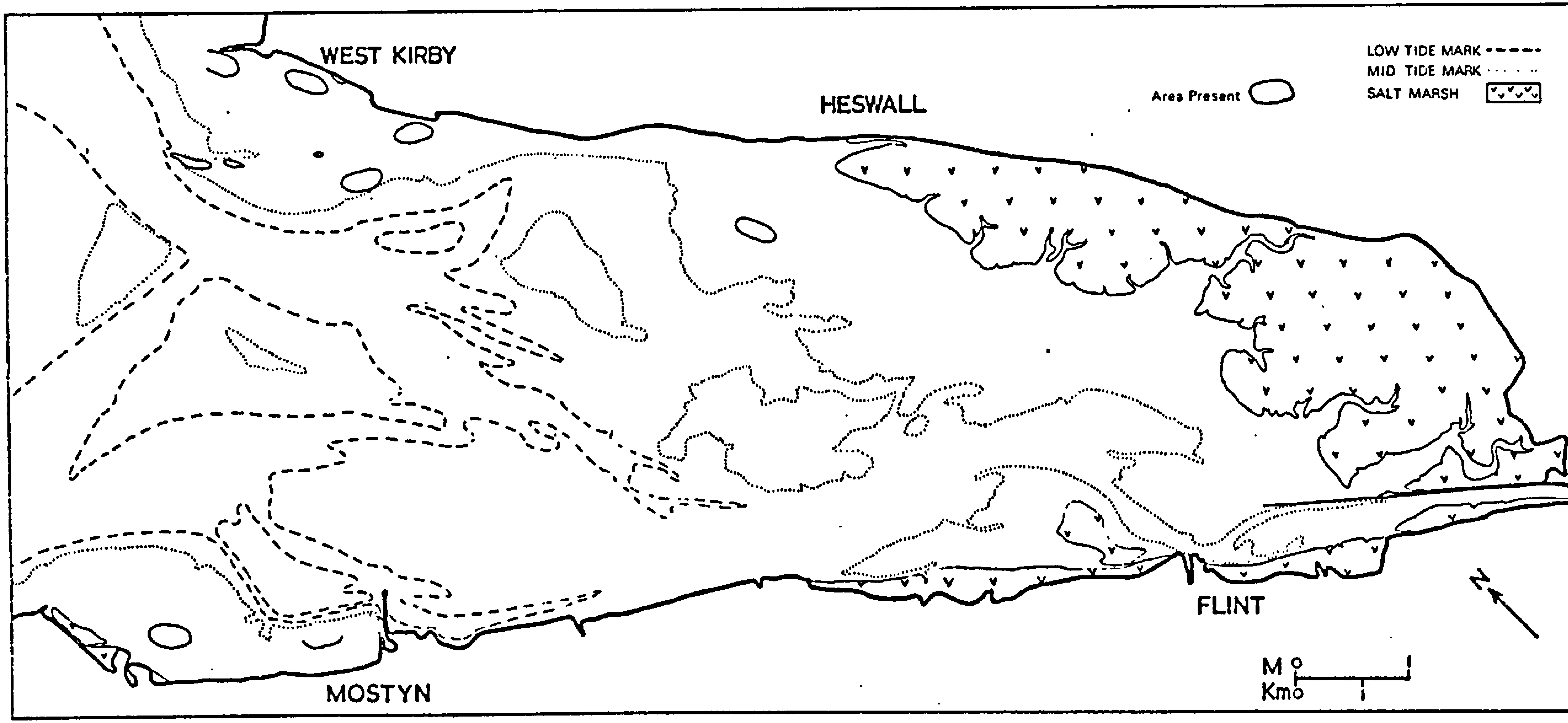
Map 110. Density distribution of Pygospio elegans in Spring 1976.



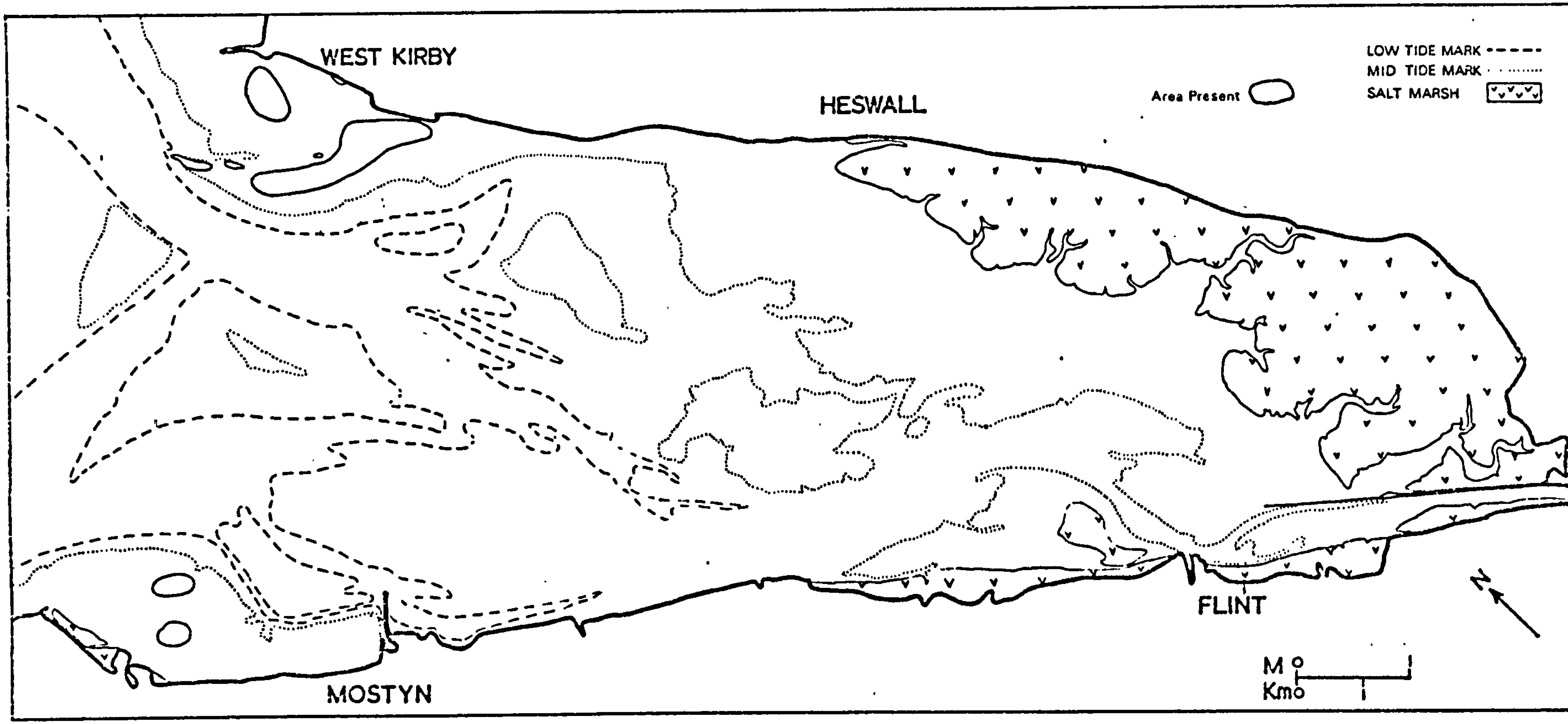
Map 111. Density distribution of <u>Pygospio elegans</u> in Autumn 1976.



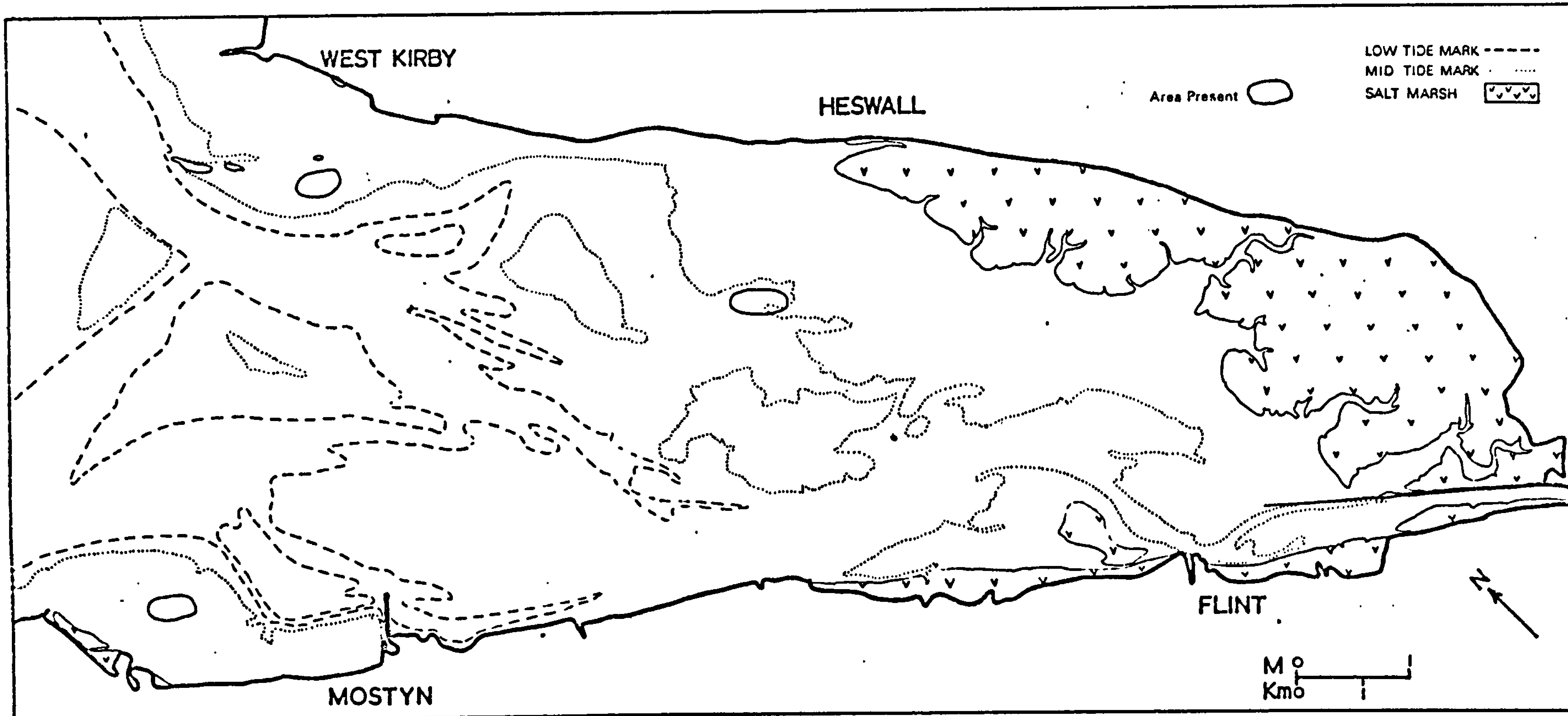
Map 112. Presence of Arenicola marina casts in Spring 1972.



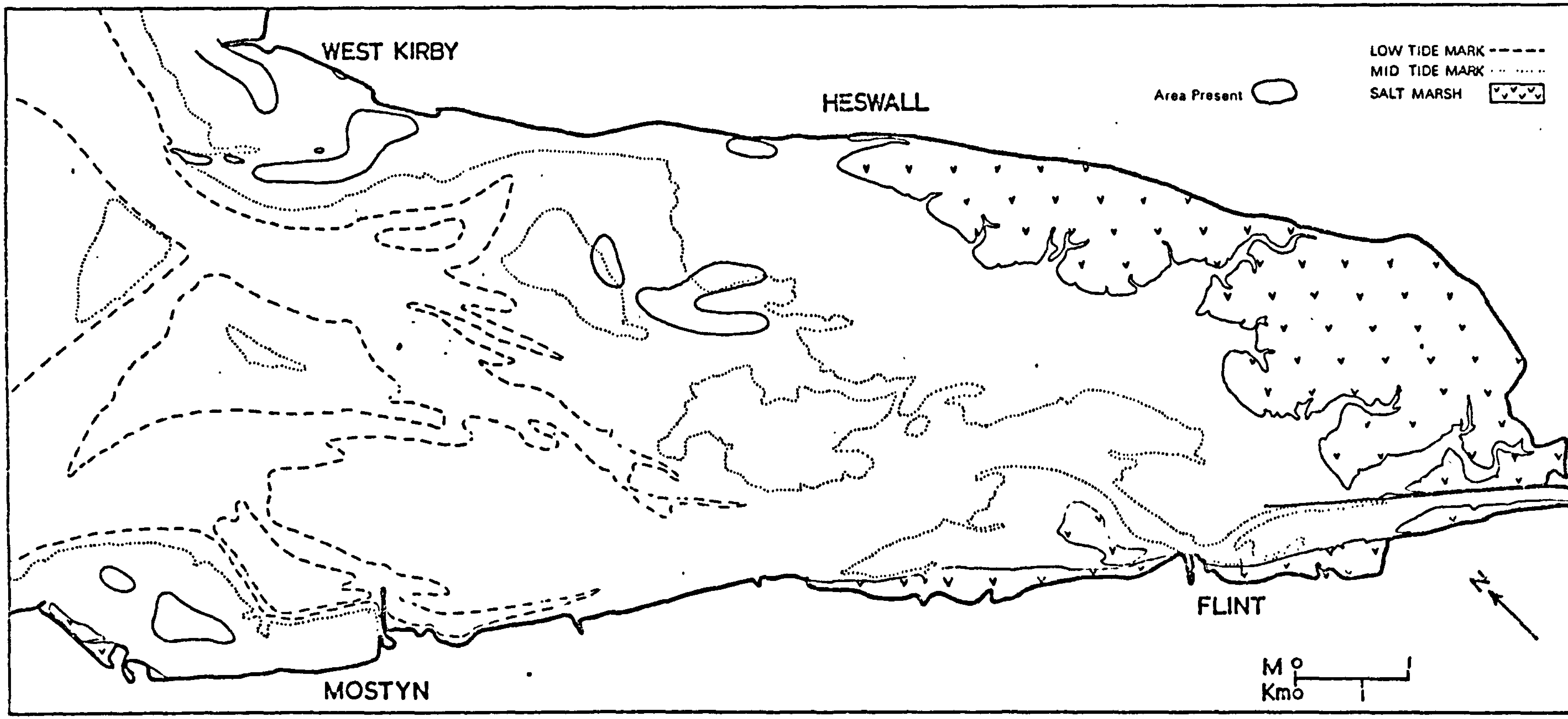
Map 113. Presence of Arenicola marina casts in Spring 1973.



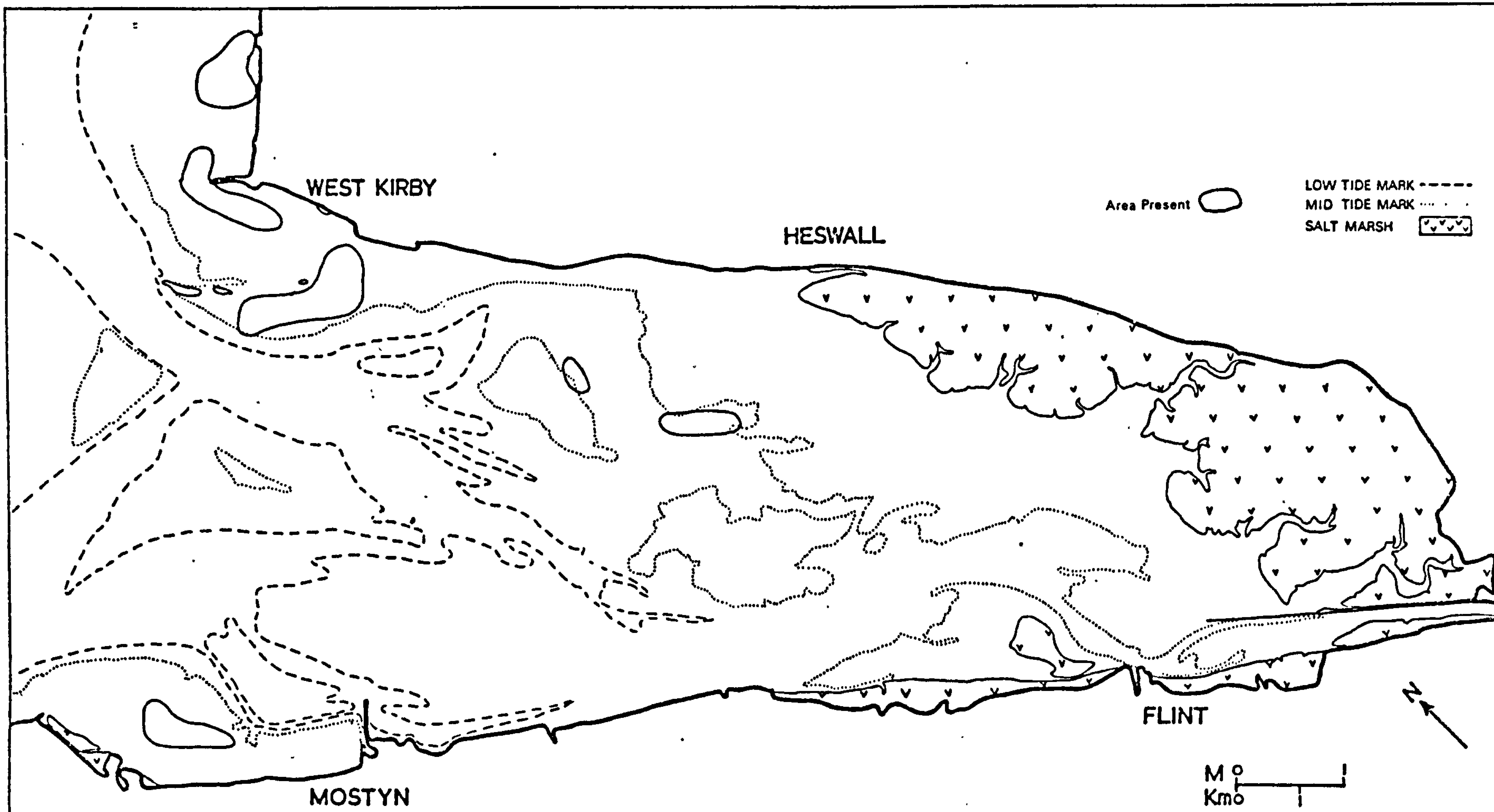
Map 114. Presence of Arenicola marina casts in Spring 1974.



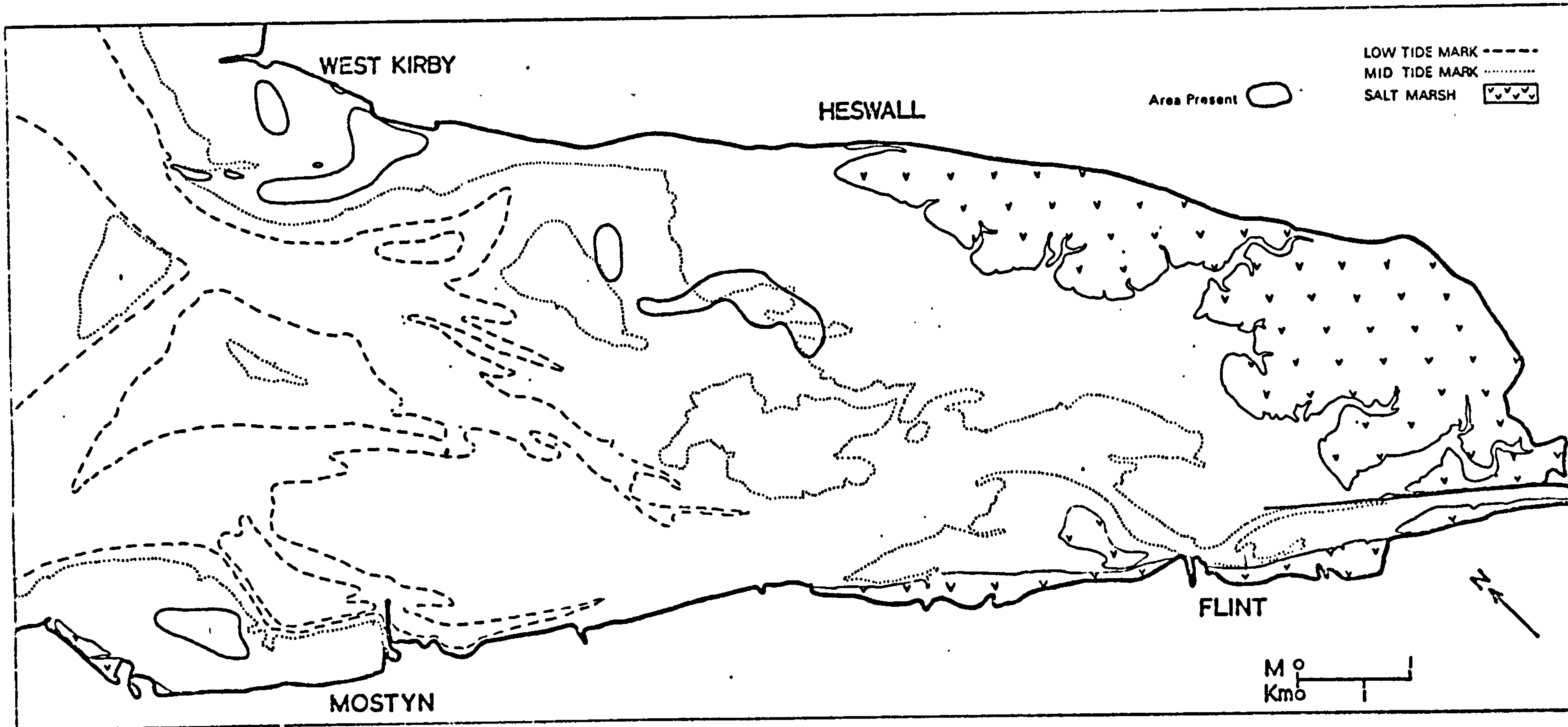
Map 115. Presence of Arenicola marina casts in Spring 1975.



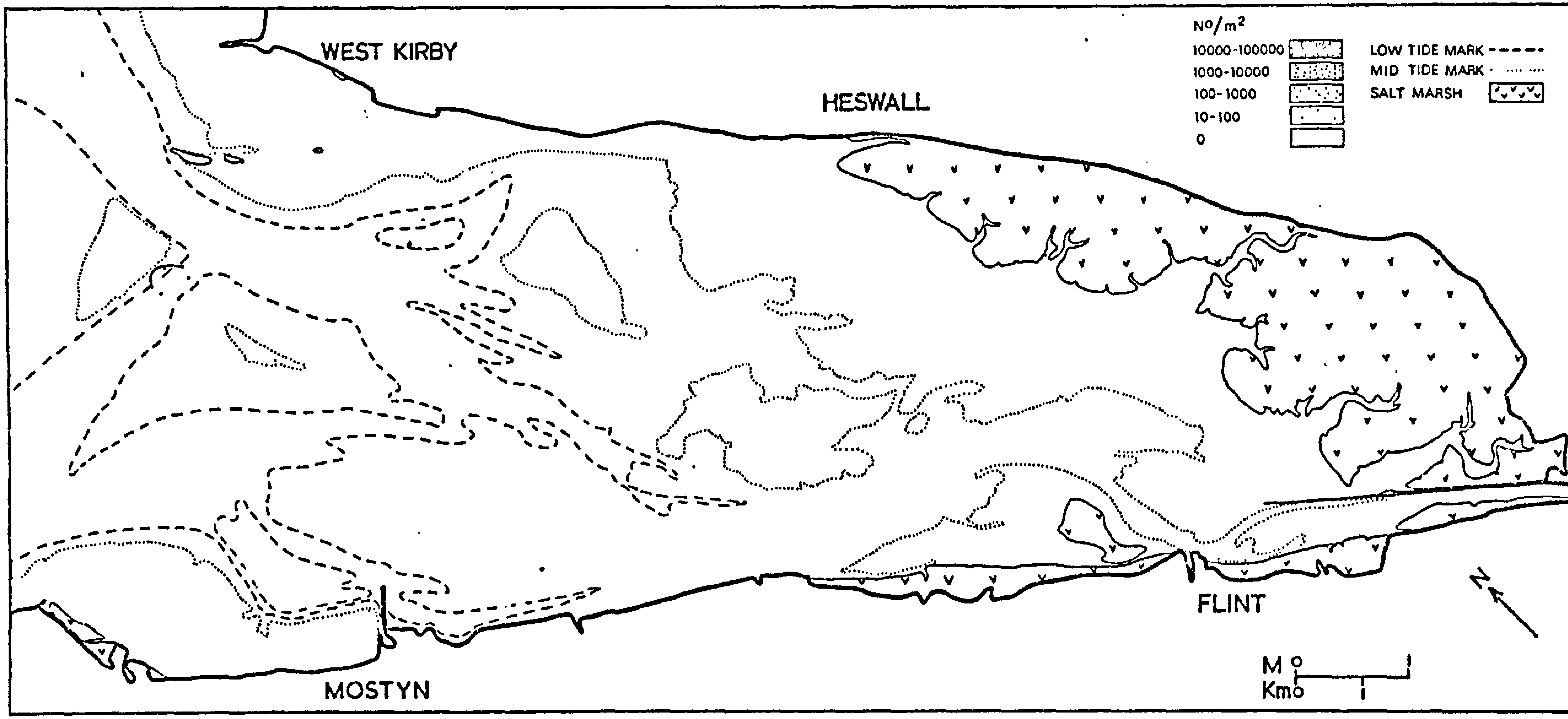
Map 116. Presence of <u>Arenicola marina</u> casts in Autumn 1975.



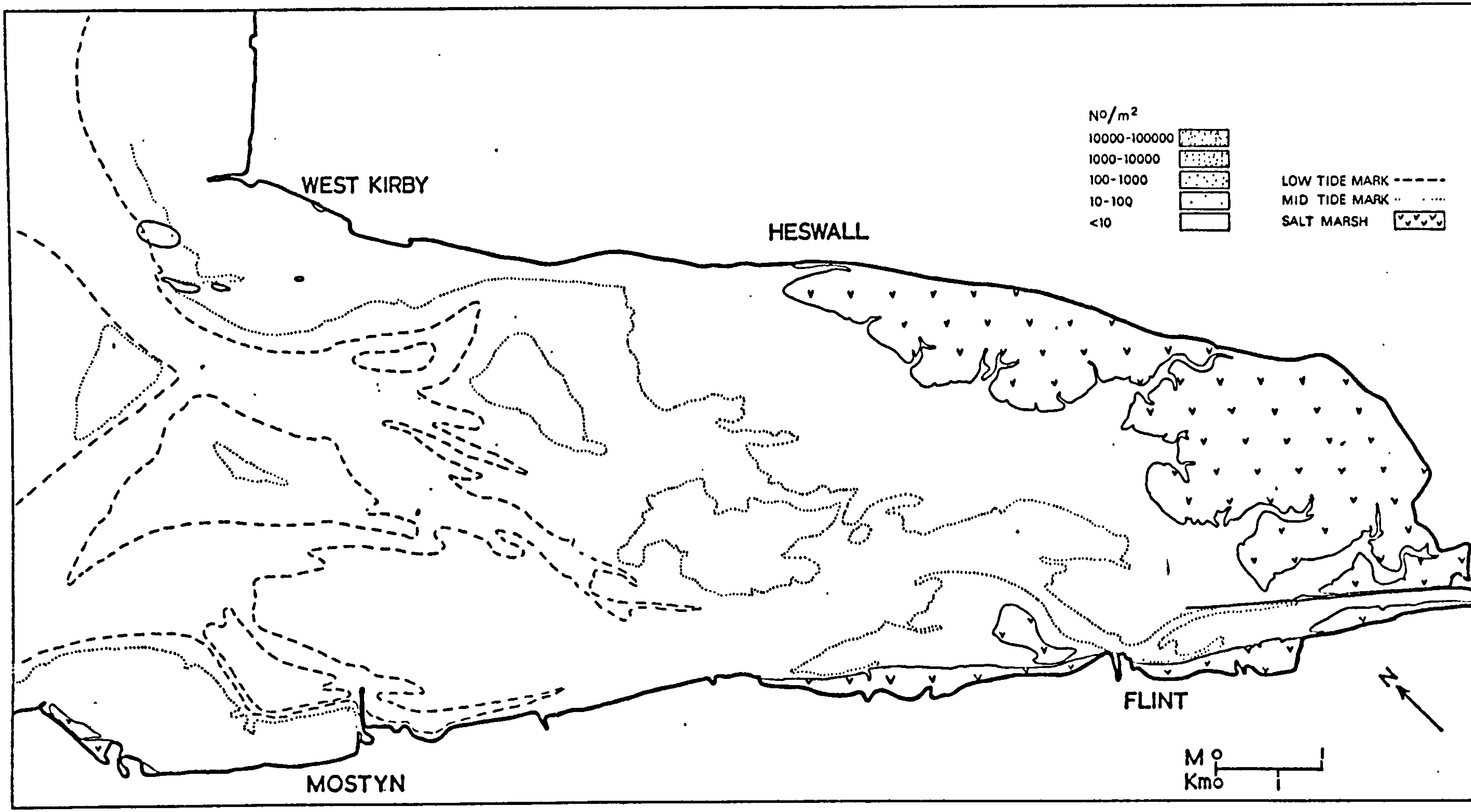
Map 117. Presence of <u>Arenicola marina</u> casts in Spring 1976.



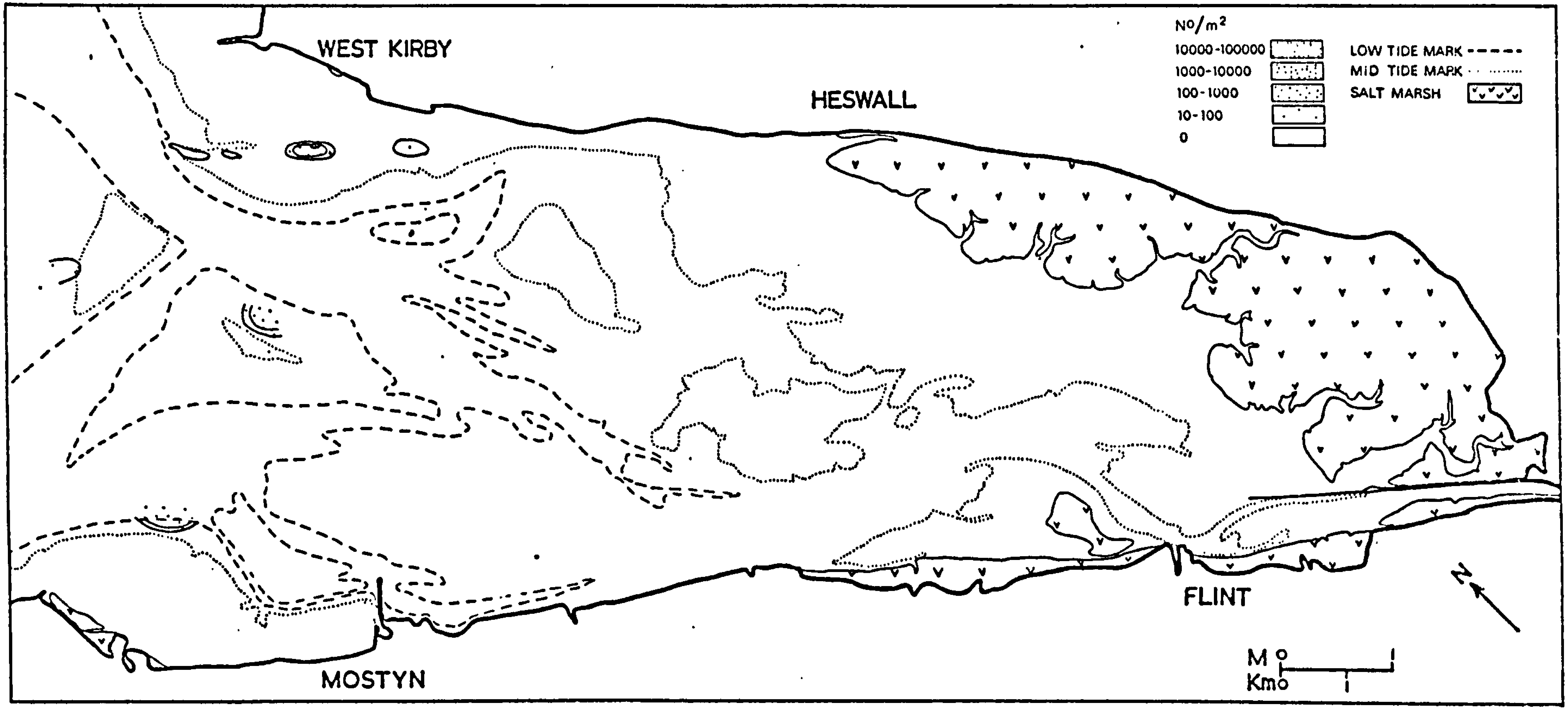
Map 118. Presence of <u>Arenicola marina</u> casts in Autumn 1976.



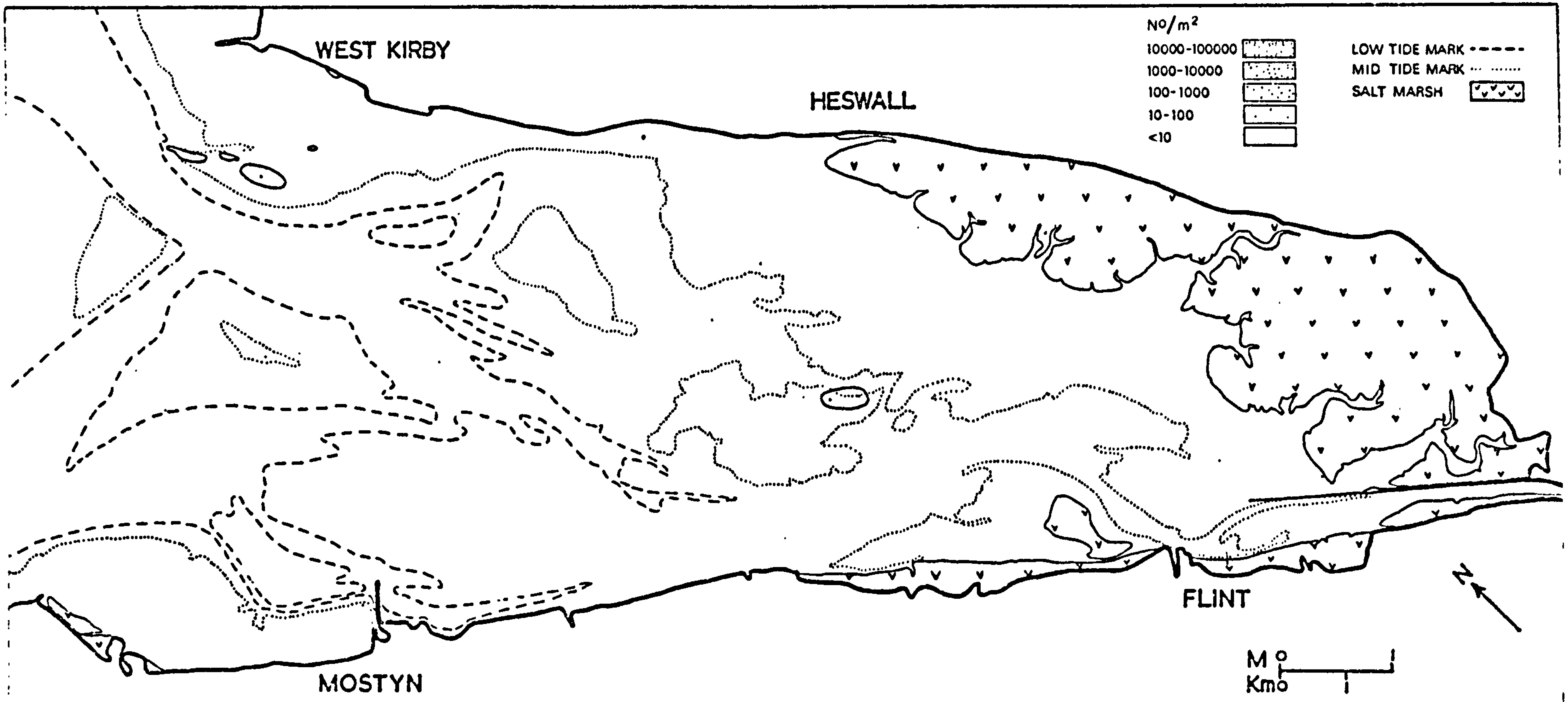
Map 119. **Density distribution of Pectinaria koreni in Autumn 1971.**



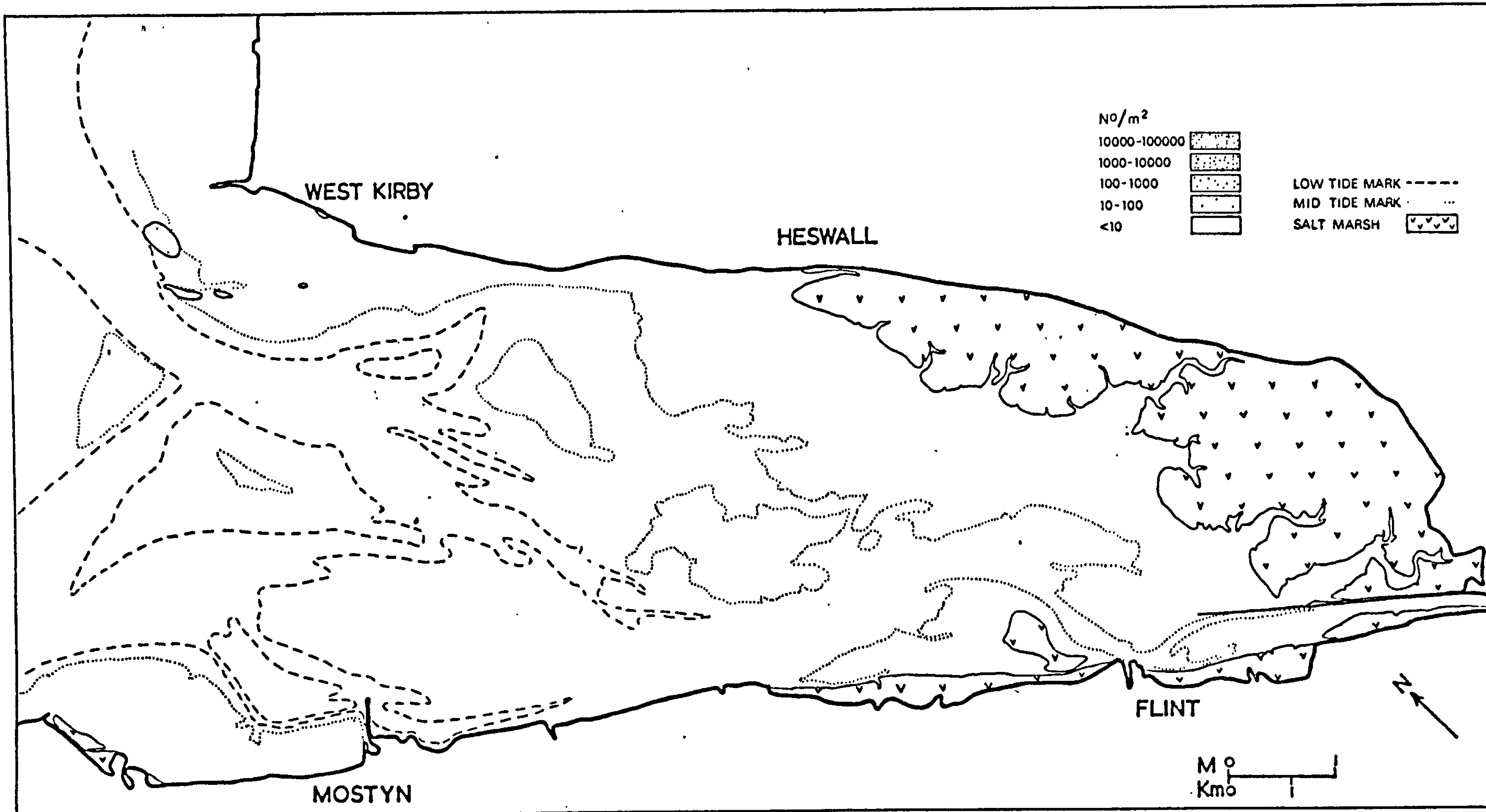
Map 120. Density distribution of Pectinaria koreni in Spring 1976.



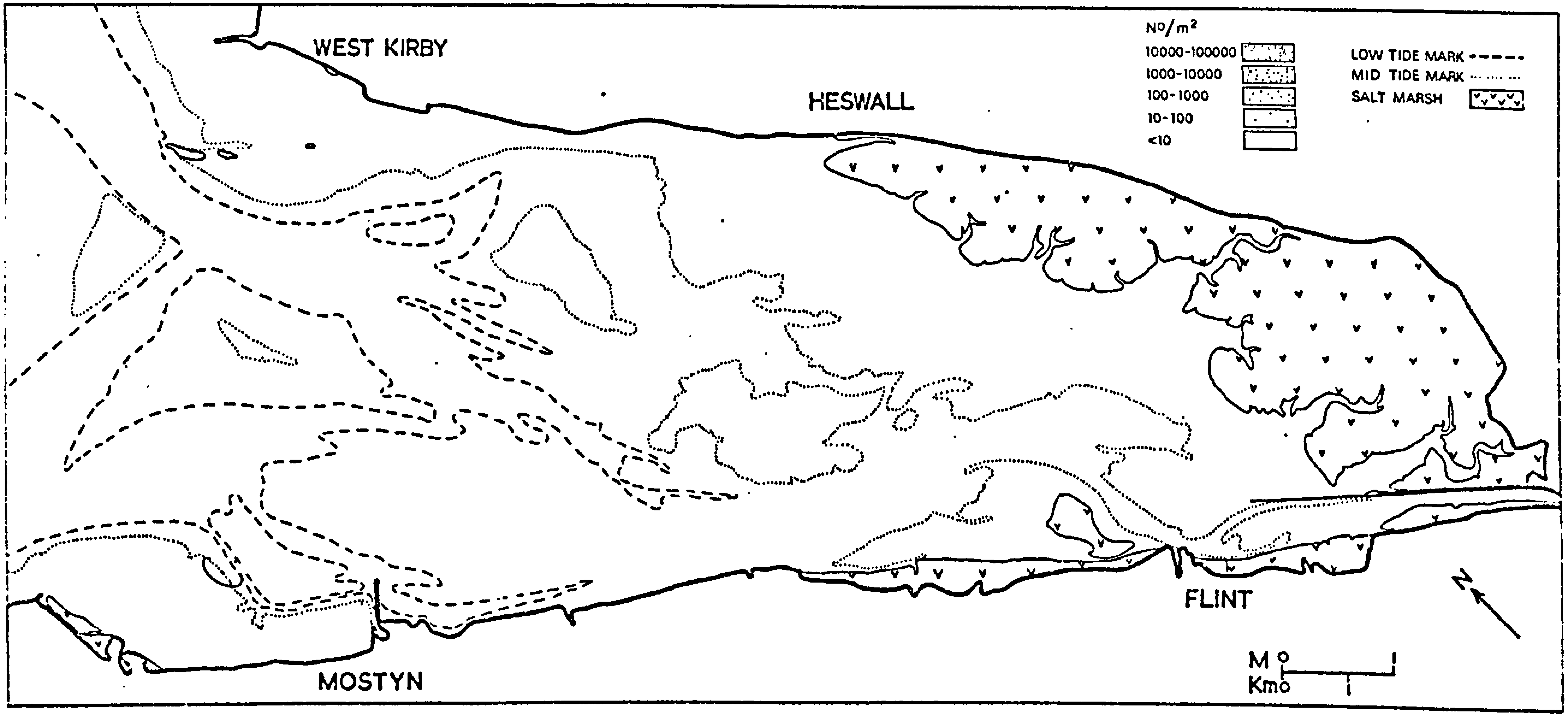
Map 121. Density distribution of Lanice conchilega in Autumn 1971.



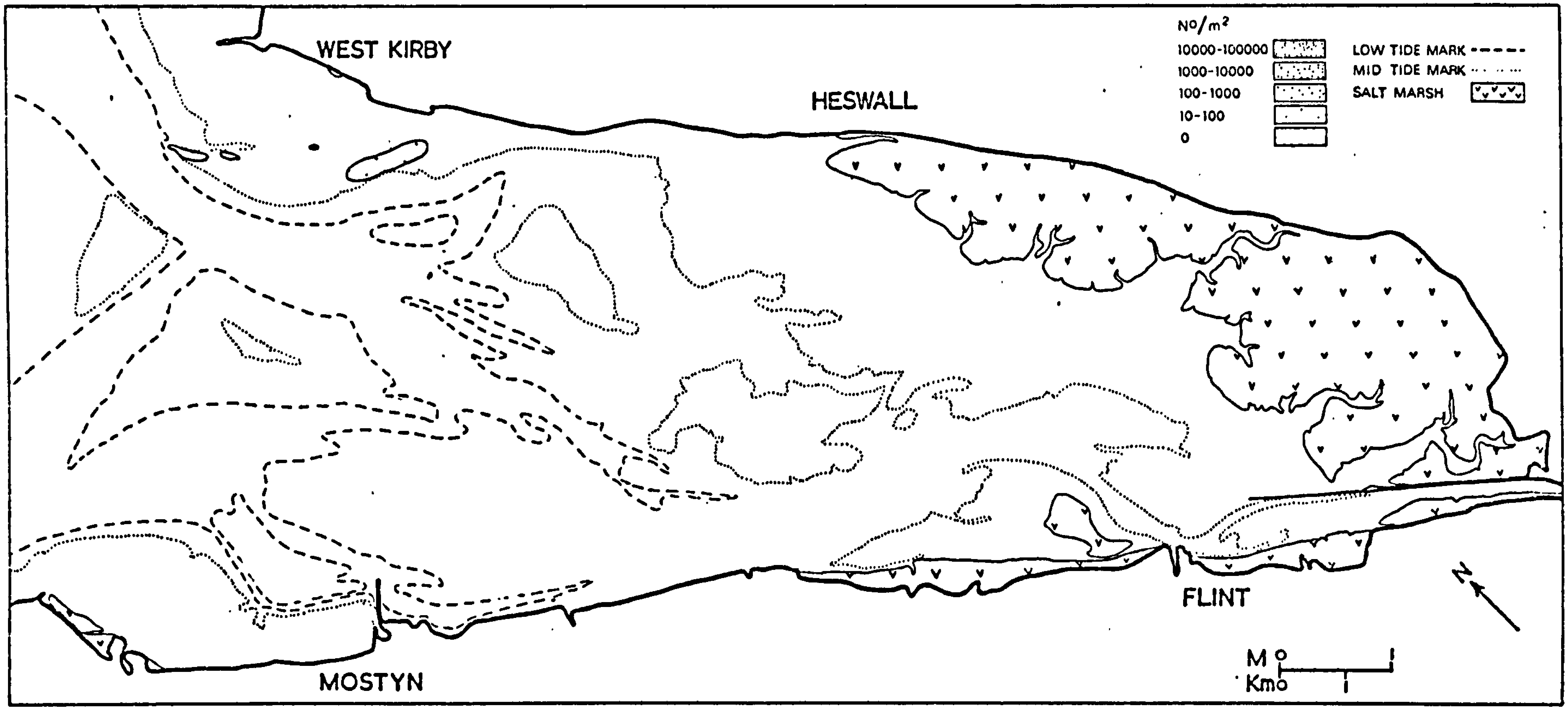
Map 122. Density distribution of Lanice conchilega in Autumn 1975.



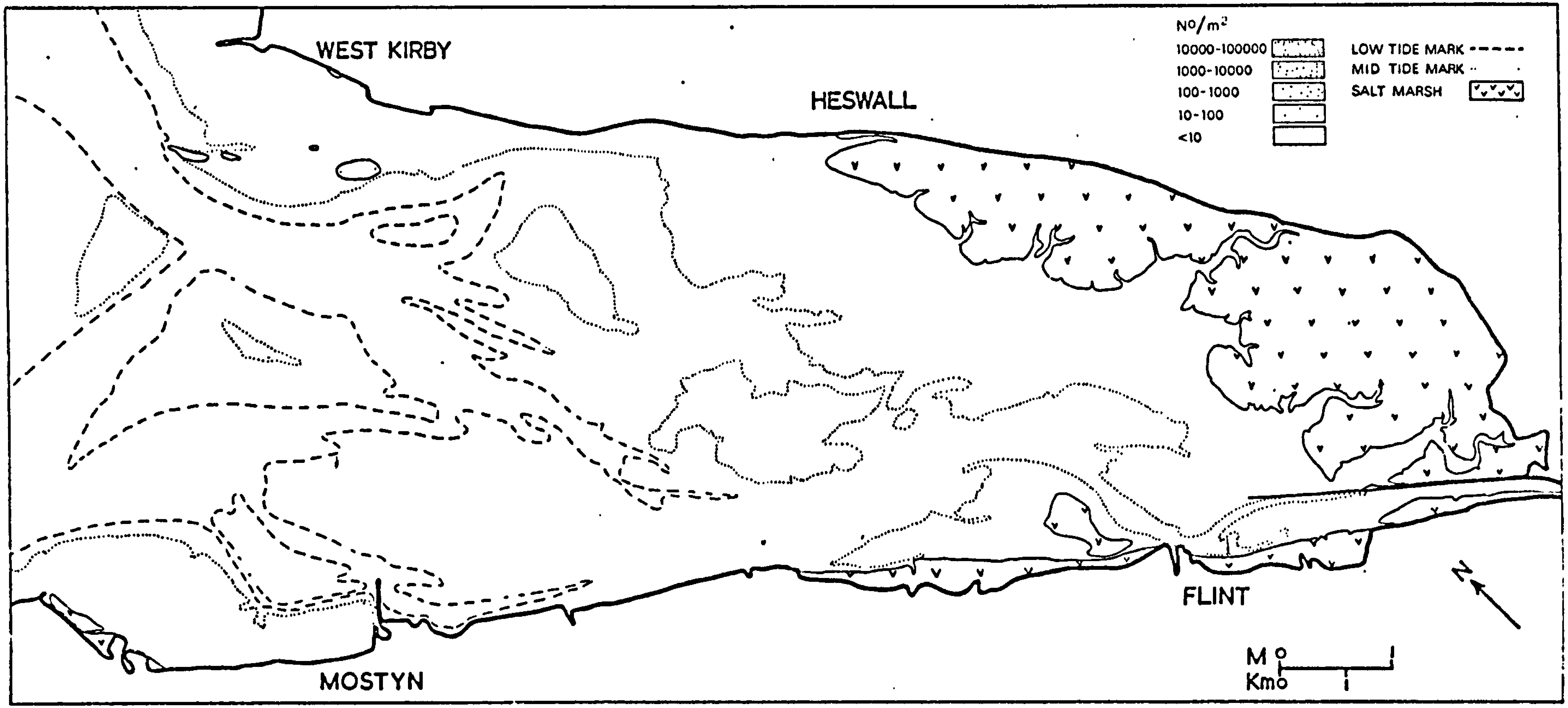
Map 123. Density distribution of Lanice conchilega in Spring 1976.



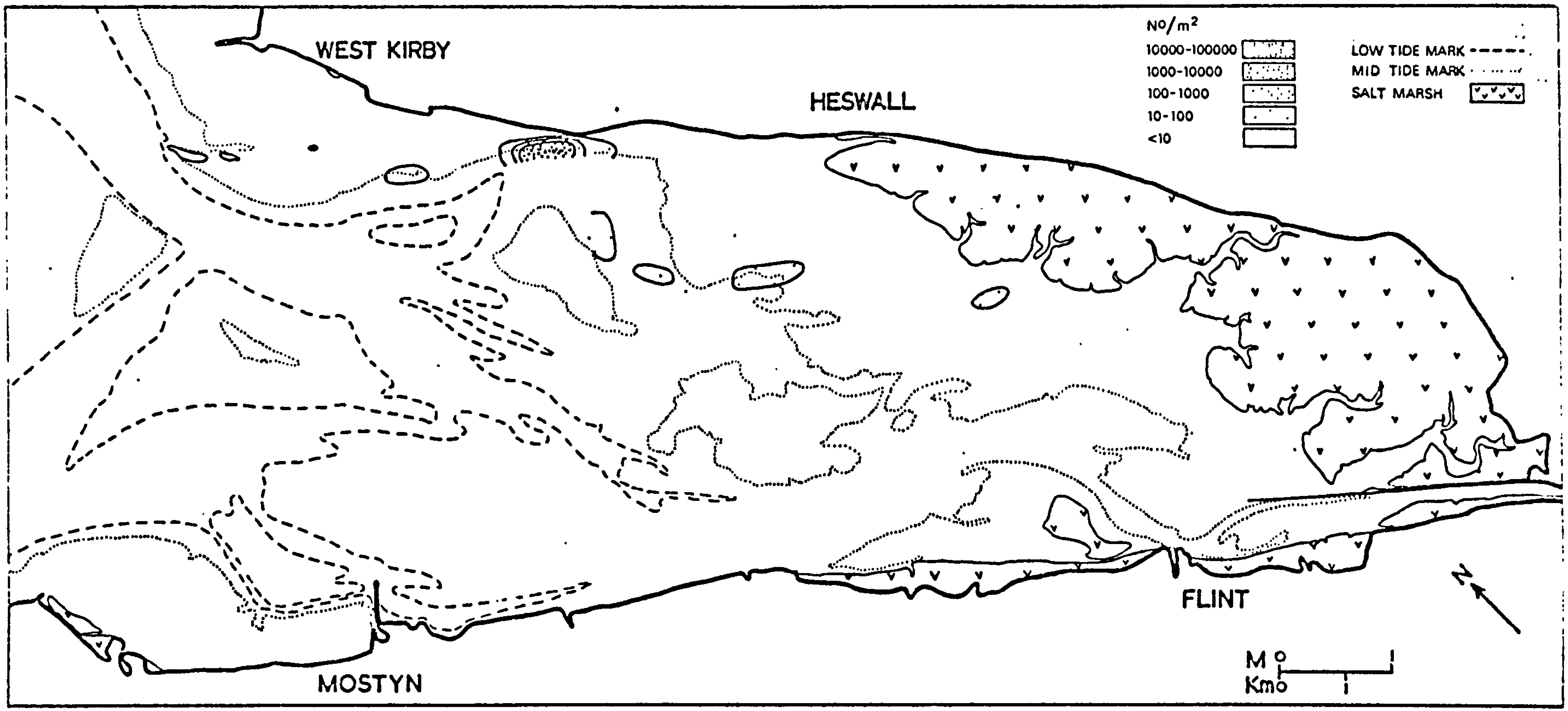
Map 124. Density distribution of Lanice conchilega in Autumn 1976.



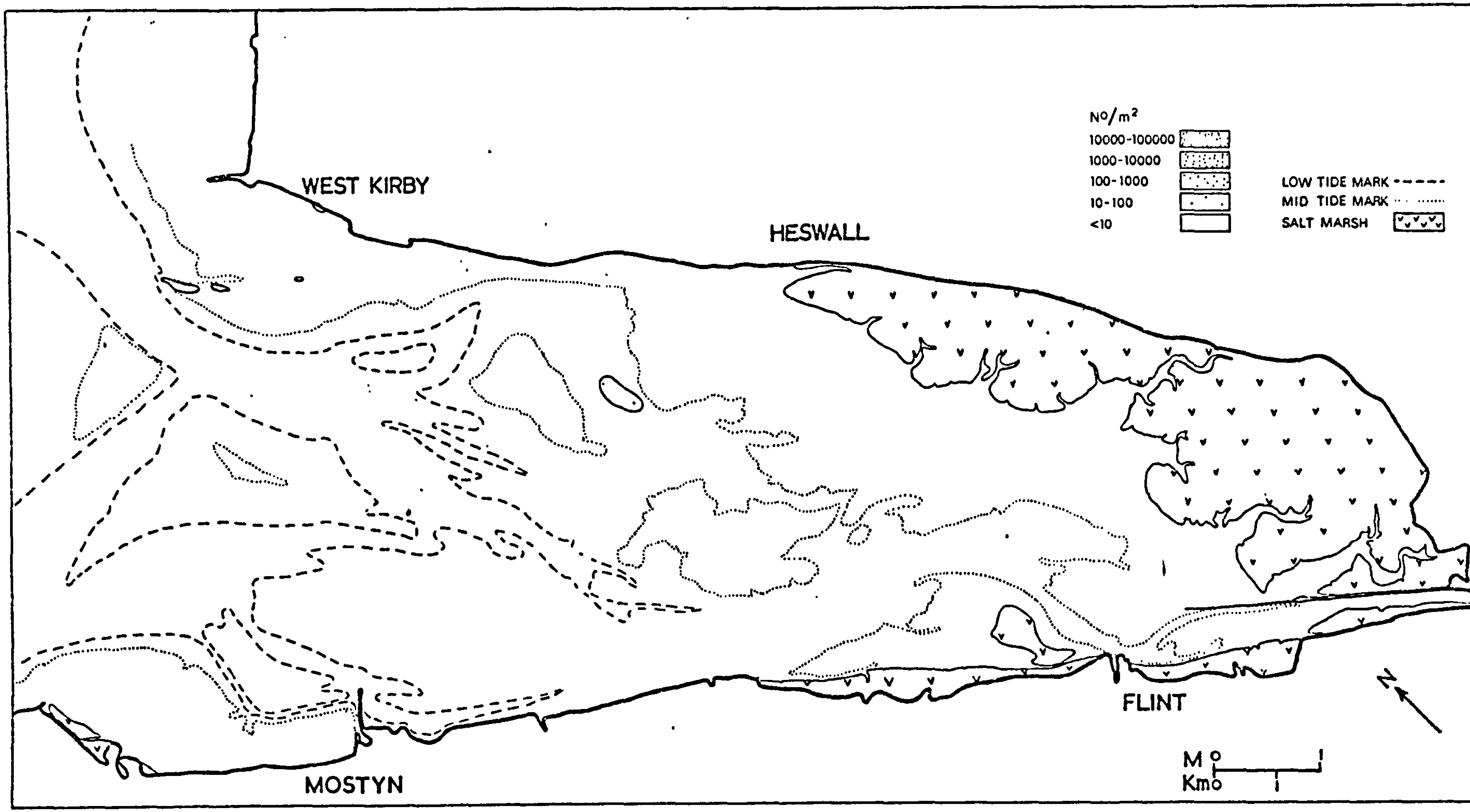
Map 125. Density distribution of *Mytilus edulis* in Autumn 1971.



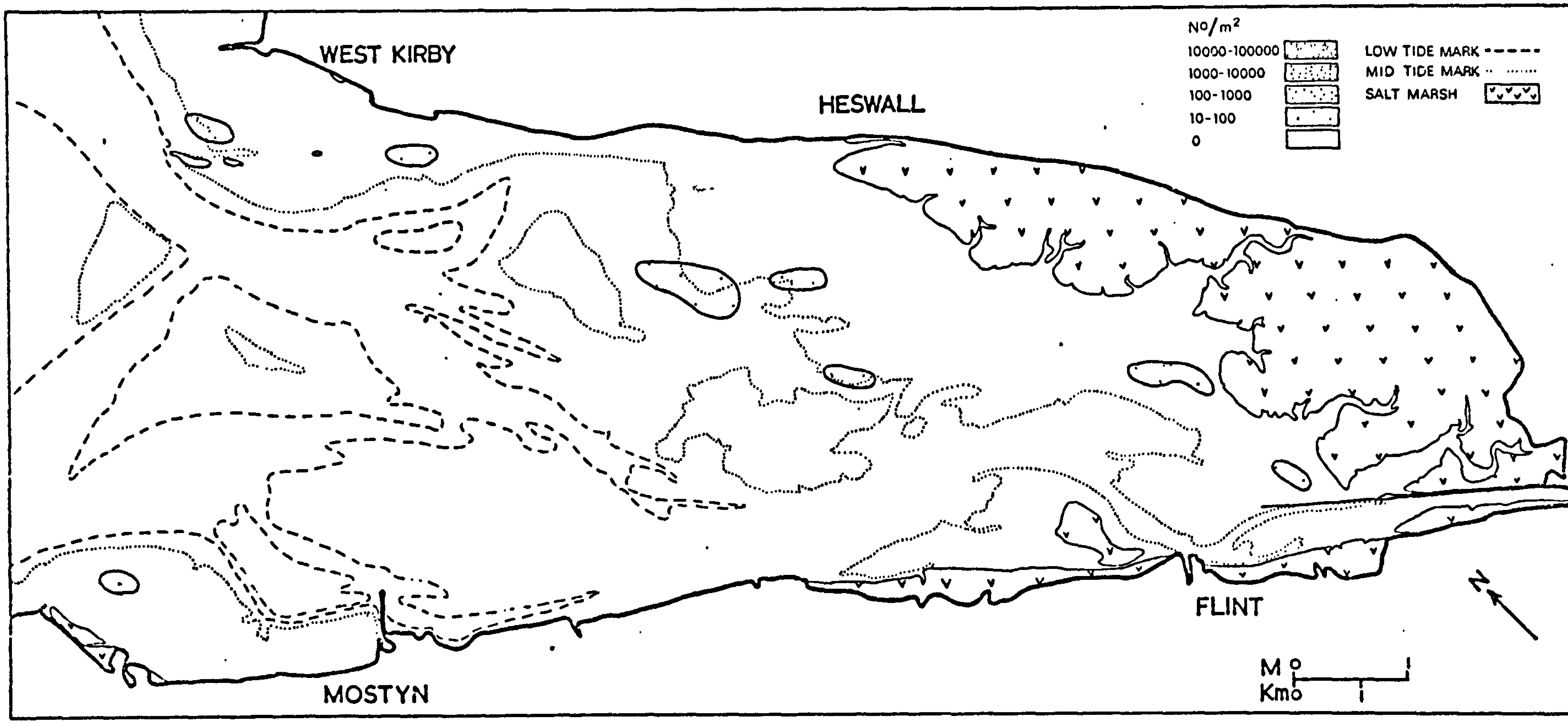
Map 126. **Density distribution of <u>Mytilus edulis</u> in Spring 1975.**



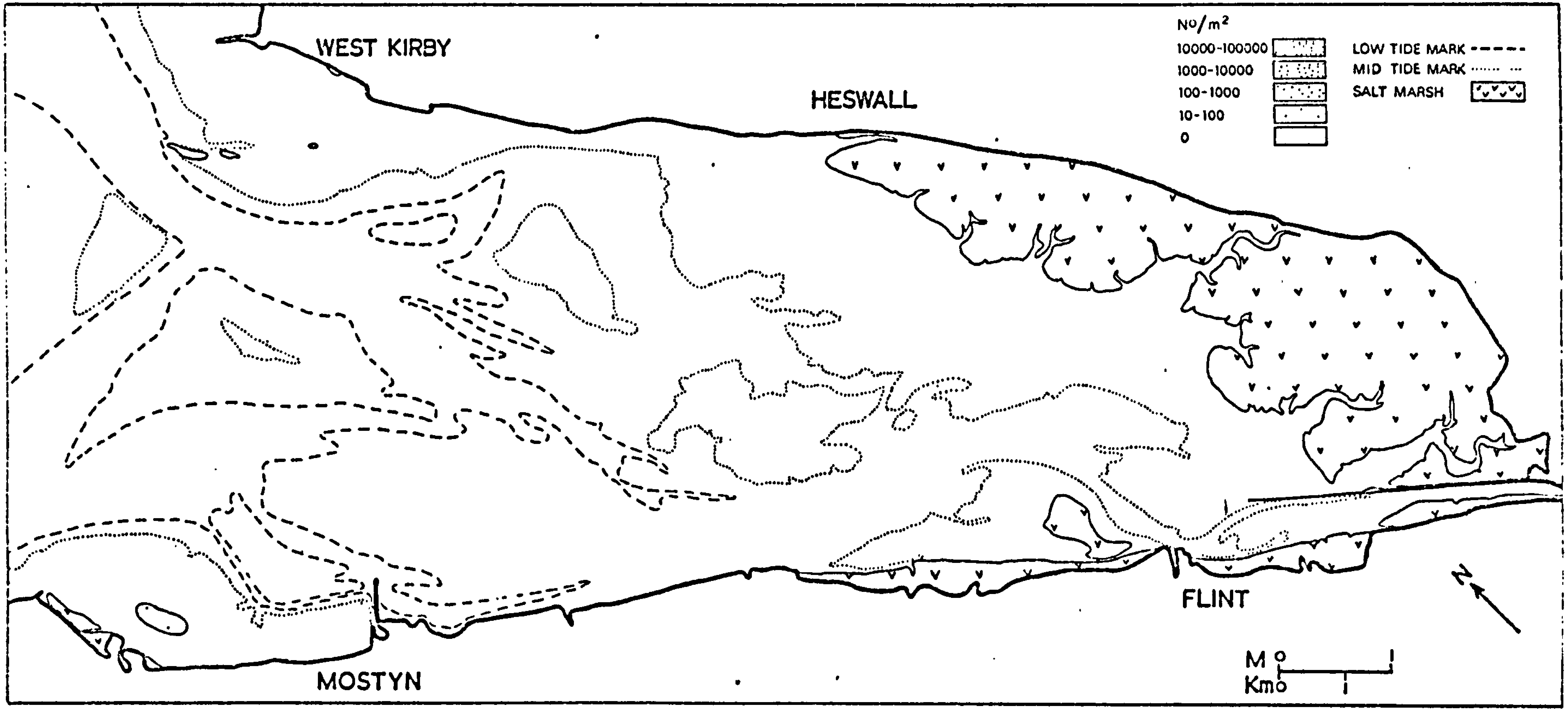
Map 127. Density distribution of Mytilus edulis in Autumn 1975.



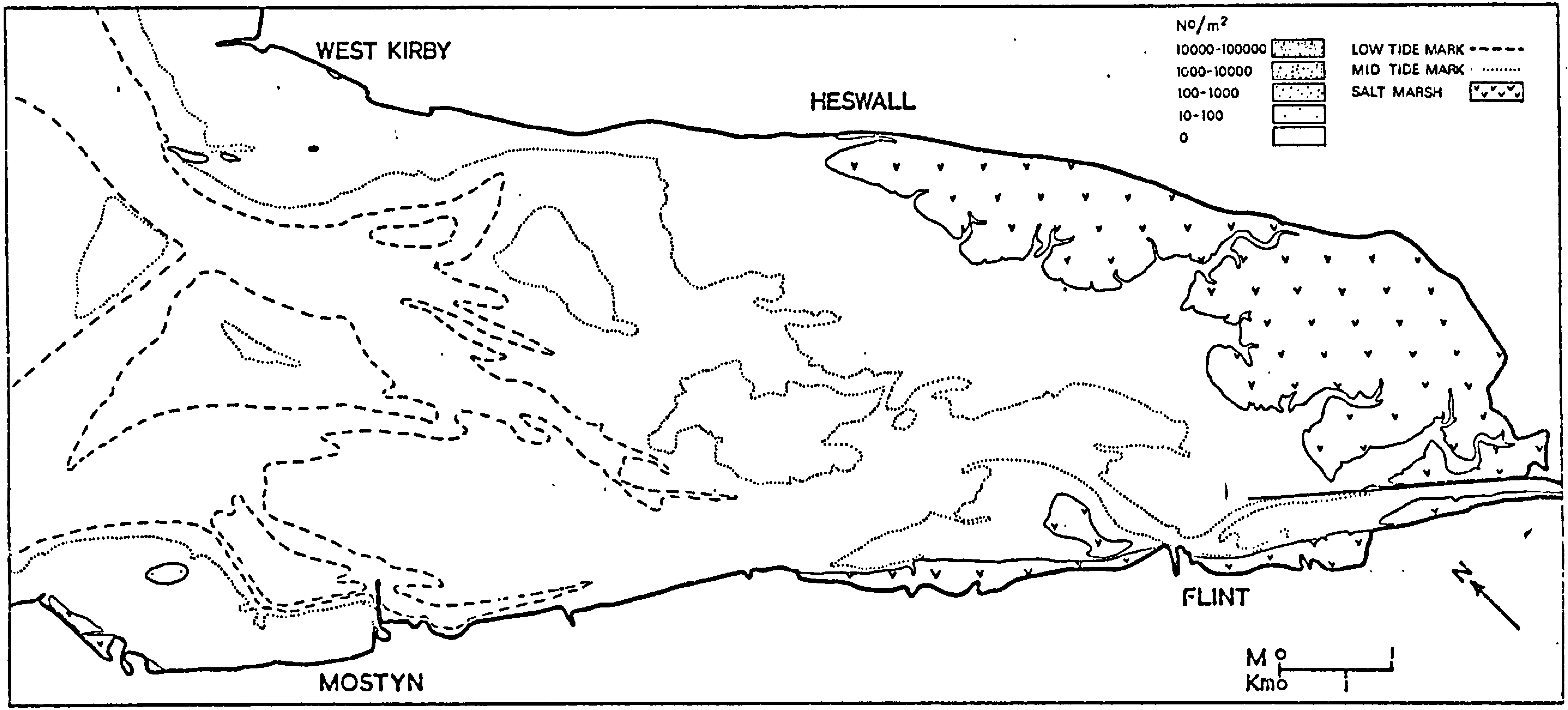
Map 128. Density distribution of Mytilus edulis in Spring 1976.



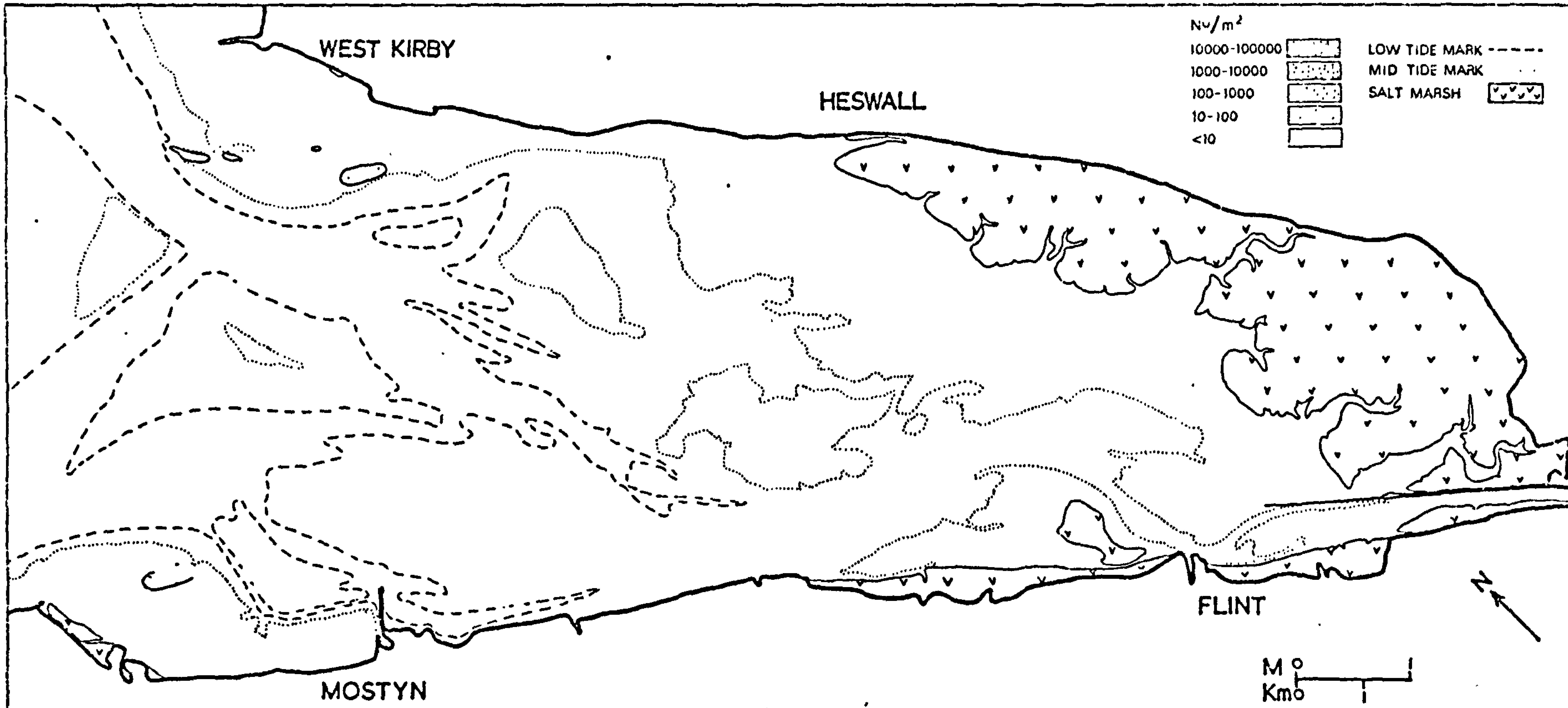
Map 129. Density distribution of Cerastoderma edule in Autumn 1971.



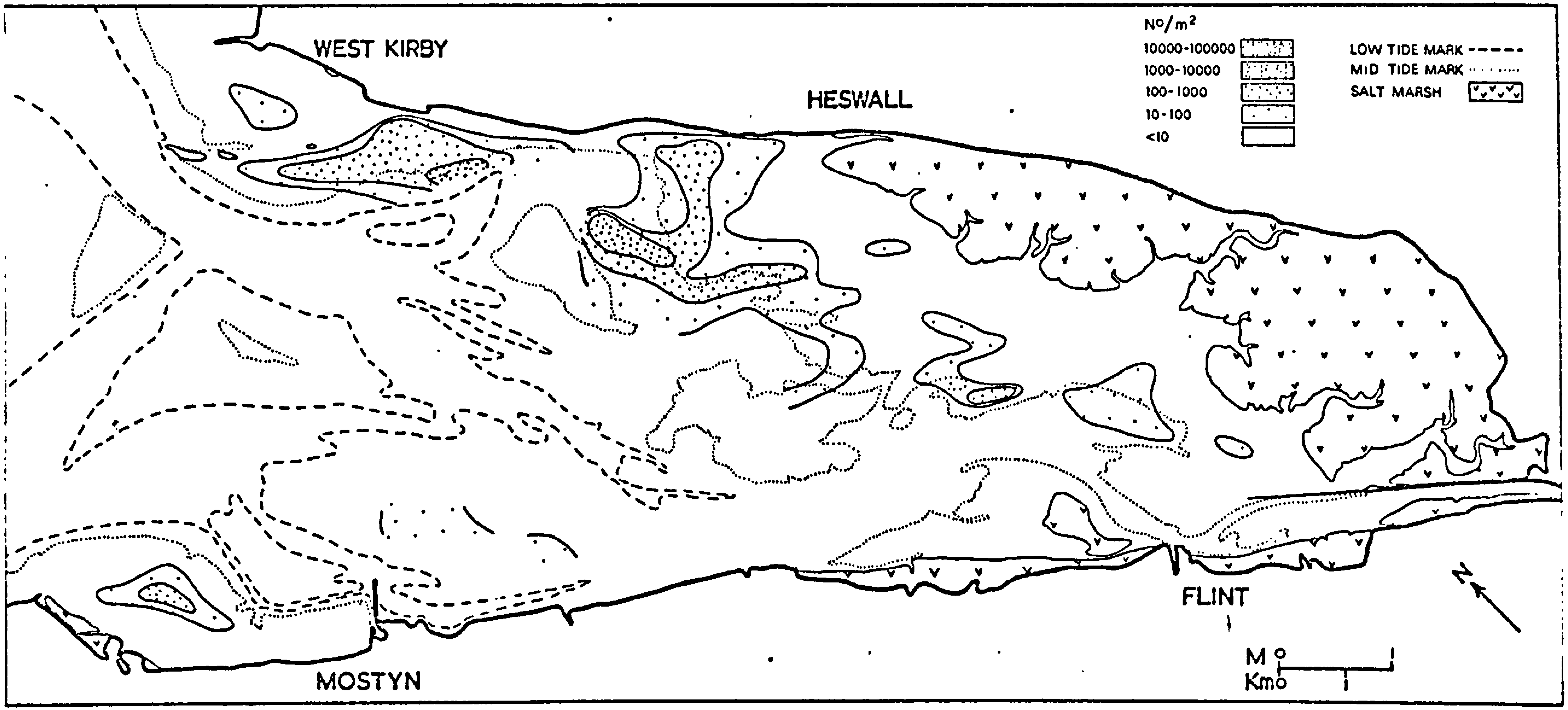
Map 130. Density distribution of <u>Cerastoderma edule</u> in Spring 1972.



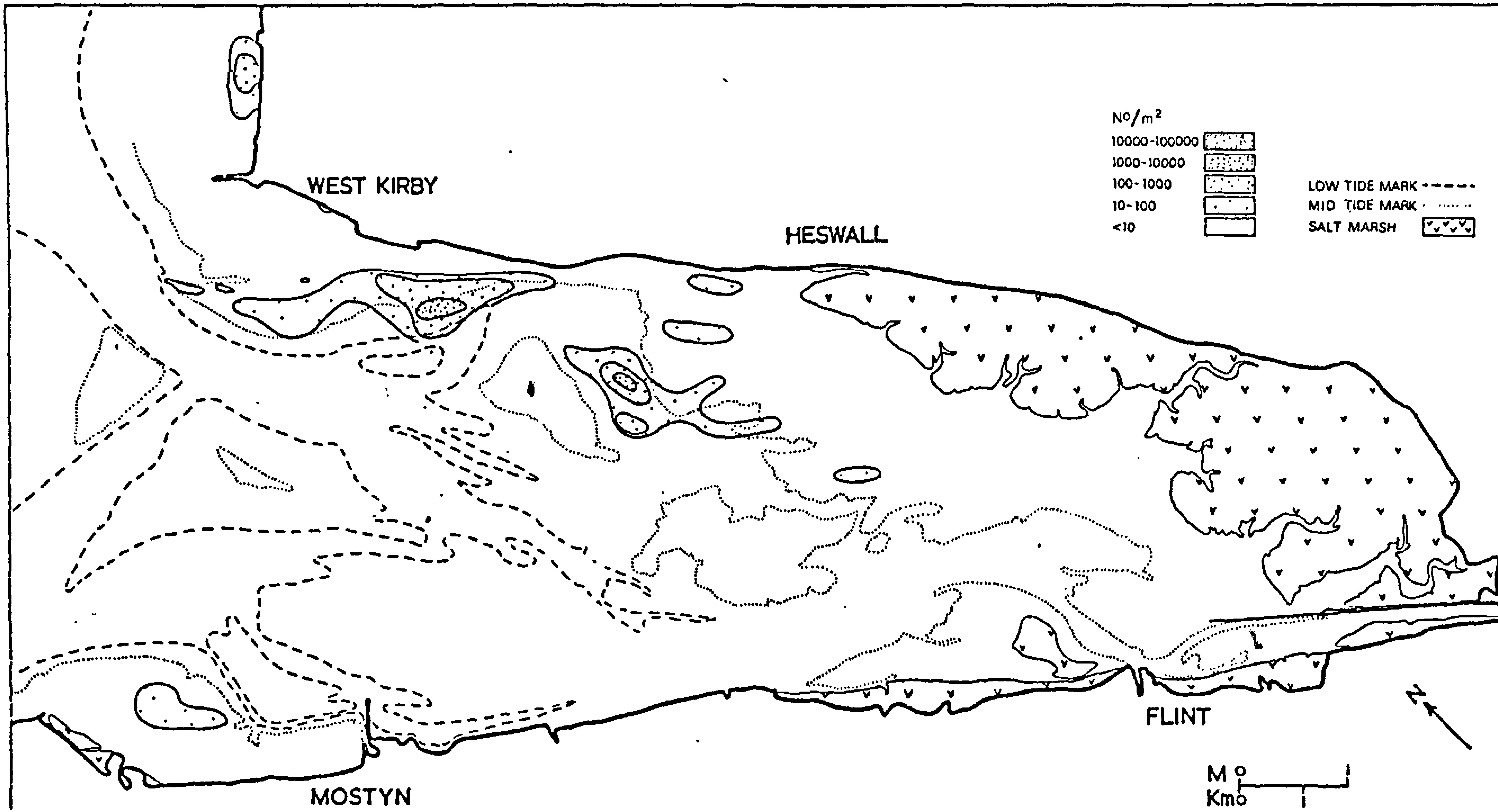
Map 131. Density distribution of <u>Cerastoderma edule</u> in Spring 1973.



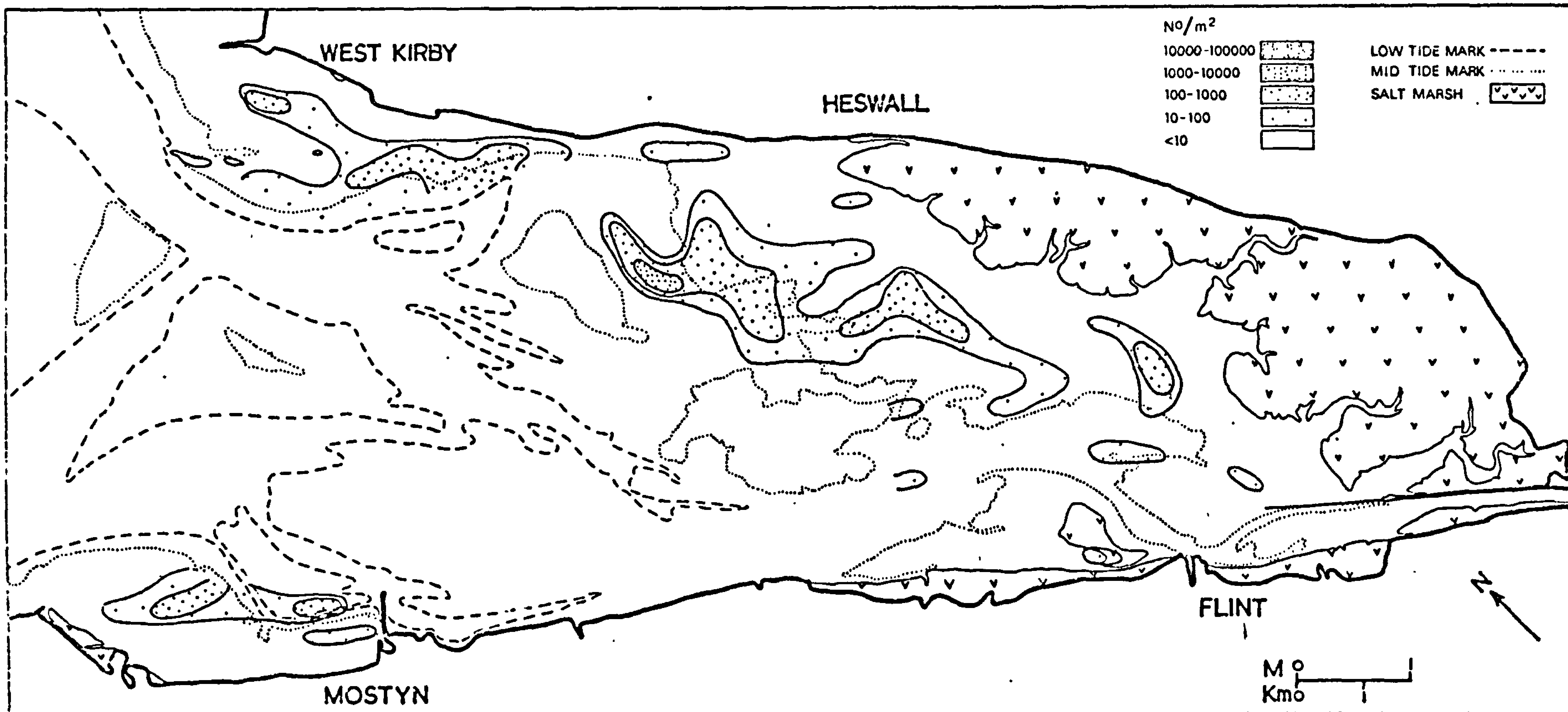
Map 132. Density distribution of <u>Cerastoderma edule</u> in Spring 1975.



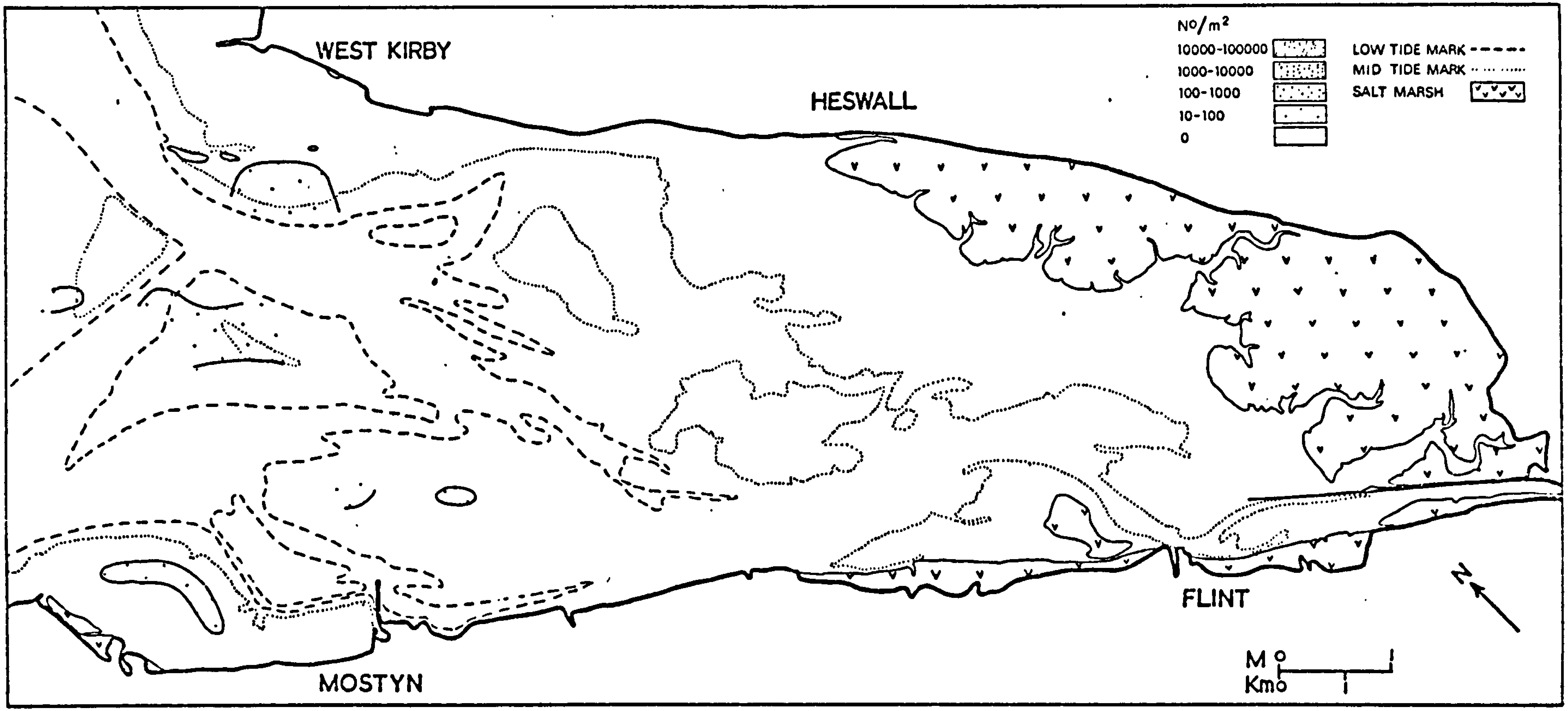
Map 133. Density distribution of Cerastoderma edule in Autumn 1975.



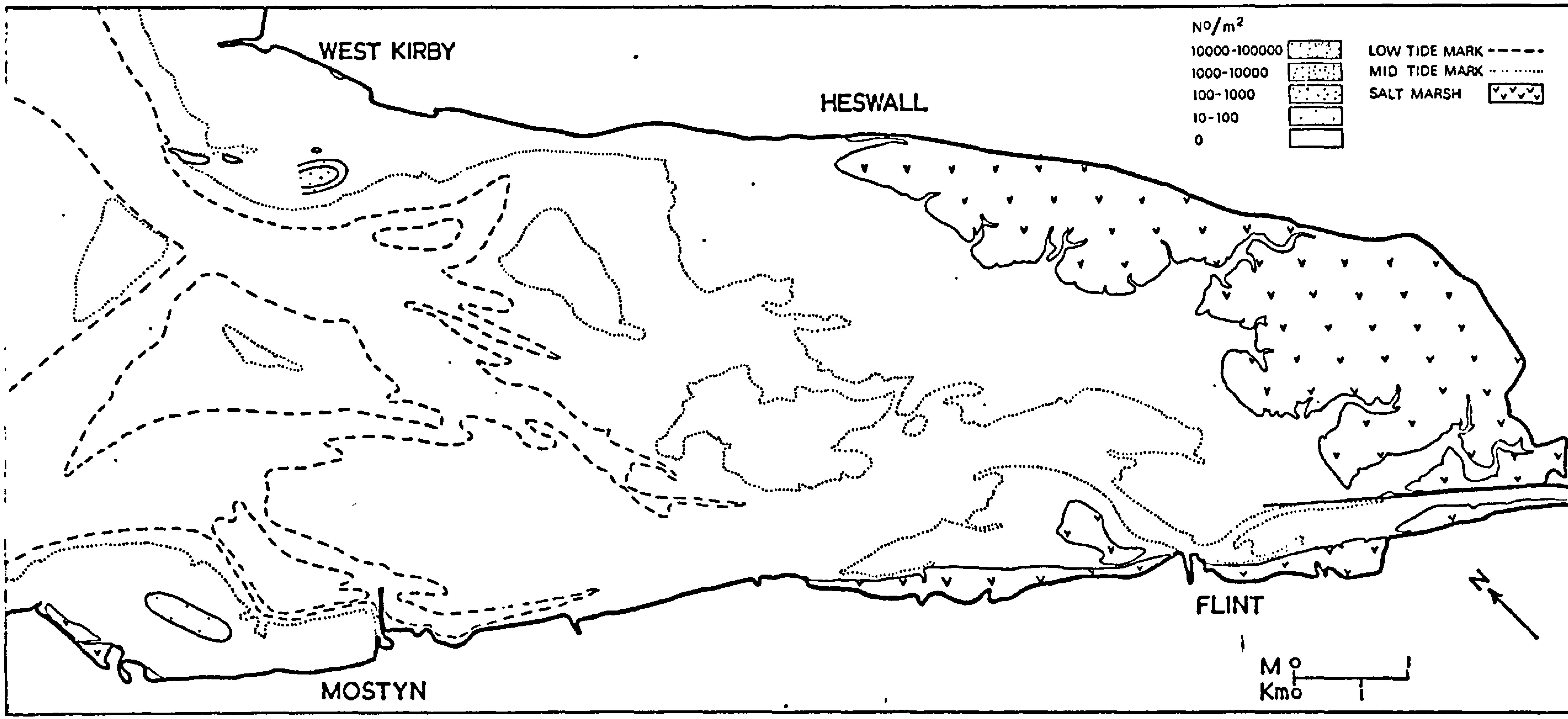
Map 134. Density distribution of Cerastoderma edule in Spring 1976.



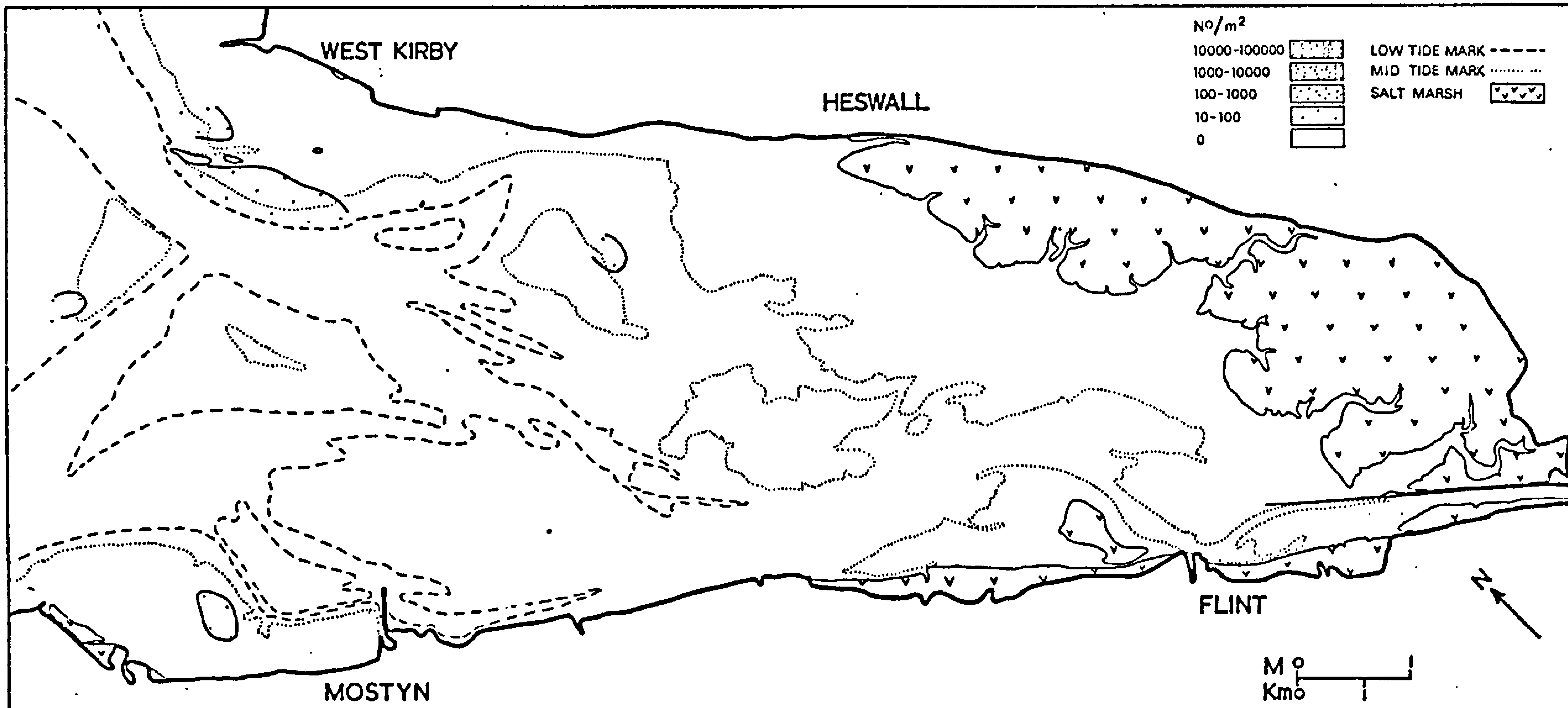
Map 135. Density distribution of Cerastoderma edule in Autumn 1976.



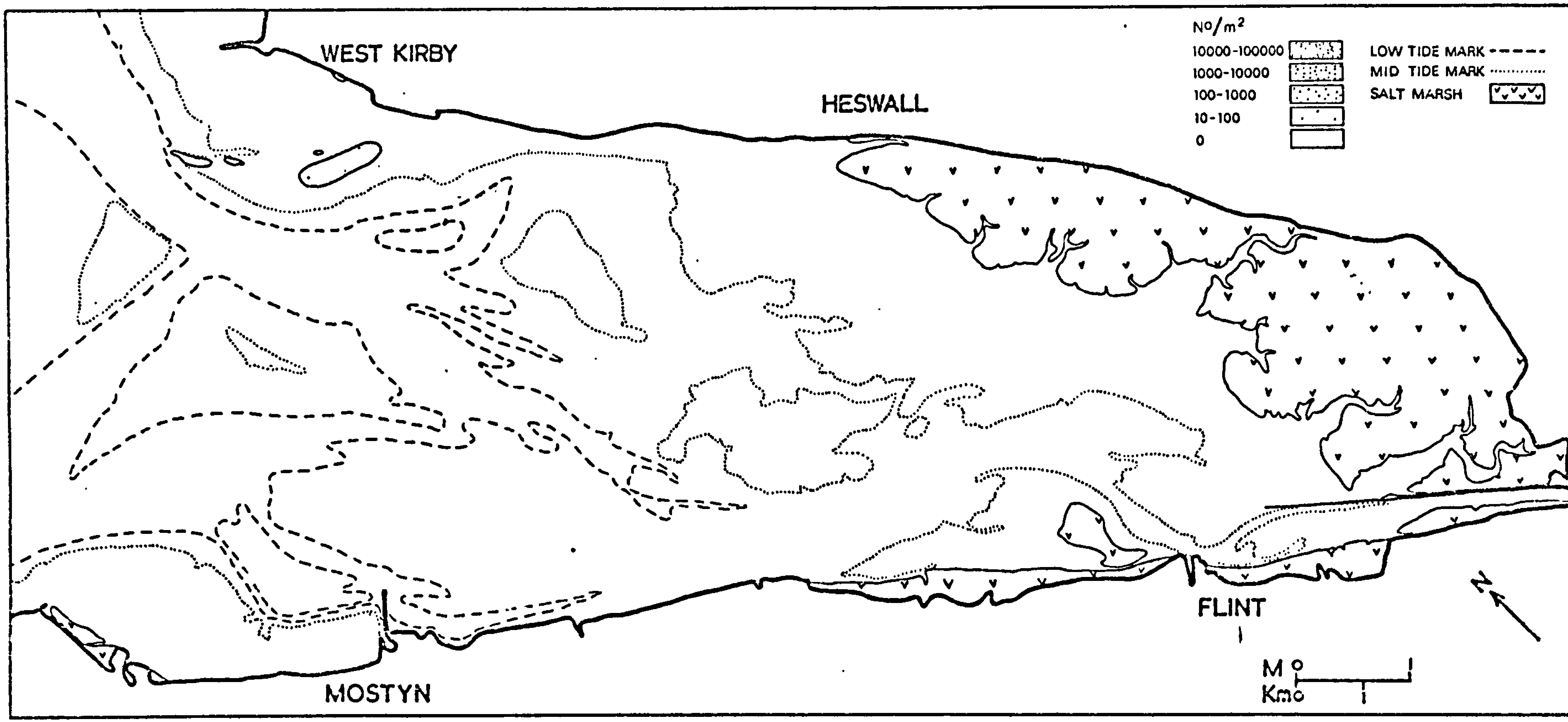
Map 136. Density distribution of <u>Tellina tenuis</u> in Autumn 1971.



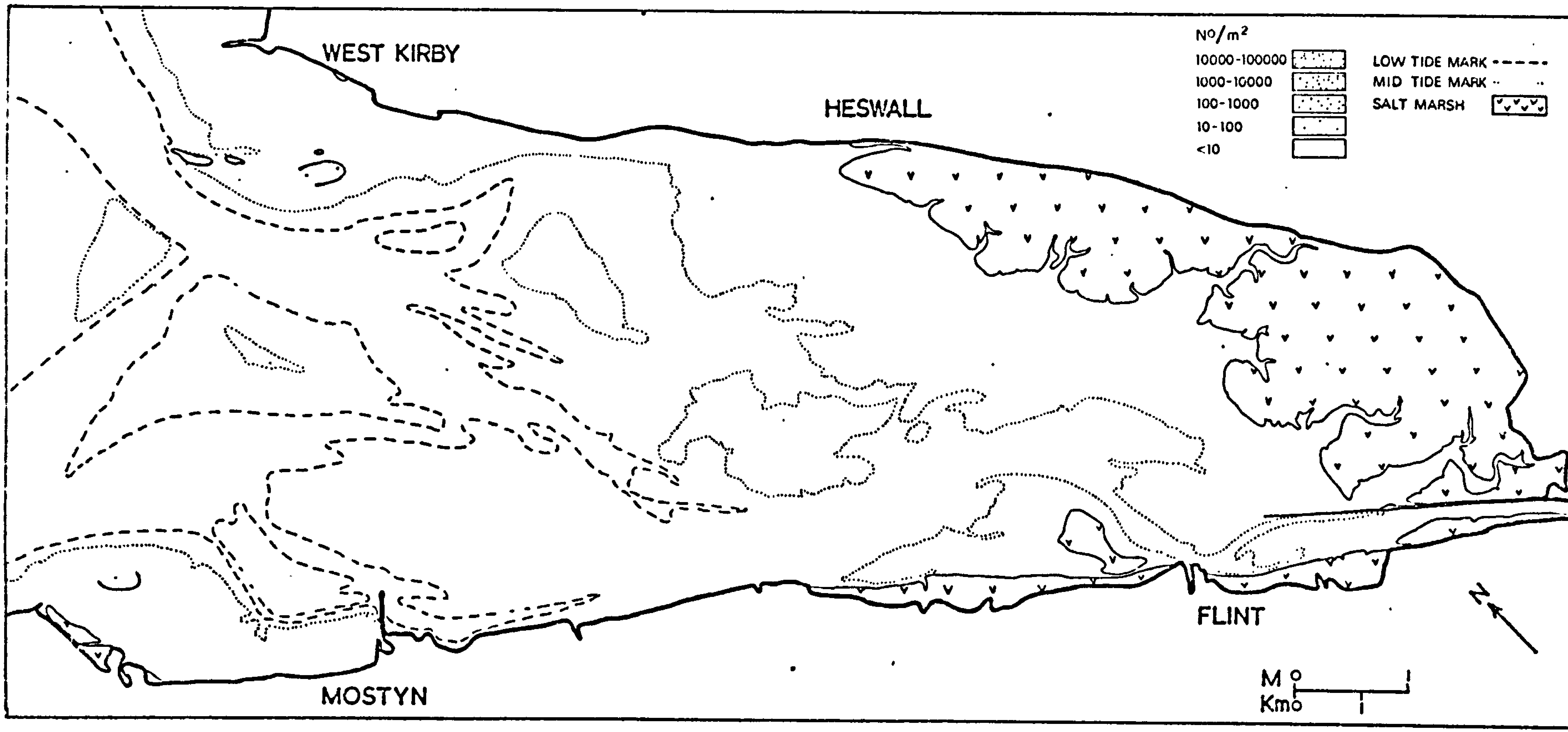
Map 137. Density distribution of Tellina tenuis in Spring 1972.



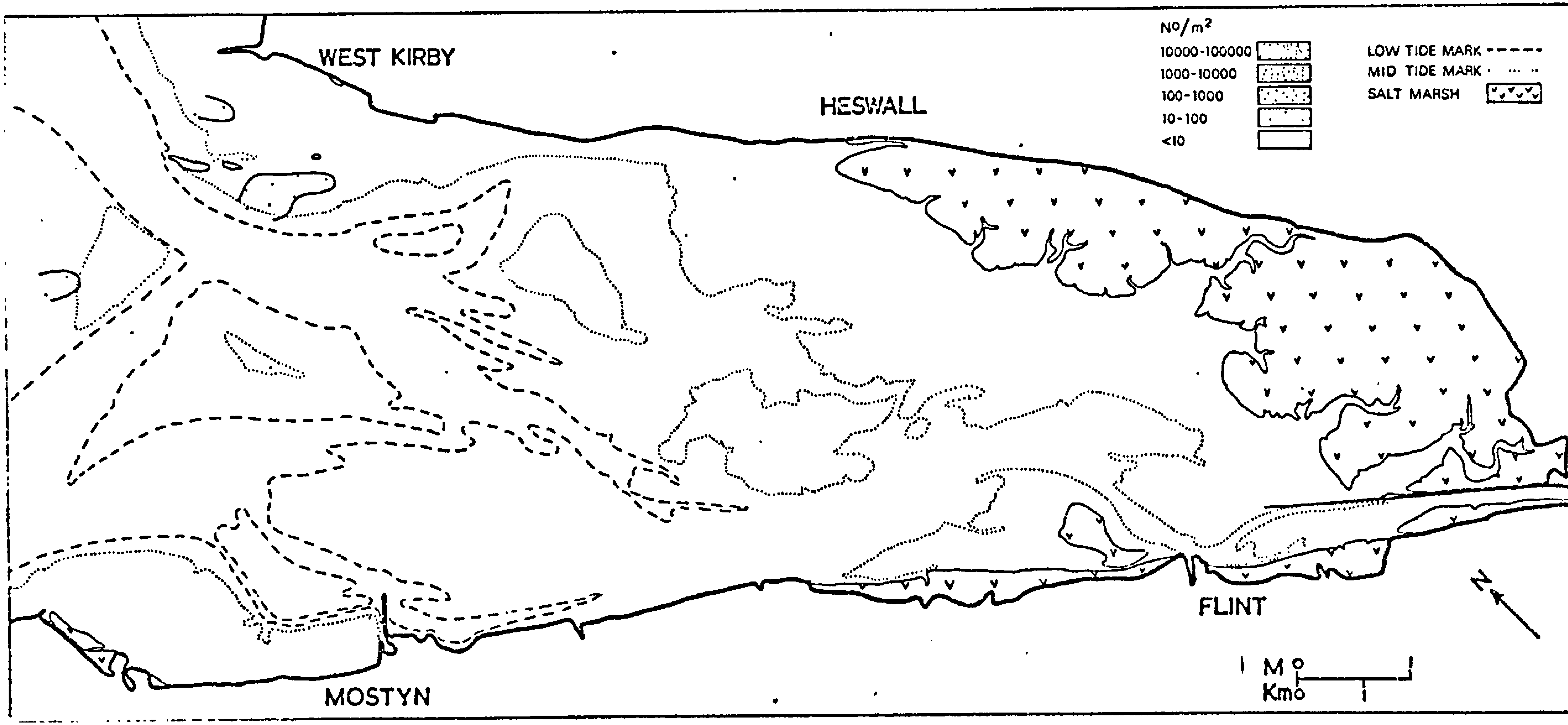
Map 138. Density distribution of <u>Tellina tenuis</u> in Spring 1973.



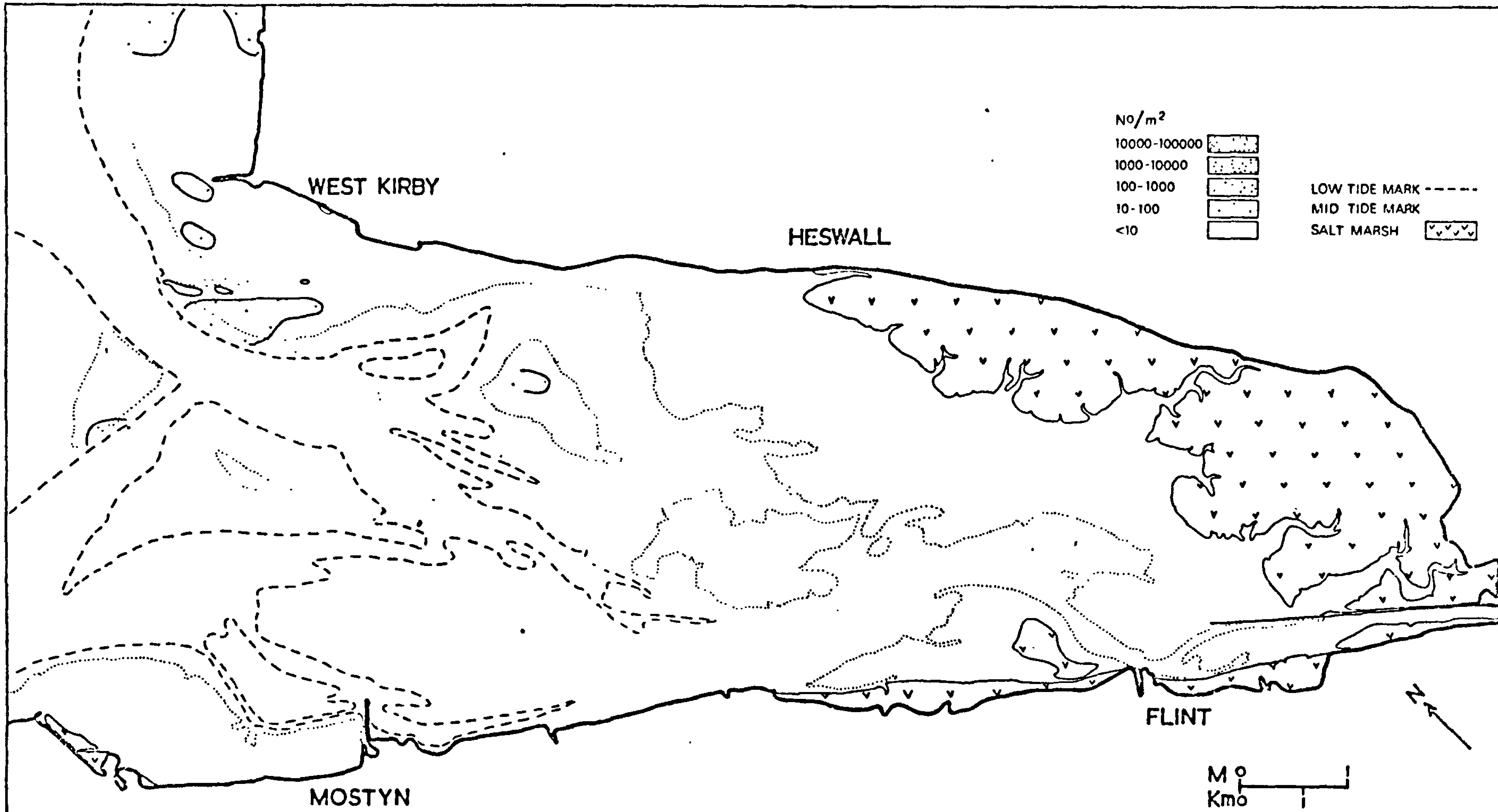
Map 139. Density distribution of Tellina tenuis in Spring 1974.



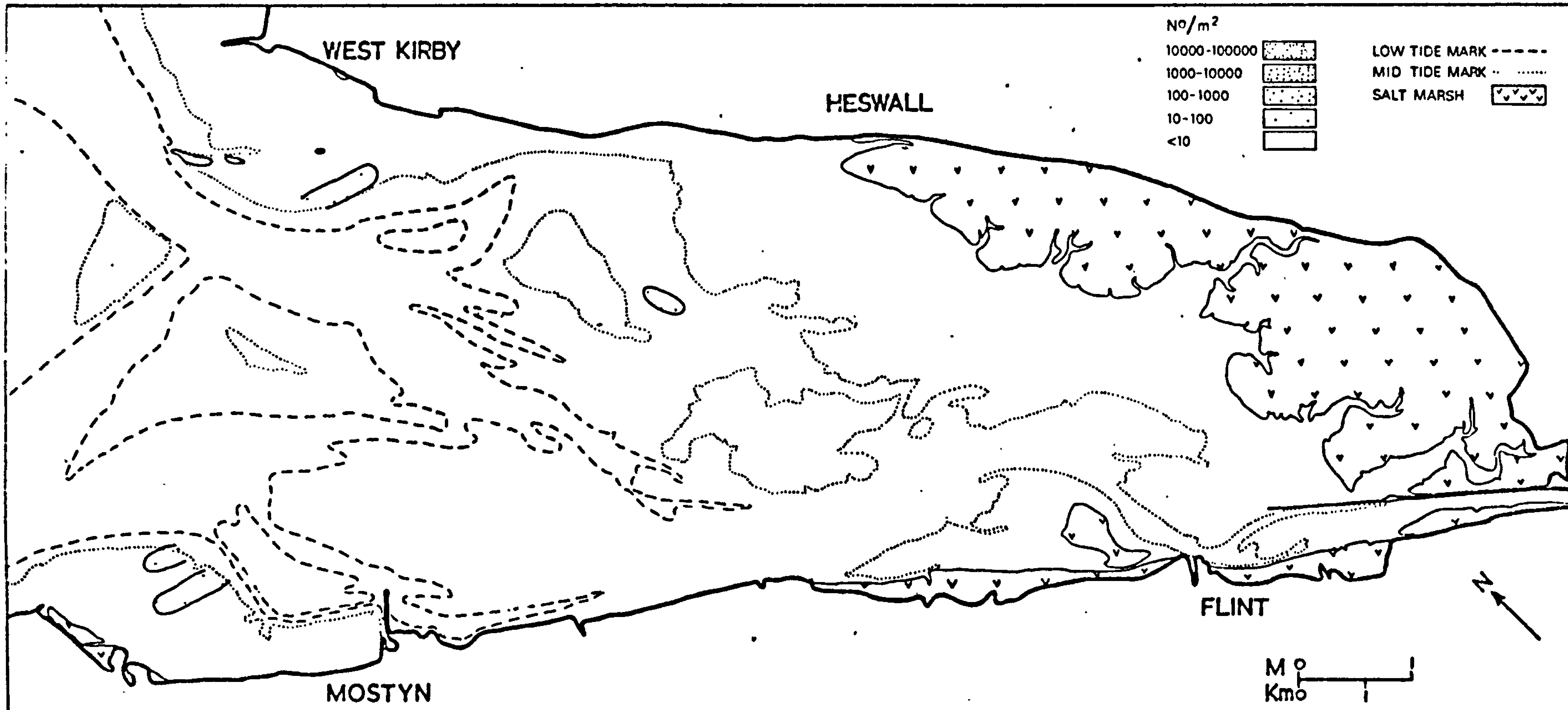
Map 140. Density distribution of Tellina tenuis in Spring 1975.



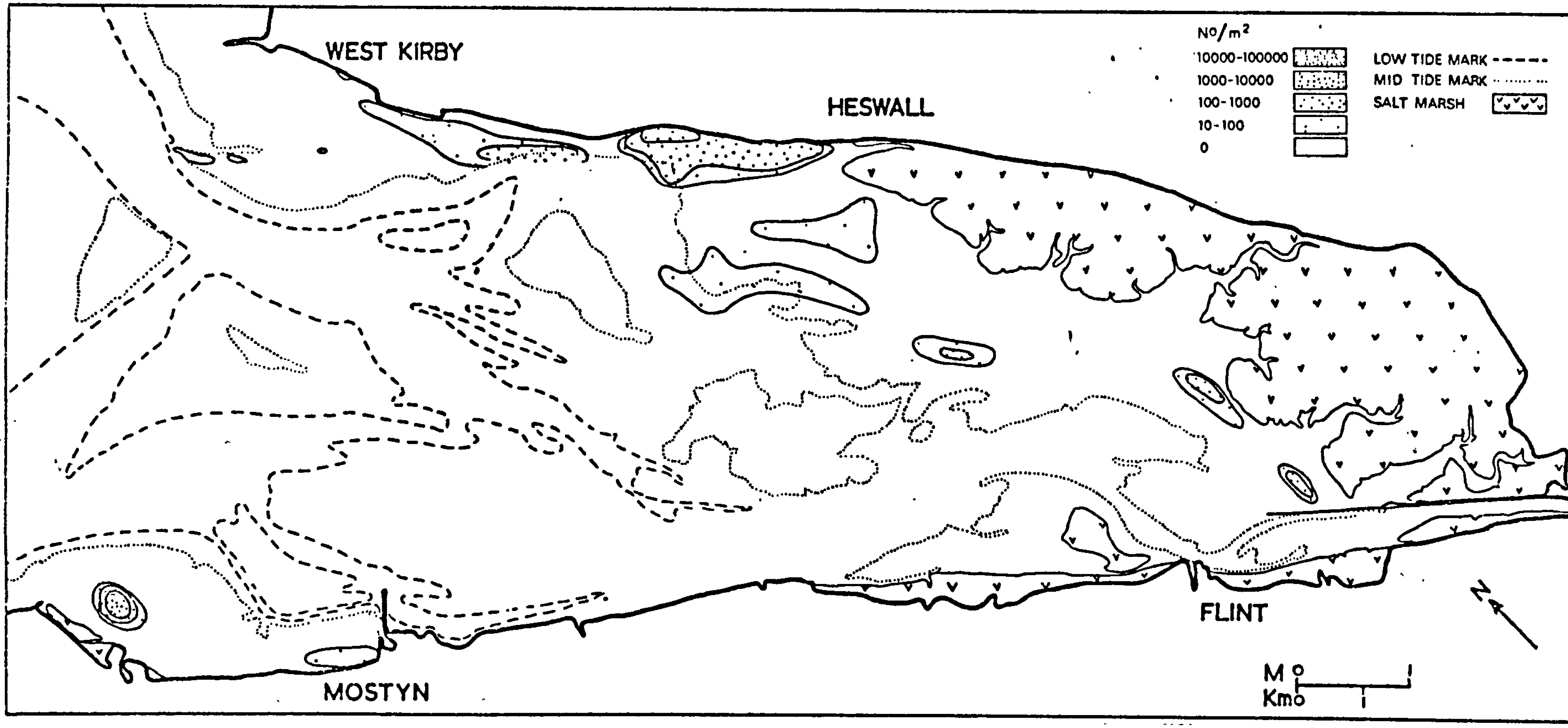
Map 141. Density distribution of <u>Tellina tenuis</u> in Autumn 1975.



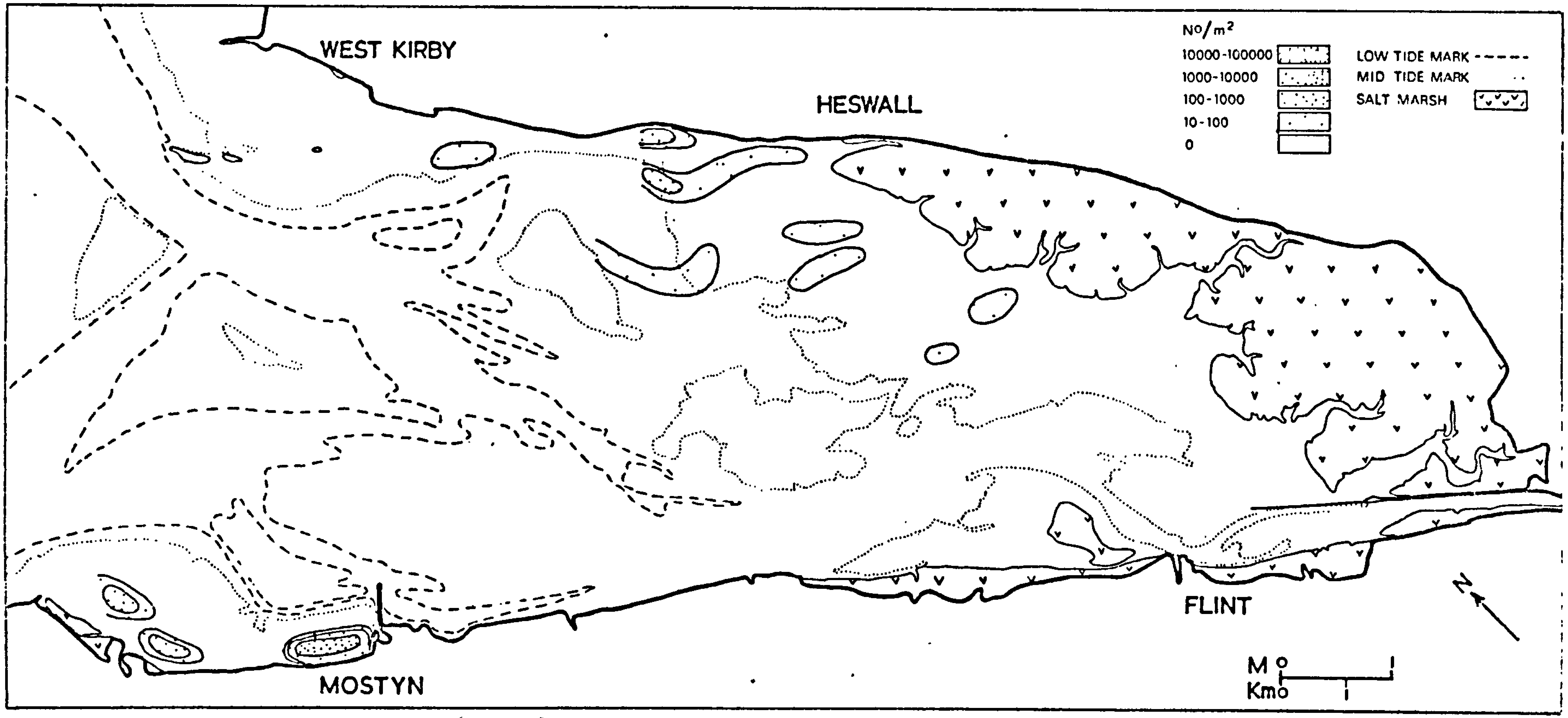
Map 142. Density distribution of <u>Tellina tenuis</u> in Spring 1976.



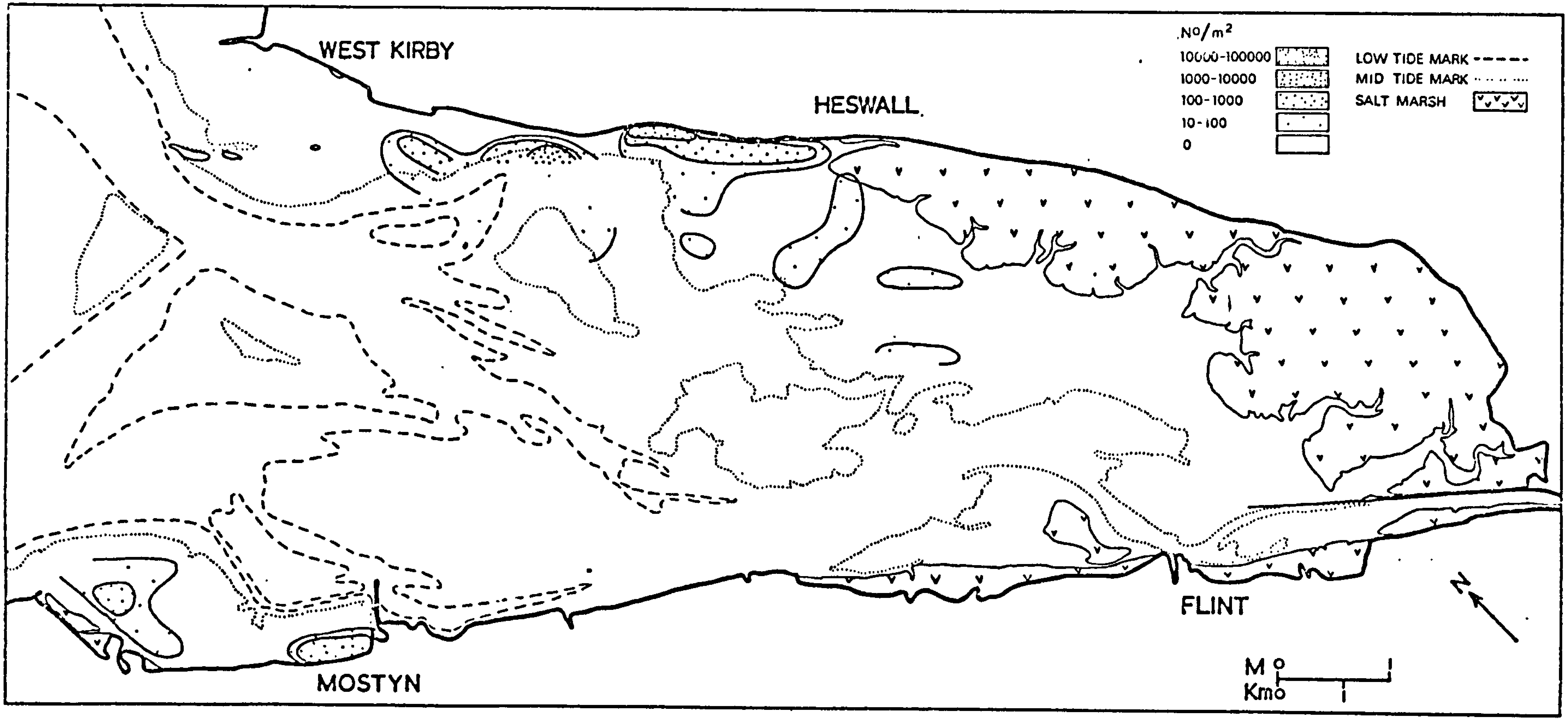
Map 143. Density distribution of Tellina tenuis in Autumn 1976.



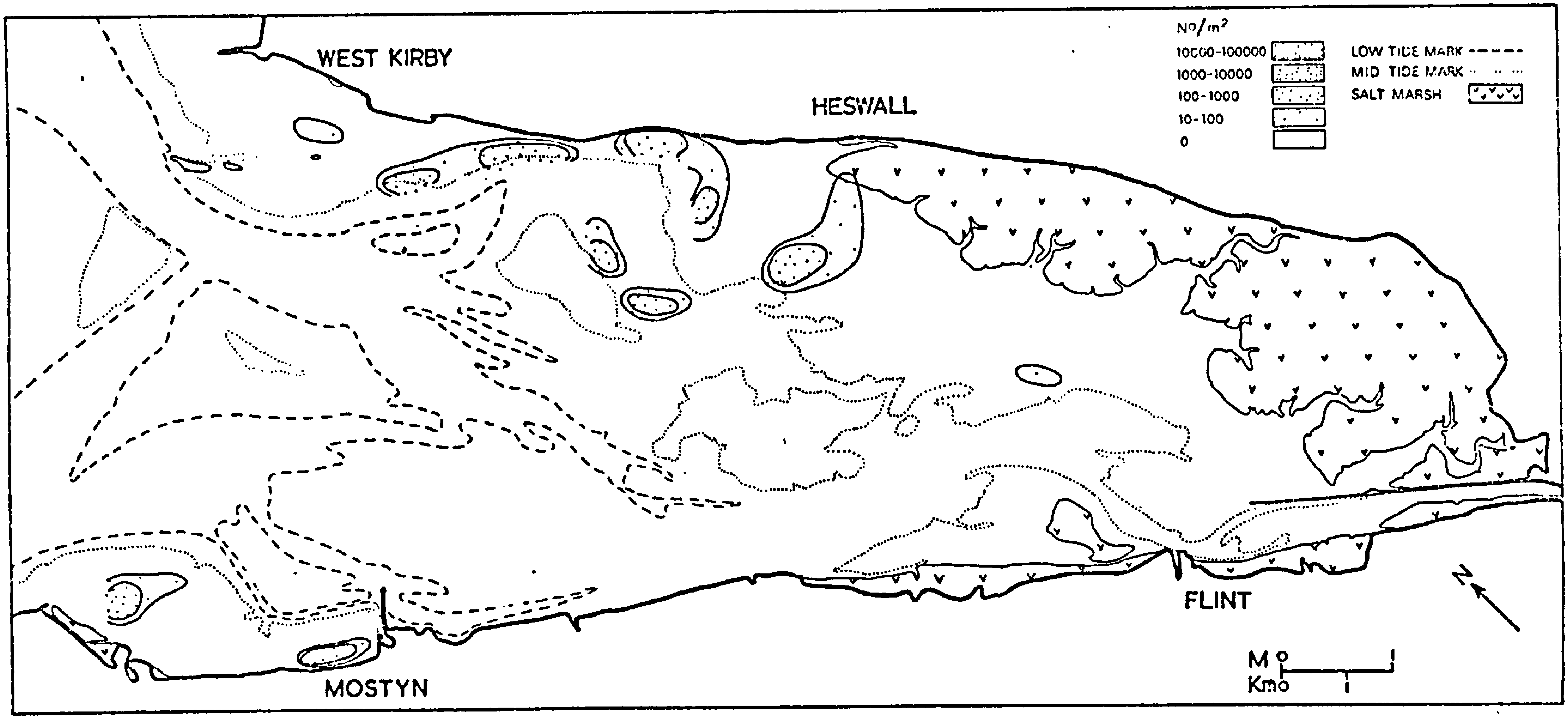
Map 144. Density distribution of Scrobicularia plana in Autumn 1971.



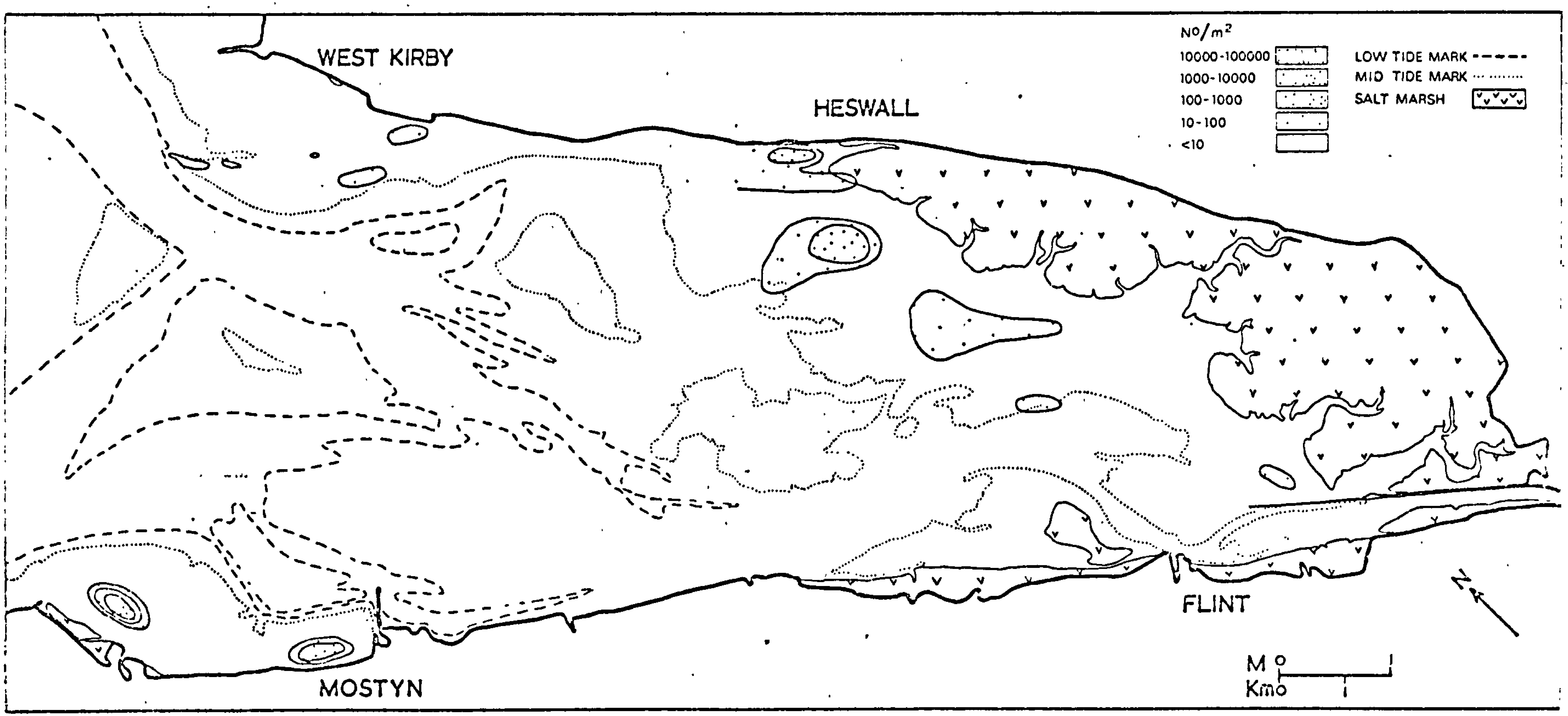
Map 145. Density distribution of <u>Scrobicularia plana</u> in Spring 1972.



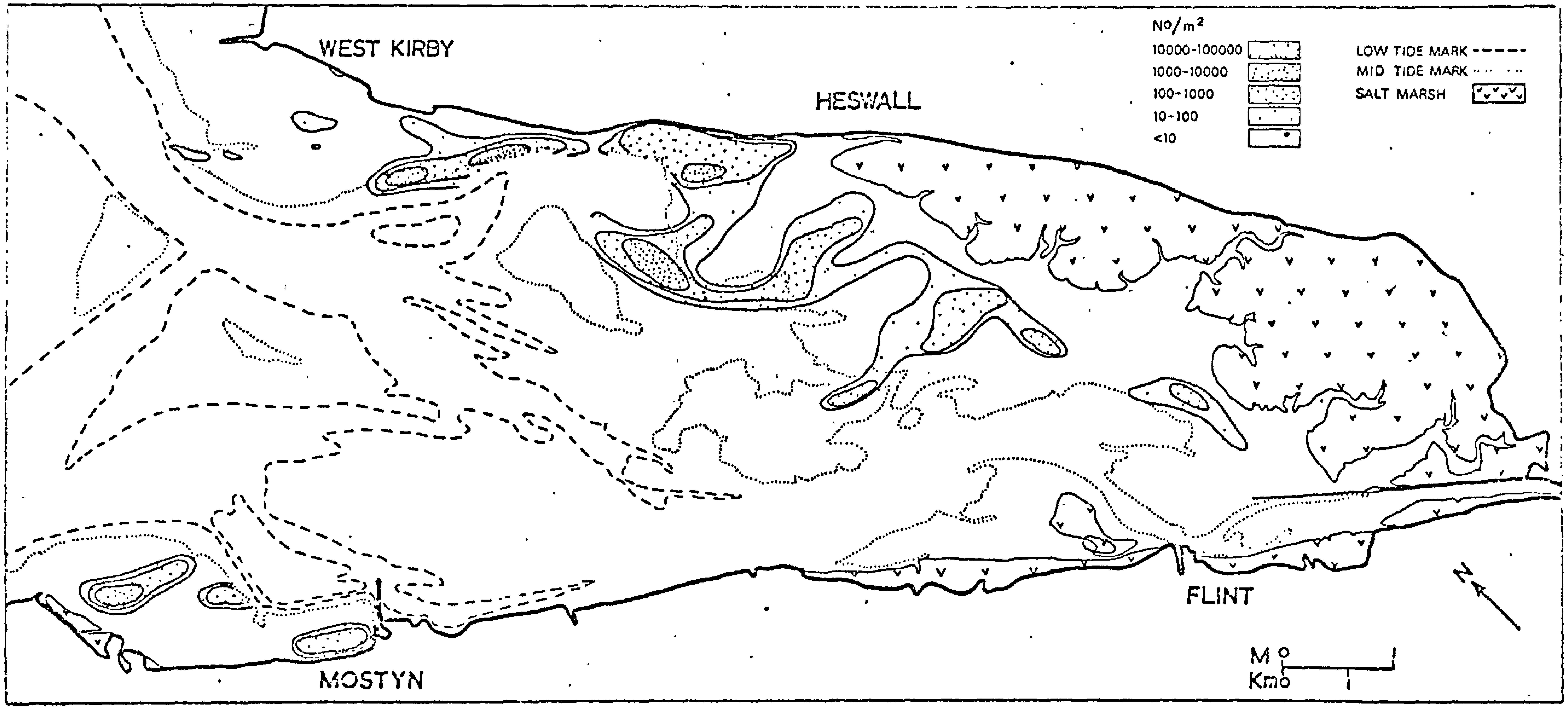
Map 146. Density distribution of Scrobicularia plana in Spring 1973.



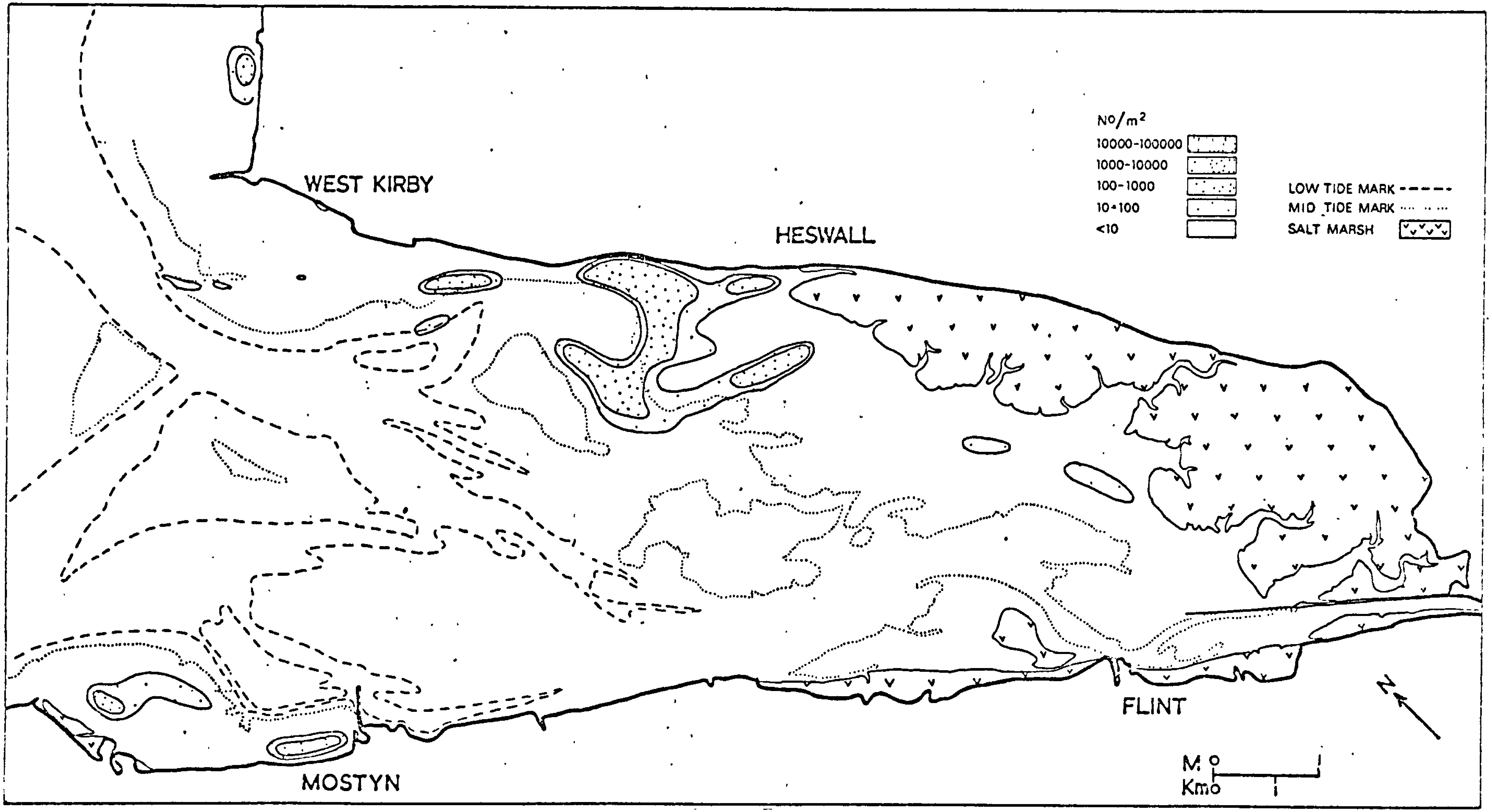
Map 147. Density distribution of Scrobicularia plana in Spring 1974.



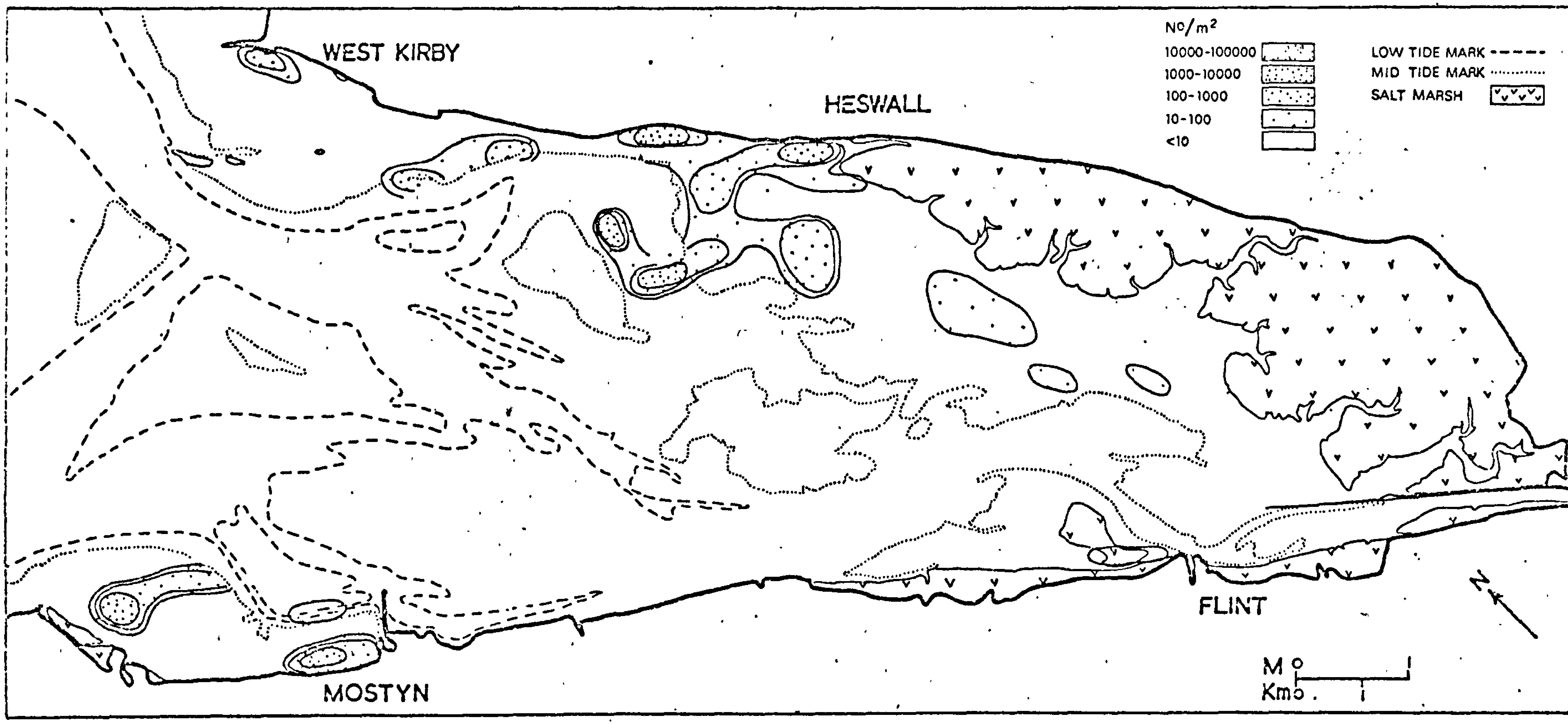
Map 148. Density distribution of Scrobicularia plana in Spring 1975.



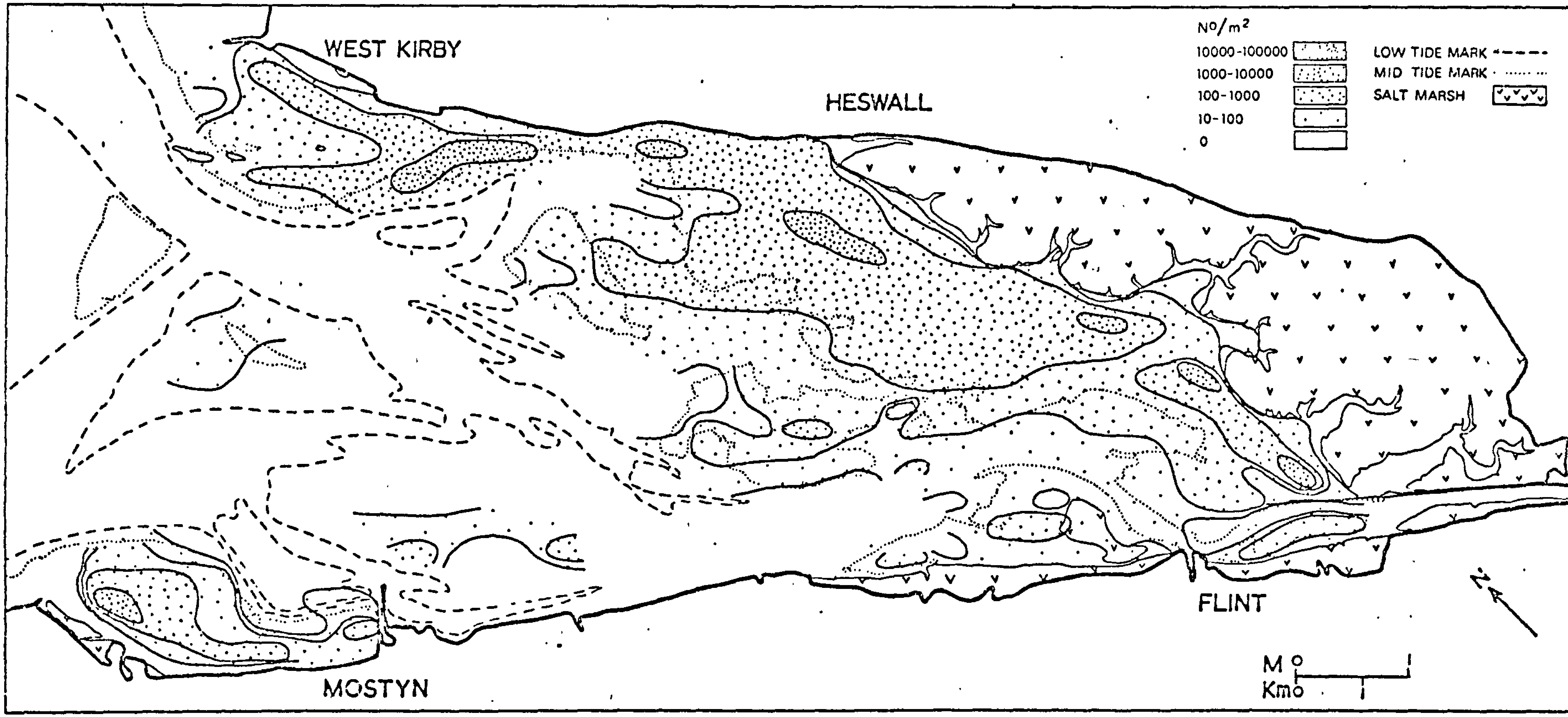
Map 149. Density distribution of Scrobicularia plana in Autumn 1975.



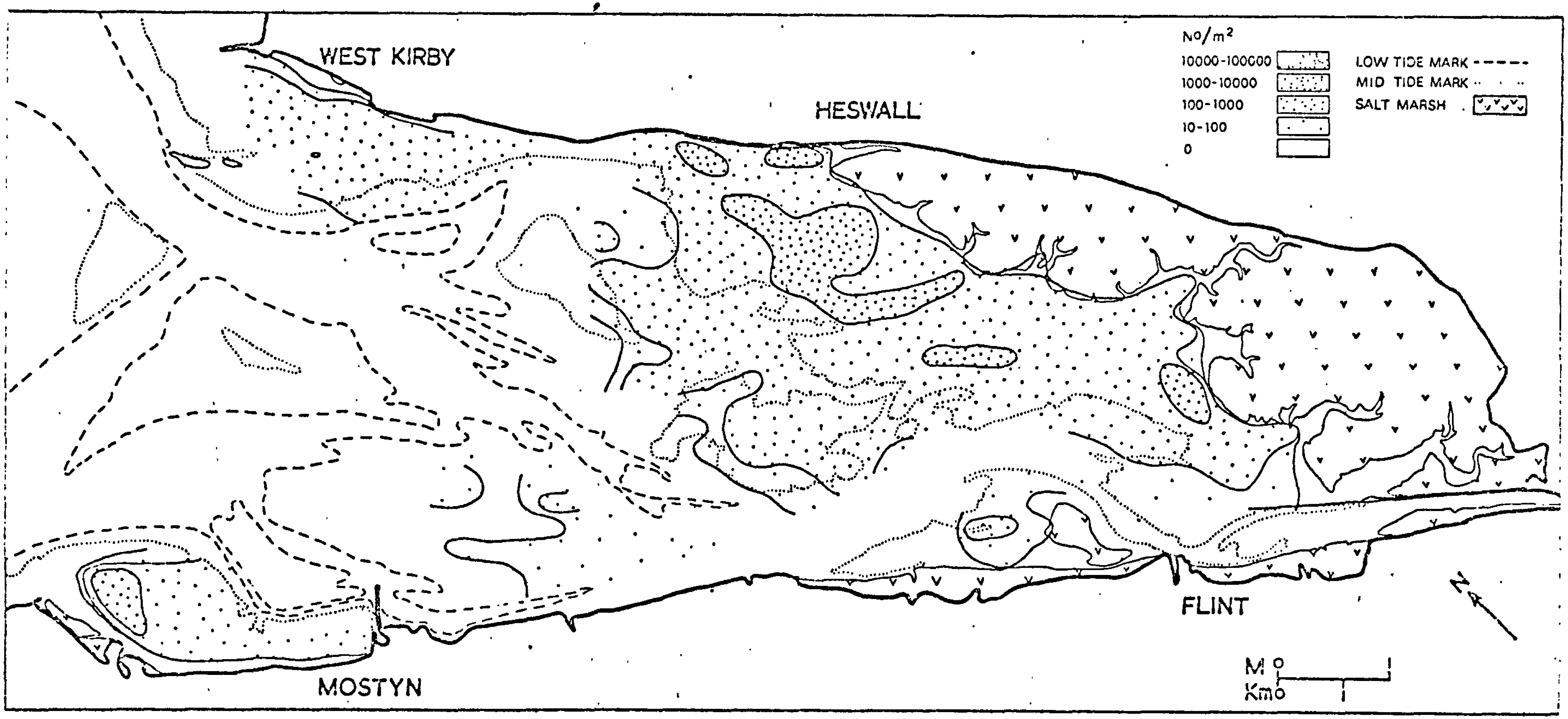
Map 150. Density distribution of Scrobicularia plana in Spring 1976.



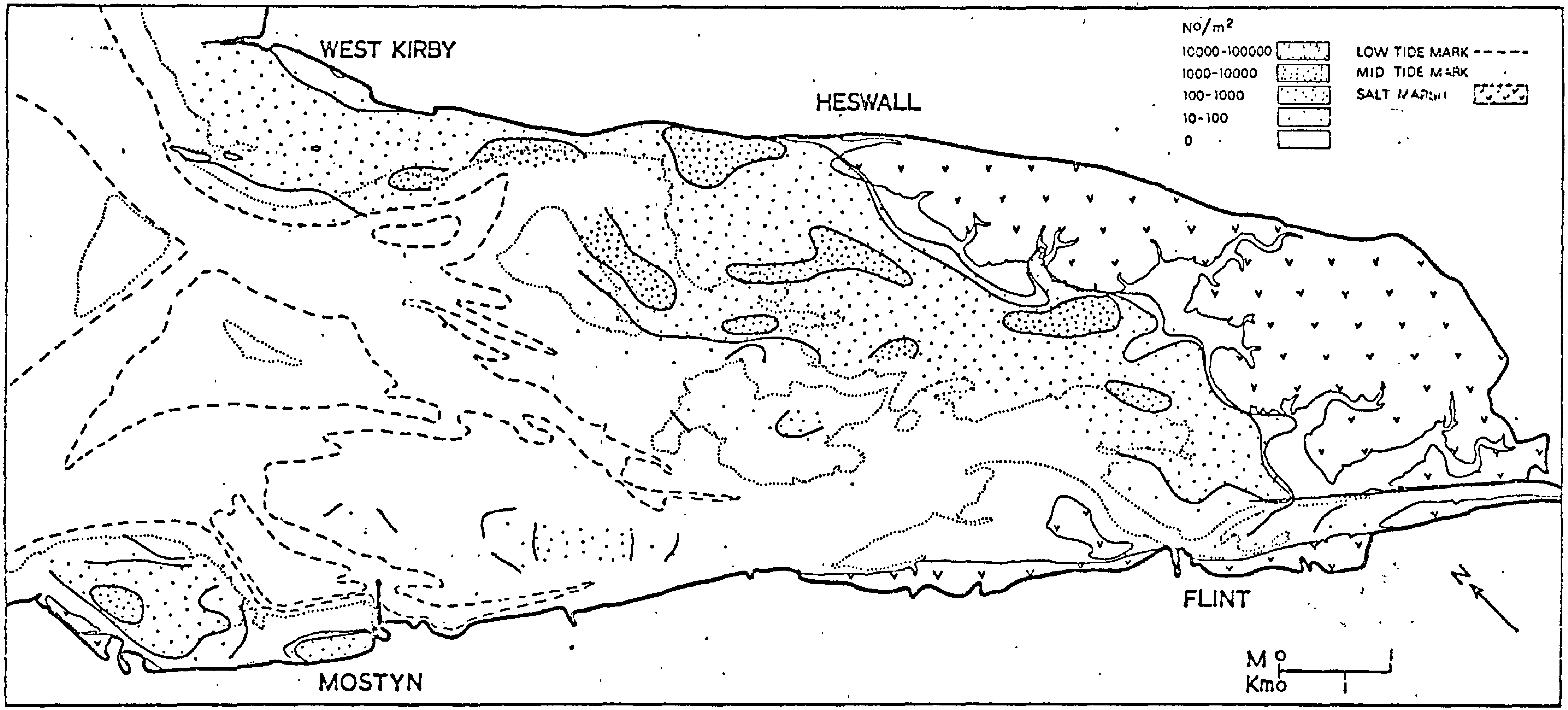
Map 151. Density distribution of Scrobicularia plana in Autumn 1976.



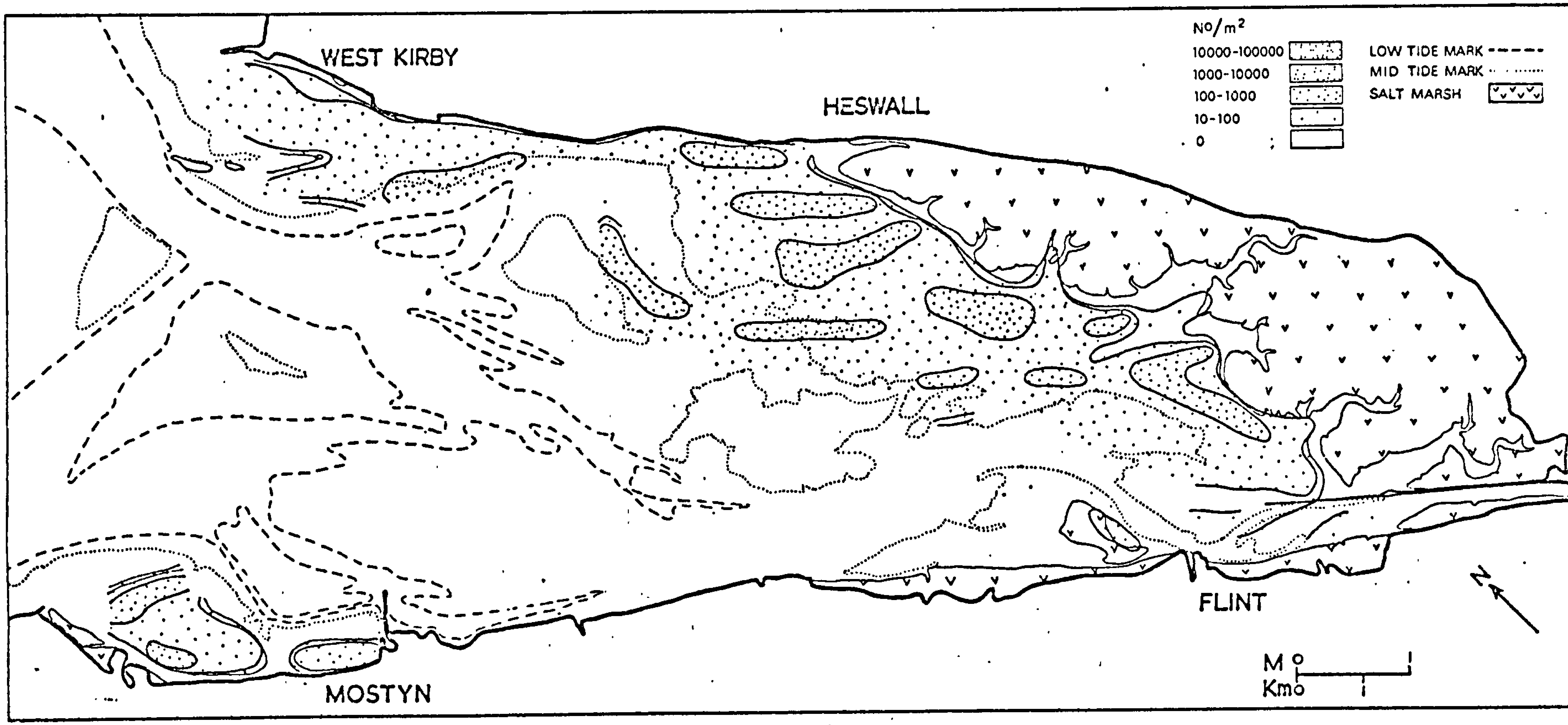
Map 152. Density distribution of Macoma balthica in Autumn 1971.



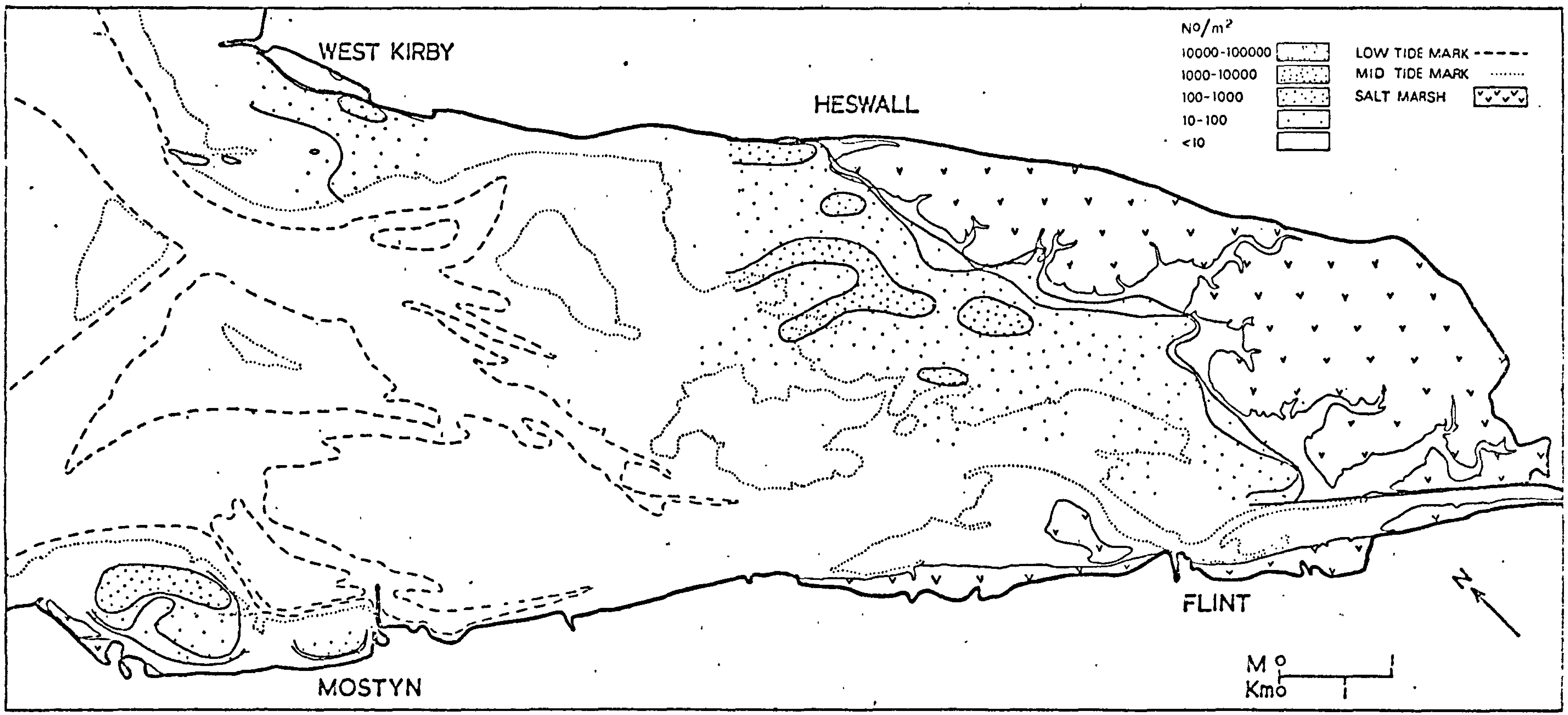
Map 153. Density distribution of Macoma balthica in Spring 1972.



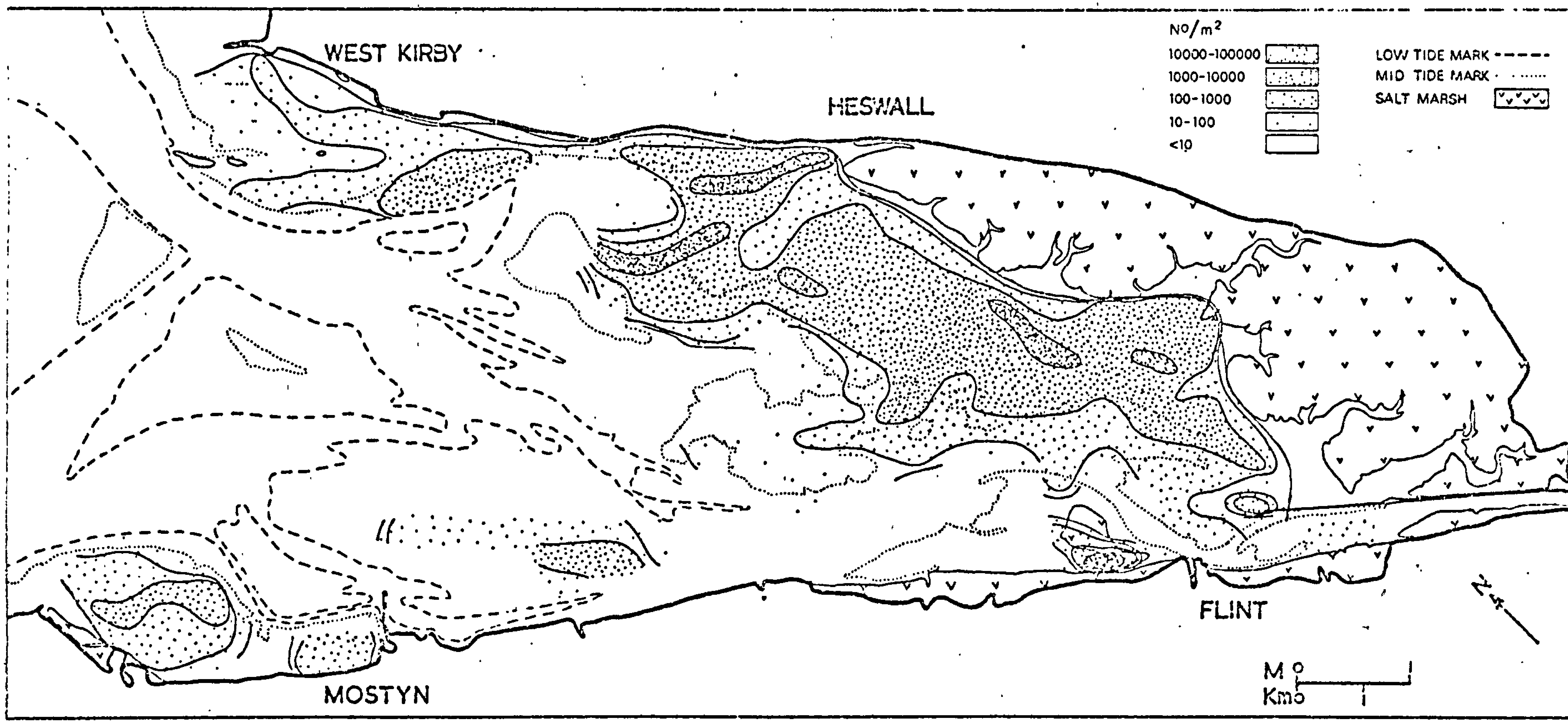
Map 154. Density distribution of Macoma balthica in Spring 1973.



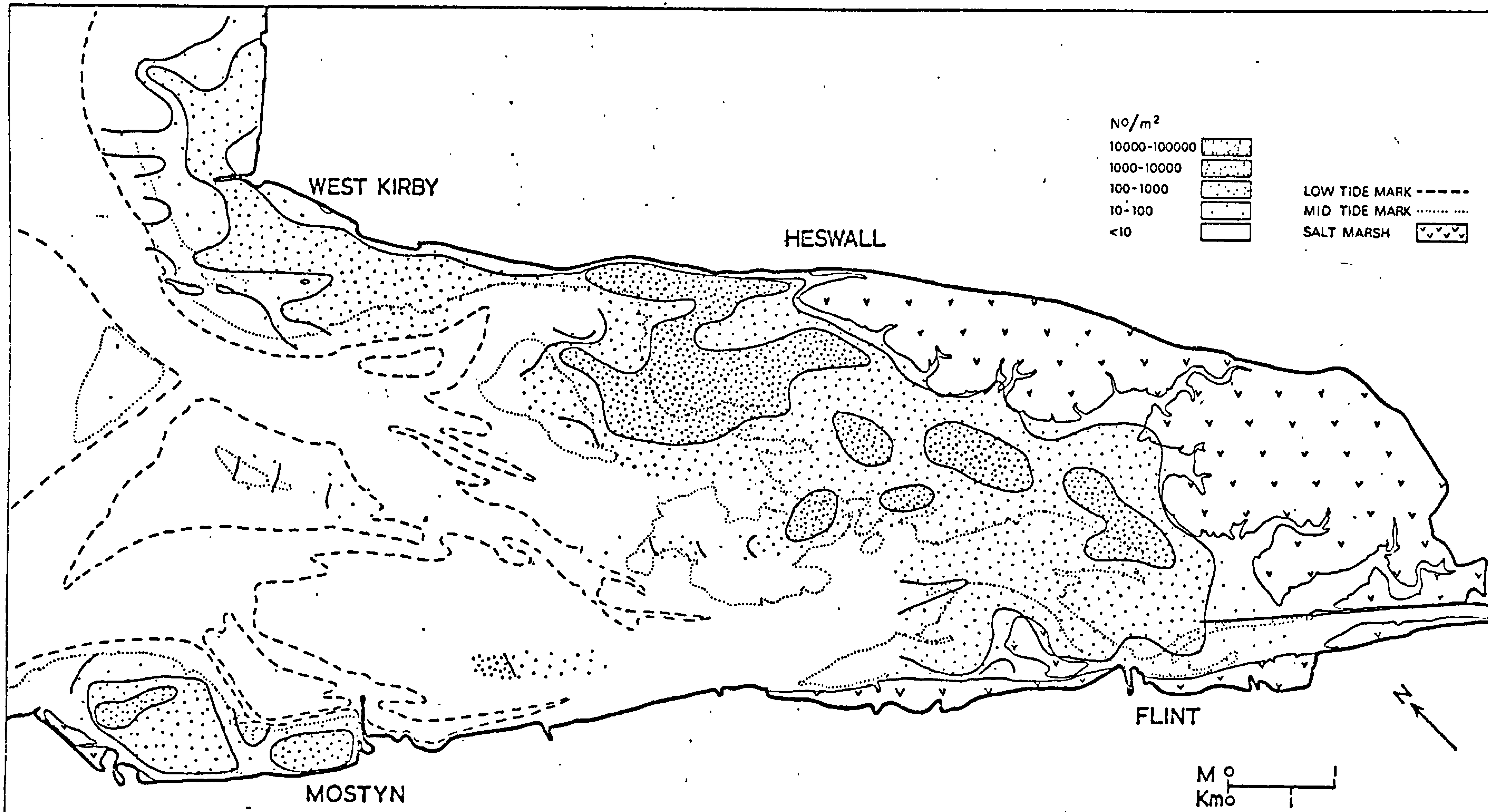
Map 155. Density distribution of Macoma balthica in Spring 1974.



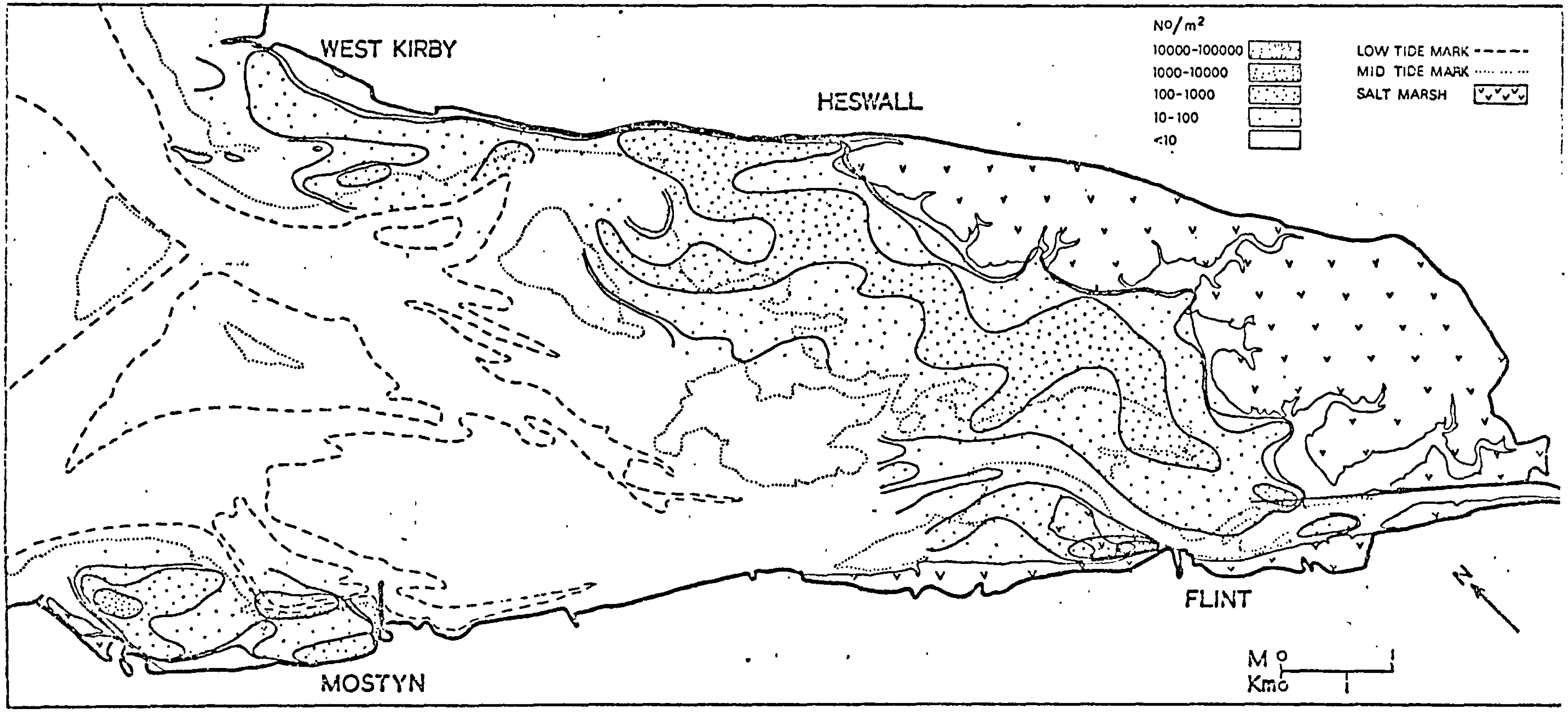
Map 156. Density distribution of Macoma balthica in Spring 1975.



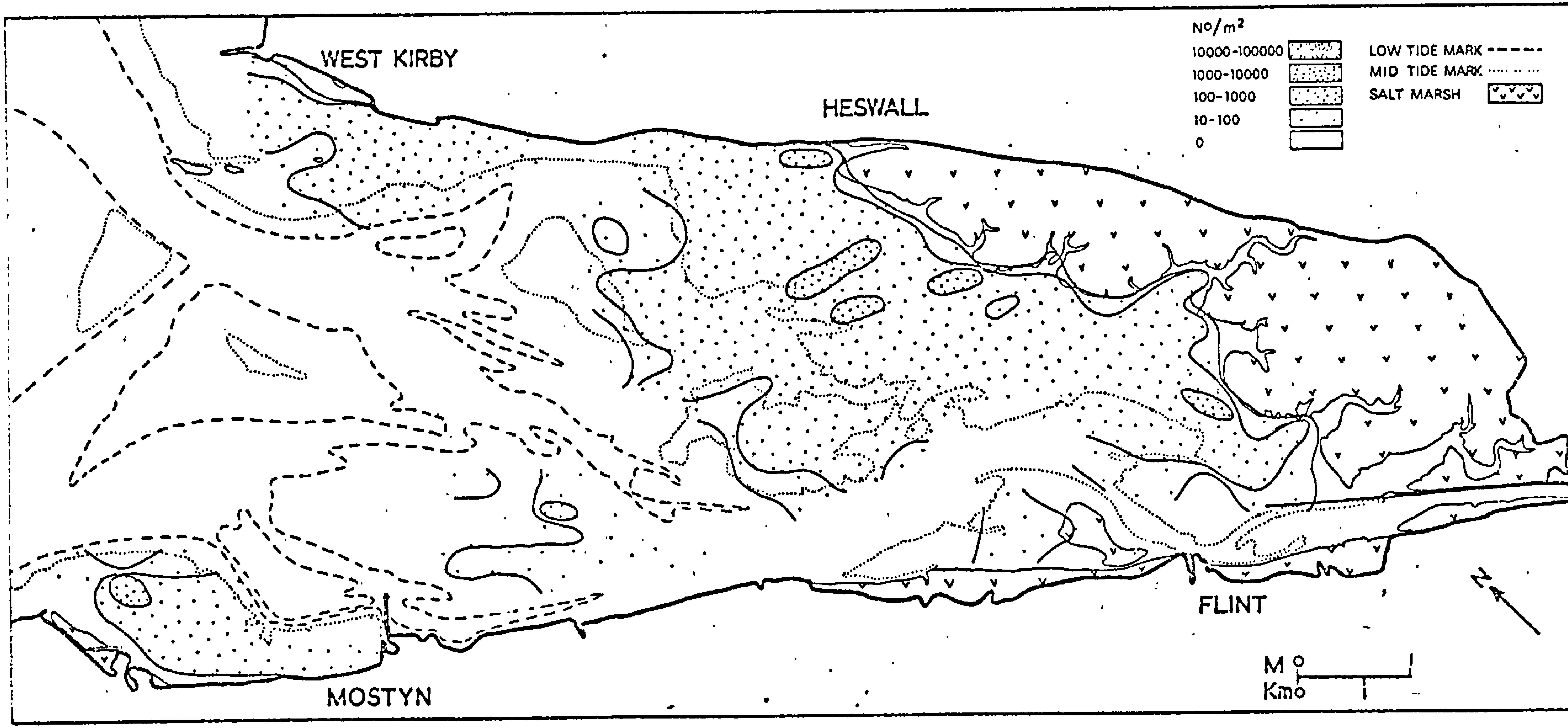
Map 157. Density distribution of Macoma balthica in Autumn 1975.



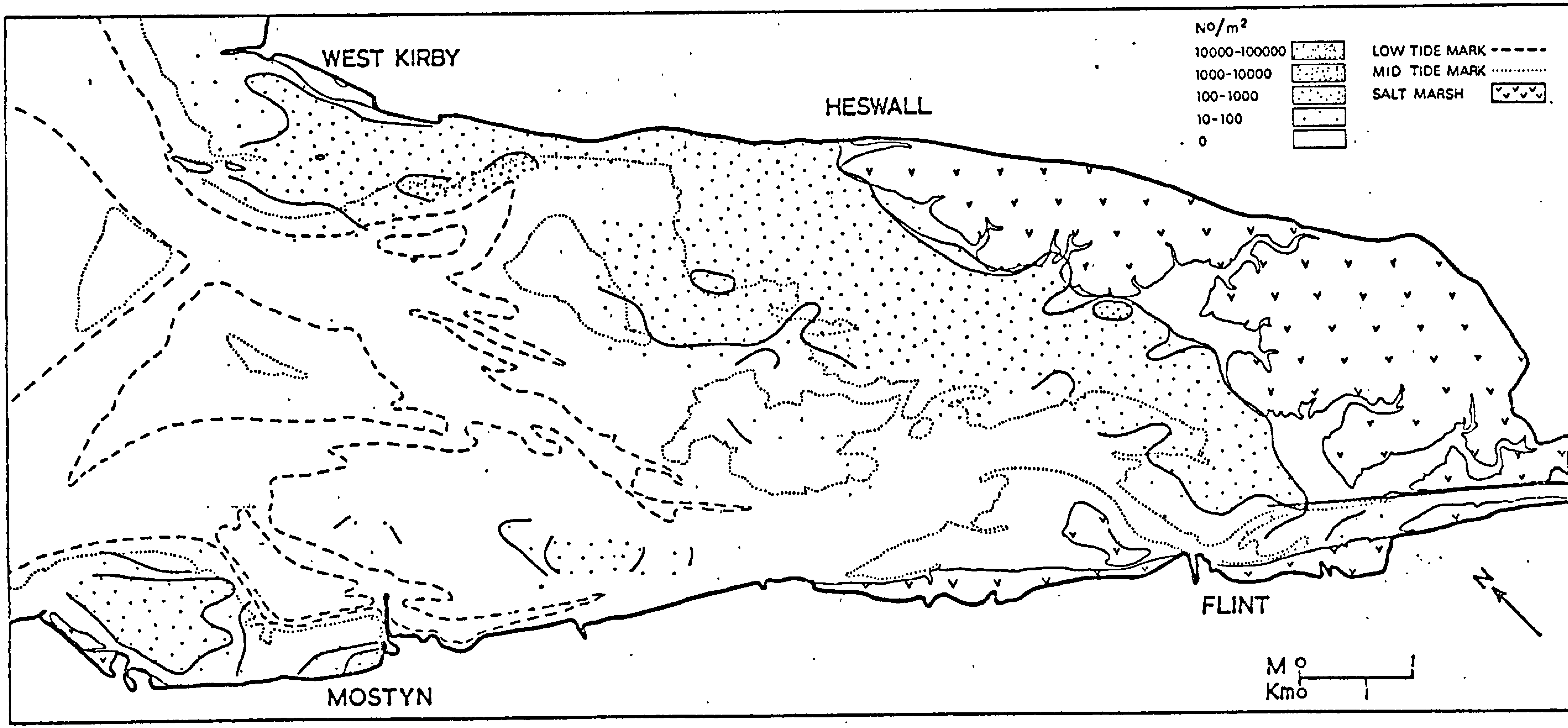
Map 158. Density distribution of <u>Macoma balthica</u> in Spring 1976.



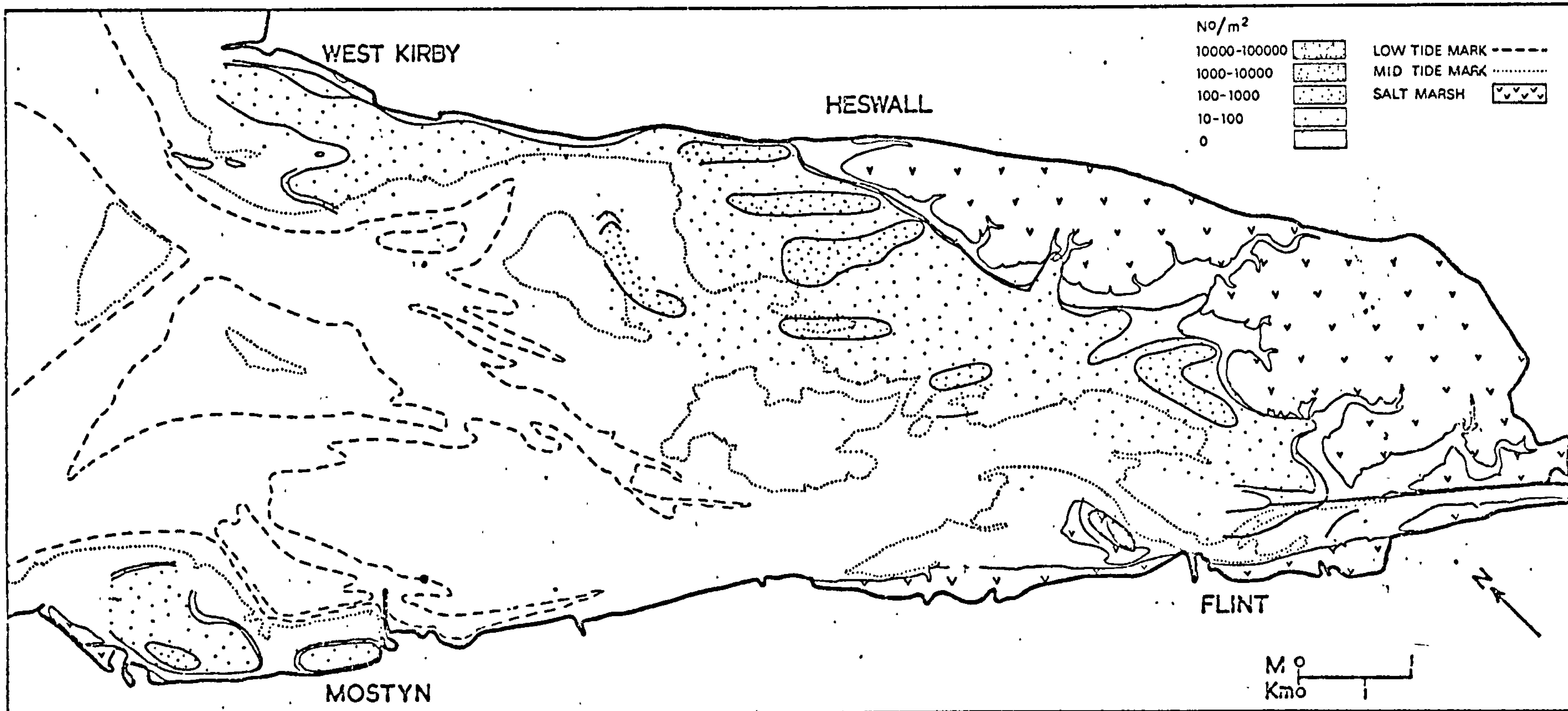
Map 159. Density distribution of <u>Macoma balthica</u> in Autumn 1976.



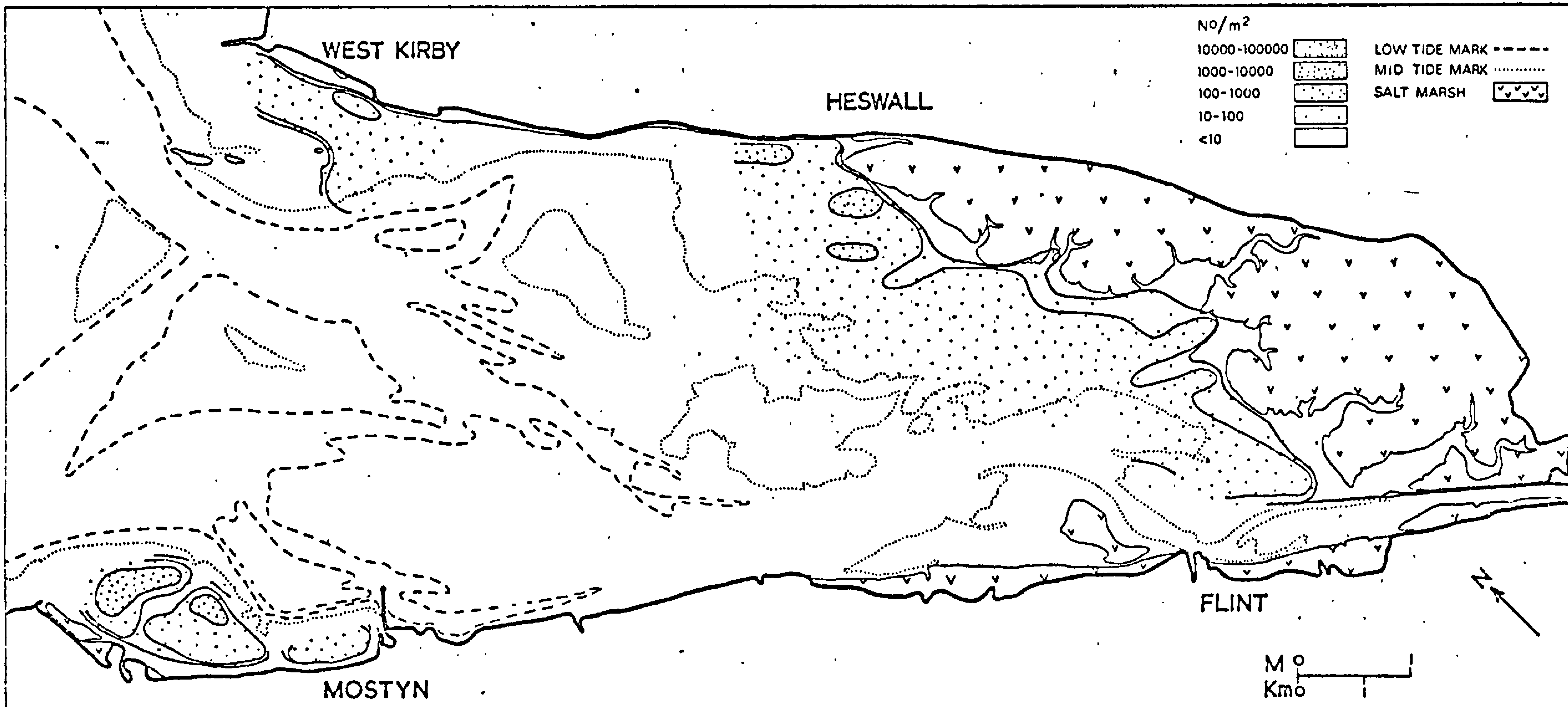
Map 160. Density distribution of <u>Macoma balthica</u> 10 mm and less in length in Spring 1972.



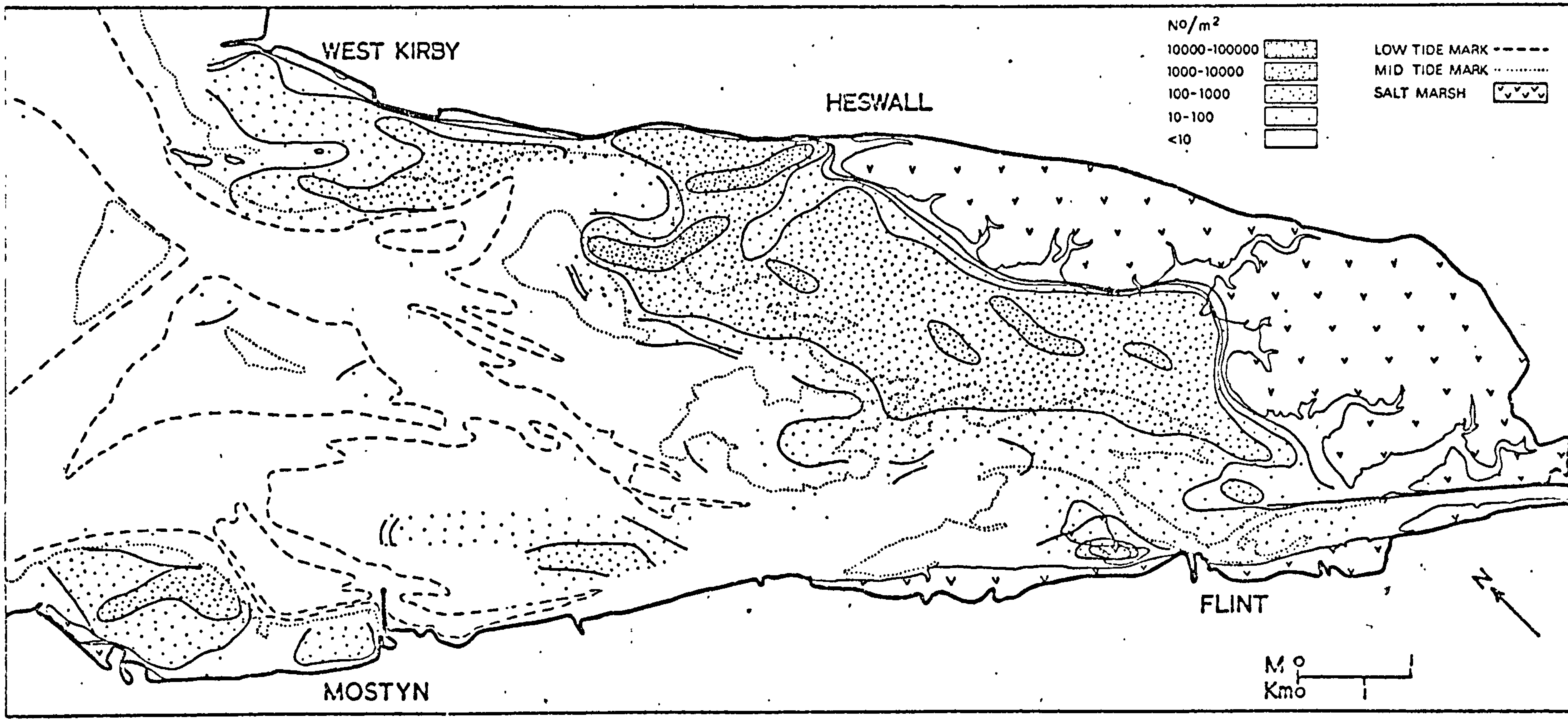
Map 161. Density distribution of Macoma balthica 10mm and less in length in Spring 1973.



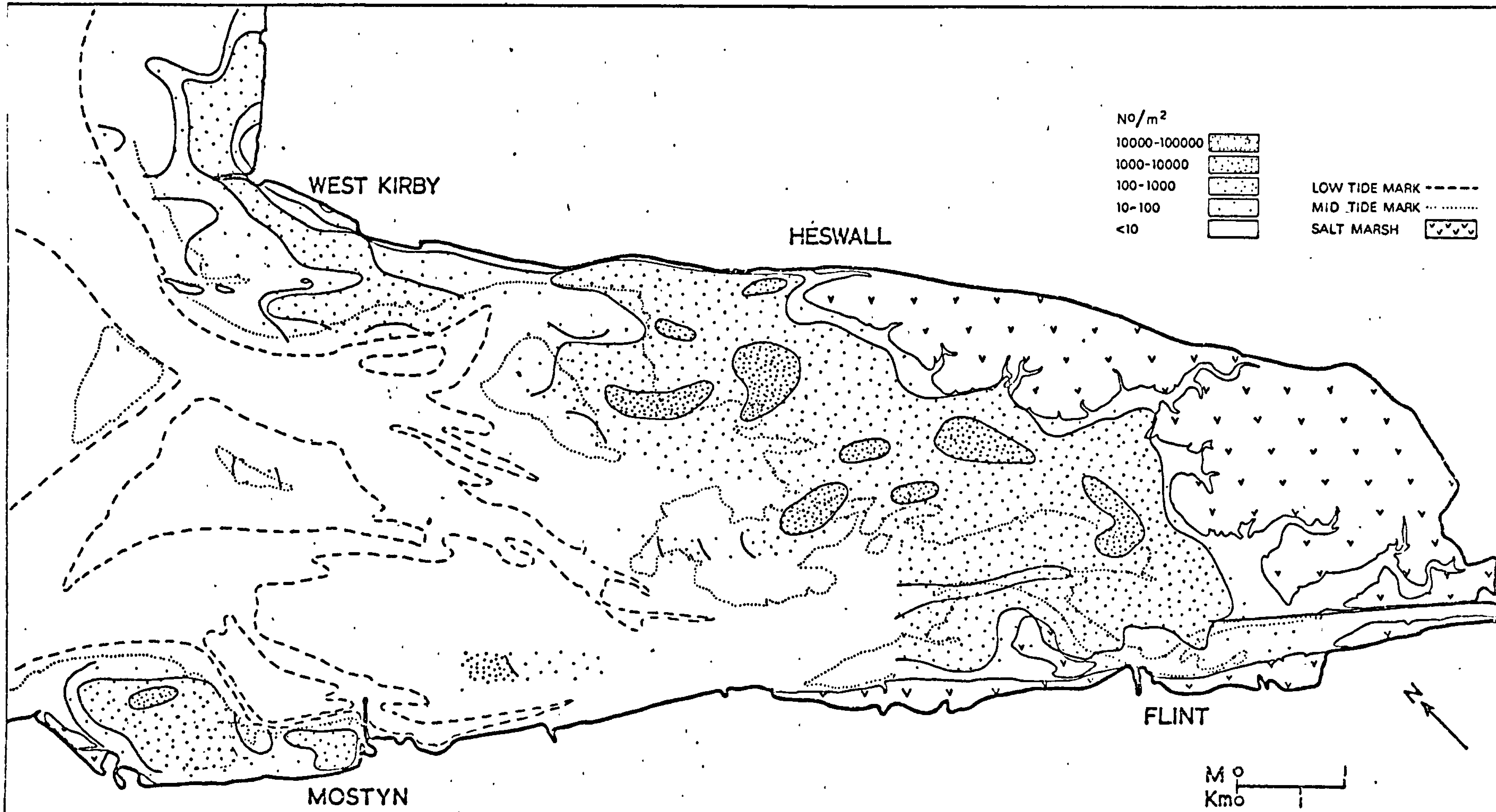
Map 162. Density distribution of Macoma balthica 10 mm and less in length in Spring 1974.



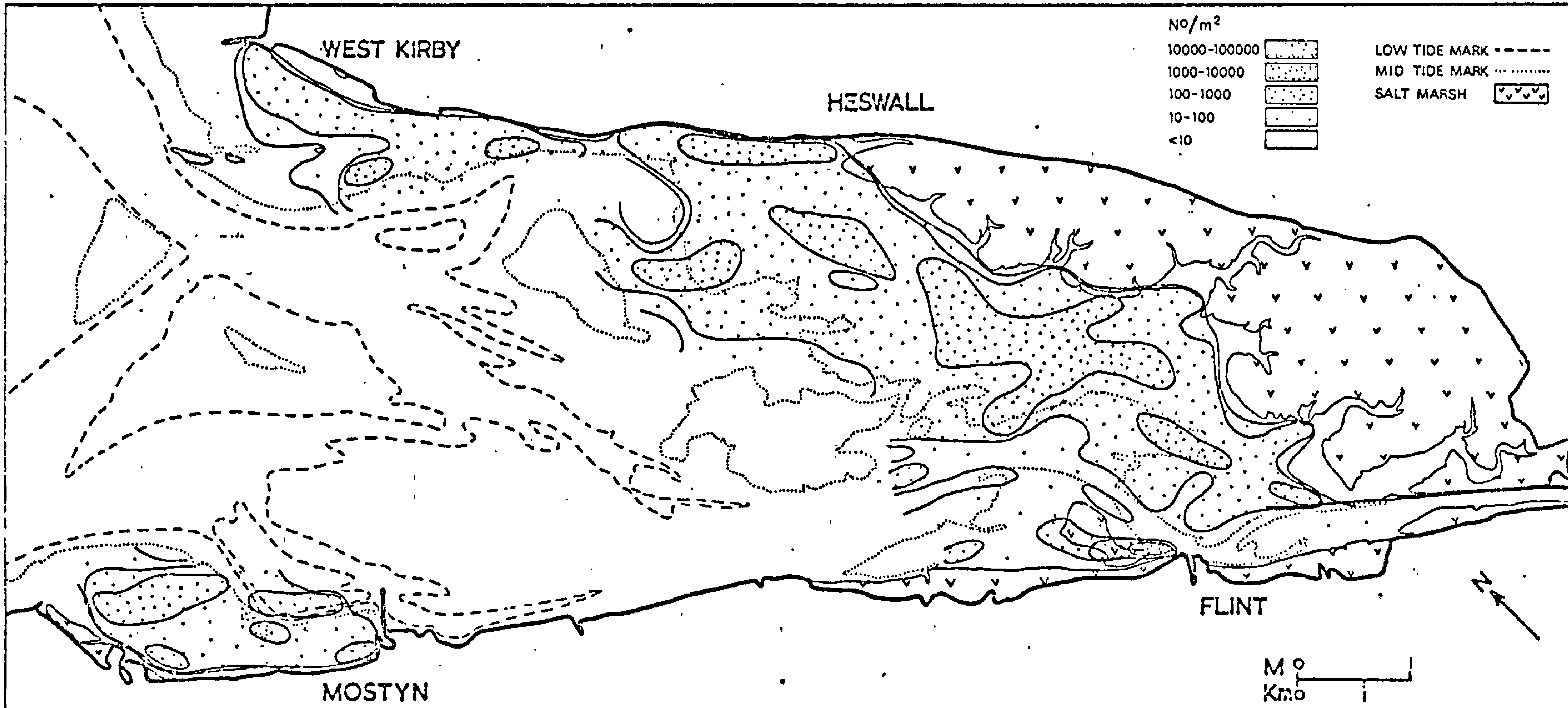
Map 163. Density distribution of <u>Macoma balthica</u> 10 mm and less in length in Spring 1975.



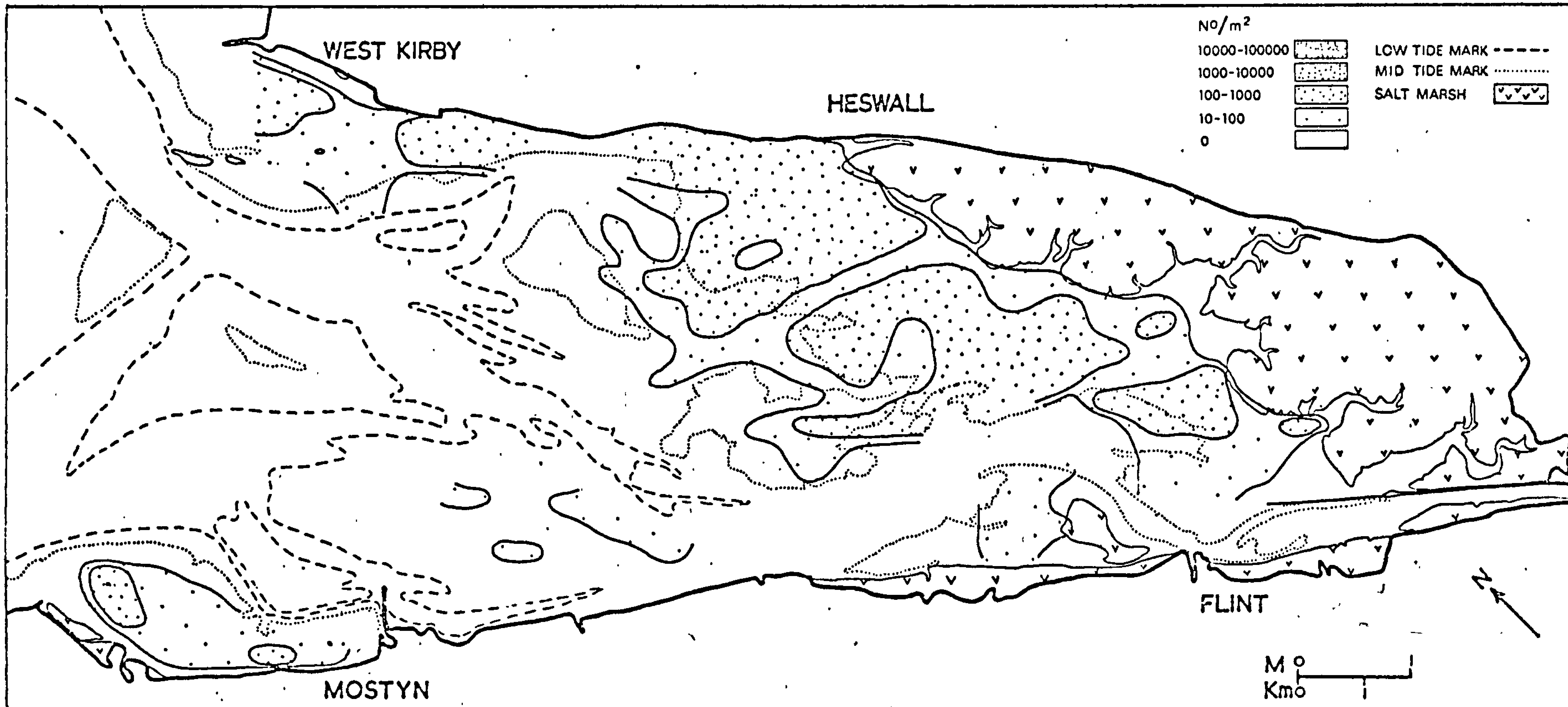
Map 164. Density distribution of <u>Macoma balthica</u> 10 mm and less in length in Autumn 1975.



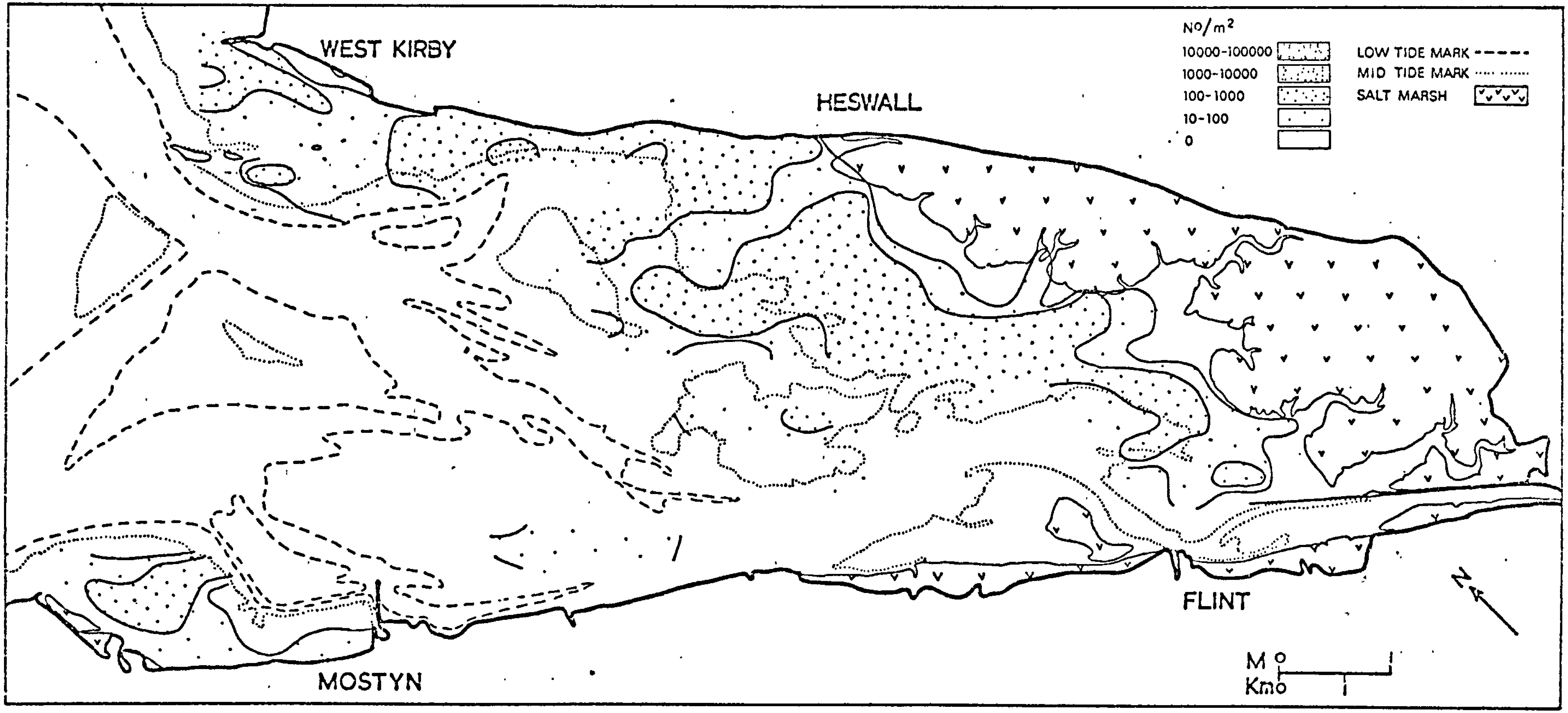
Map 165. Density distribution of Macoma balthica 10 mm and less in length in Spring 1976.



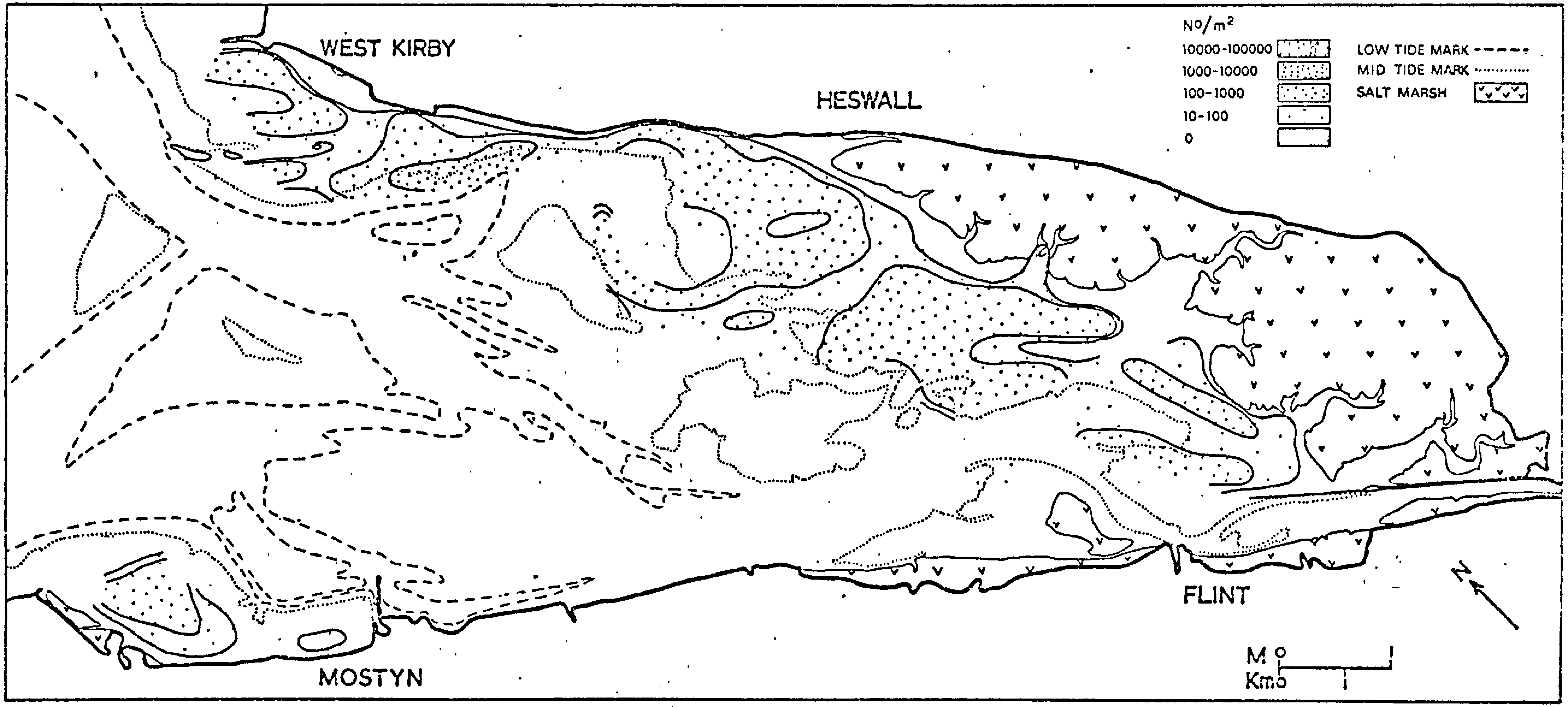
Map 166. Density distribution of <u>Macoma balthica</u> 10 mm and less in length in Autumn 1976.



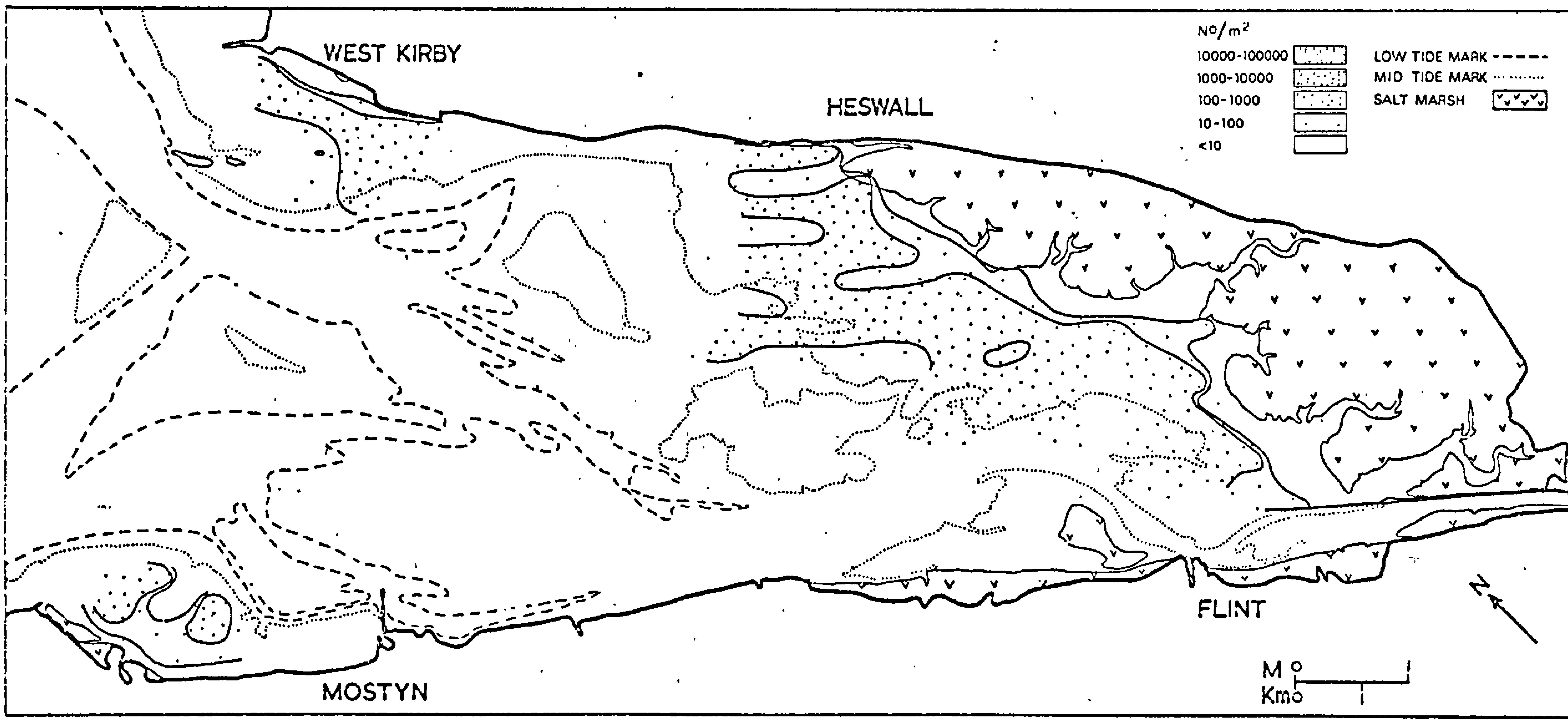
Map 167. Density distribution of Macoma balthica more than 10 mm in length in Spring 1972.



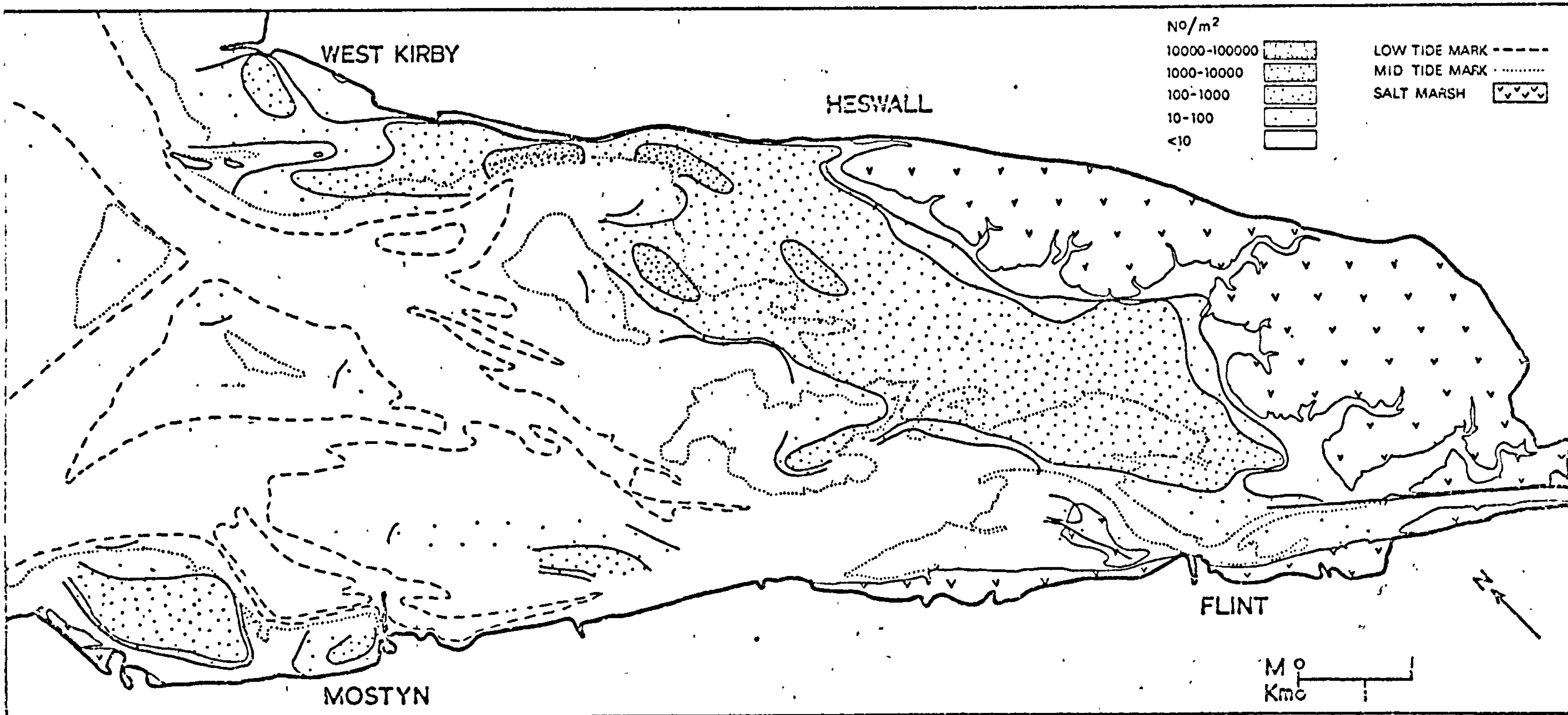
Map 168. Density distribution of <u>Macoma balthica</u> more than 10 mm in length in Spring 1973.



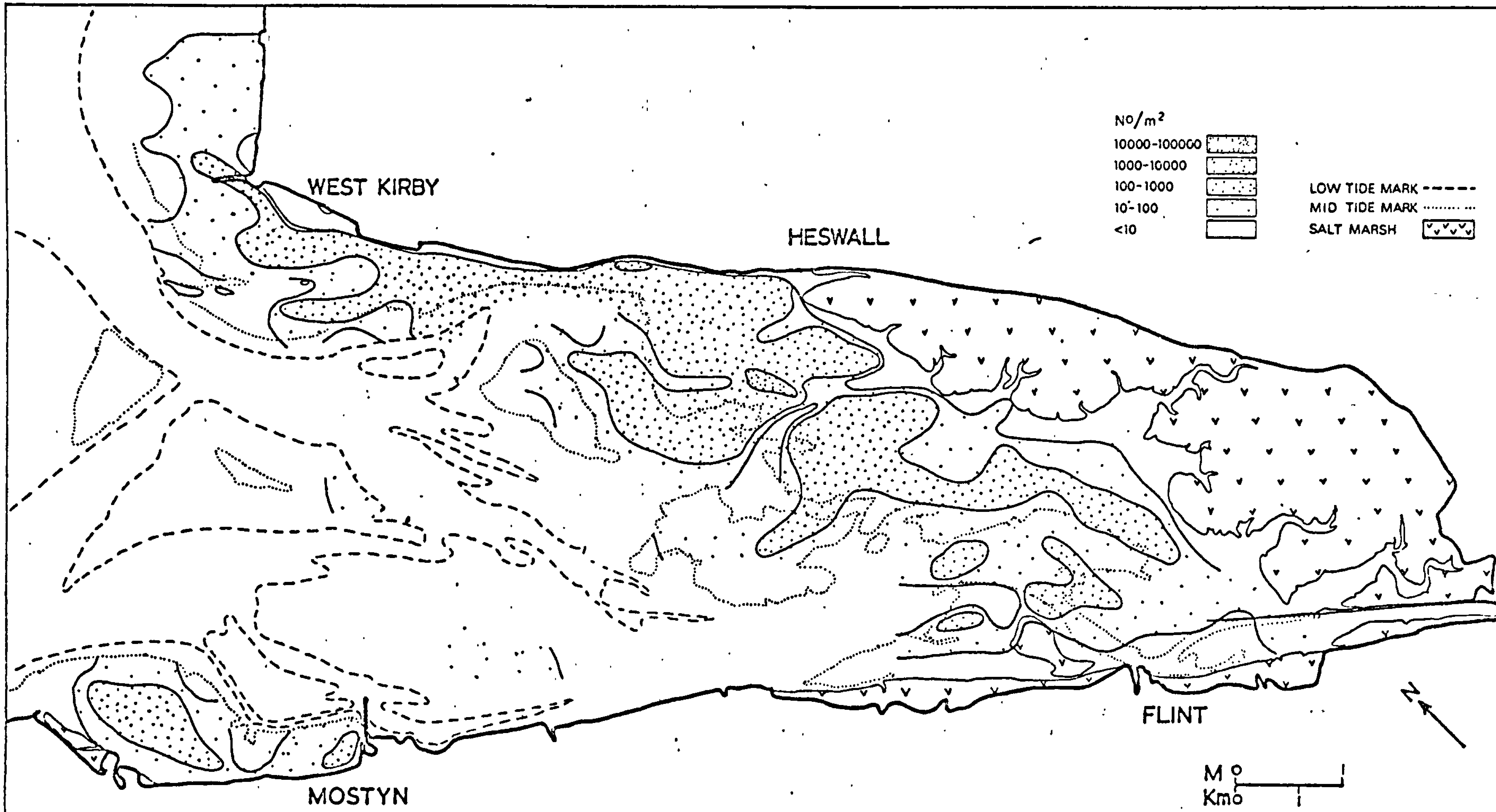
Map 169. Density distribution of Macoma balthica more than 10 mm in length in Spring 1974.



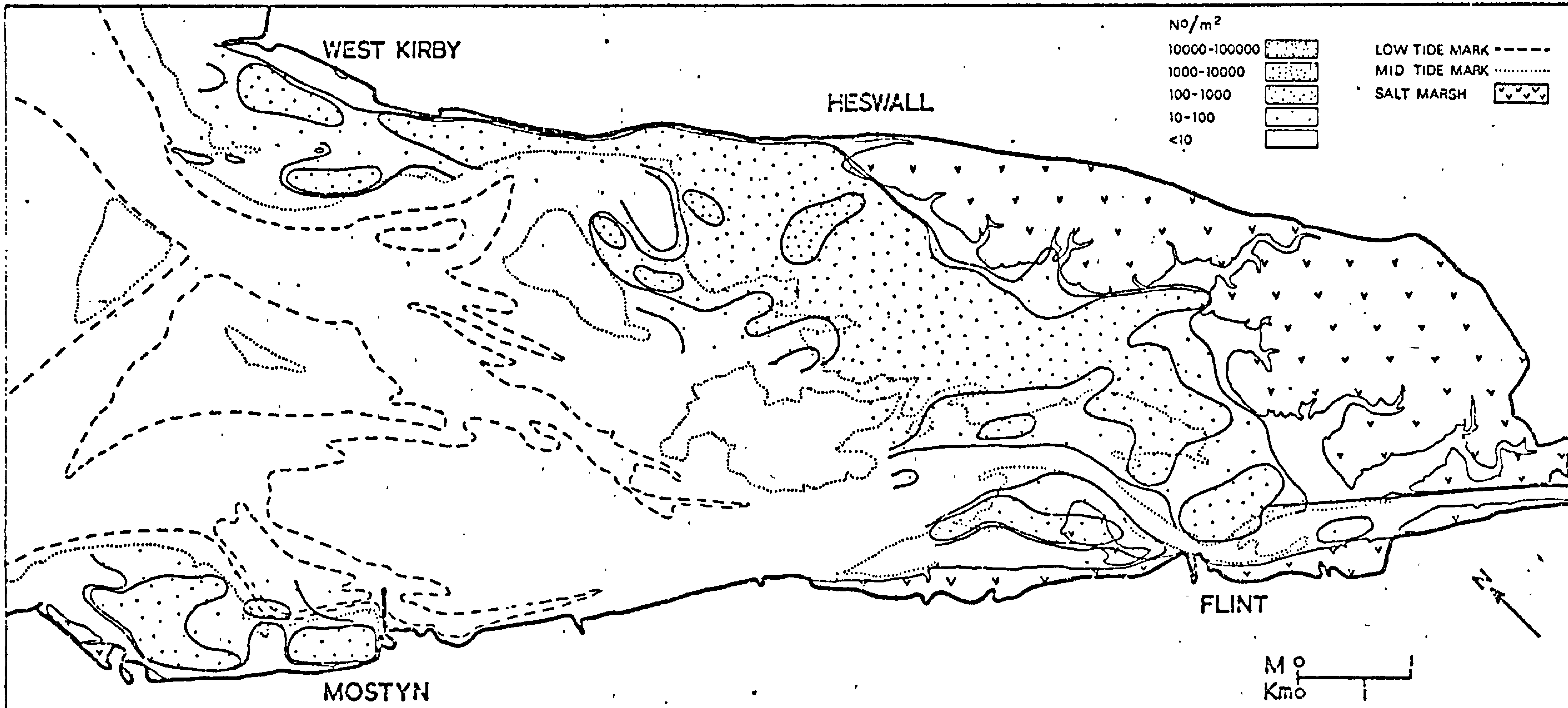
Map 170.. Density distribution of Macoma balthica more than 10 mm in length in Spring 1975.



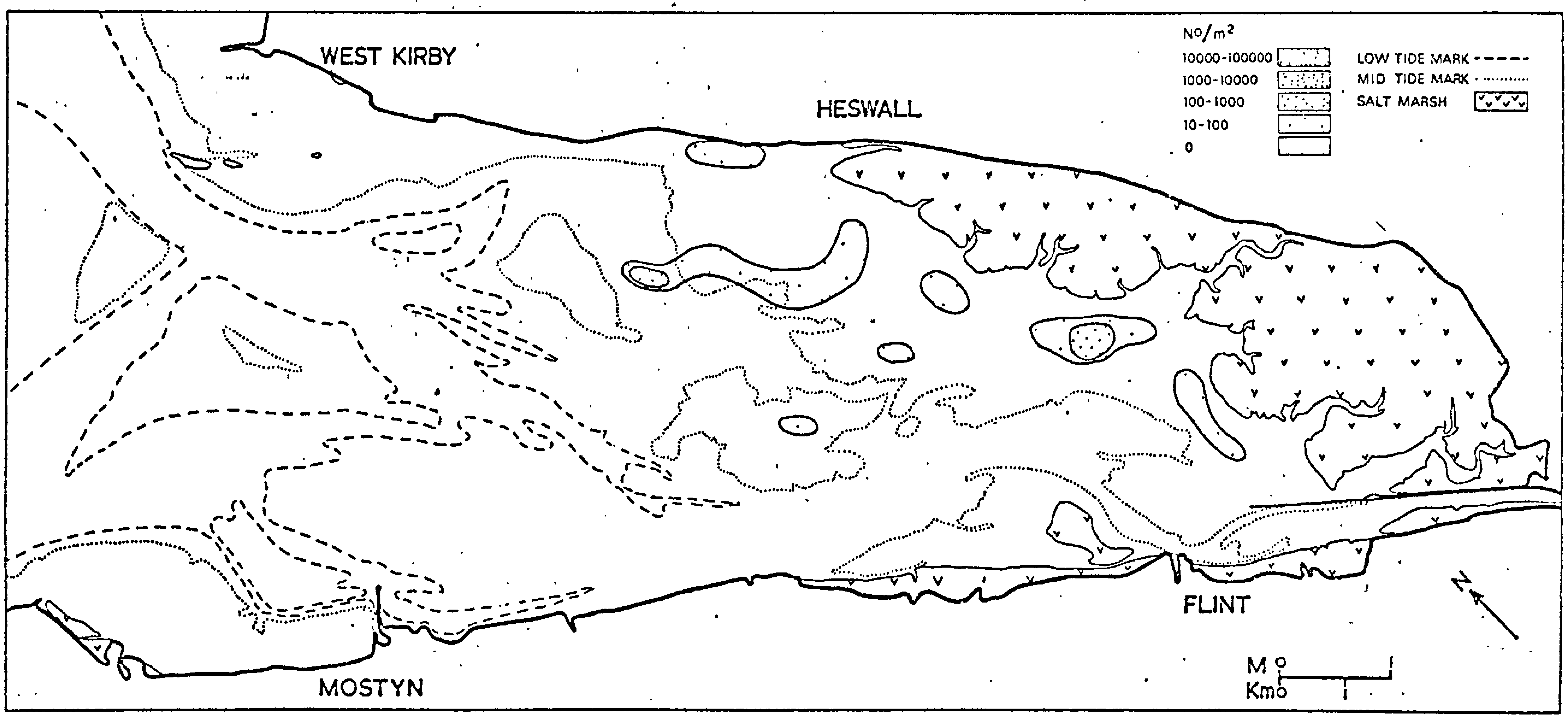
Map 171. Density distribution of <u>Macoma balthica</u> more than 10 mm in length in Autumn 1975.



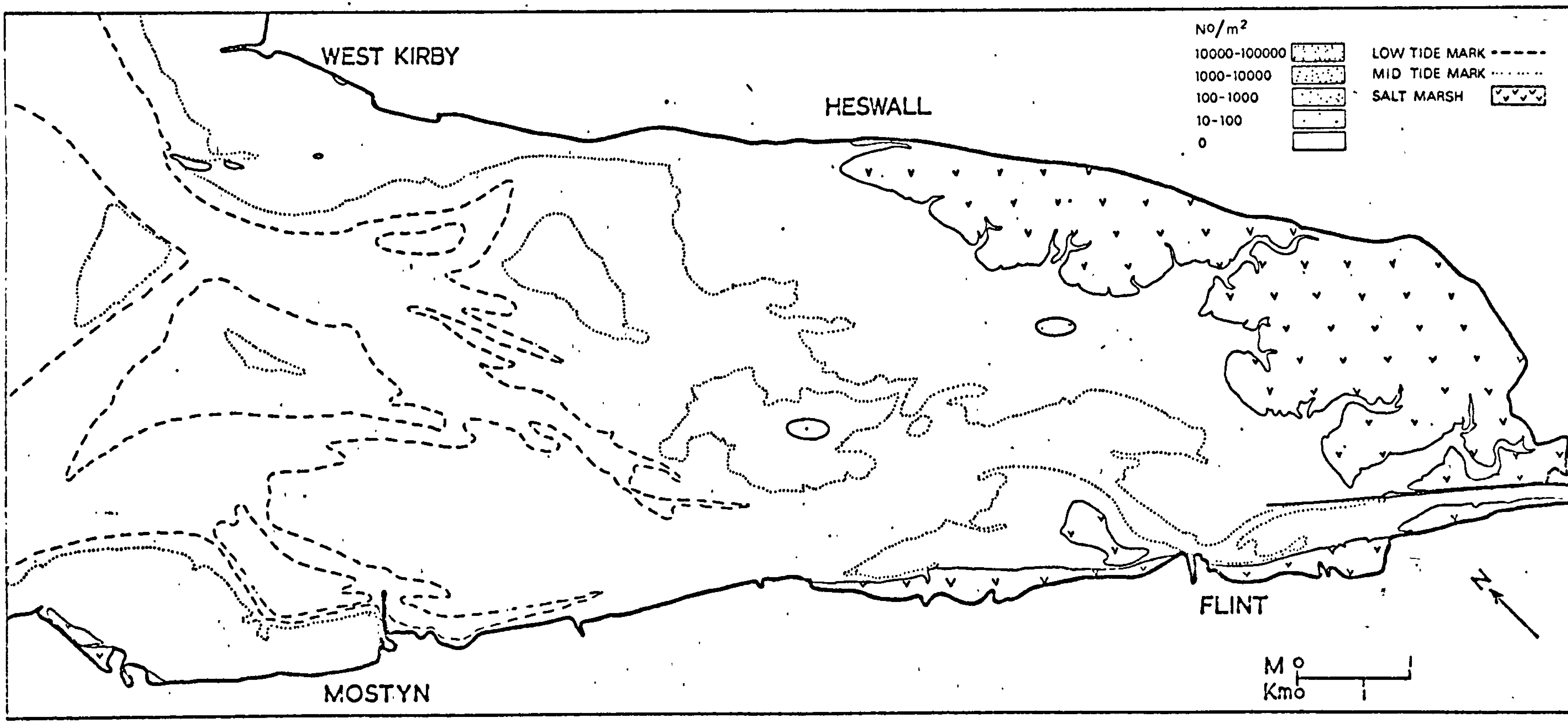
Map 172. Density distribution of <u>Macoma balthica</u> more than 10 mm in length in Spring 1976.



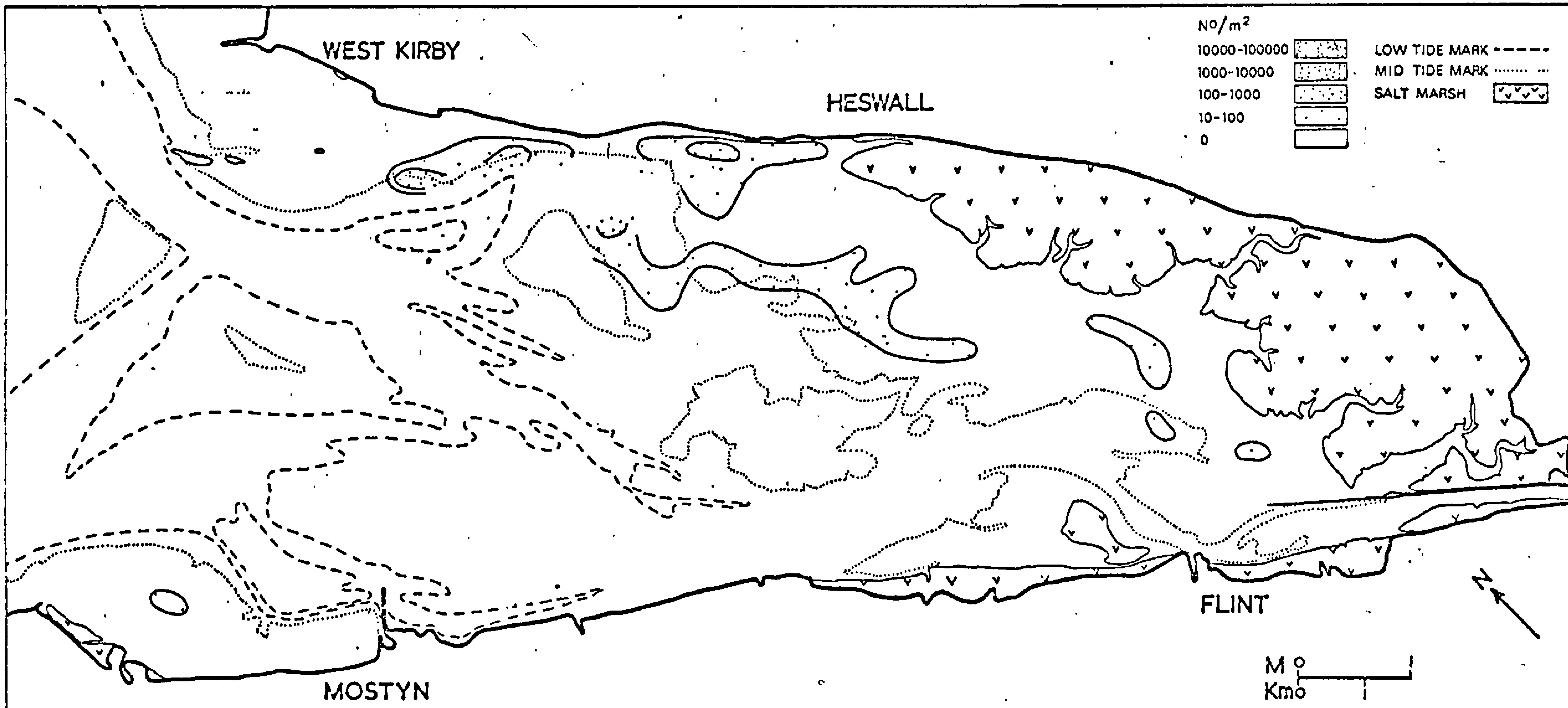
Map 173. Density distribution of Macoma balthica more than 10 mm in length in Autumn 1976.



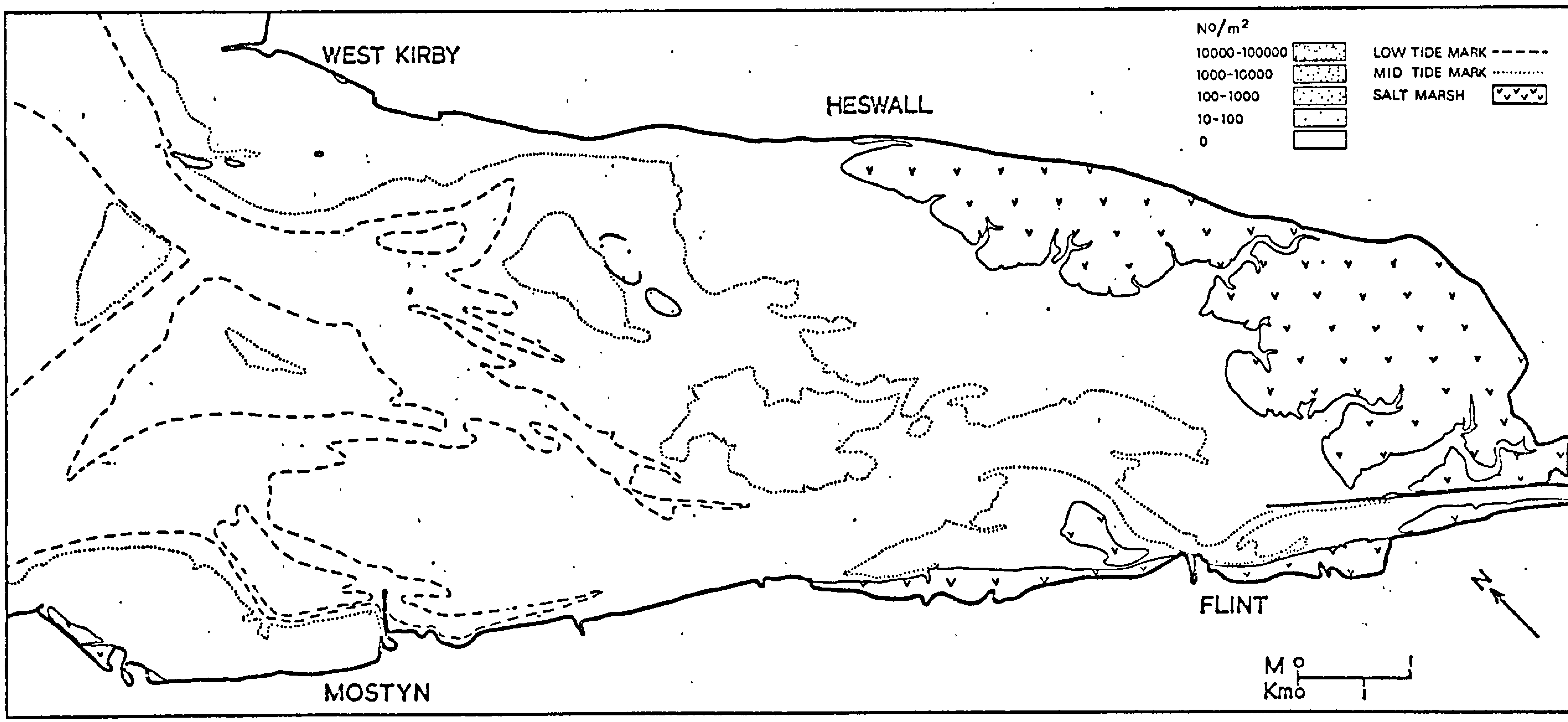
Map 174. Density distribution of Mya arenaria in Autumn 1971.



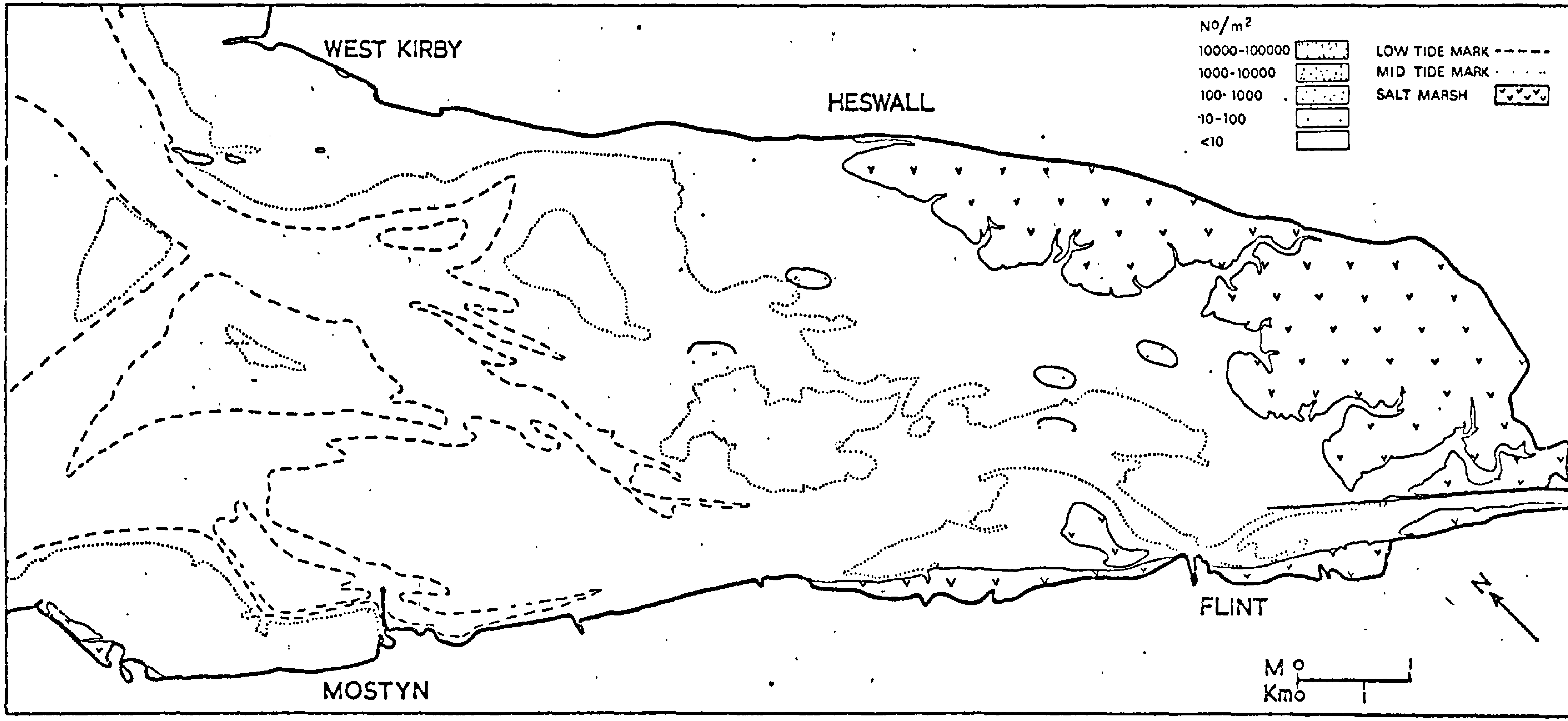
Map 175. Density distribution of <u>Mya arenaria</u> in Spring 1972.



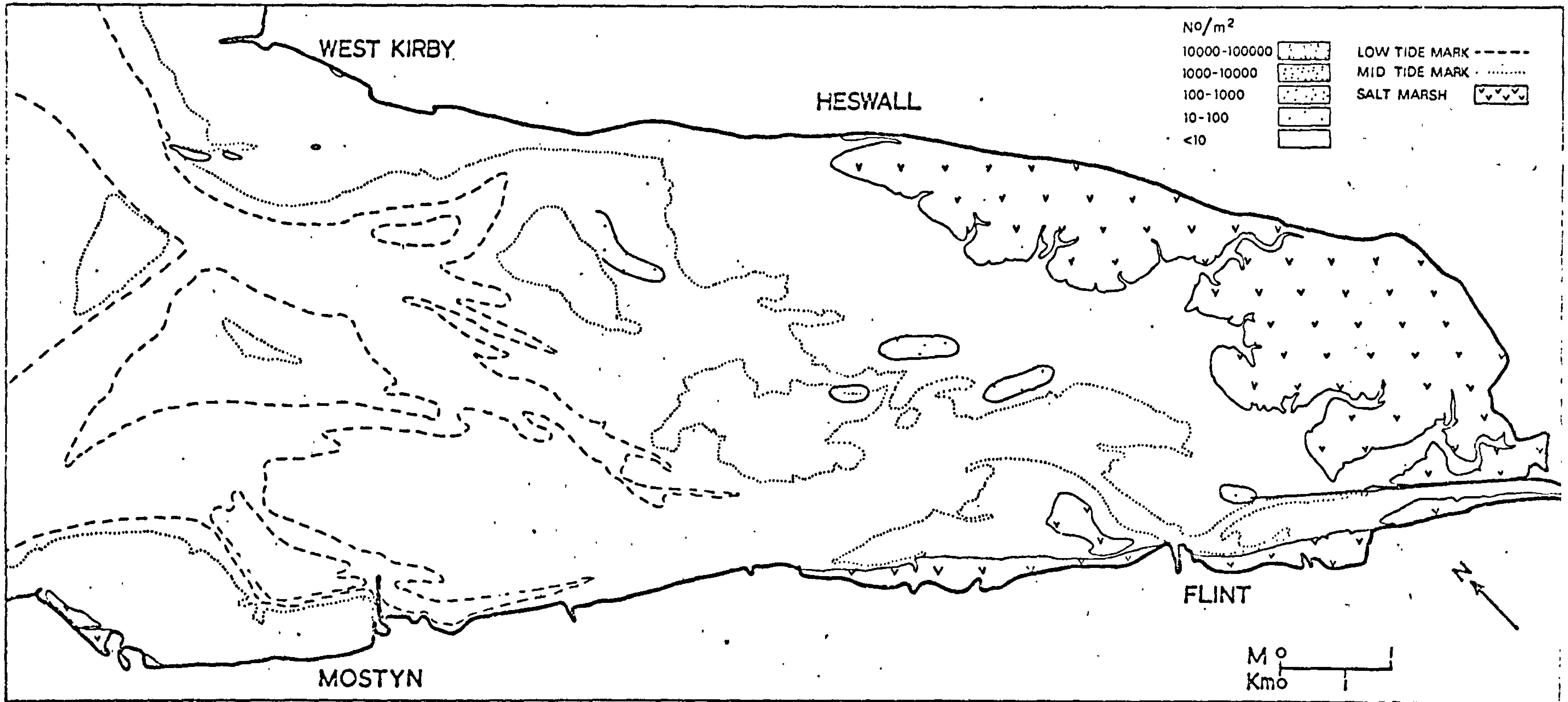
Map 176. Density distribution of Mya arenaria in Spring 1973.



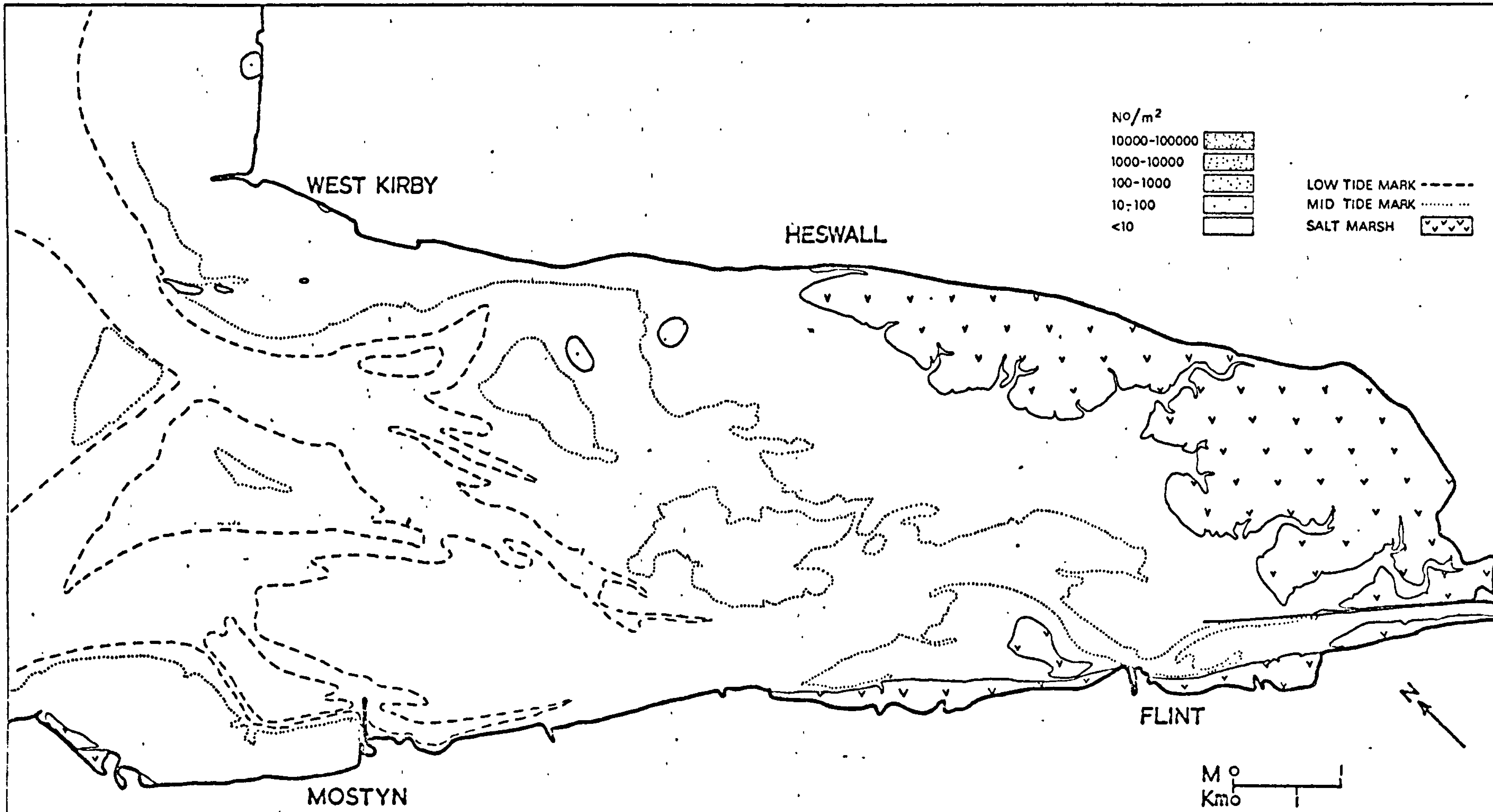
Map 177. Density distribution of Mya arenaria in Spring 1974.



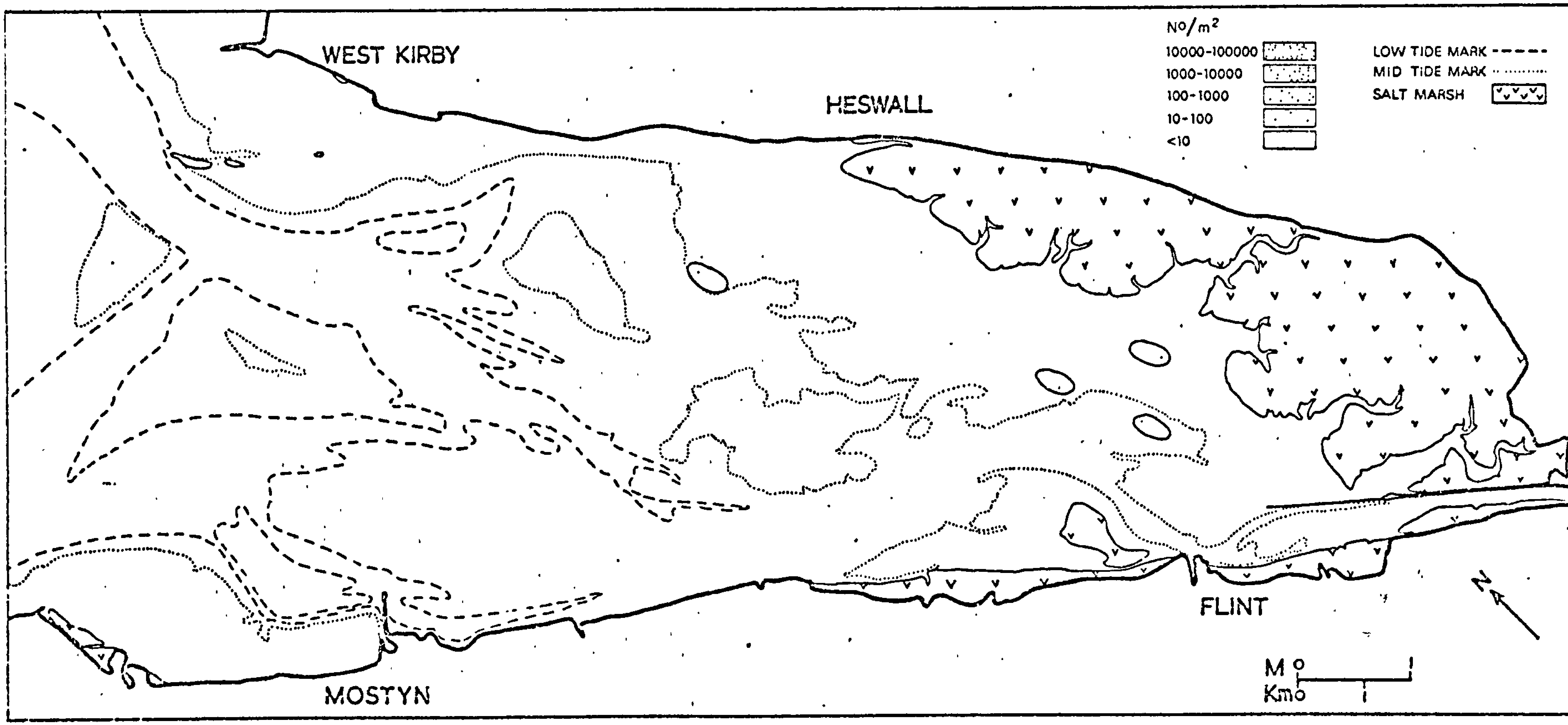
Map 178. Density distribution of Mya arenaria in Spring 1975.



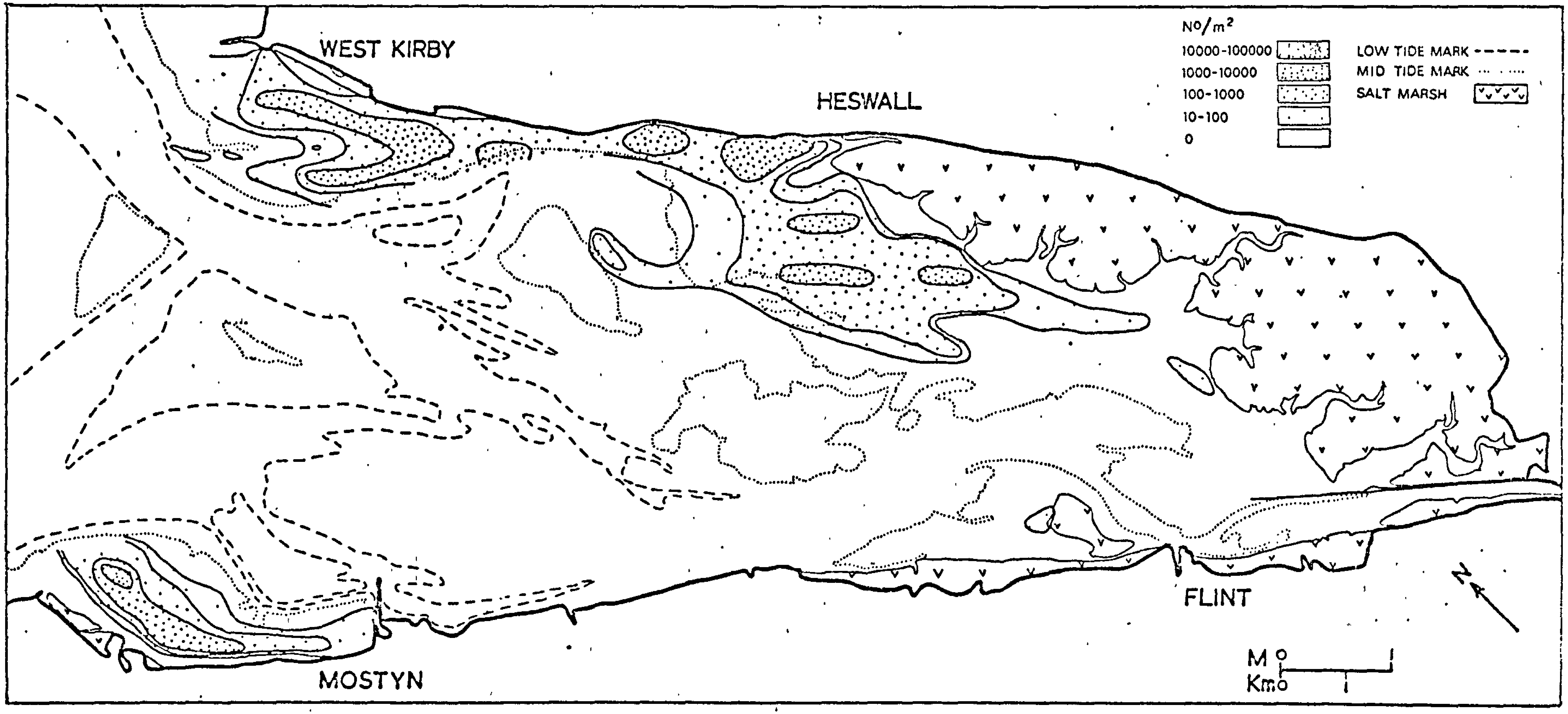
Map 179. Density distribution of <u>Mya arenaria</u> in Autumn 1975.



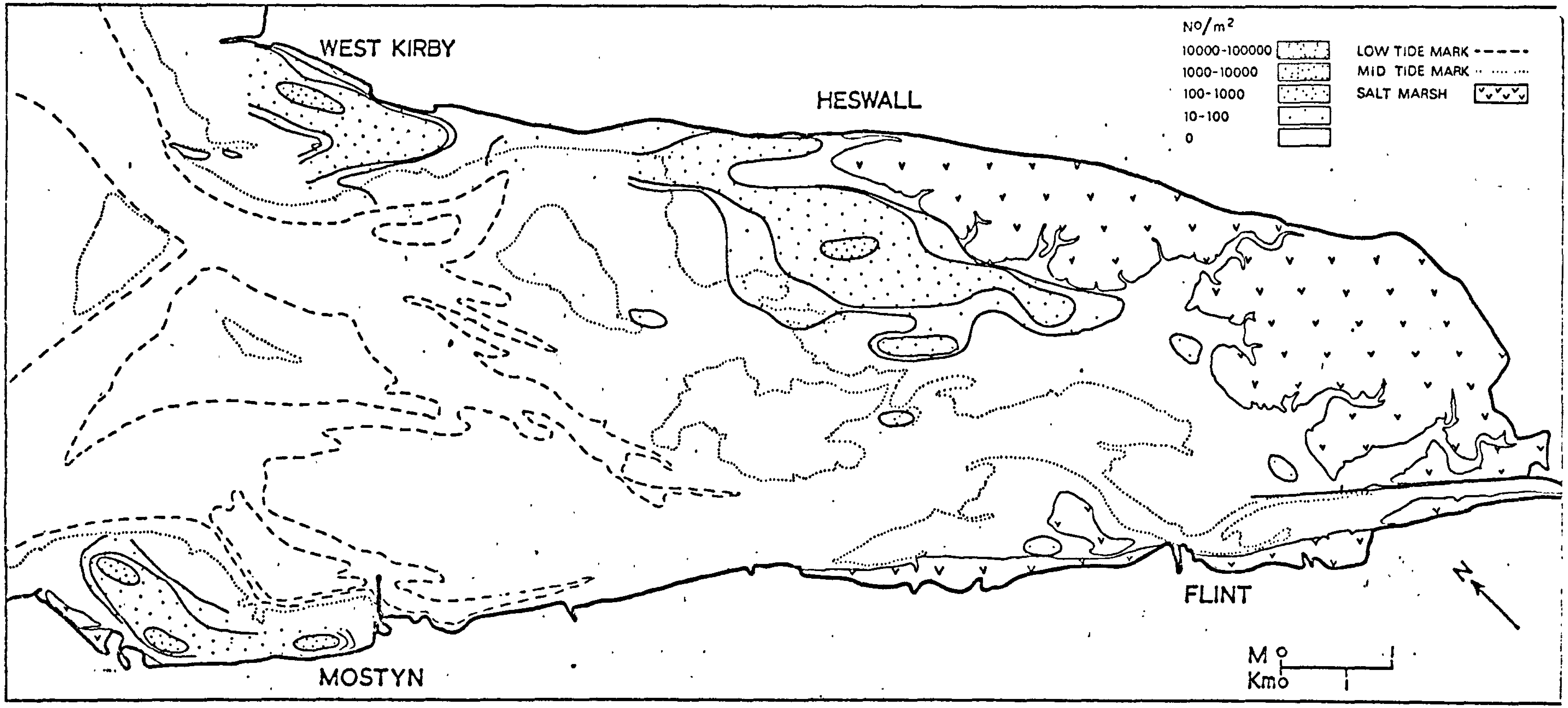
Map 180. Density distribution of _Mya arenaria_ in Spring 1976.



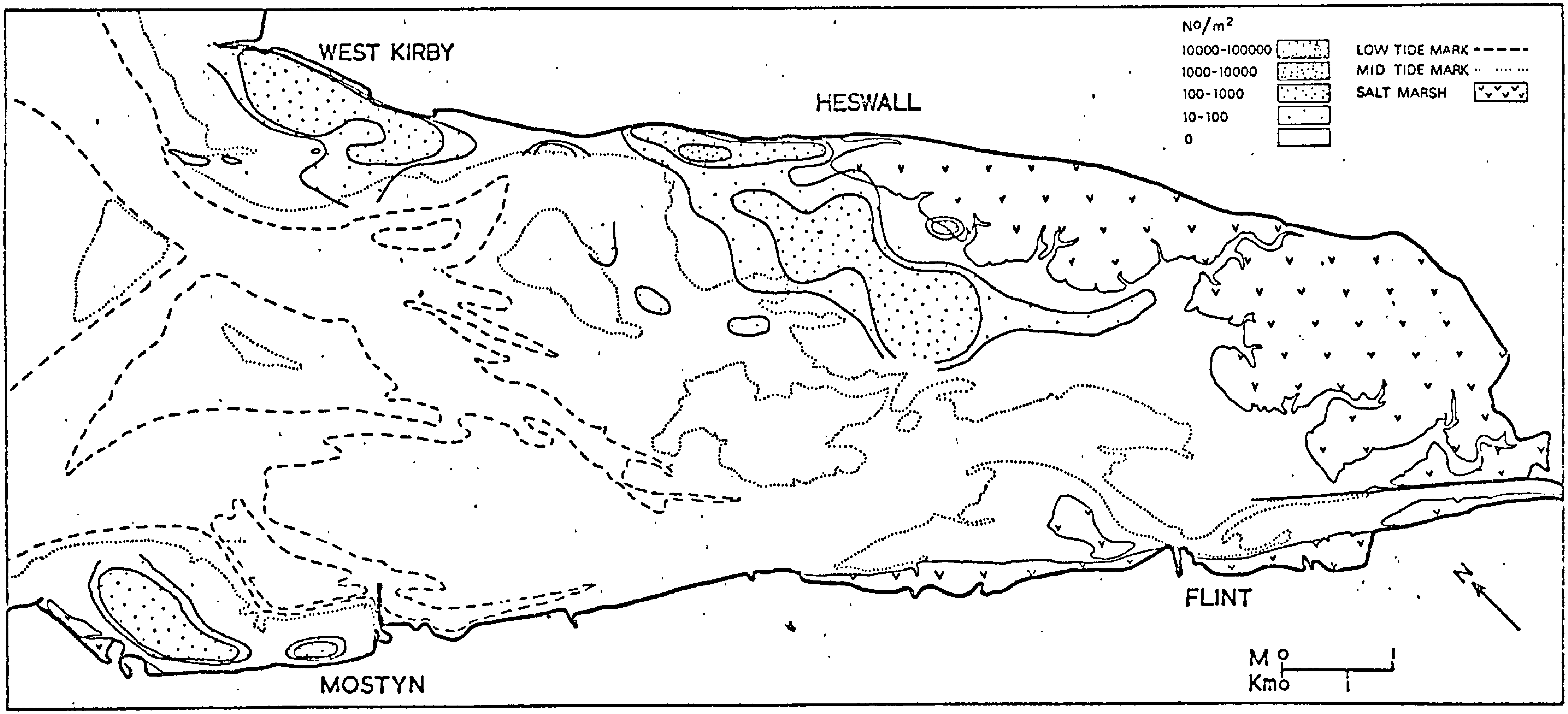
Map 181. Density distribution of <u>Mya arenaria</u> in Autumn 1976.



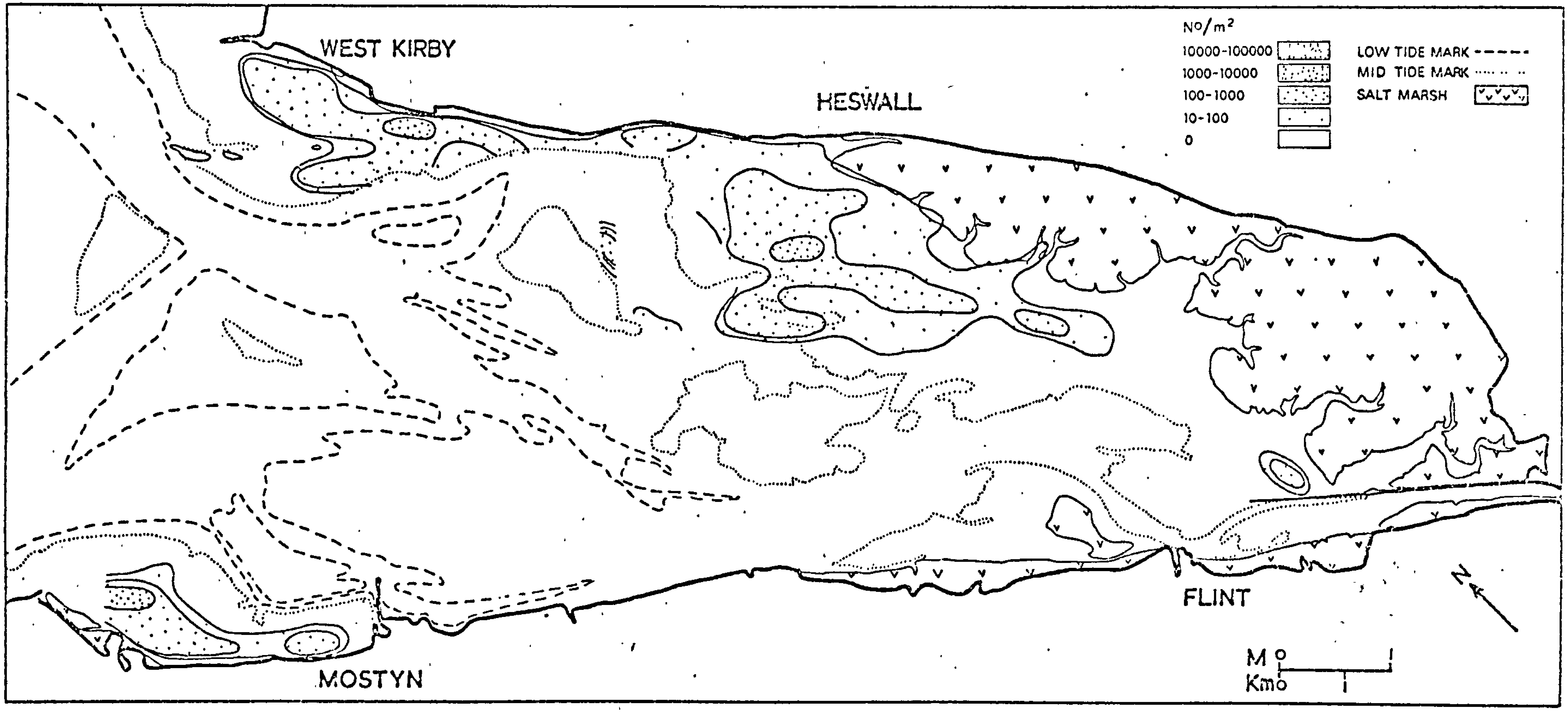
Map 182. Density distribution of <u>Hydrobia ulvae</u> in Autumn 1971.



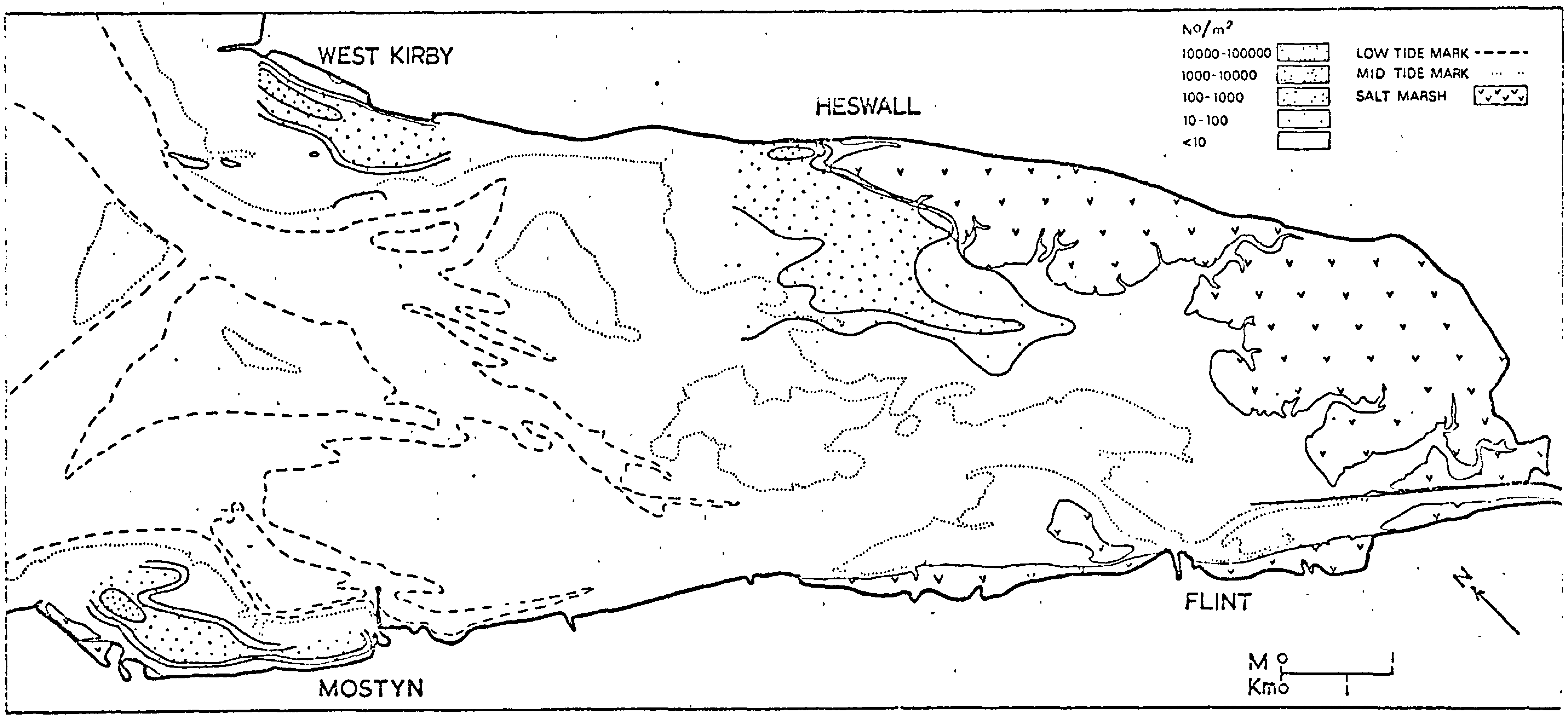
Map 183. Density distribution of _Hydrobia ulvae_ in Spring 1972.



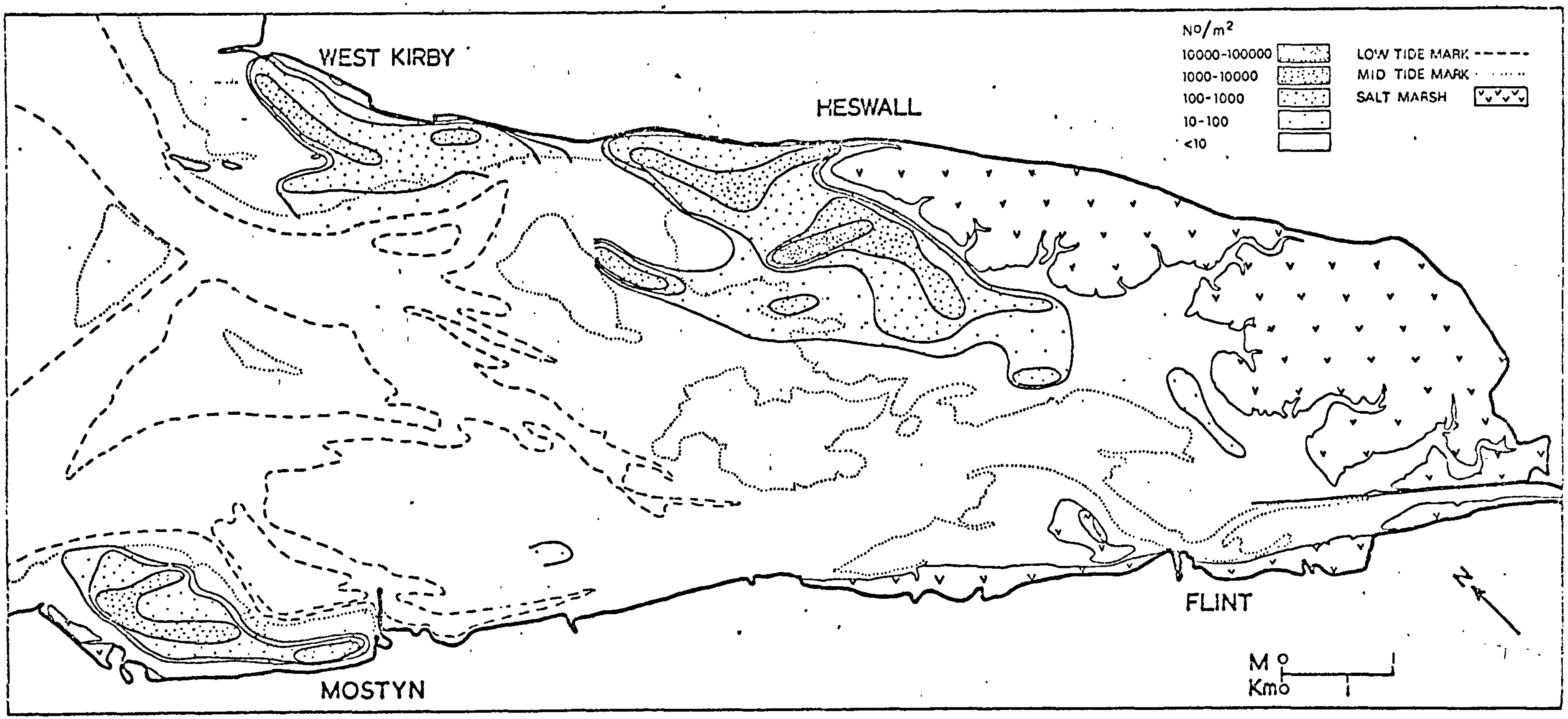
Map 184. Density distribution of Hydrobia ulvae in Spring 1973.



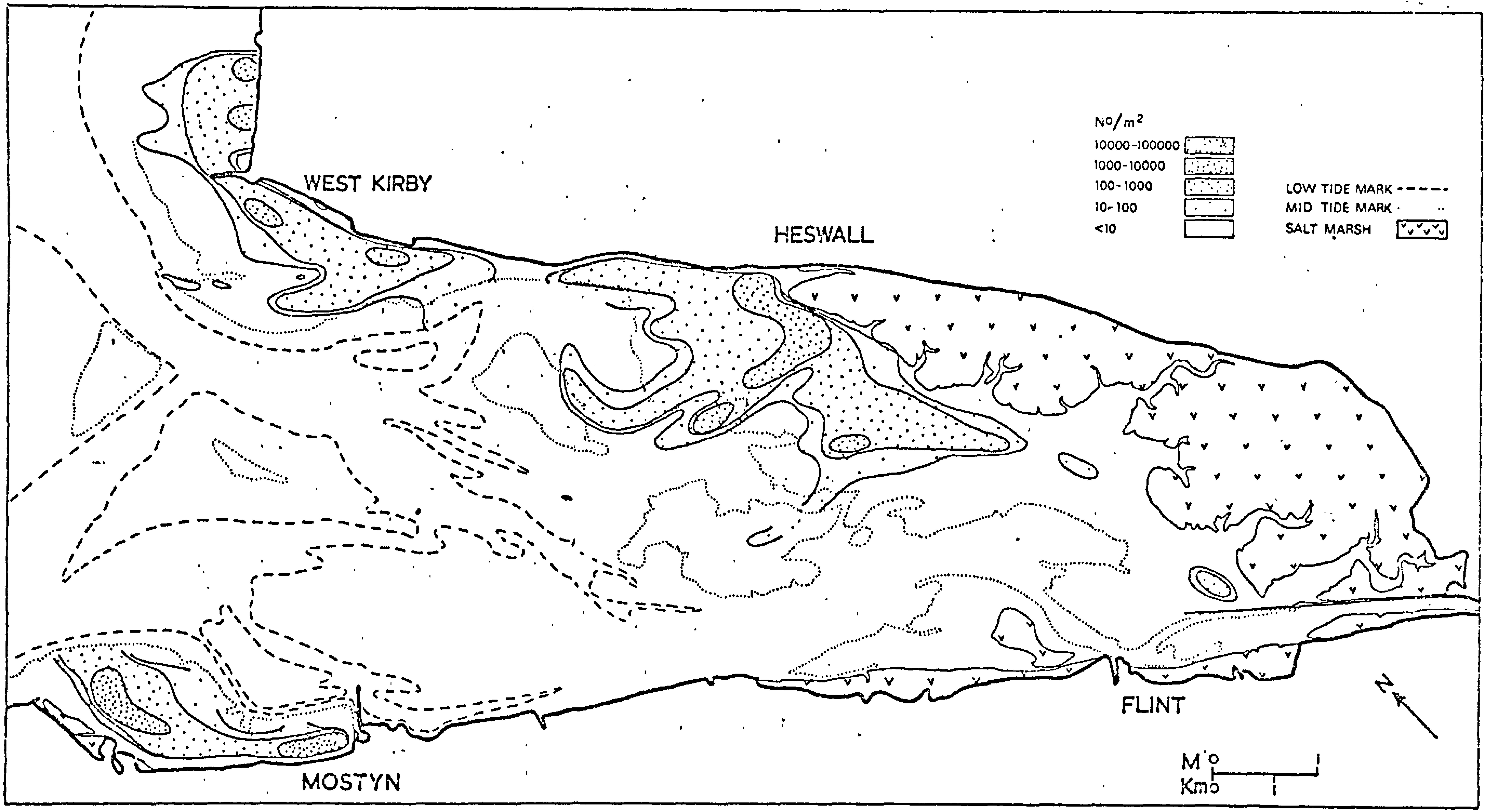
Map 185. Density distribution of Hydrobia ulvae in Spring 1974.



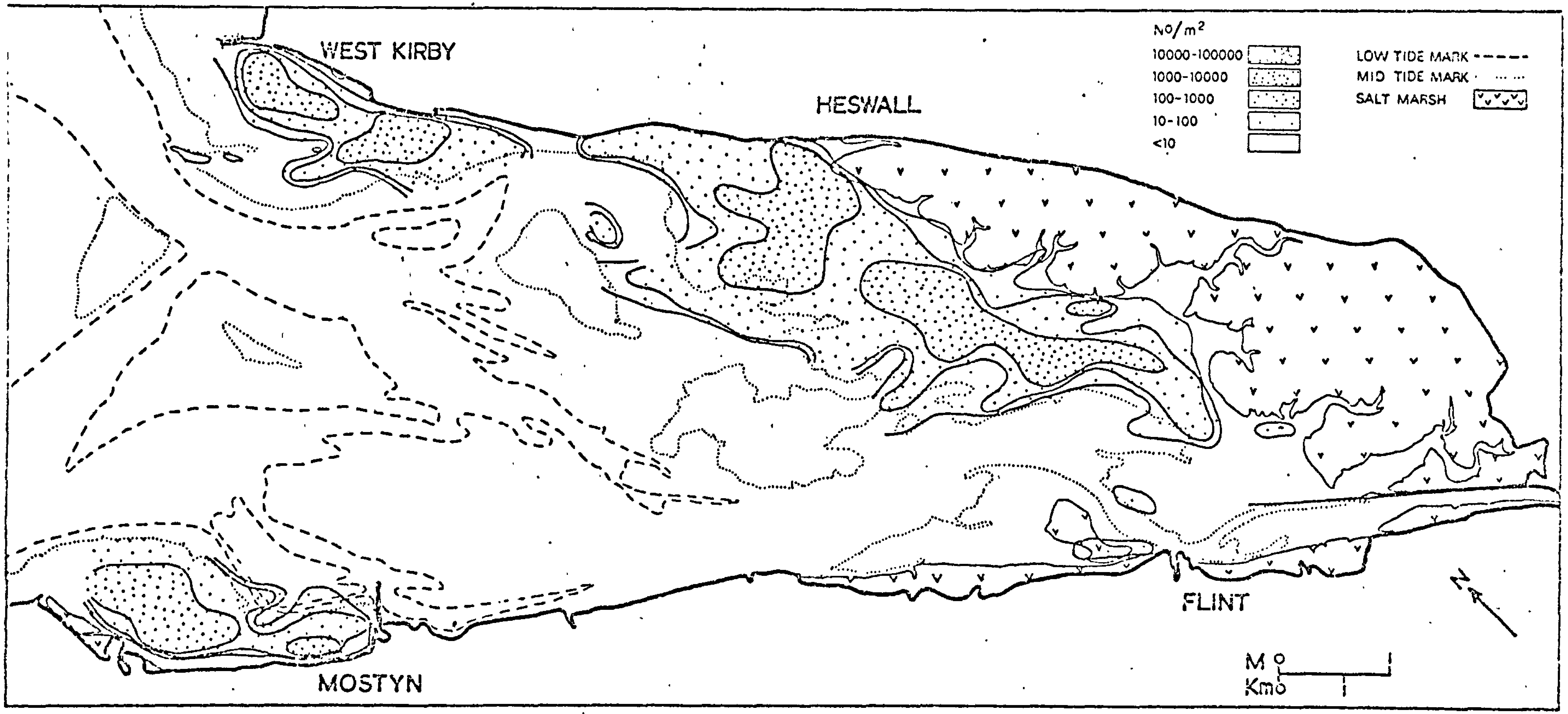
Map 186. Density distribution of Hydrobia ulvae in Spring 1975.



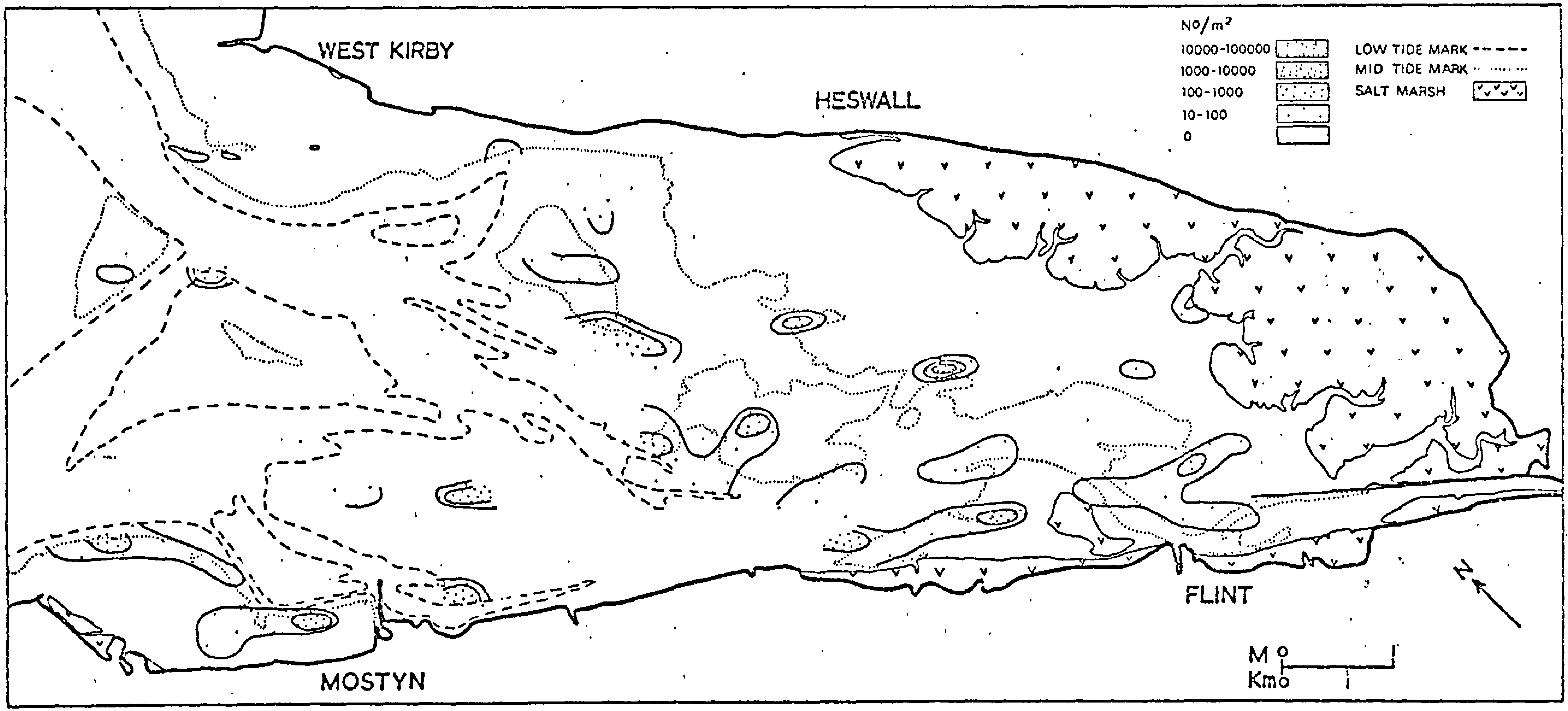
Map 187. Density distribution of <u>Hydrobia ulvae</u> in Autumn 1975.



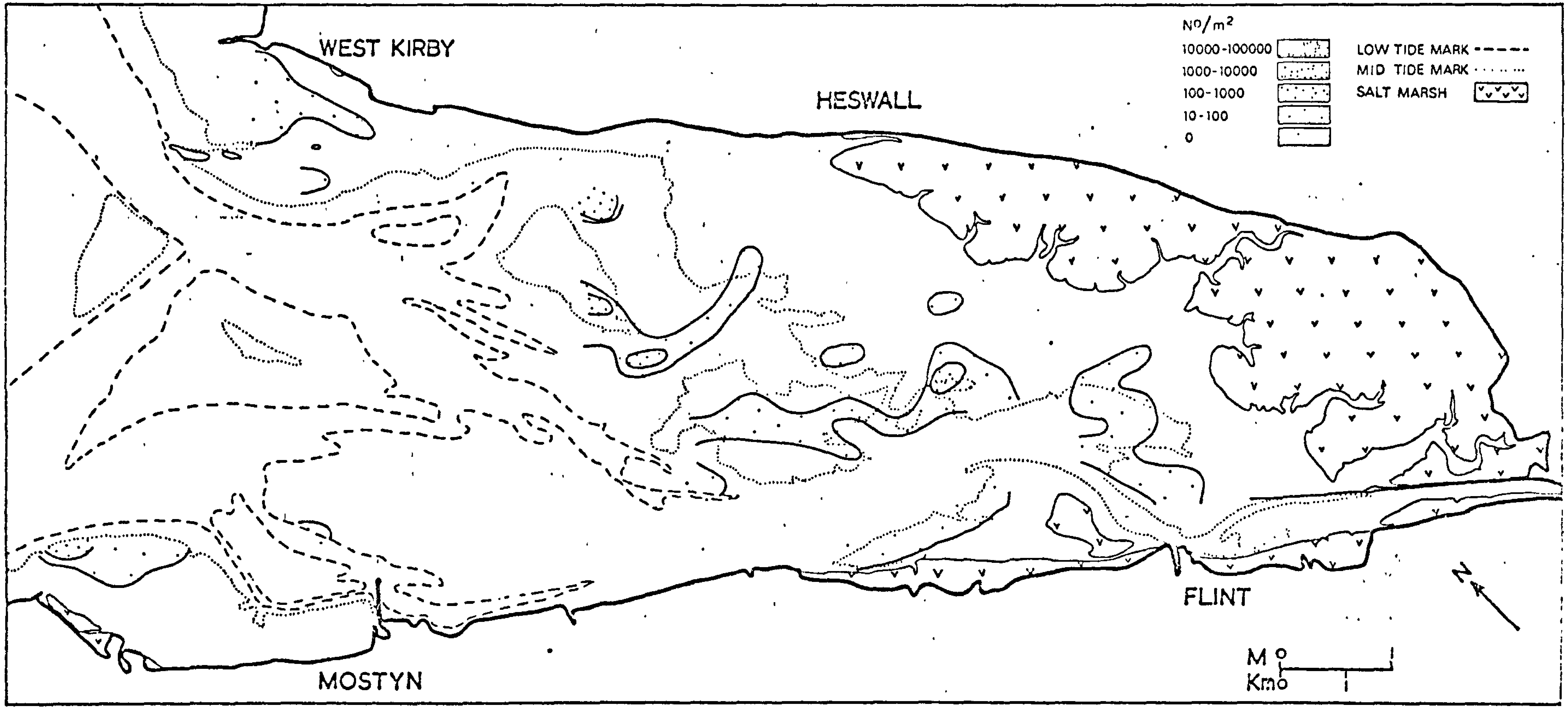
Map 188. Density distribution of Hydrobia ulvae in Spring 1976.



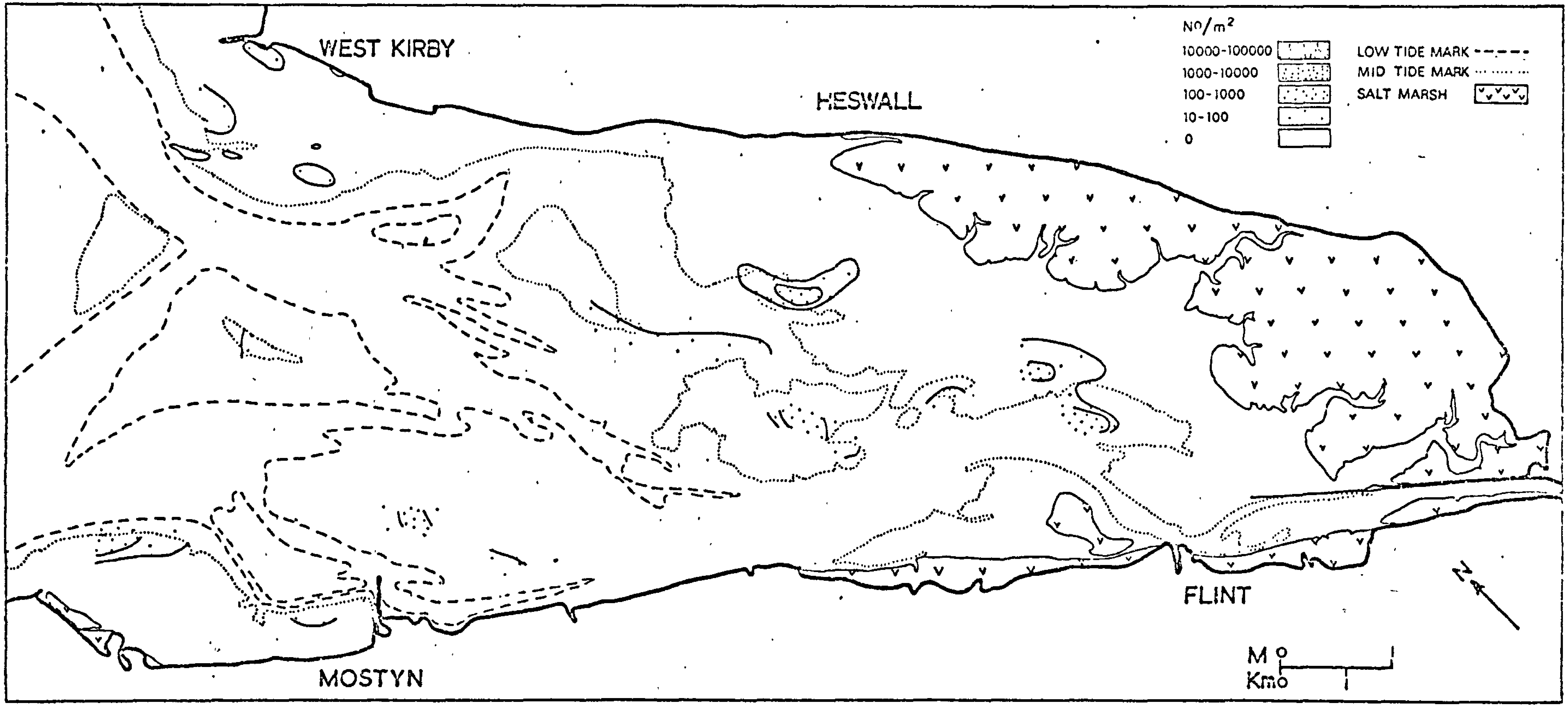
Map 189. Density distribution of <u>Hydrobia ulvae</u> in Autumn 1976.



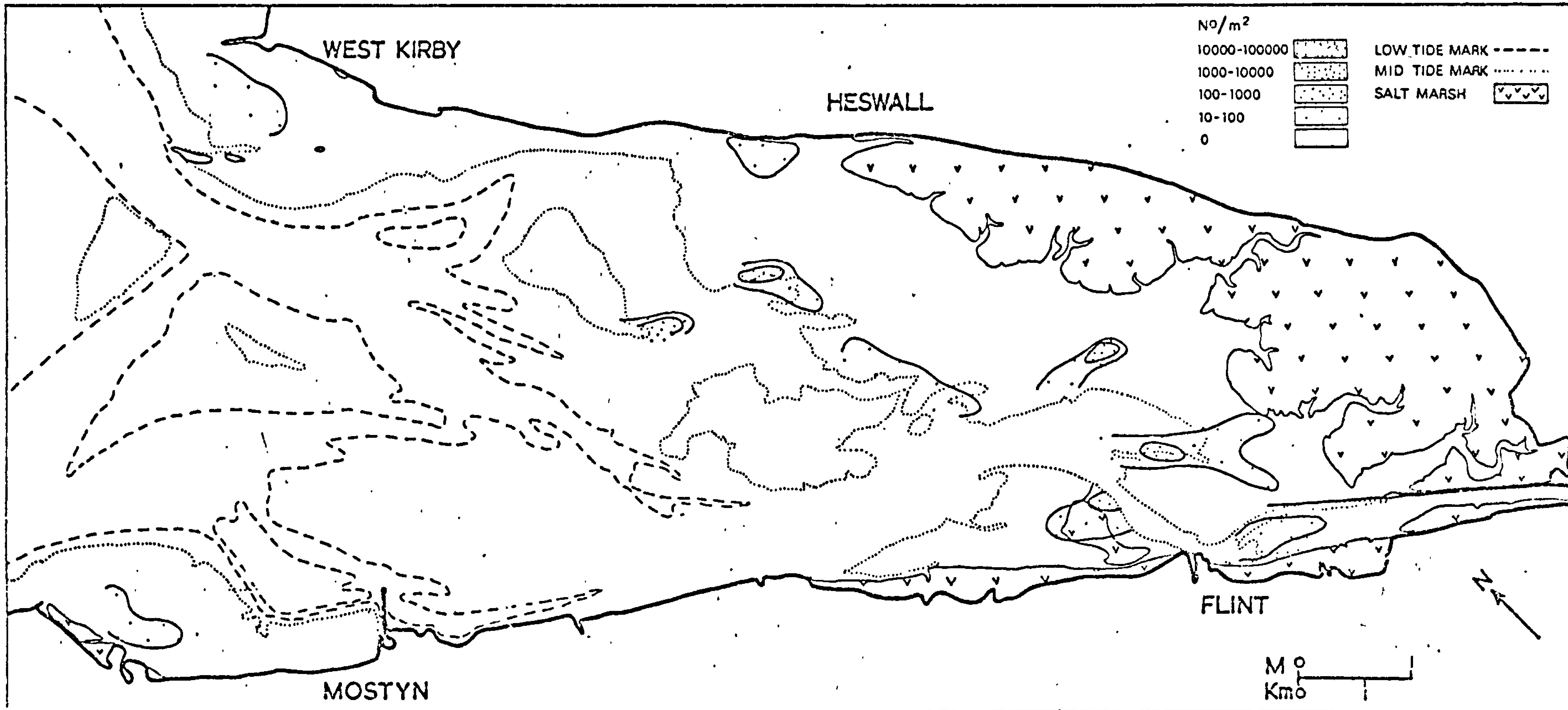
Map 190. Density distribution of Eurydice pulchra in Autumn 1971.



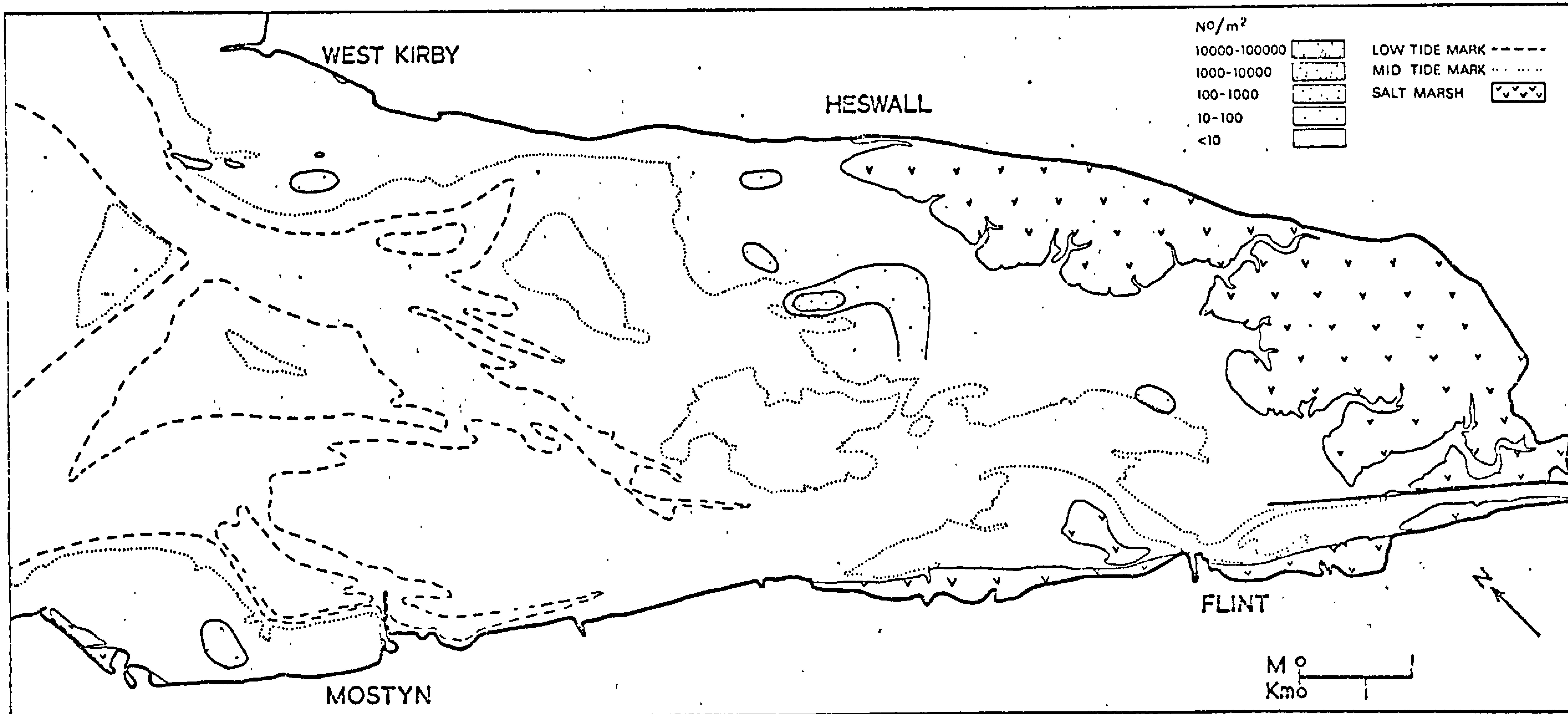
Map 191. Density distribution of Eurydice pulchra in Spring 1972.



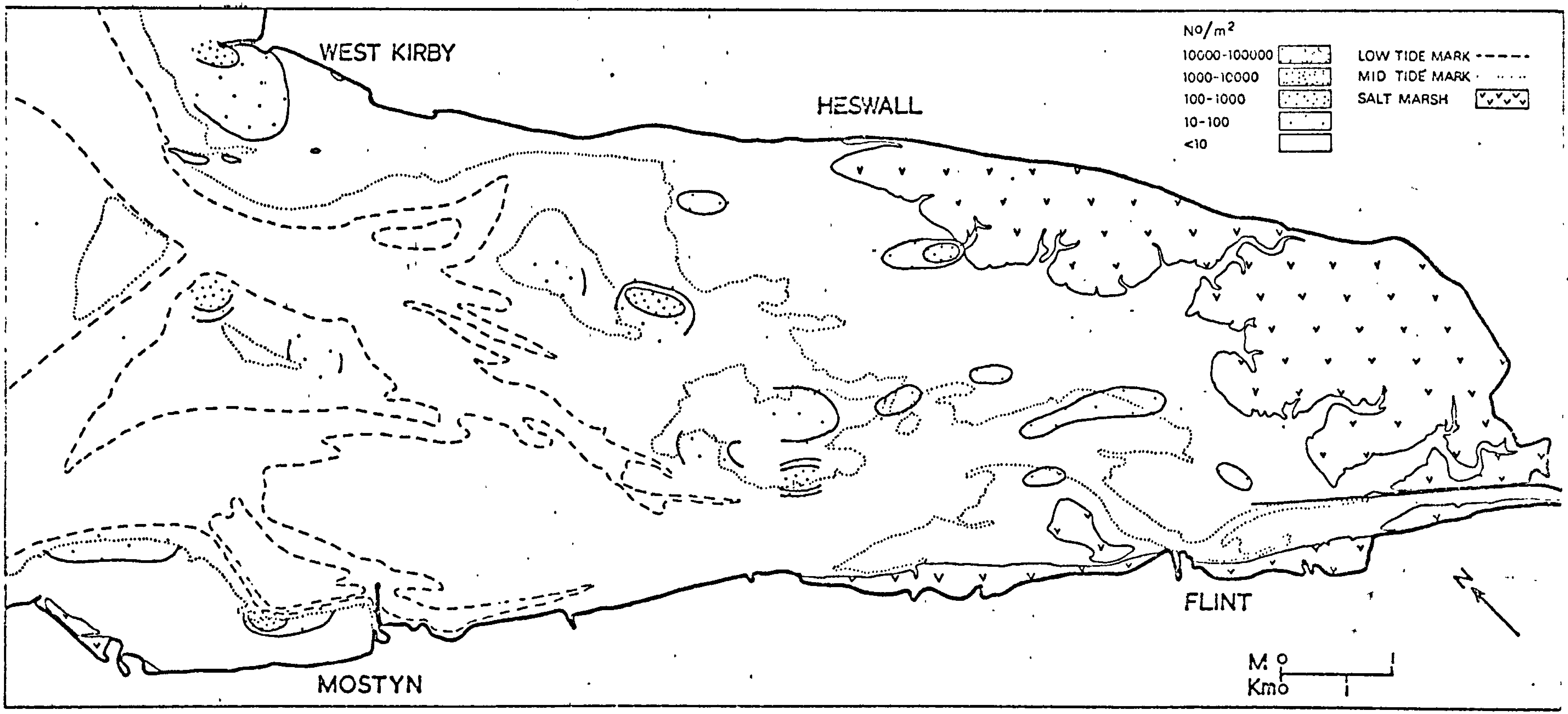
Map 192. Density distribution of Eurydice pulchra in Spring 1973.



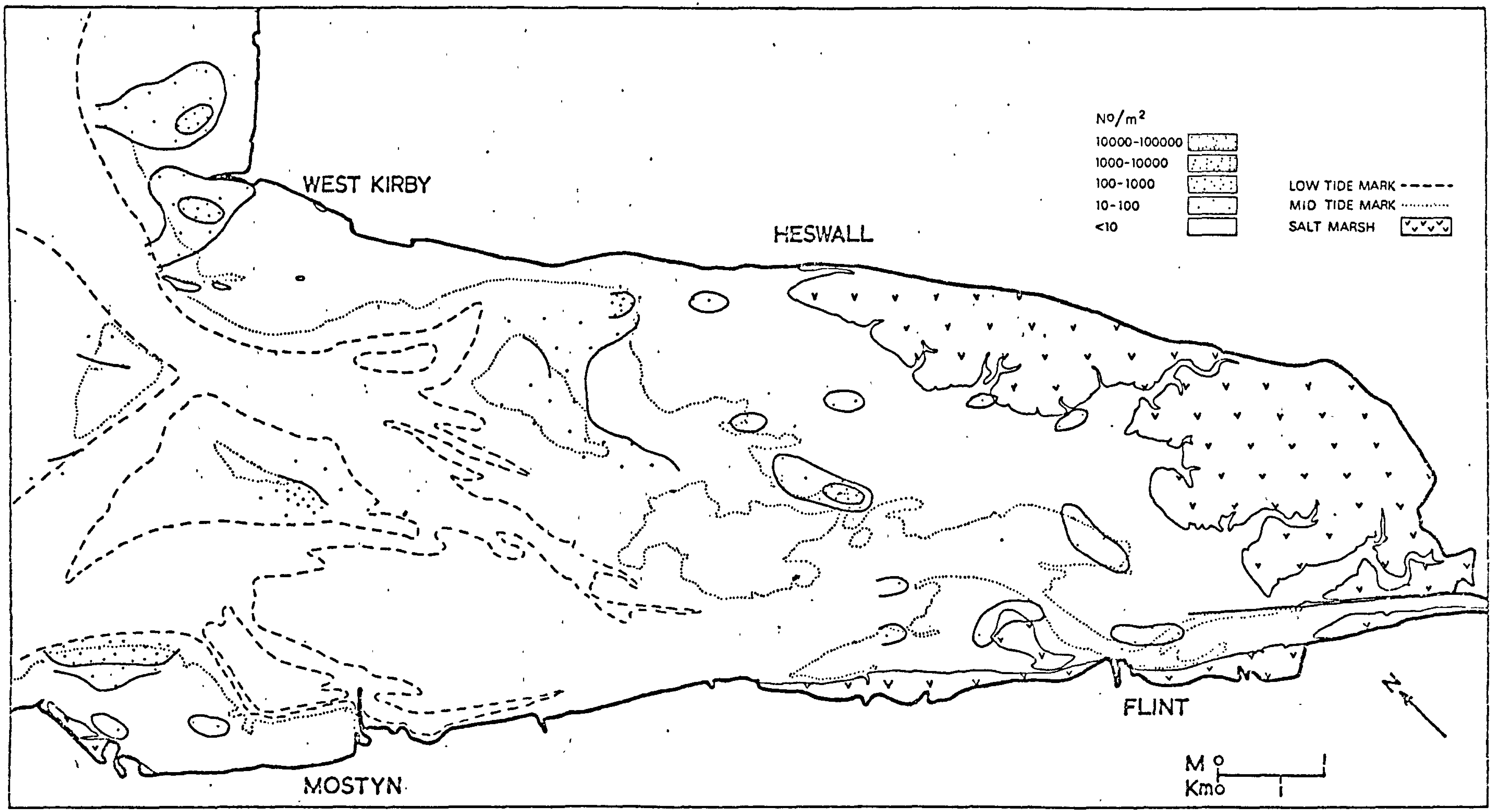
Map 193. Density distribution of <u>Eurydice pulchra</u> in Spring 1974.



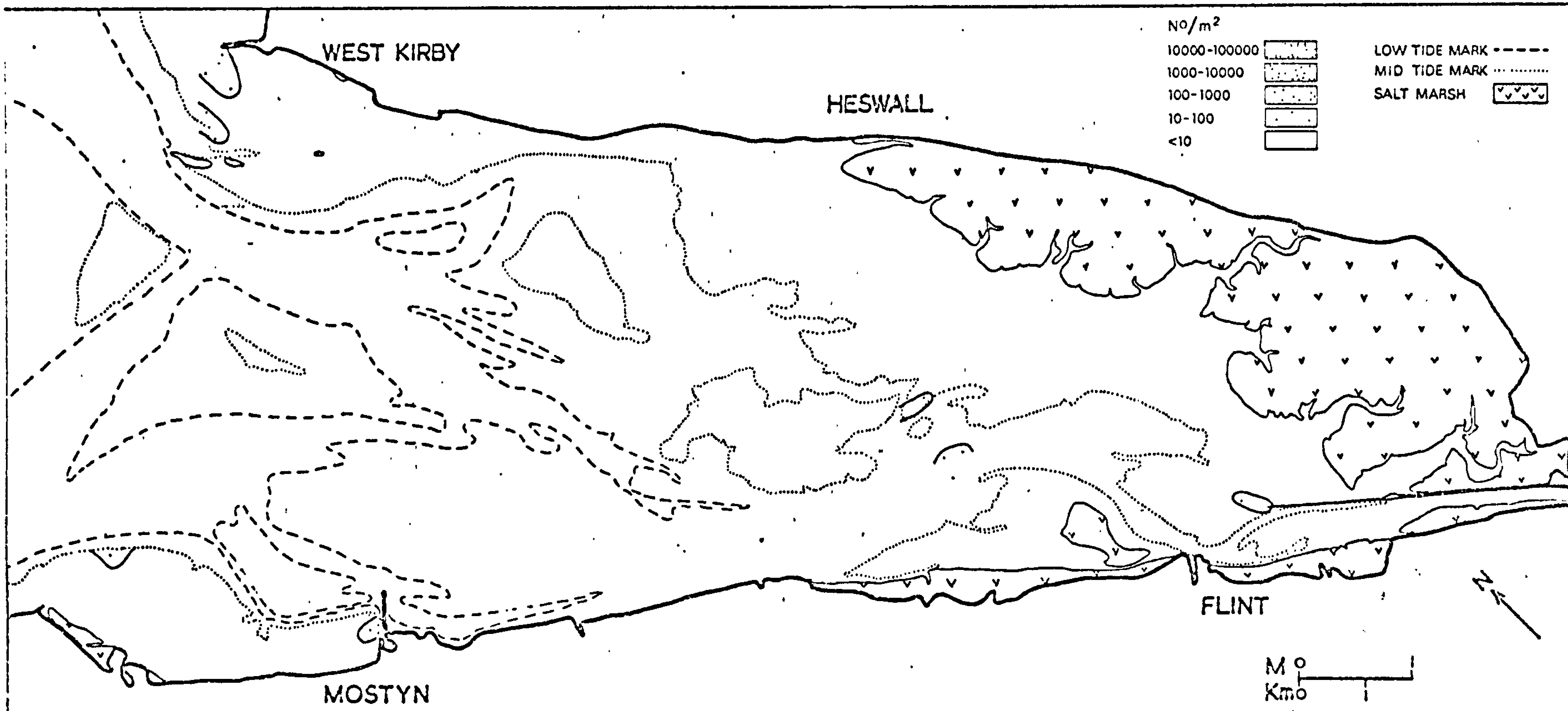
Map 194. Density distribution of *Eurydice pulchra* in Spring 1975.



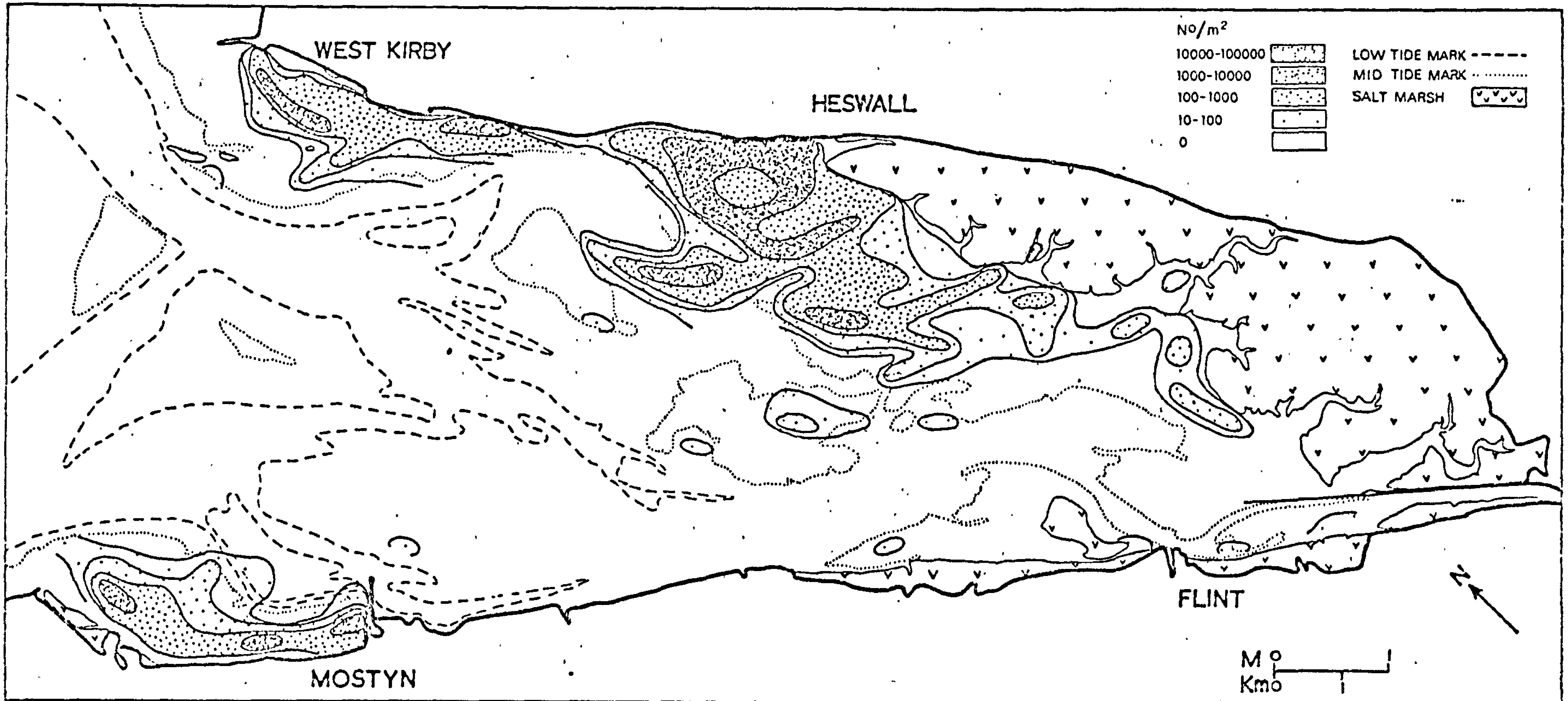
Map 195. Density distribution of Eurydice pulchra in Autumn 1975.



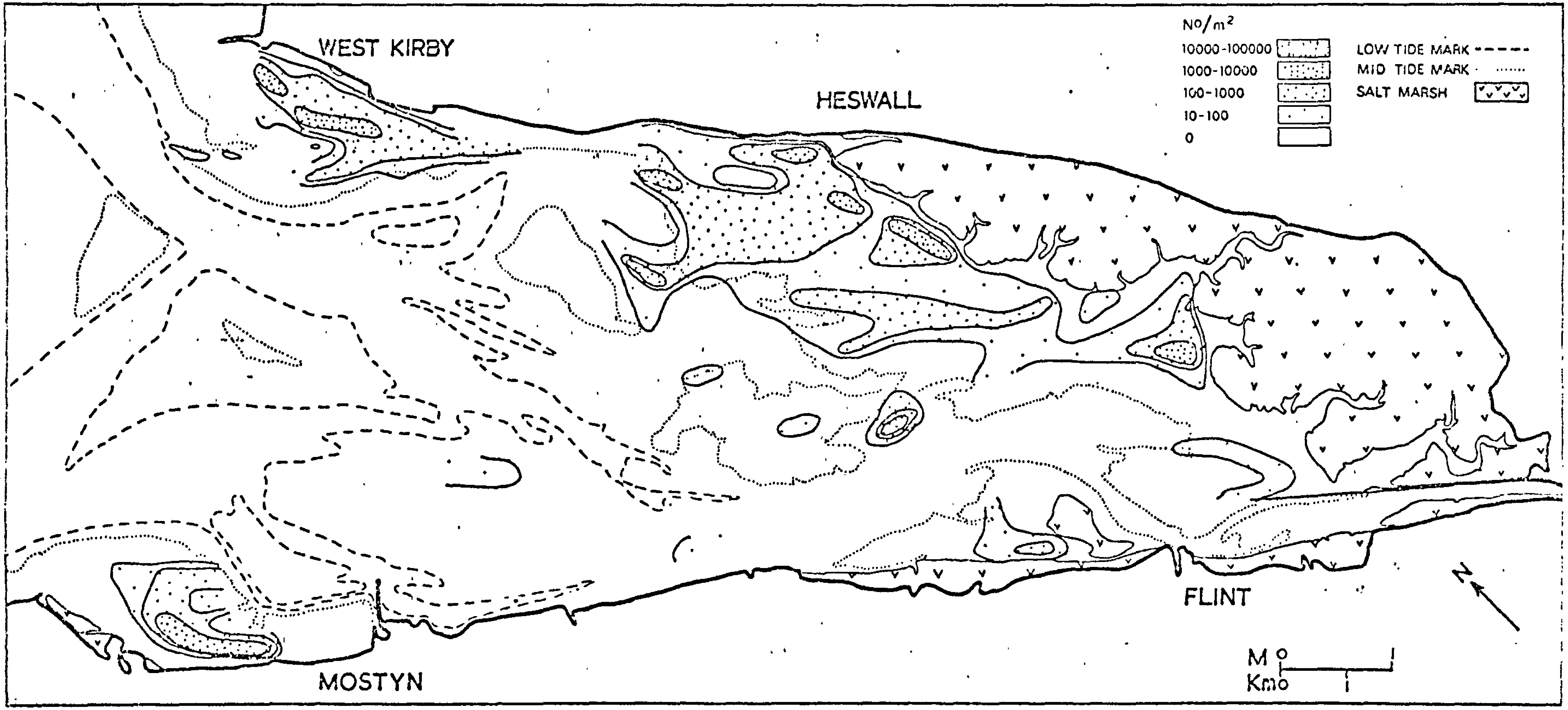
Map 196. Density distribution of Eurydice pulchra in Spring 1976.



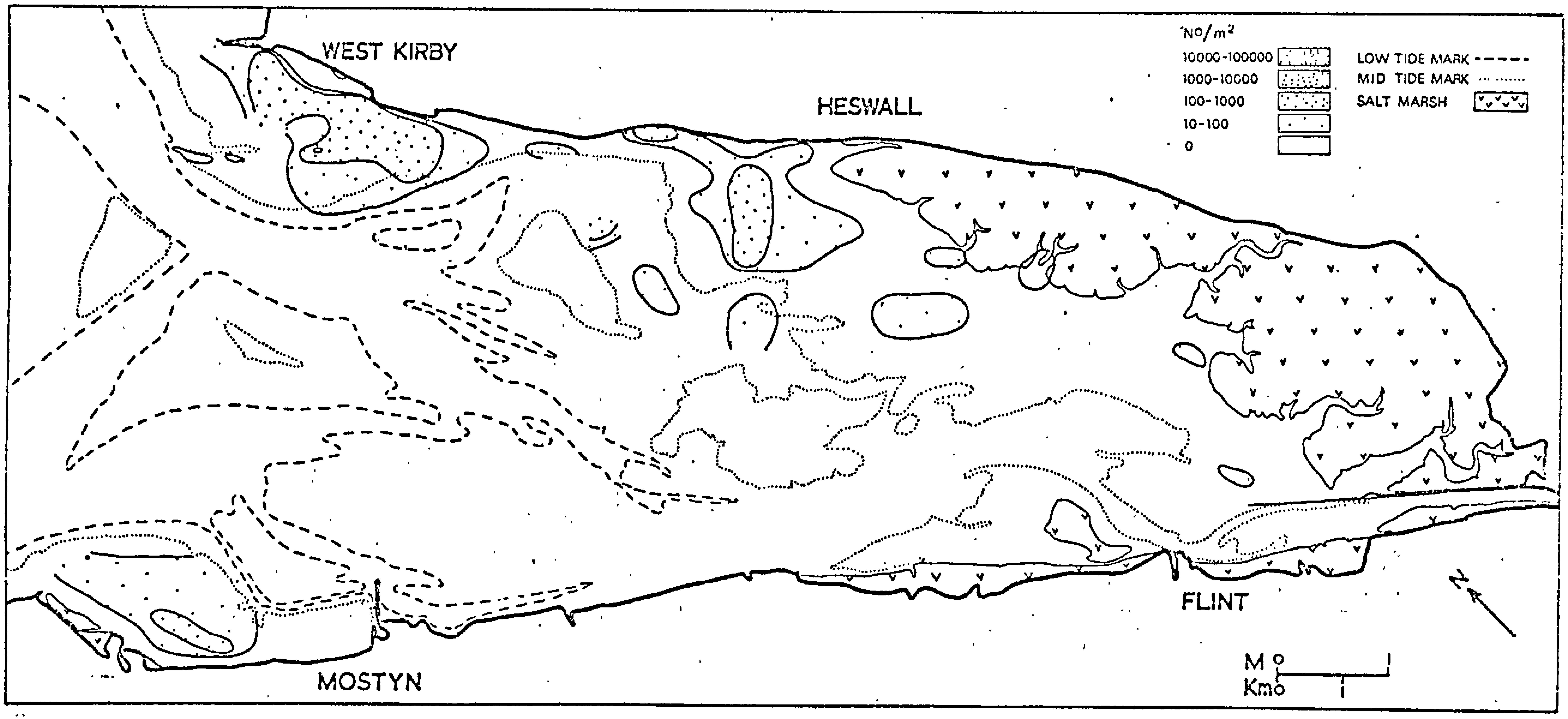
Map 197. Density distribution of <u>Eurydice pulchra</u> in Autumn 1976.



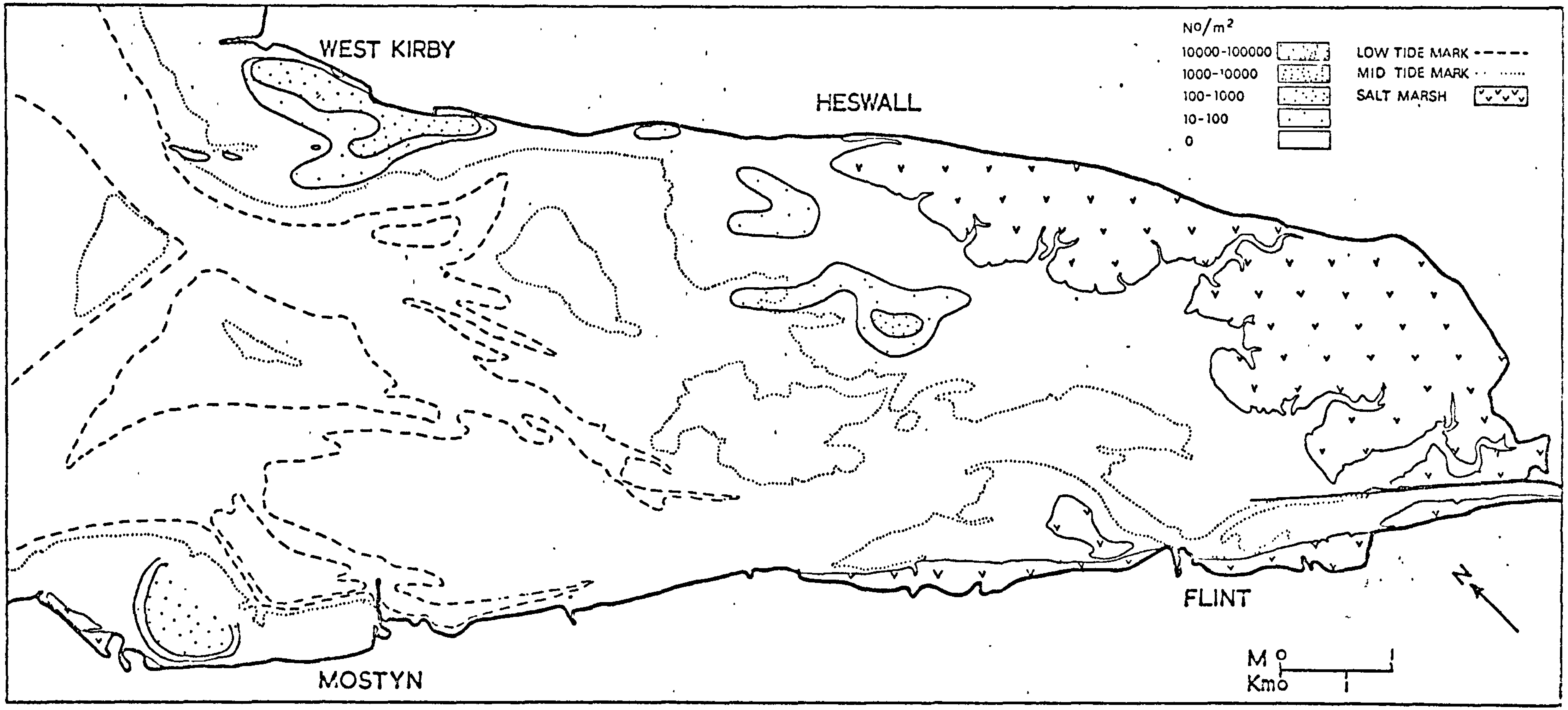
Map 198. Density distribution of <u>Corophium</u> sp. in Autumn 1971.



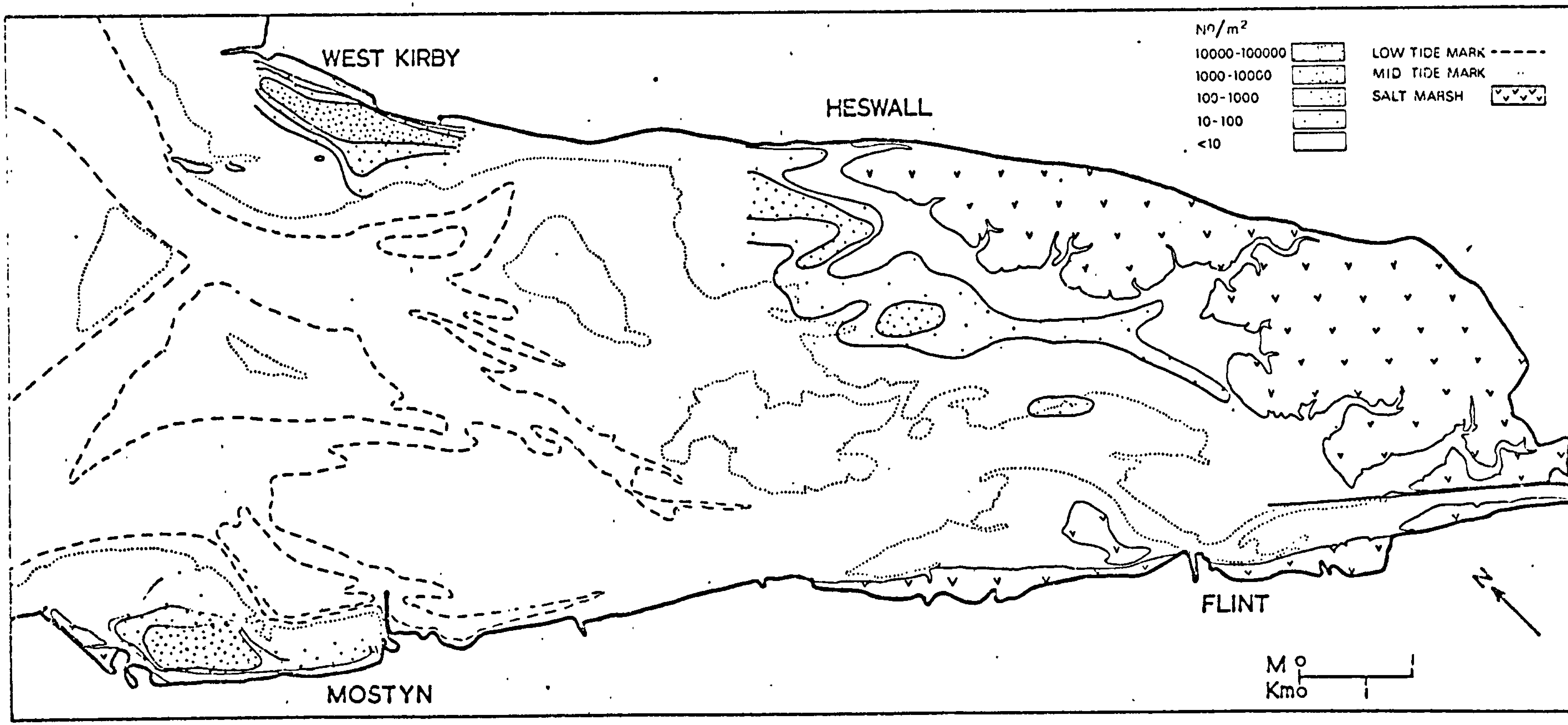
Map 199. Density distribution of Corophium sp. in Spring 1972.



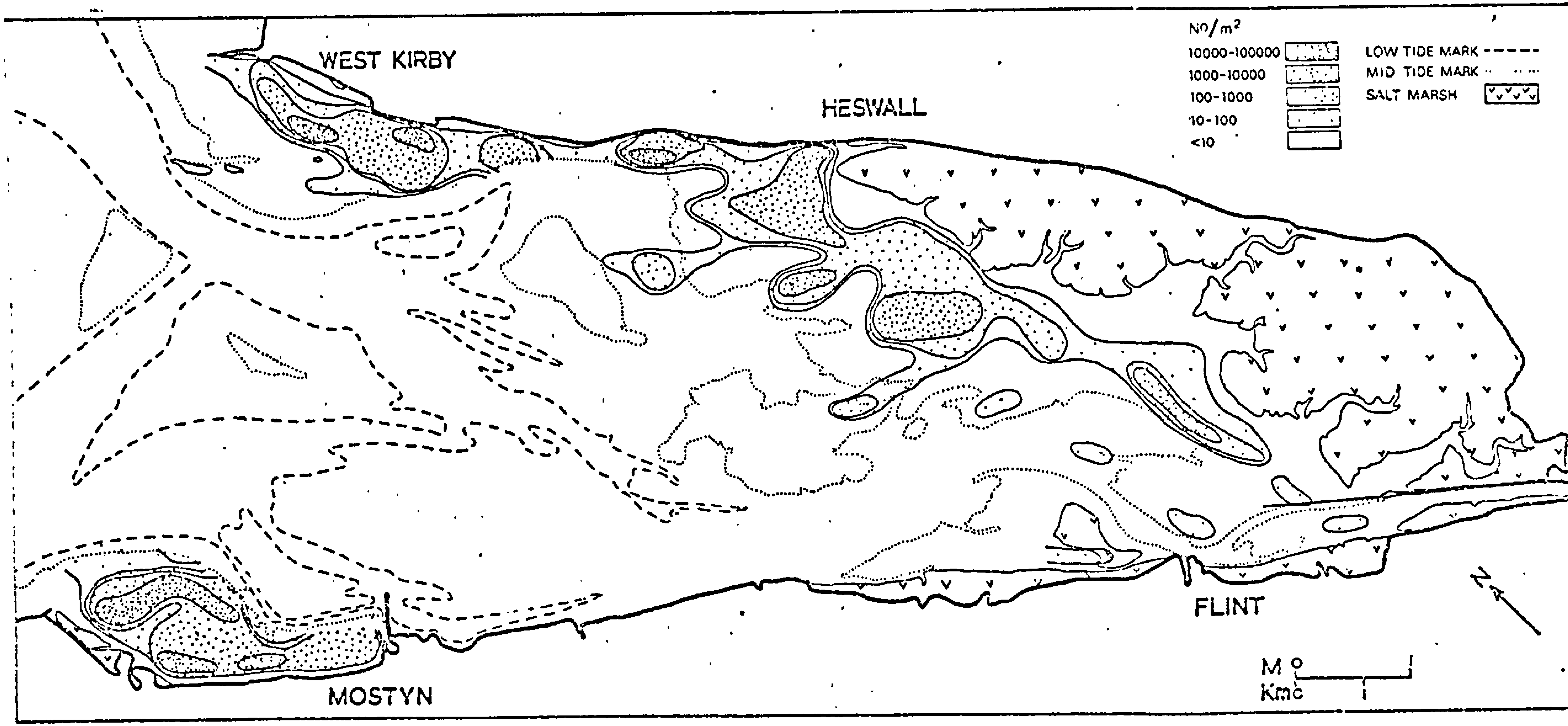
Map 200. Density distribution of Corophium sp. in Spring 1973.



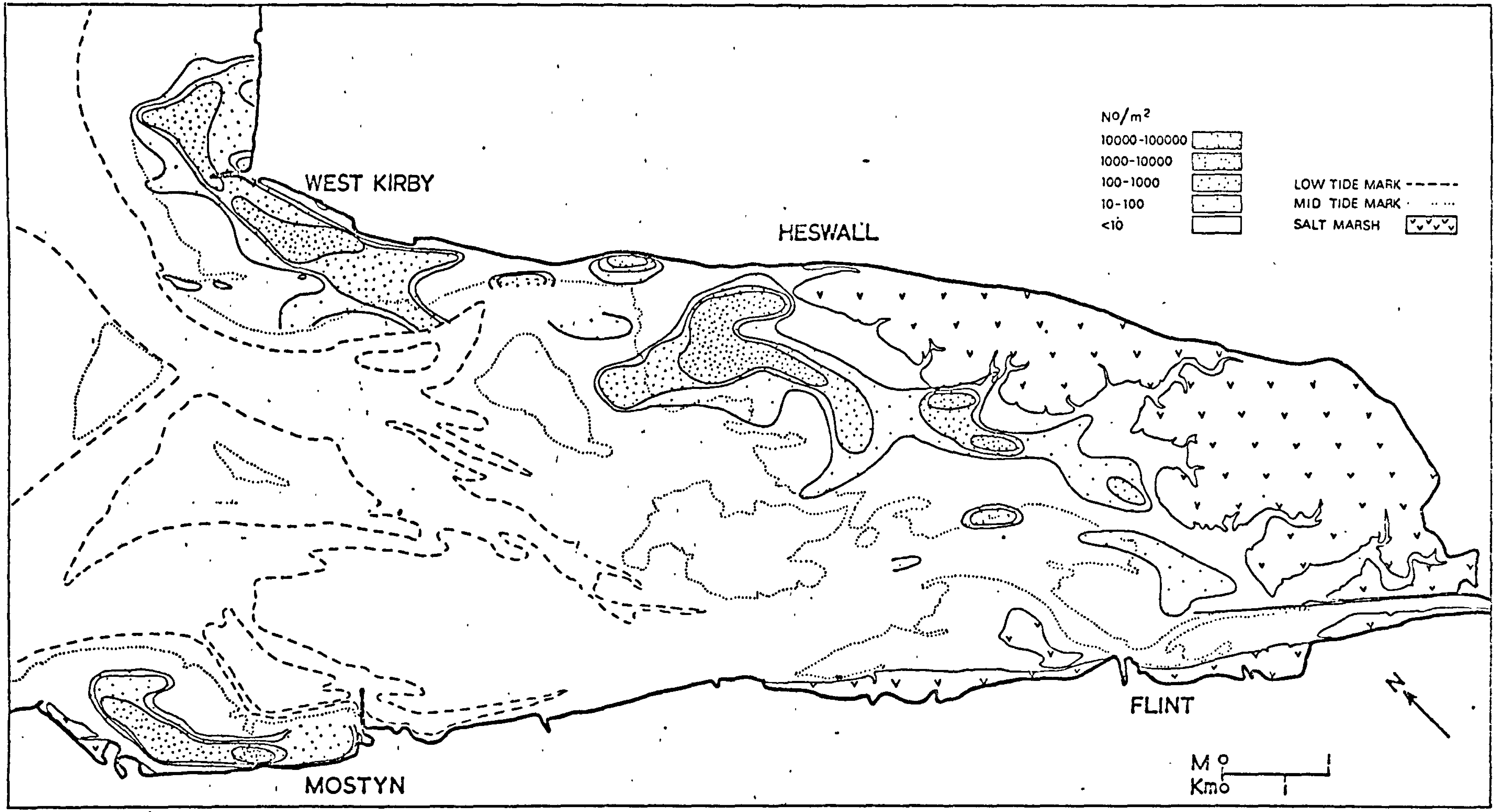
Map 201. Density distribution of Corophium sp. in Spring 1974.



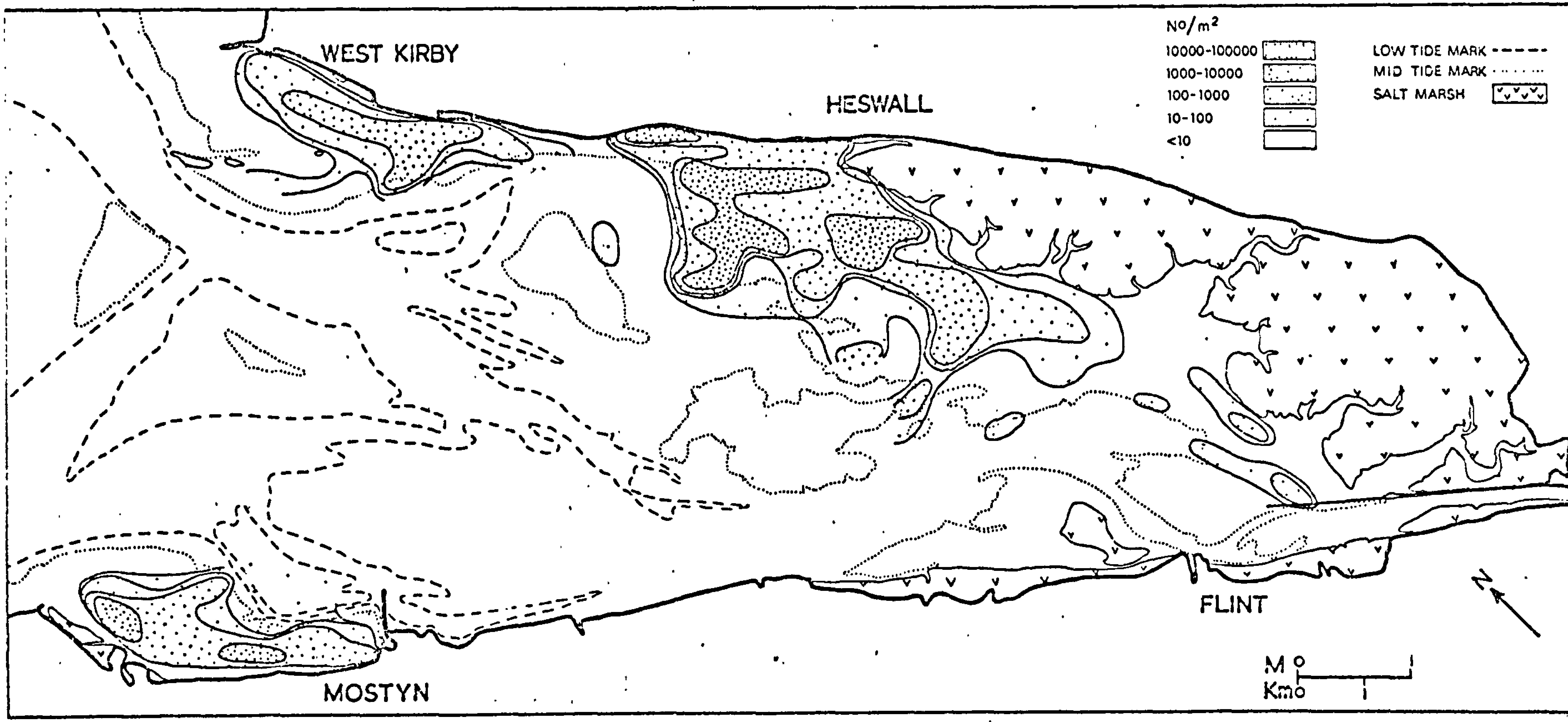
Map 202. Density distribution of Corophium sp. in Spring 1975.



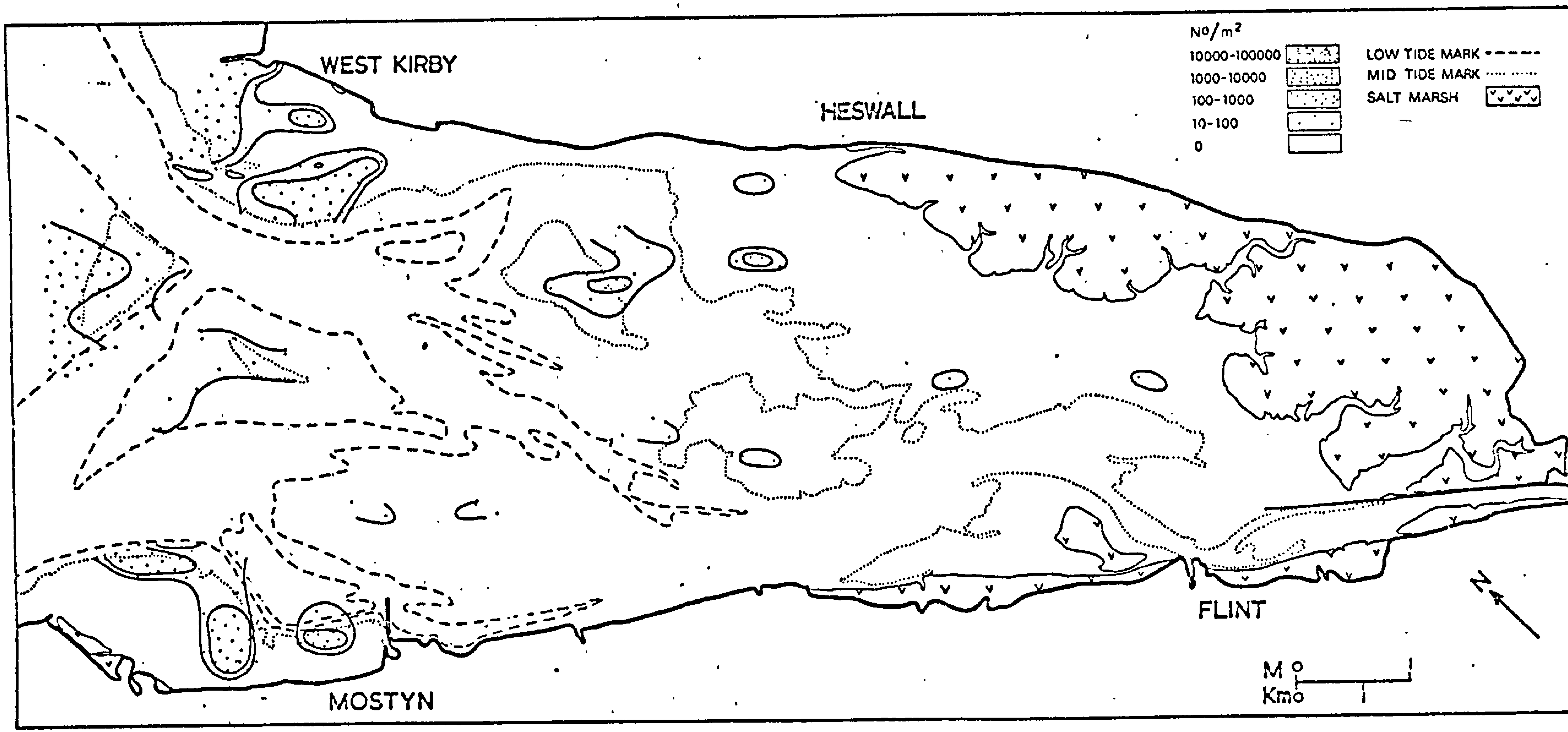
Map 203. Density distribution of Corophium sp. in Autumn 1975.



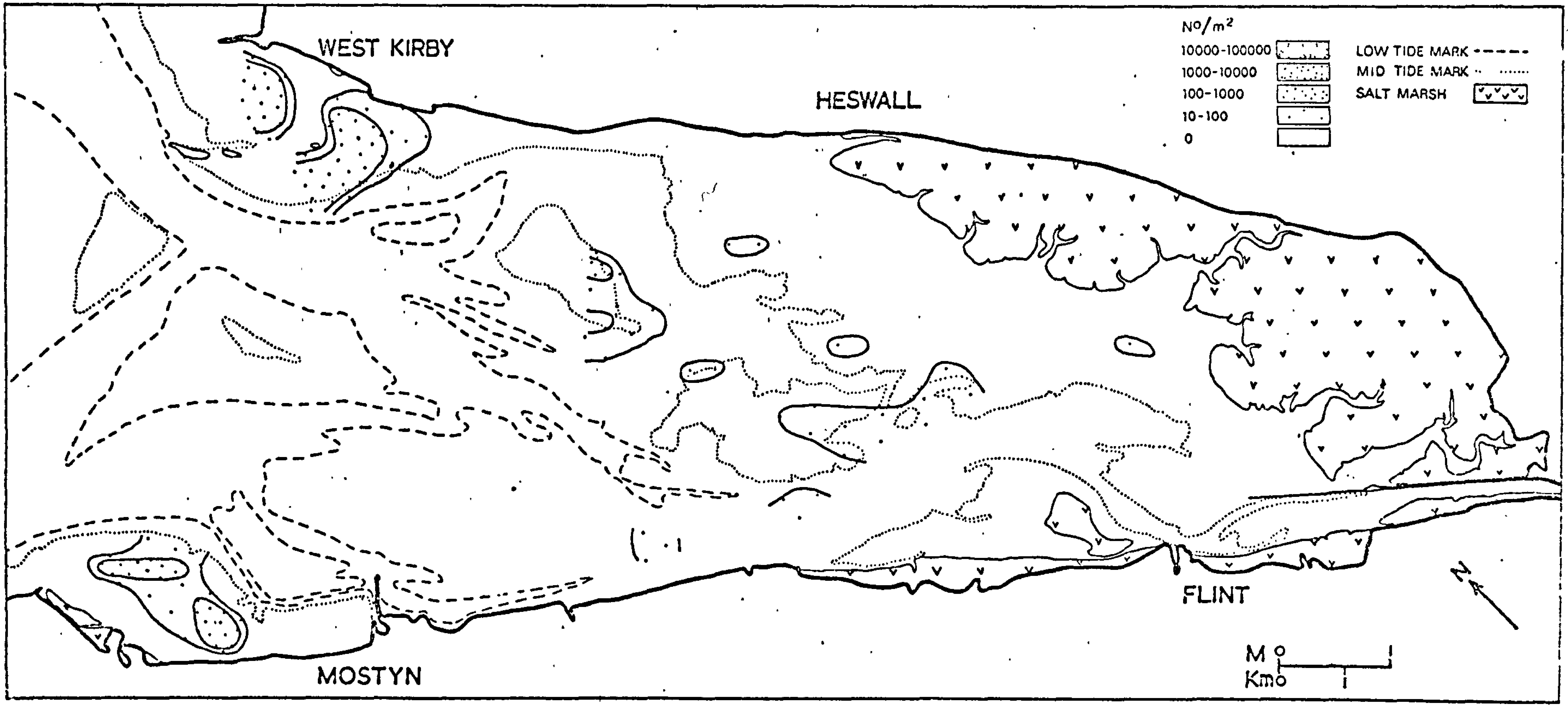
Map 204. Density distribution of <u>Corophium</u> sp. in Spring 1976.



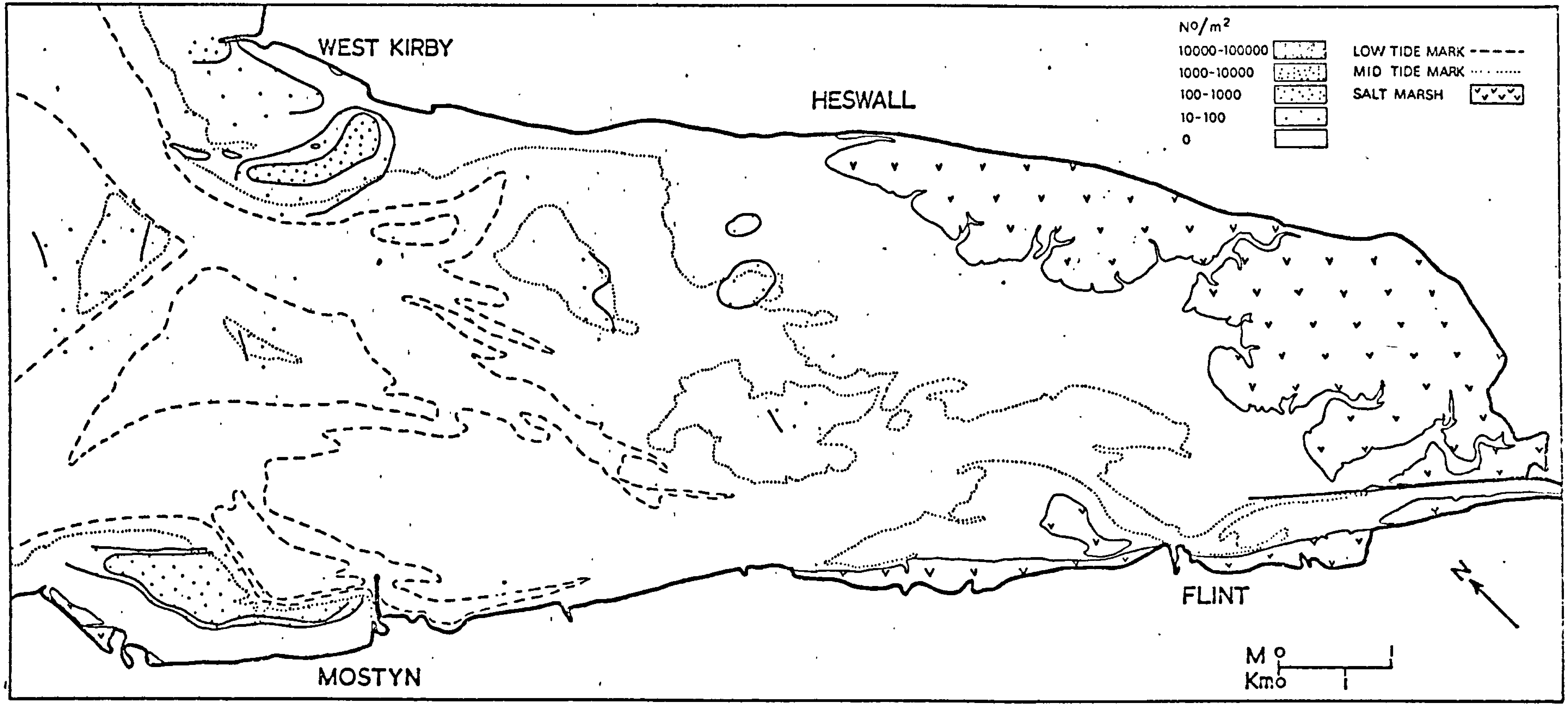
Map 205. Density distribution of Corophium sp. in Autumn 1976.



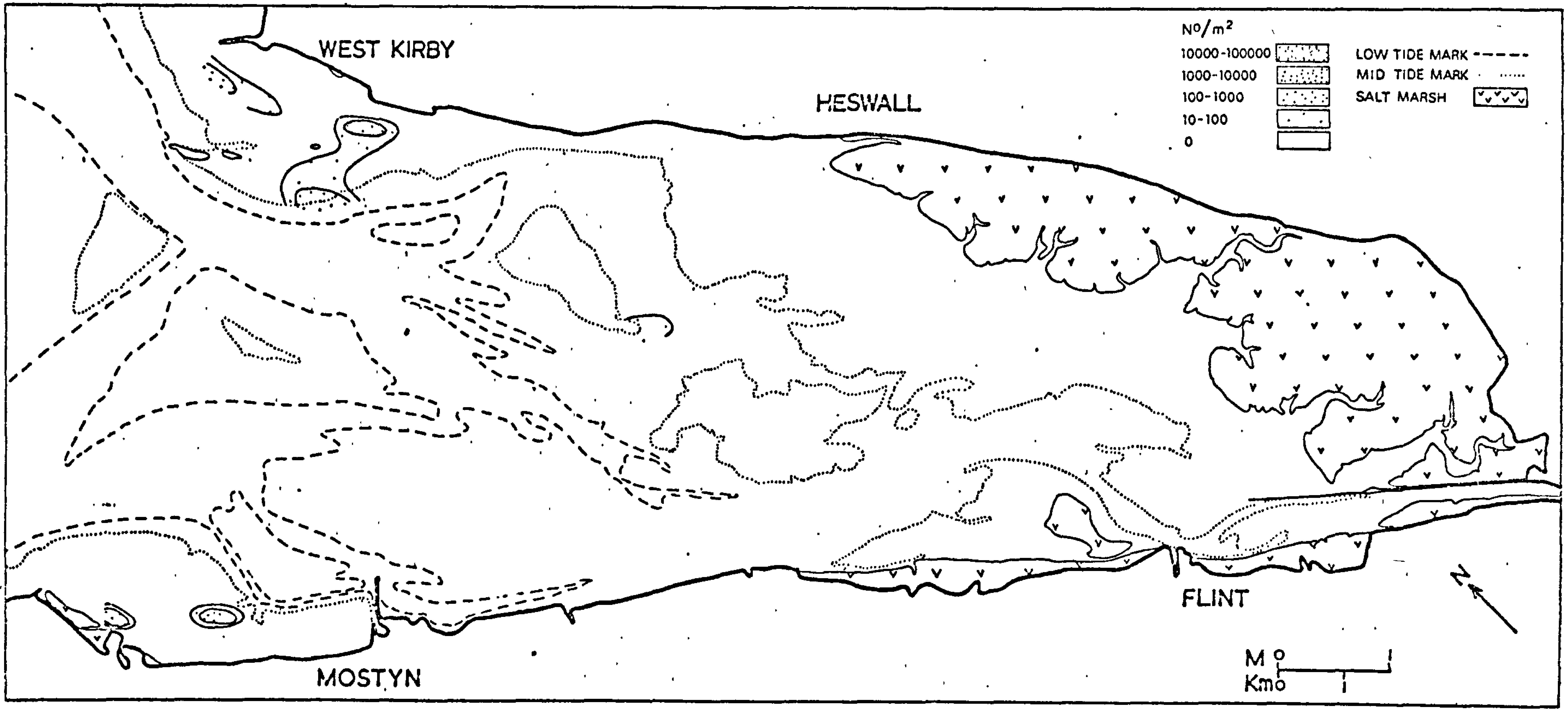
Map 206. Density distribution of <u>Bathyporeia</u> sp. in Autumn 1971.



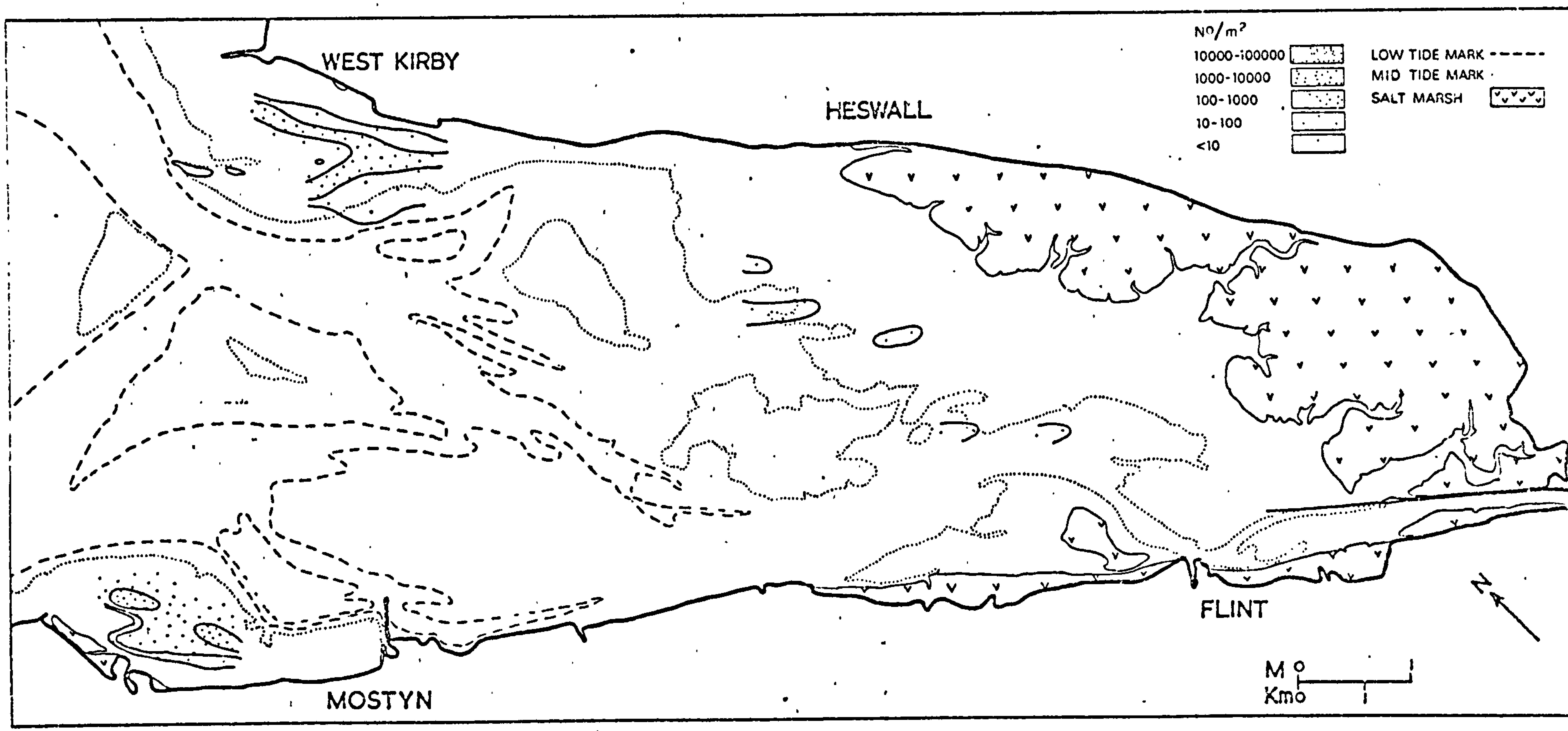
Map 207. Density distribution of Bathyporeia sp. in Spring 1972.



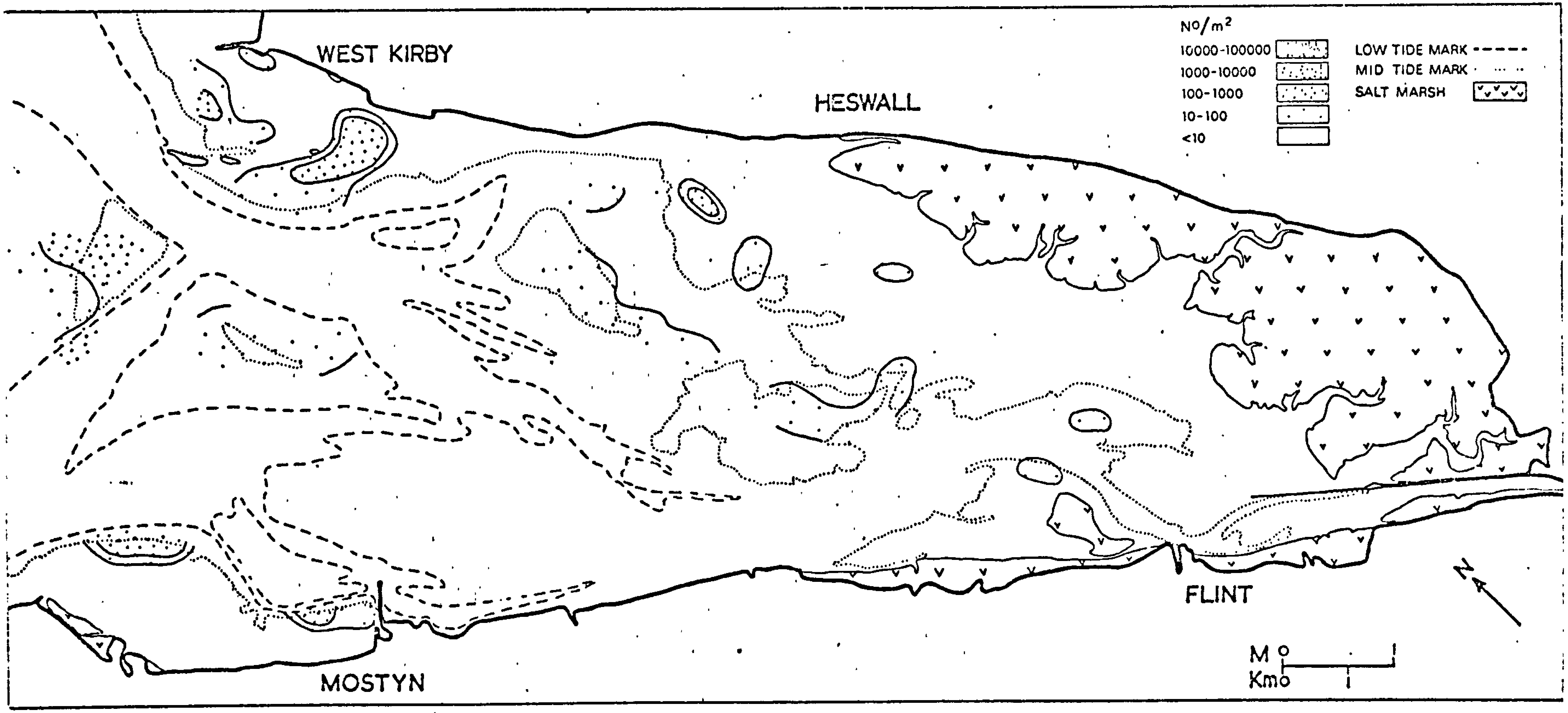
Map 208. Density distribution of Bathyporeia sp. in Spring 1973.



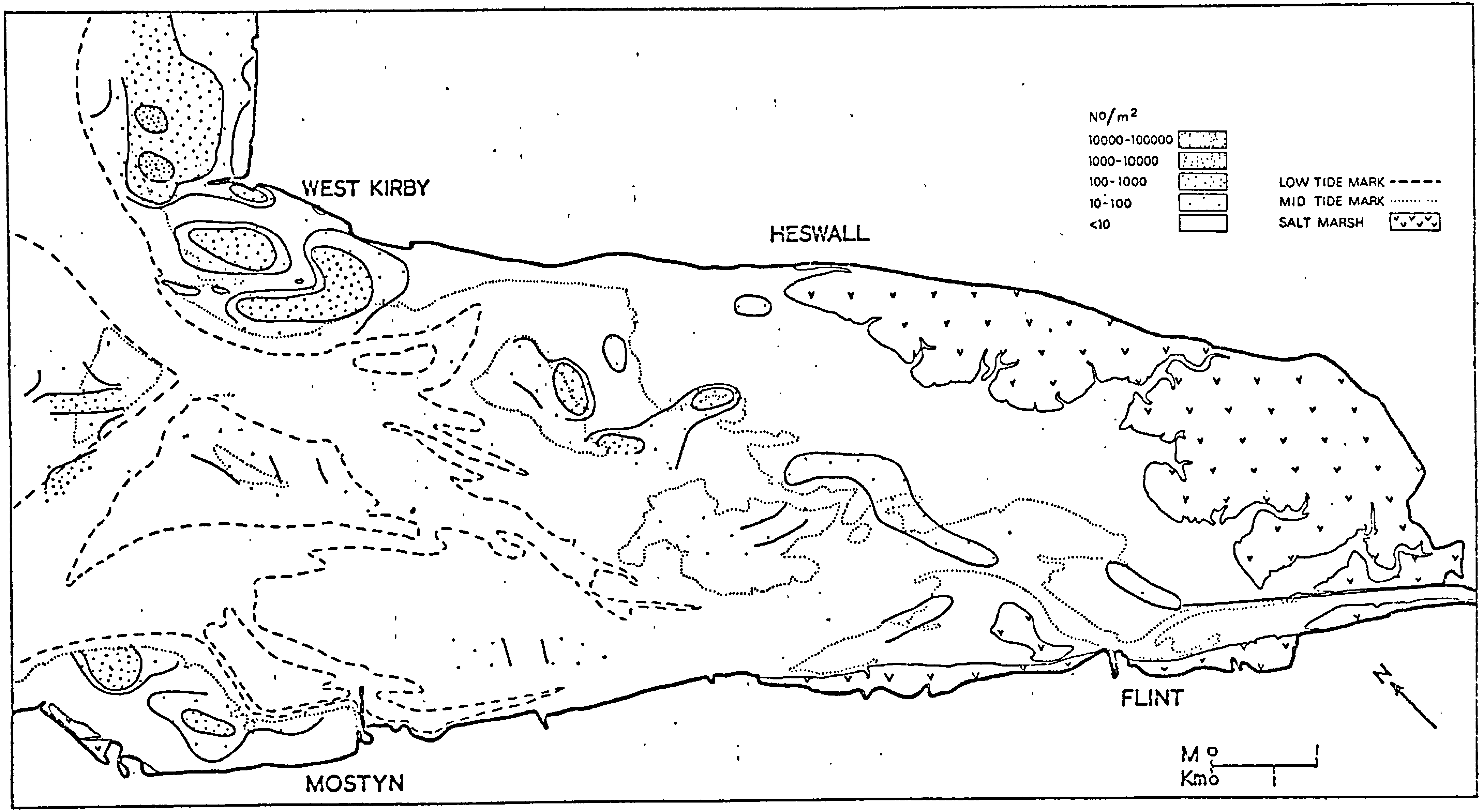
Map 209. Density distribution of Bathyporeia sp. in Spring 1974.



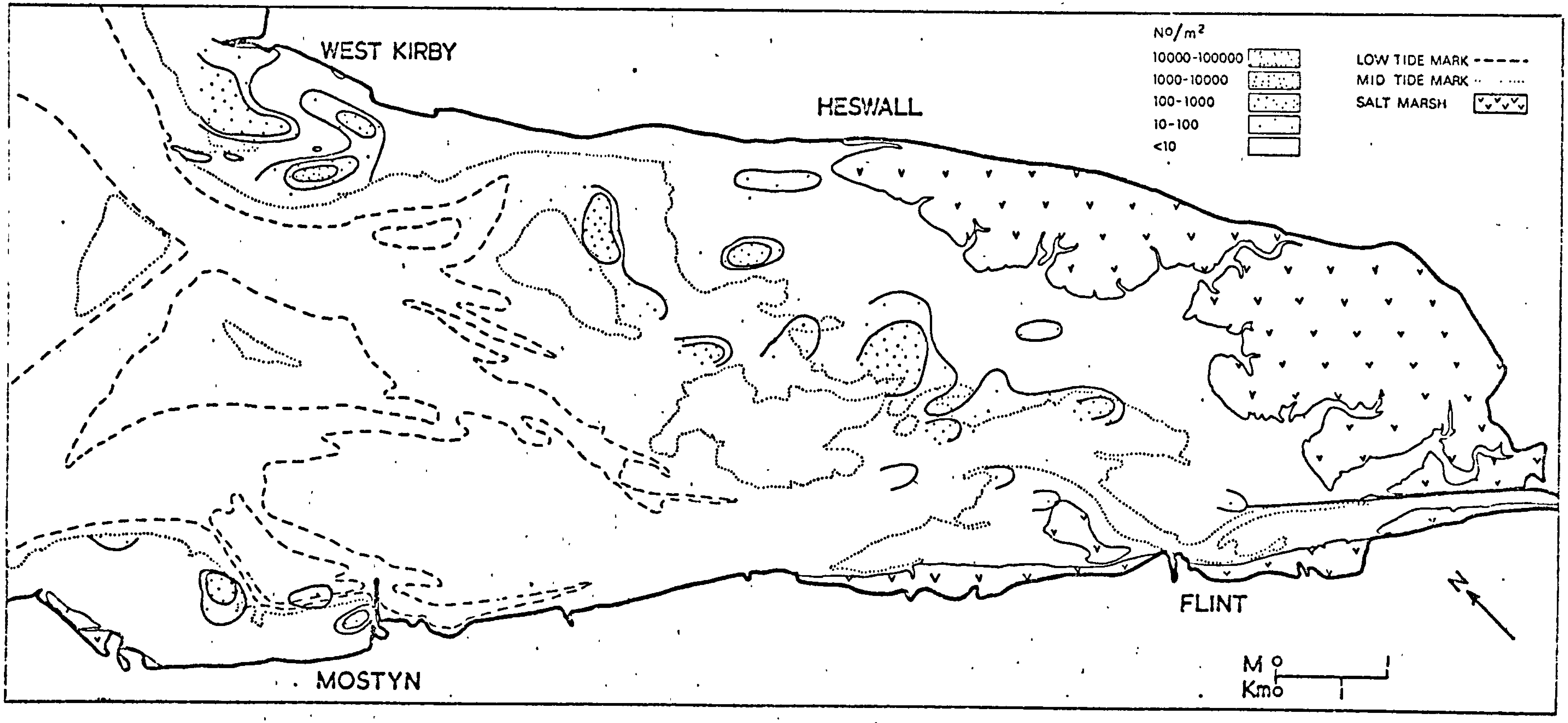
Map 210. Density distribution of <u>Bathyporeia</u> sp. in Spring 1975.



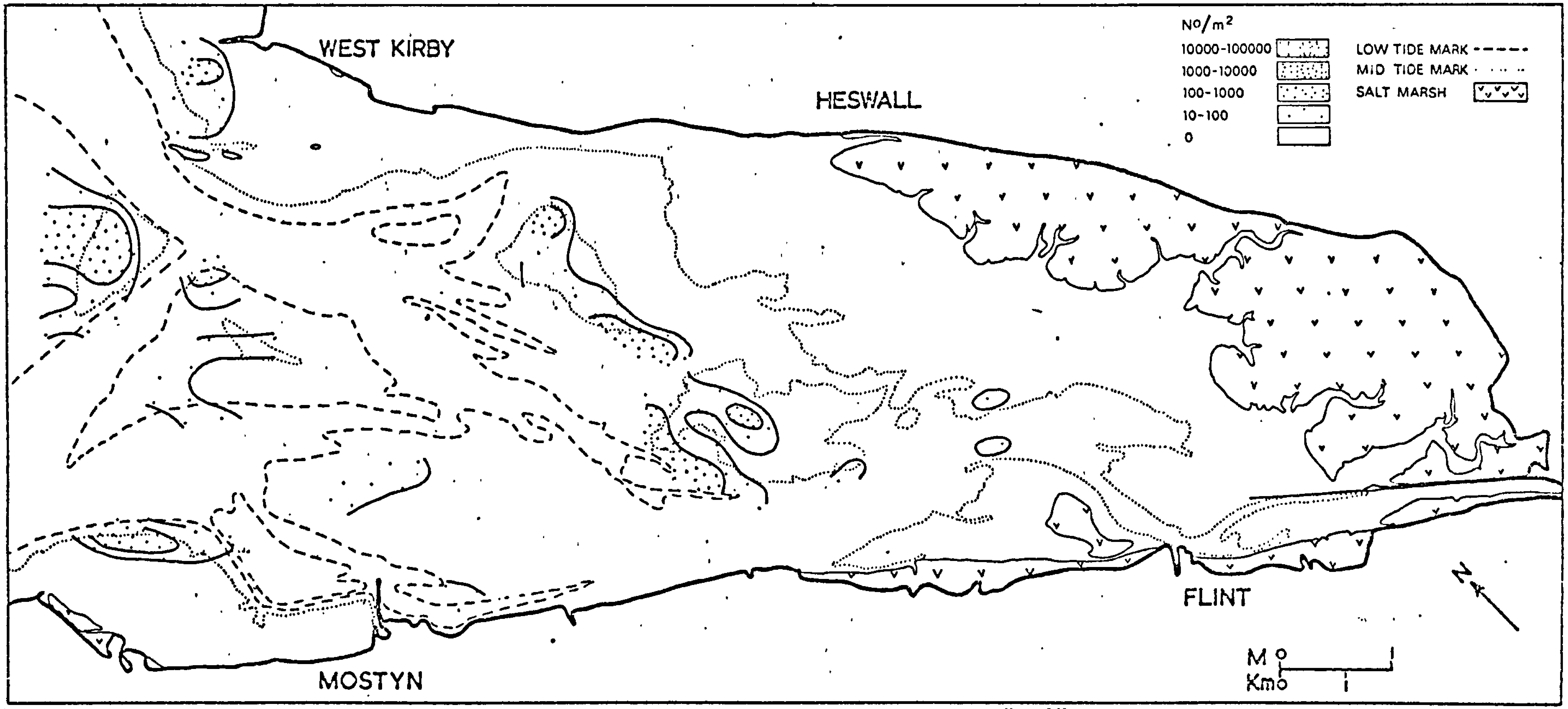
Map 211. Density distribution of Bathyporeia sp. in Autumn 1975.



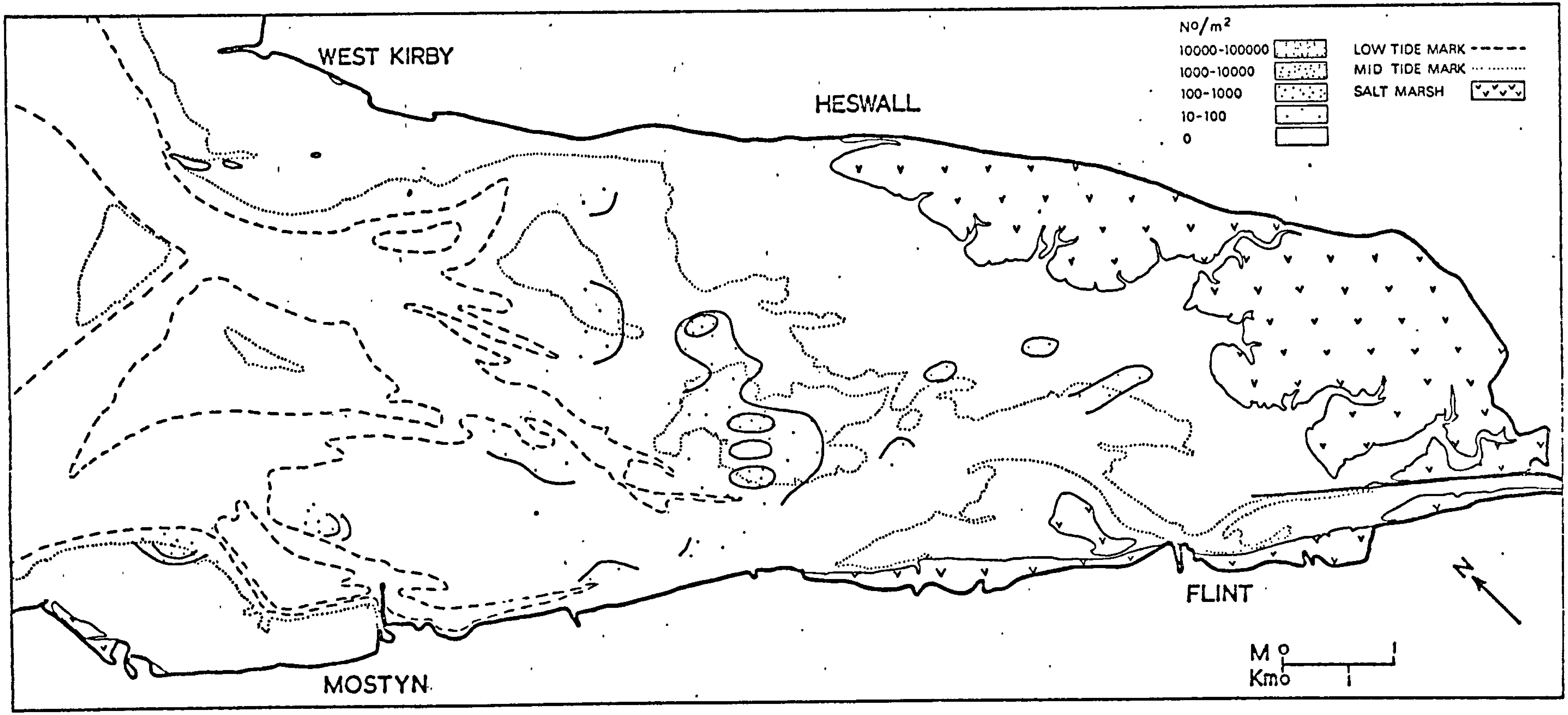
Map 212. Density distribution of <u>Bathyporeia</u> sp. in Spring 1976.



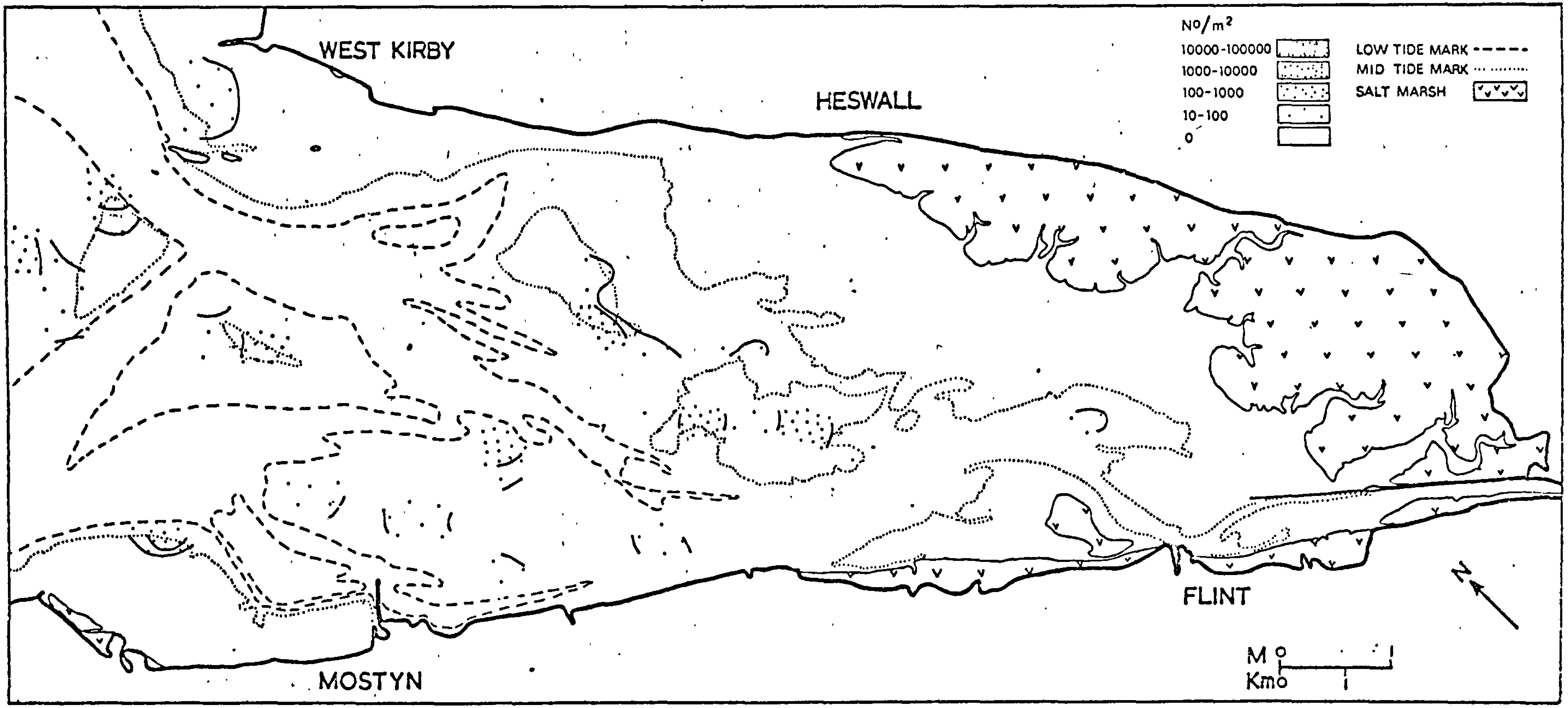
Map 213. Density distribution of Bathyporeia sp. in Autumn 1976.



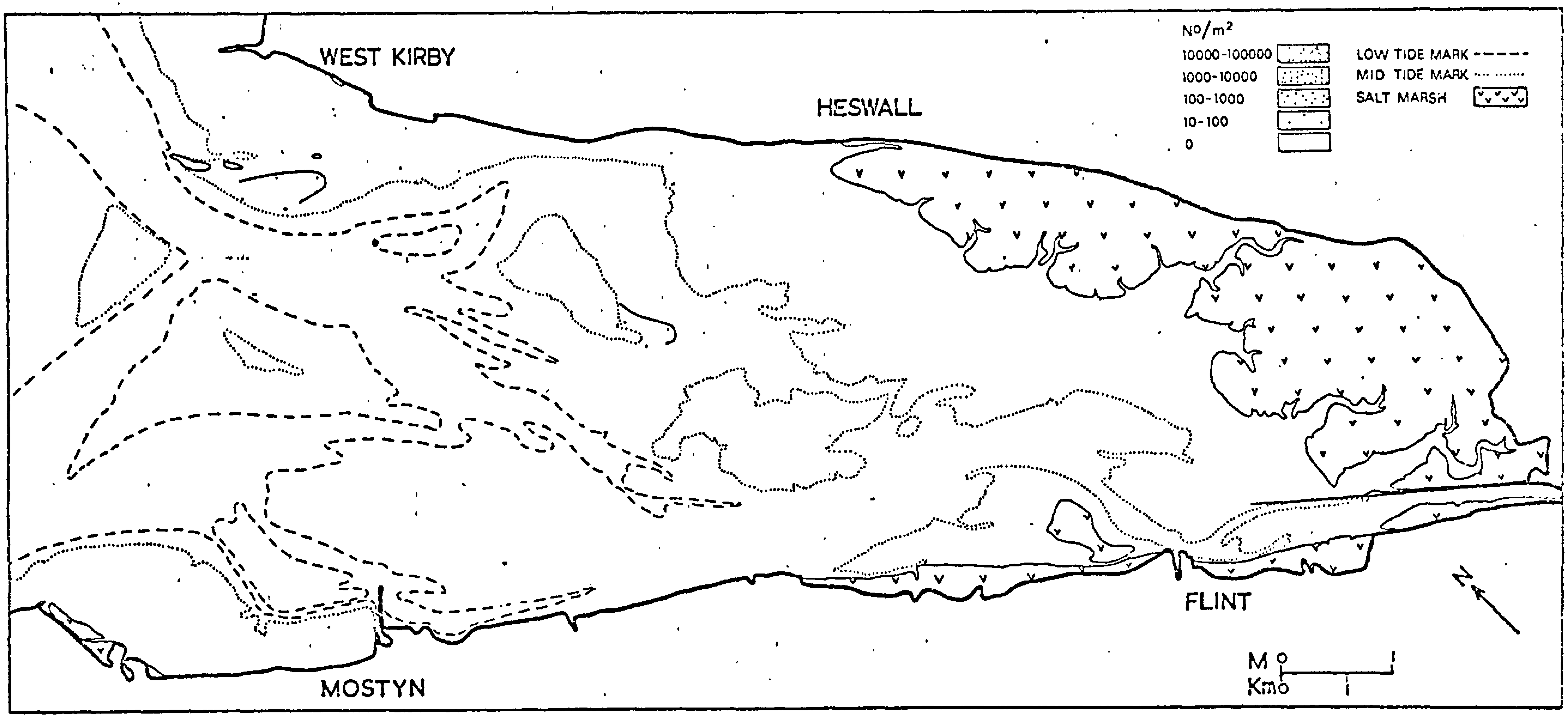
Map 214. Density distribution of <u>Haustorius arenarius</u> in Autumn 1971.



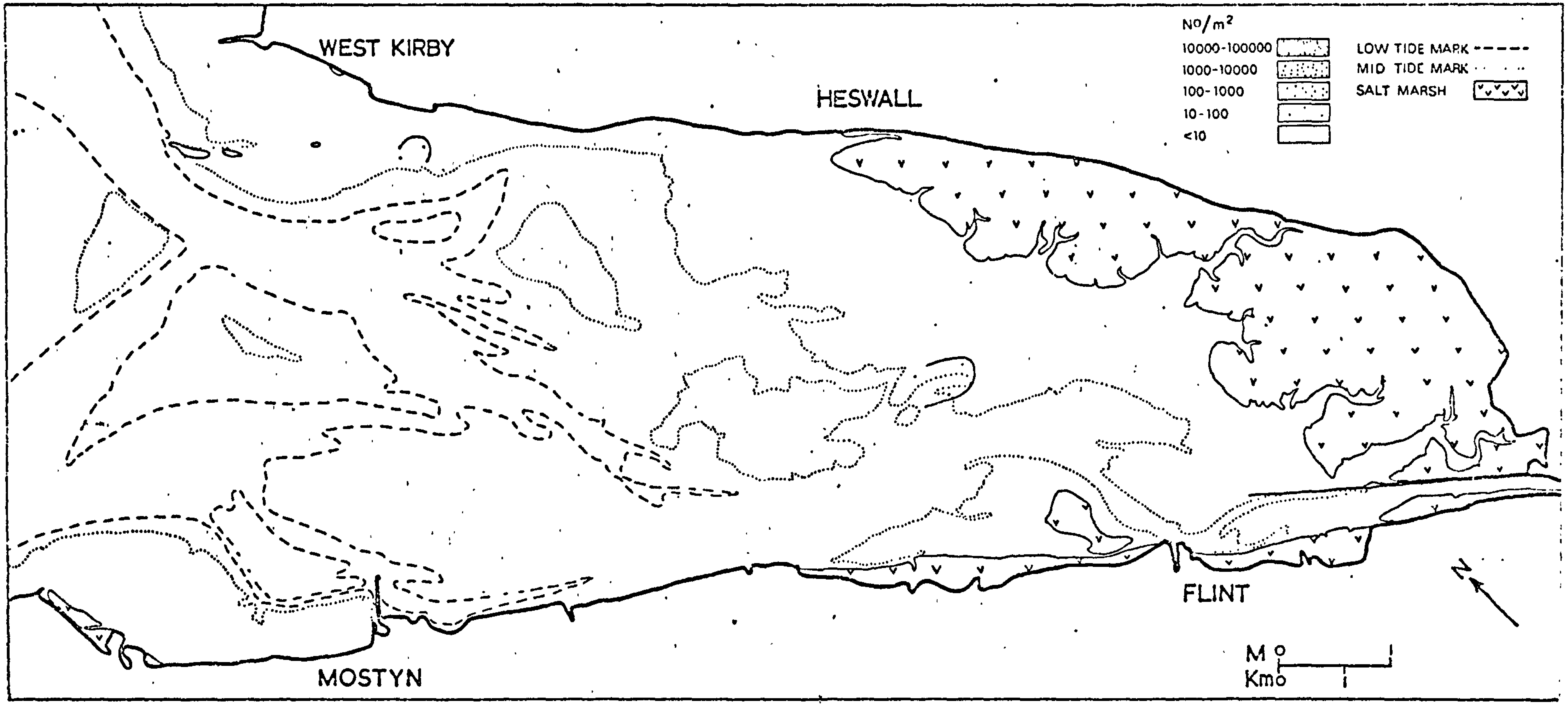
Map 215. Density distribution of <u>Haustorius arenarius</u> in Spring 1972.



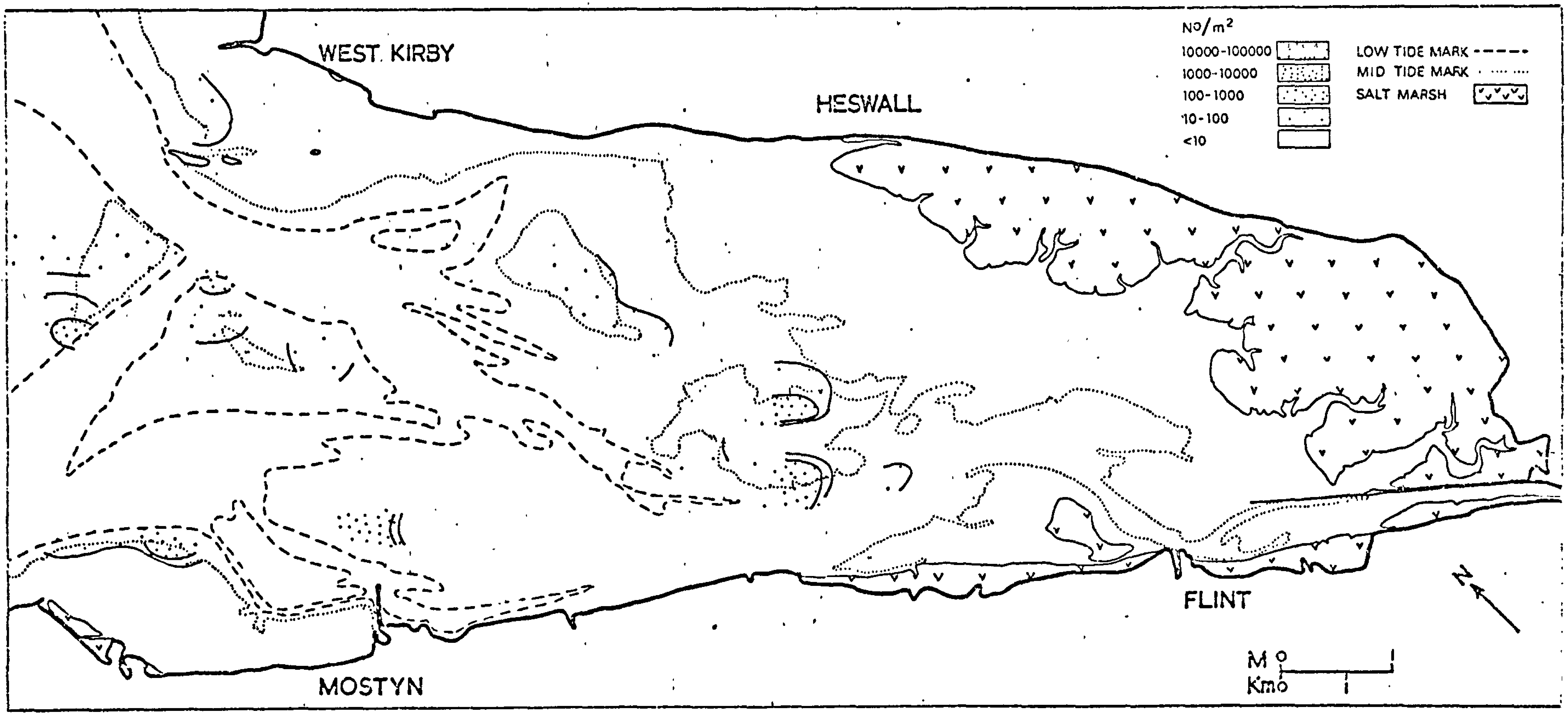
Map 216. Density distribution of <u>Haustorius arenarius</u> in Spring 1973.



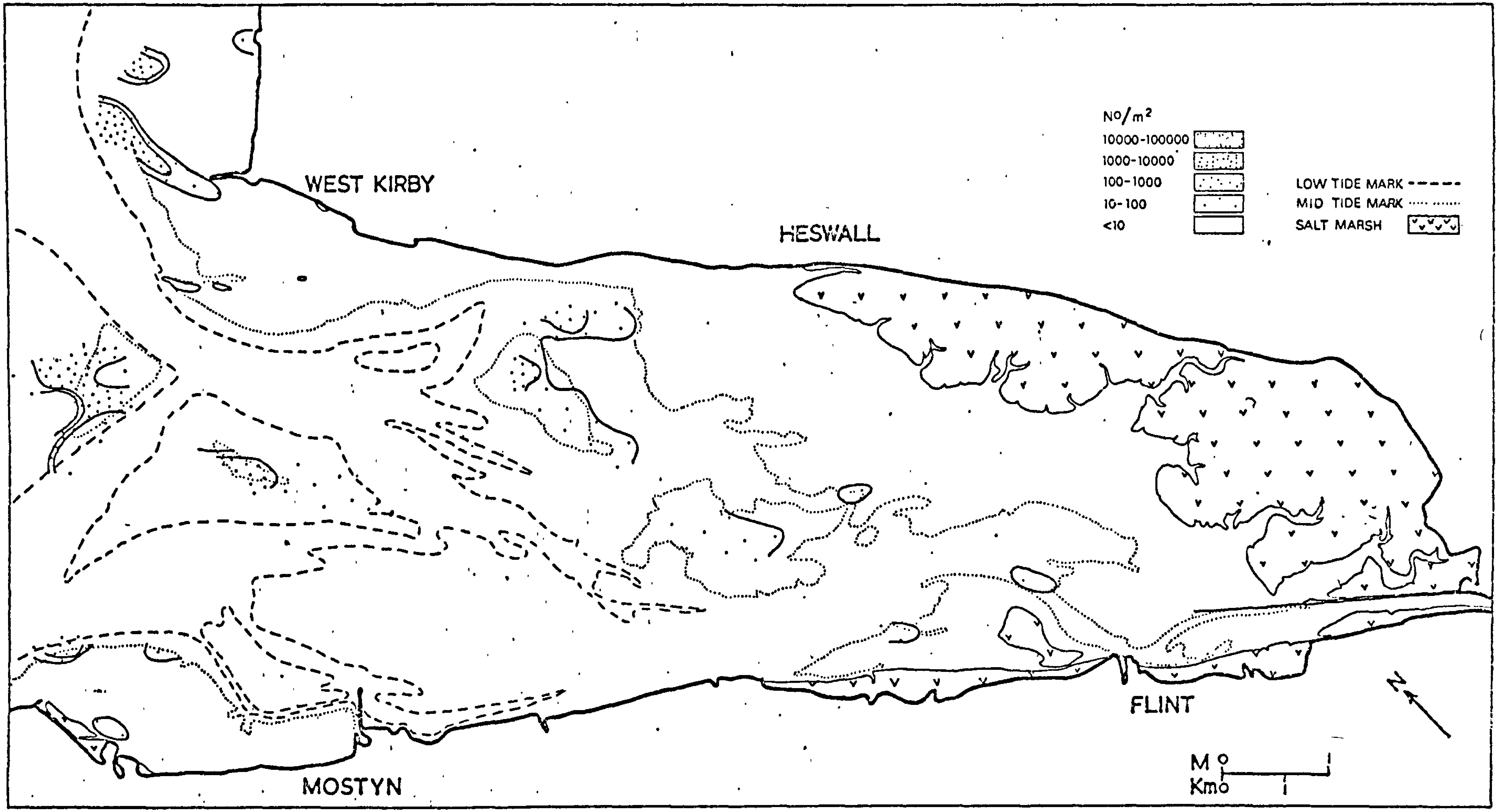
Map 217. Density distribution of Haustorius arenarius in Spring 1974.



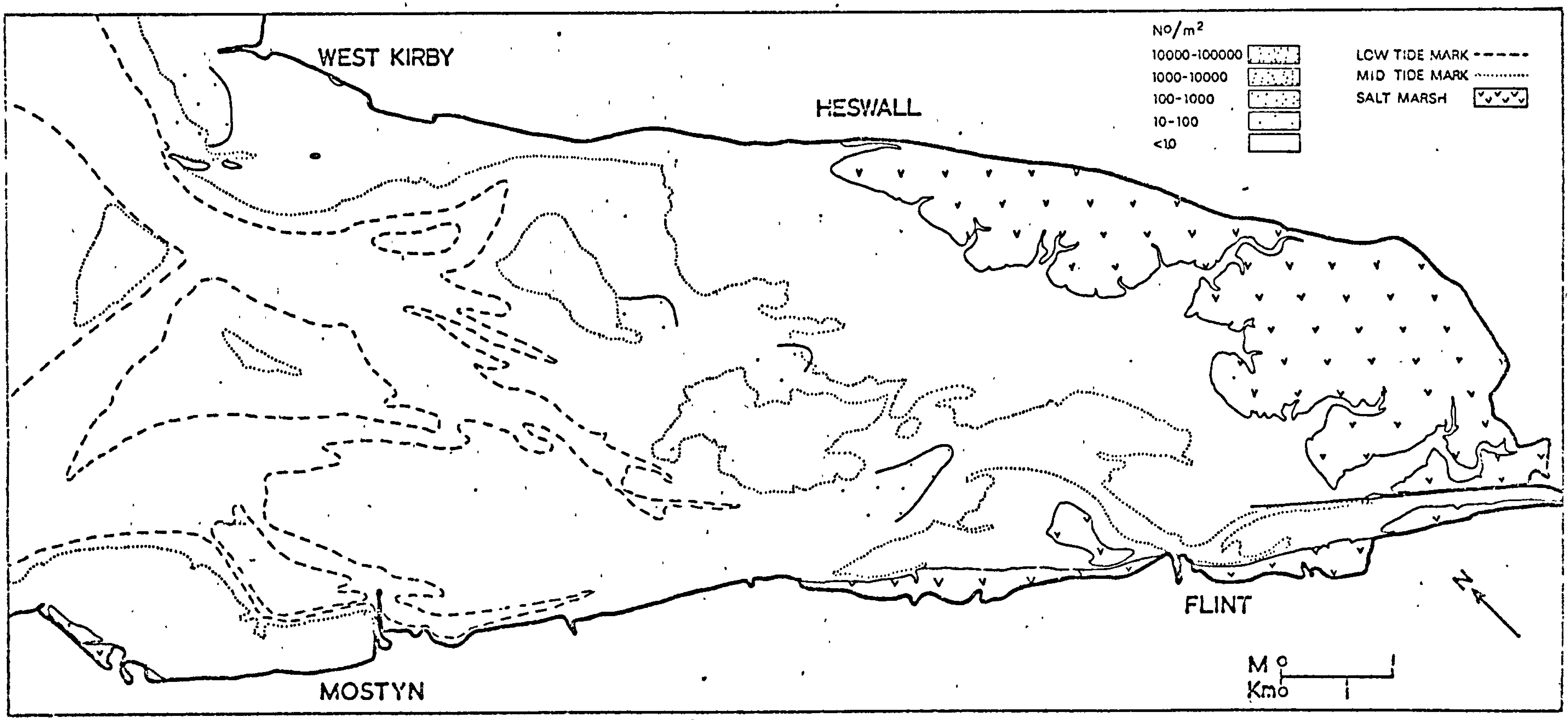
Map 218. Density distribution of <u>Haustorius arenarius</u> in Spring 1975.



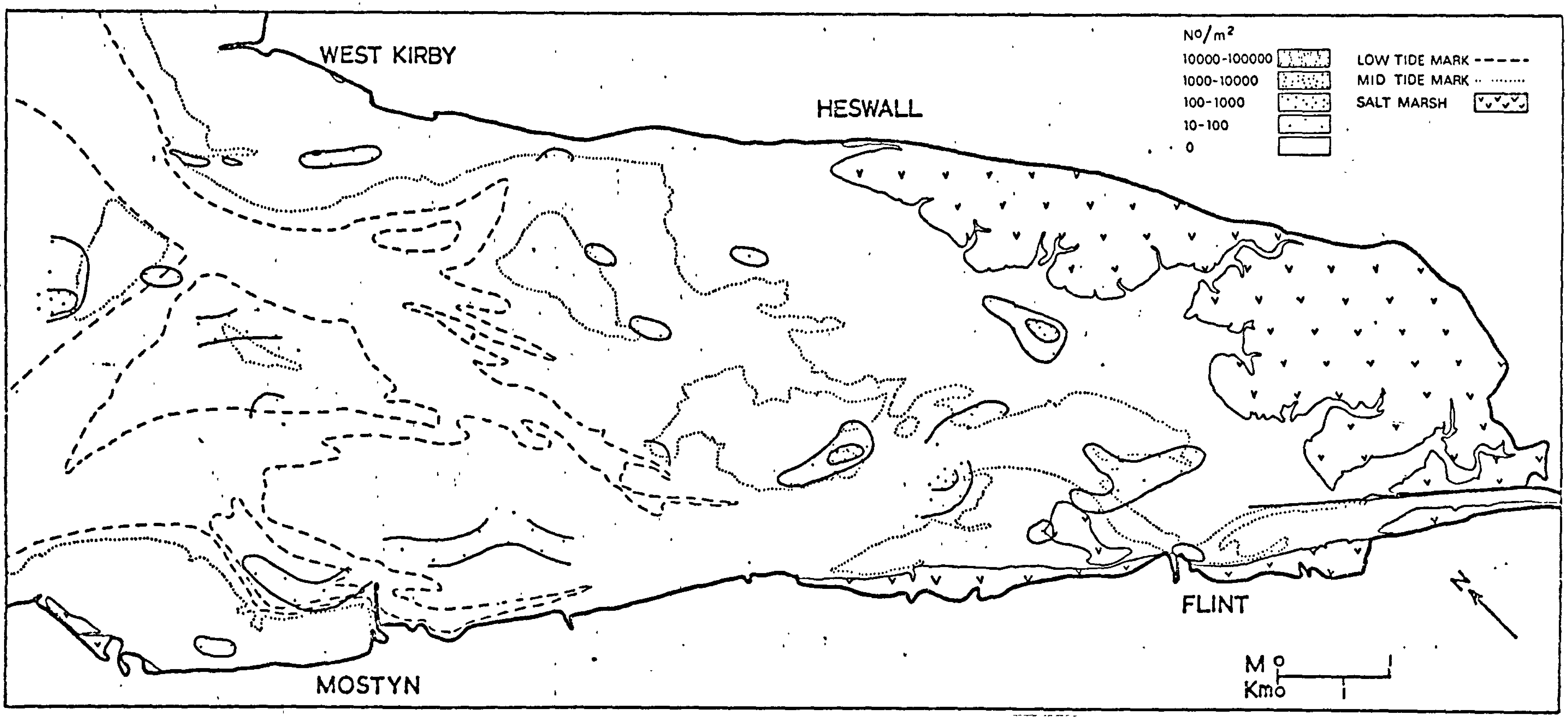
Map 219. Density distribution of <u>Haustorius arenarius</u> in Autumn 1975.



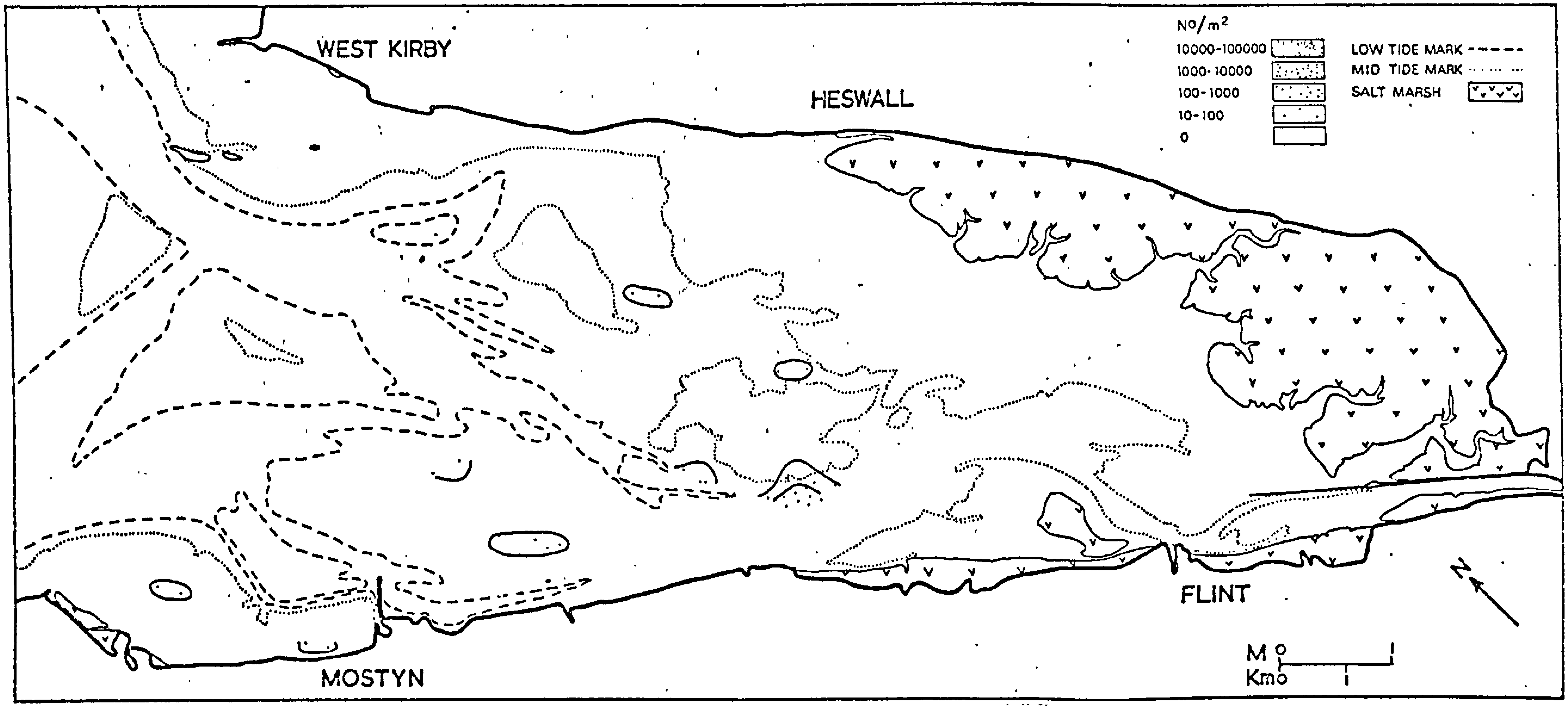
Map 220. Density distribution of Haustorius arenarius in Spring 1976.



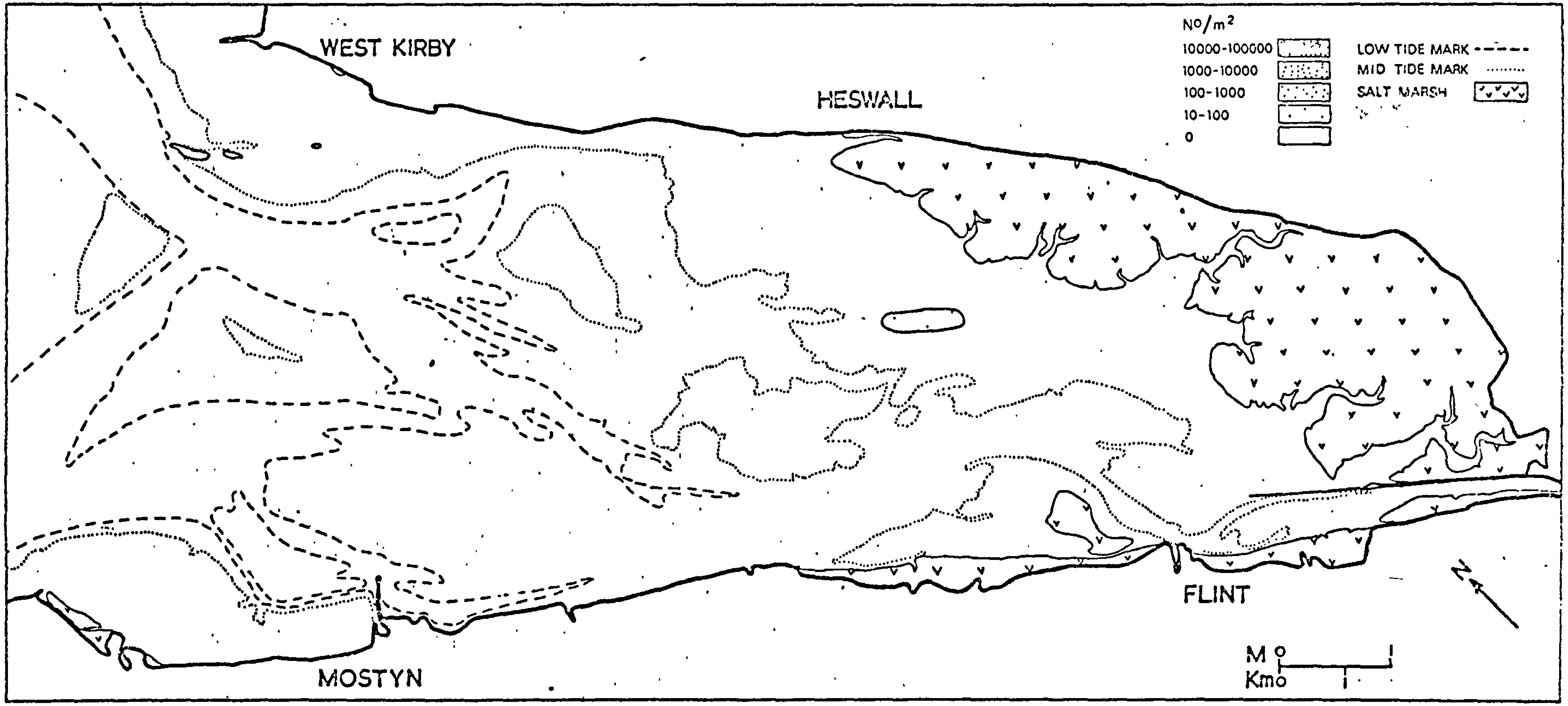
Map 221. Density distribution of _Haustorius arenarius_ in Autumn 1976.



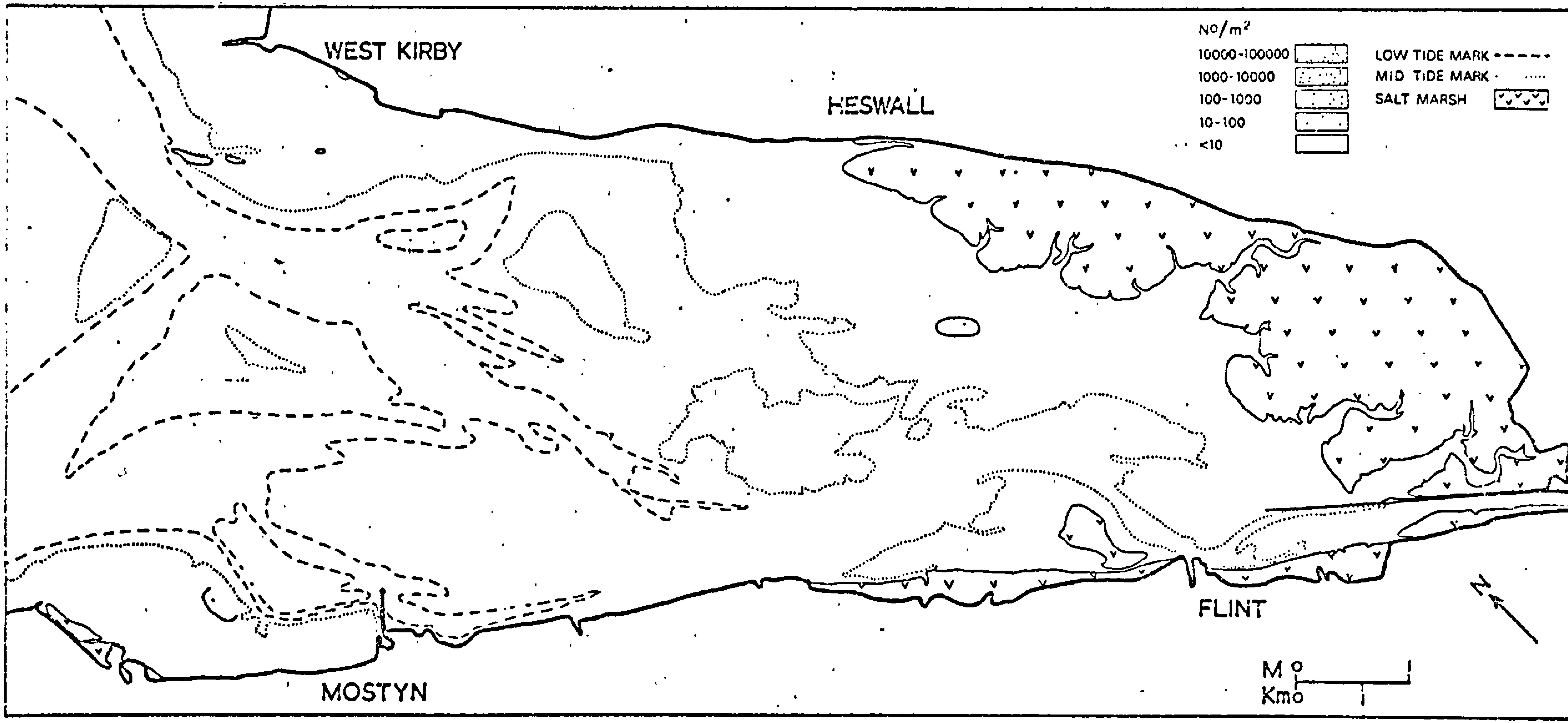
Map 222. Density distribution of Crangon vulgaris in Autumn 1971.



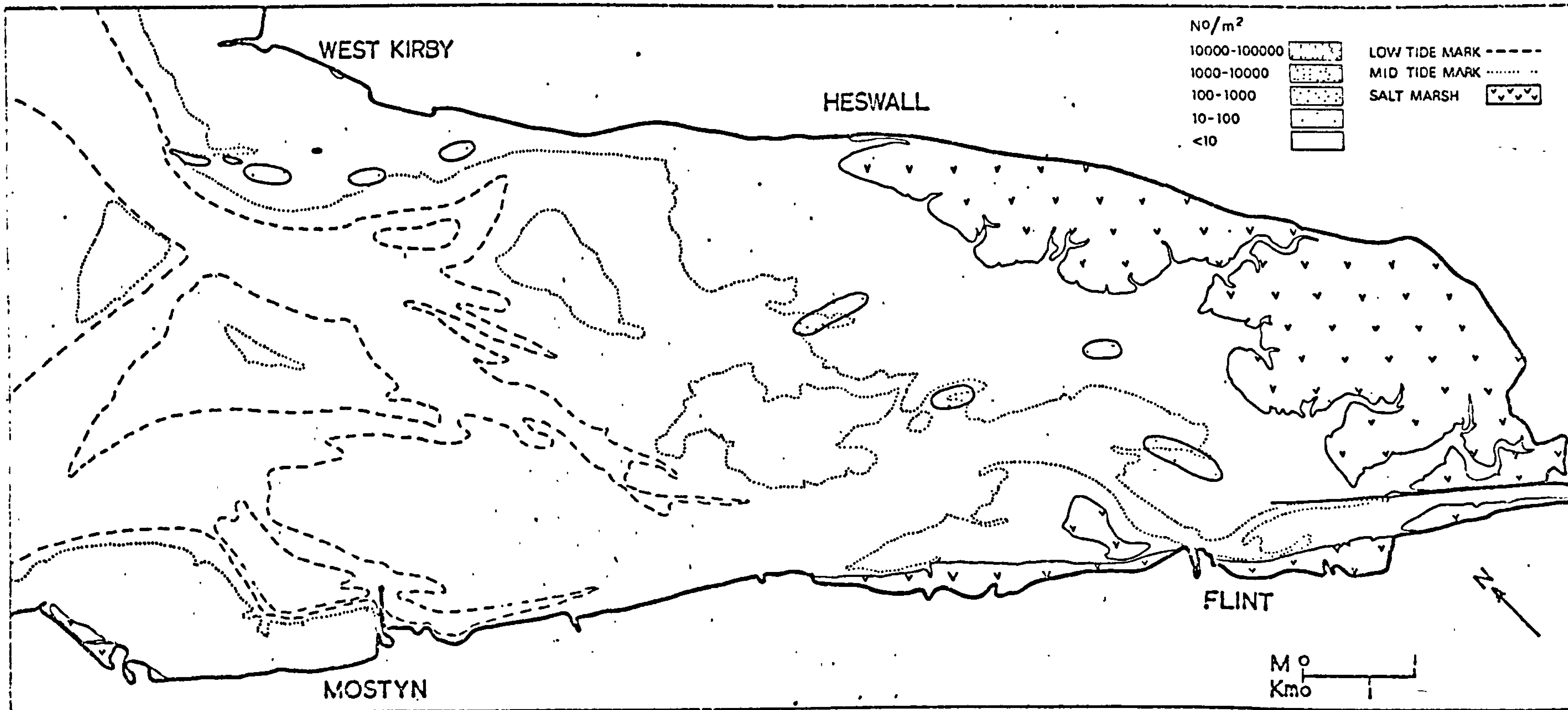
Map 223. Density distribution of _Crangon vulgaris_ in Spring 1972.



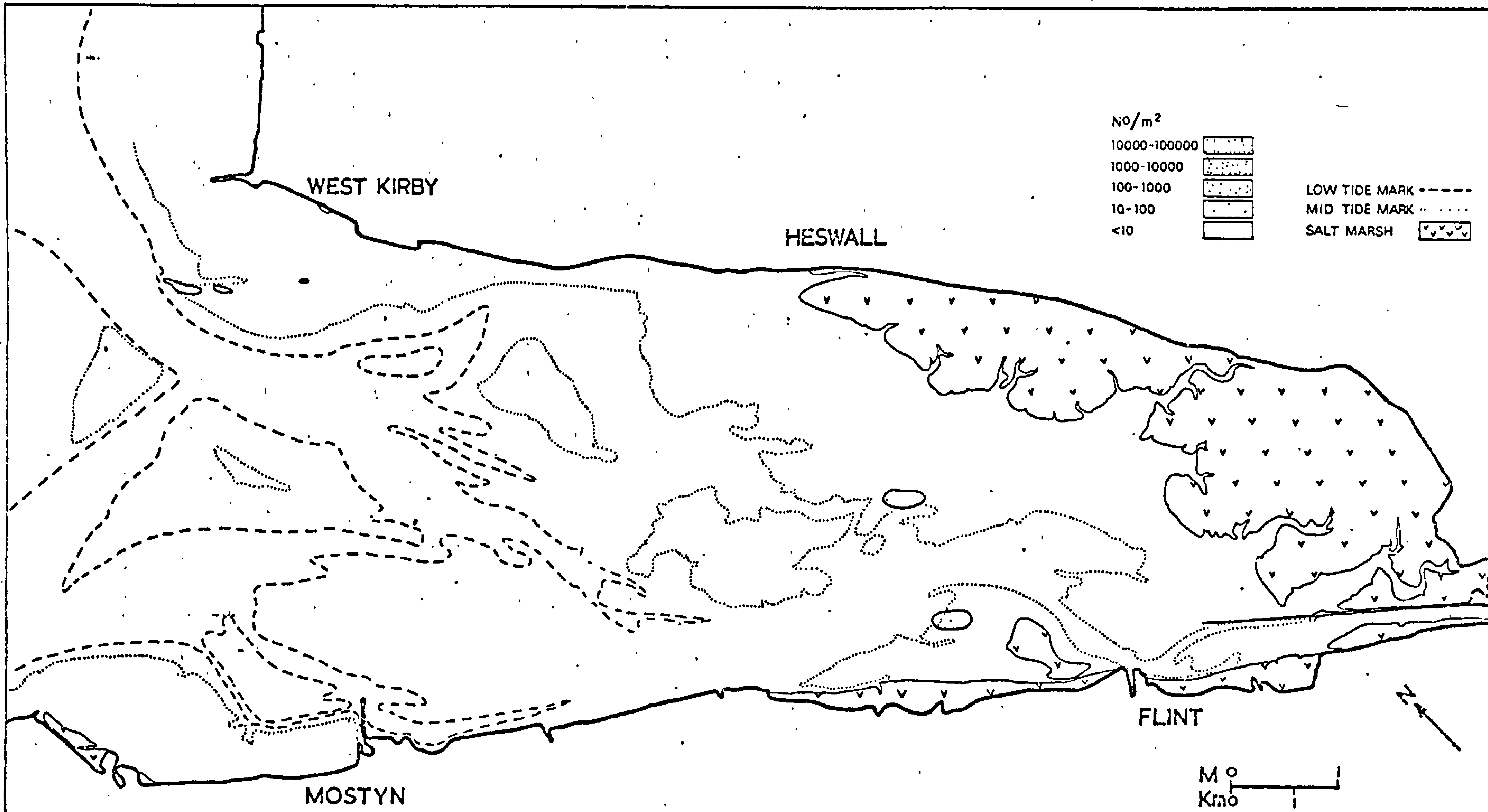
Map 224. Density distribution of Crangon vulgaris in Spring 1973.



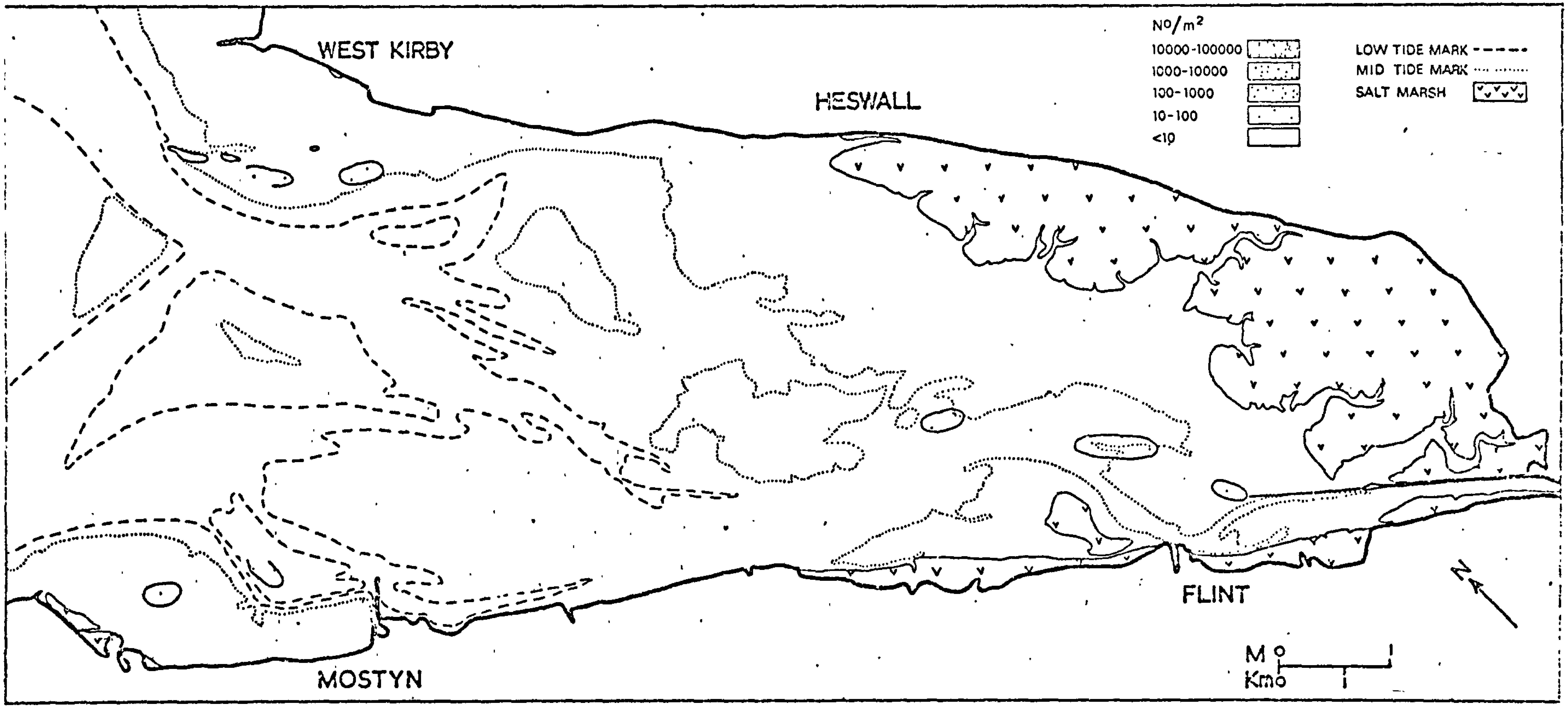
Map 225. Density distribution of <u>Crangon vulgaris</u> in Spring 1975.



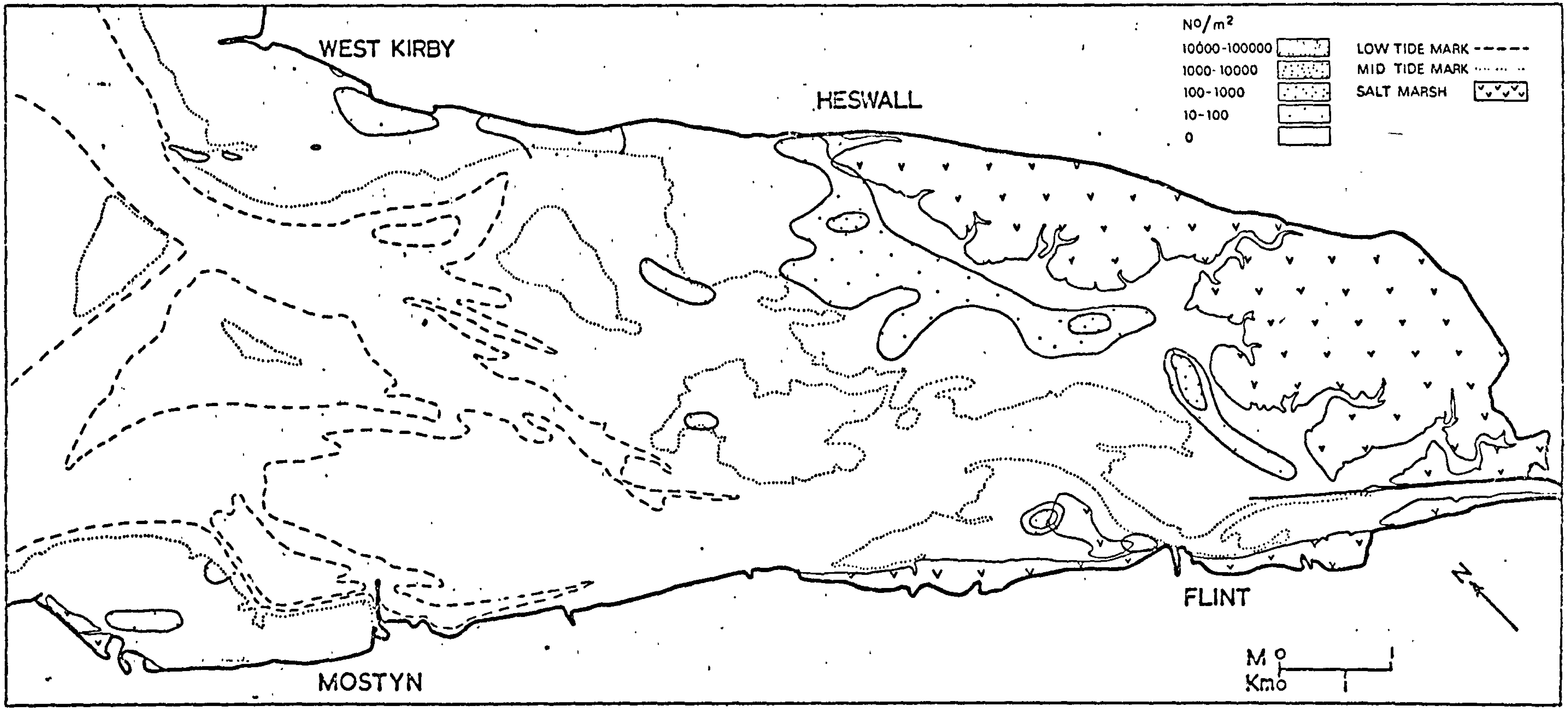
Map 226. Density distribution of <u>Crangon vulgaris</u> in Autumn 1975.



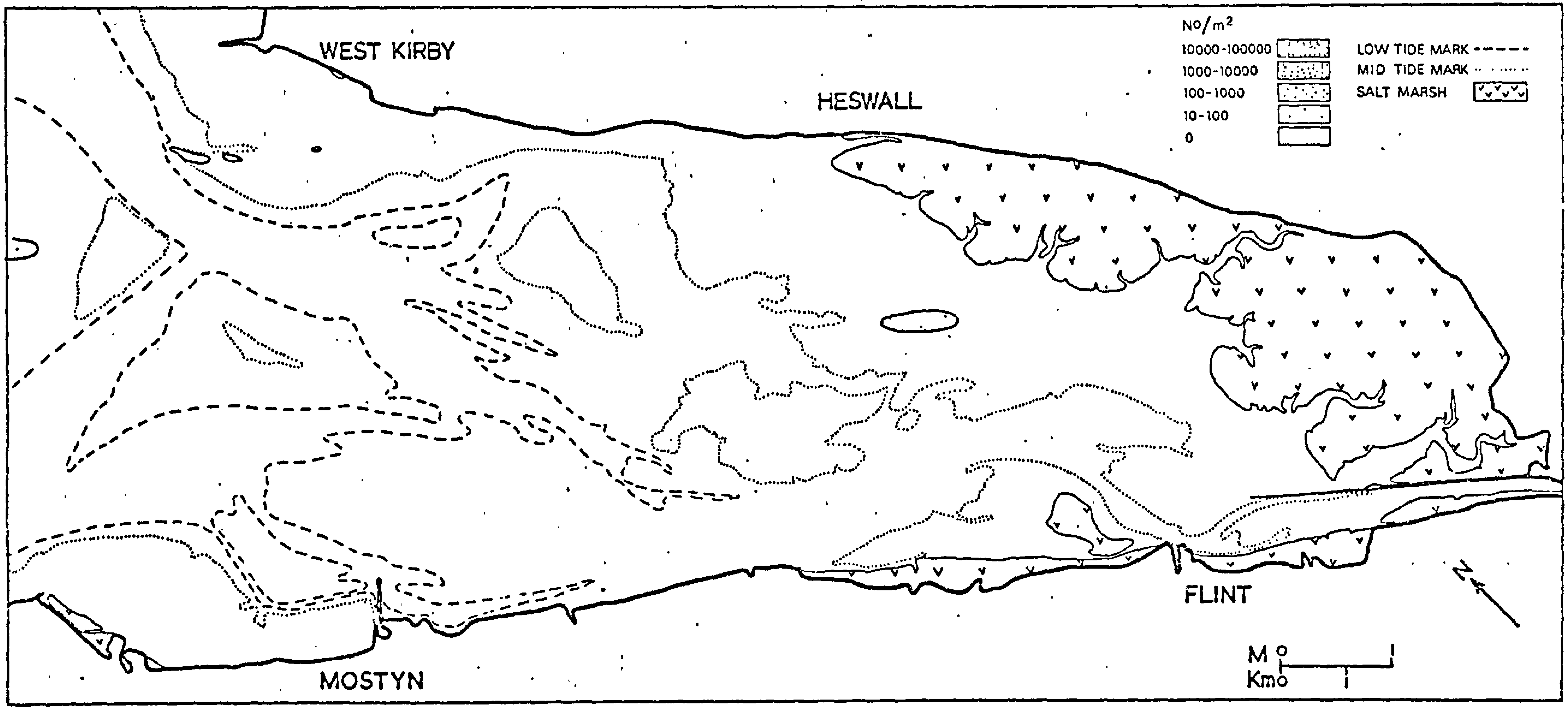
Map 227. Density distribution of <u>Crangon vulgaris</u> in Spring 1976.



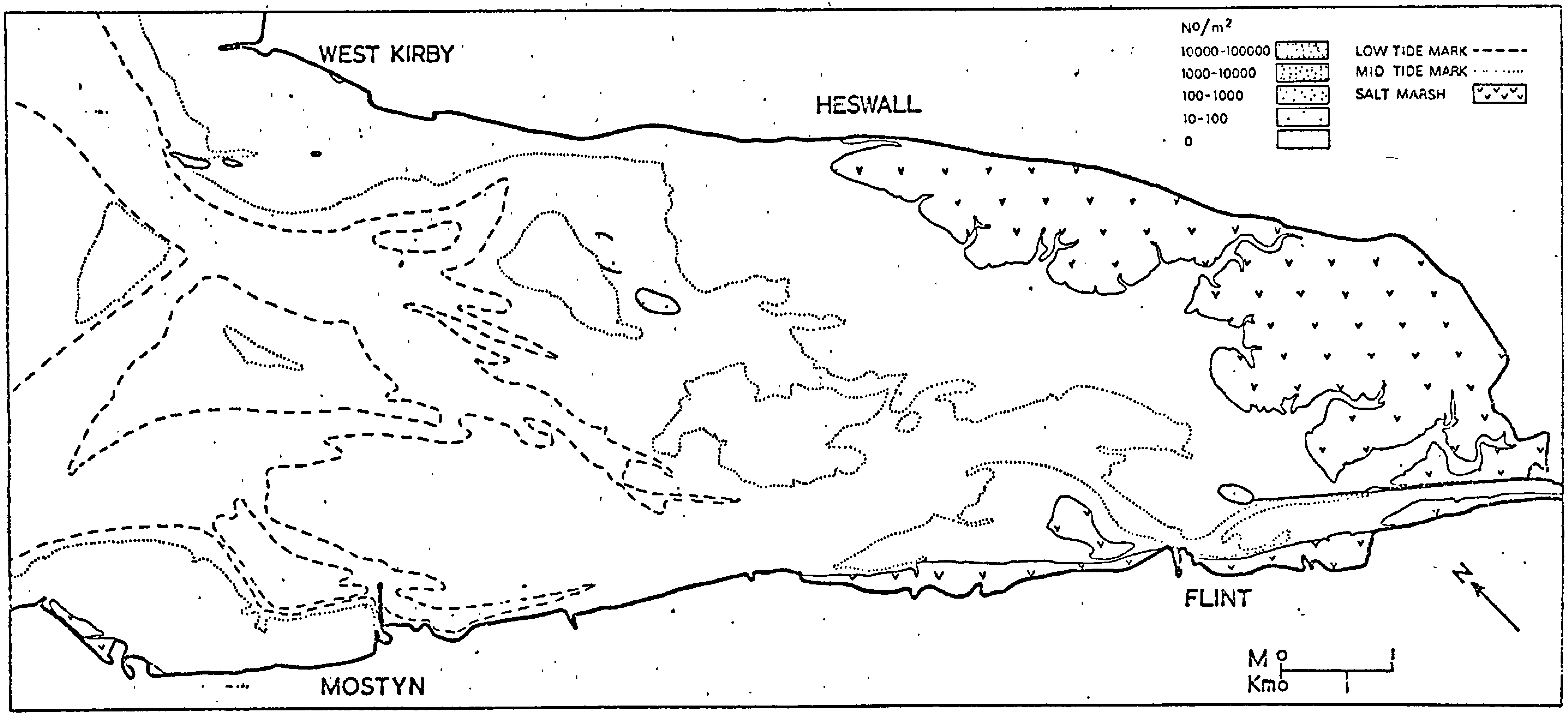
Map 228. Density distribution of Crangon vulgaris in Autumn 1976.



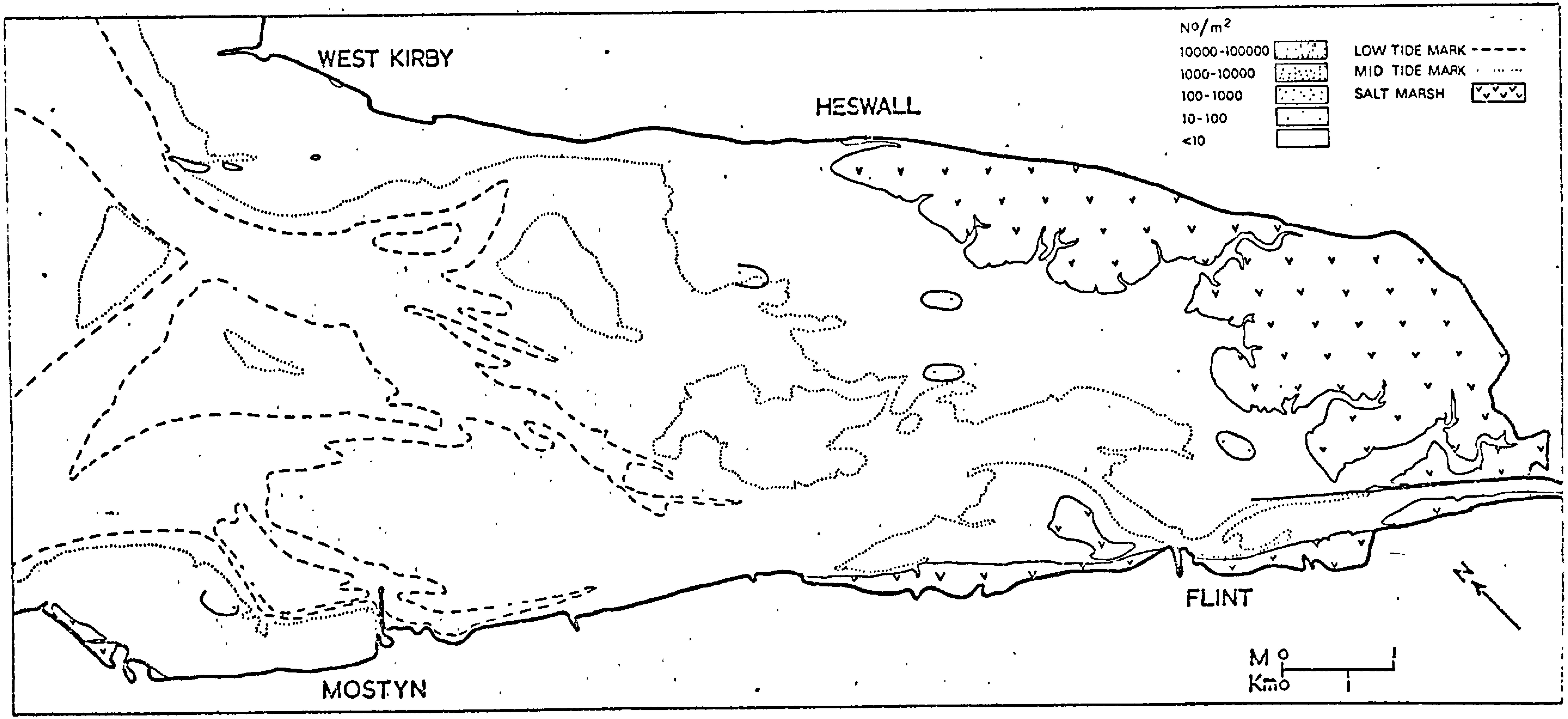
Map 229. Density distribution of Carcinus maenas in Autumn 1971.



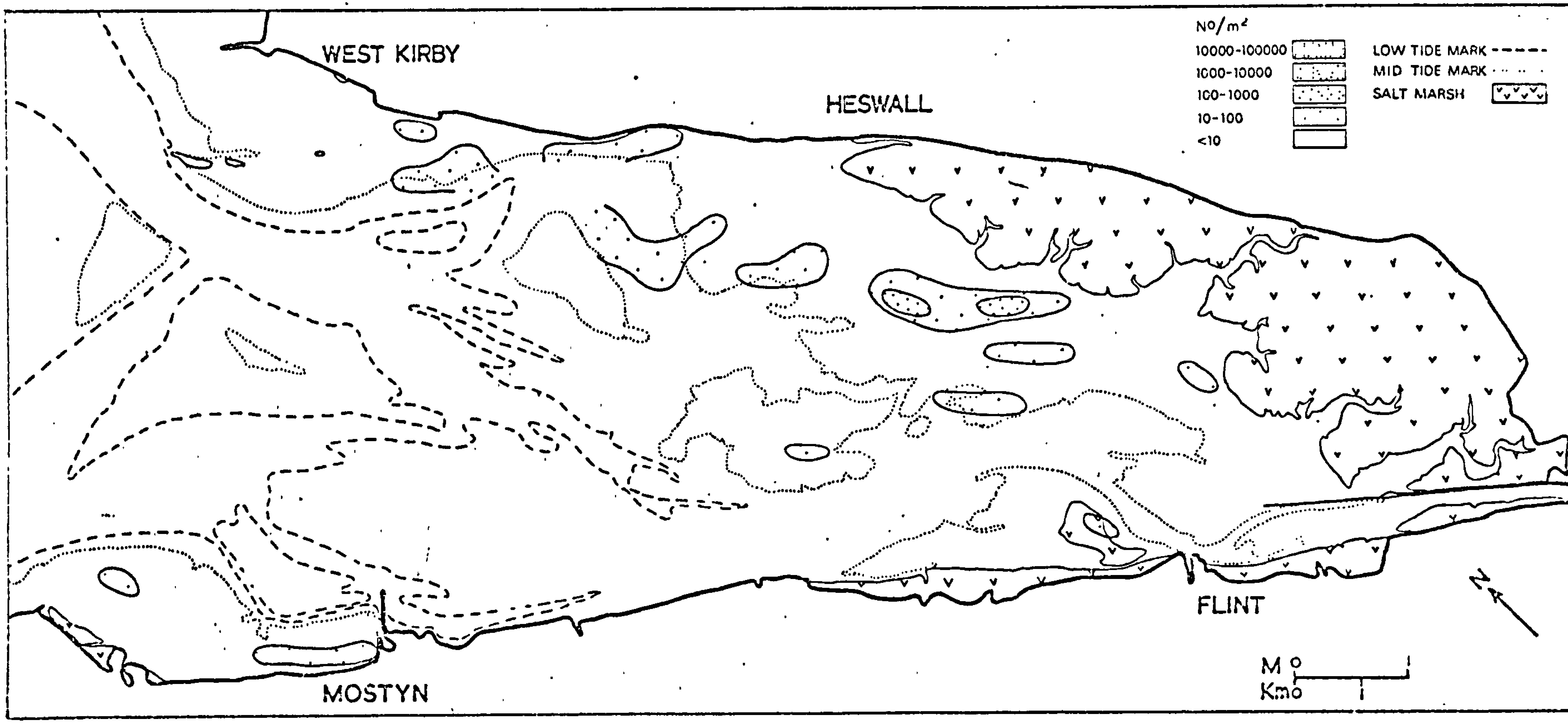
Map 230. Density distribution of <u>Carcinus maenas</u> in Spring 1973.



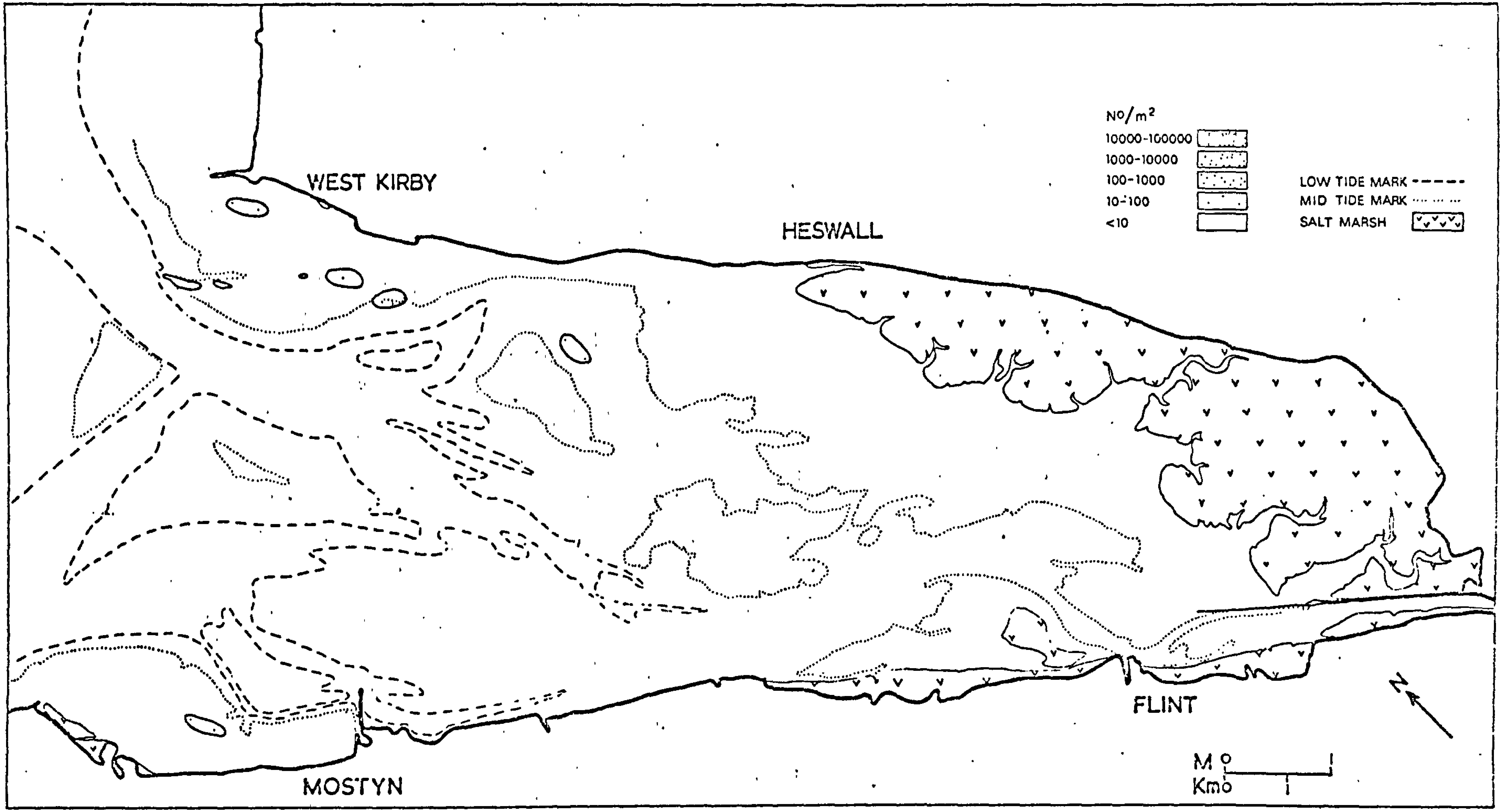
Map 231. Density distribution of Carcinus maenas in Spring 1974.



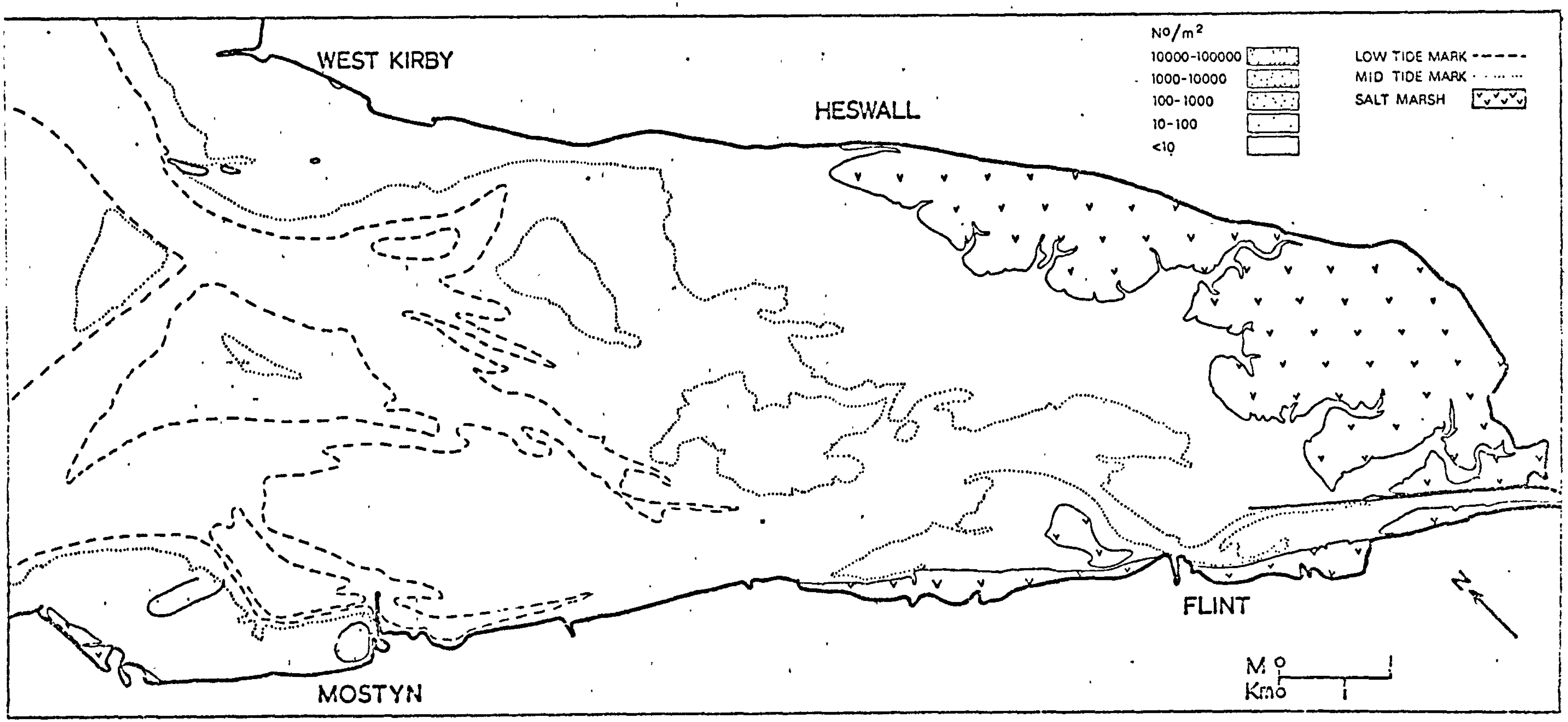
Map 232. Density distribution of <u>Carcinus maenas</u> in Spring 1975.



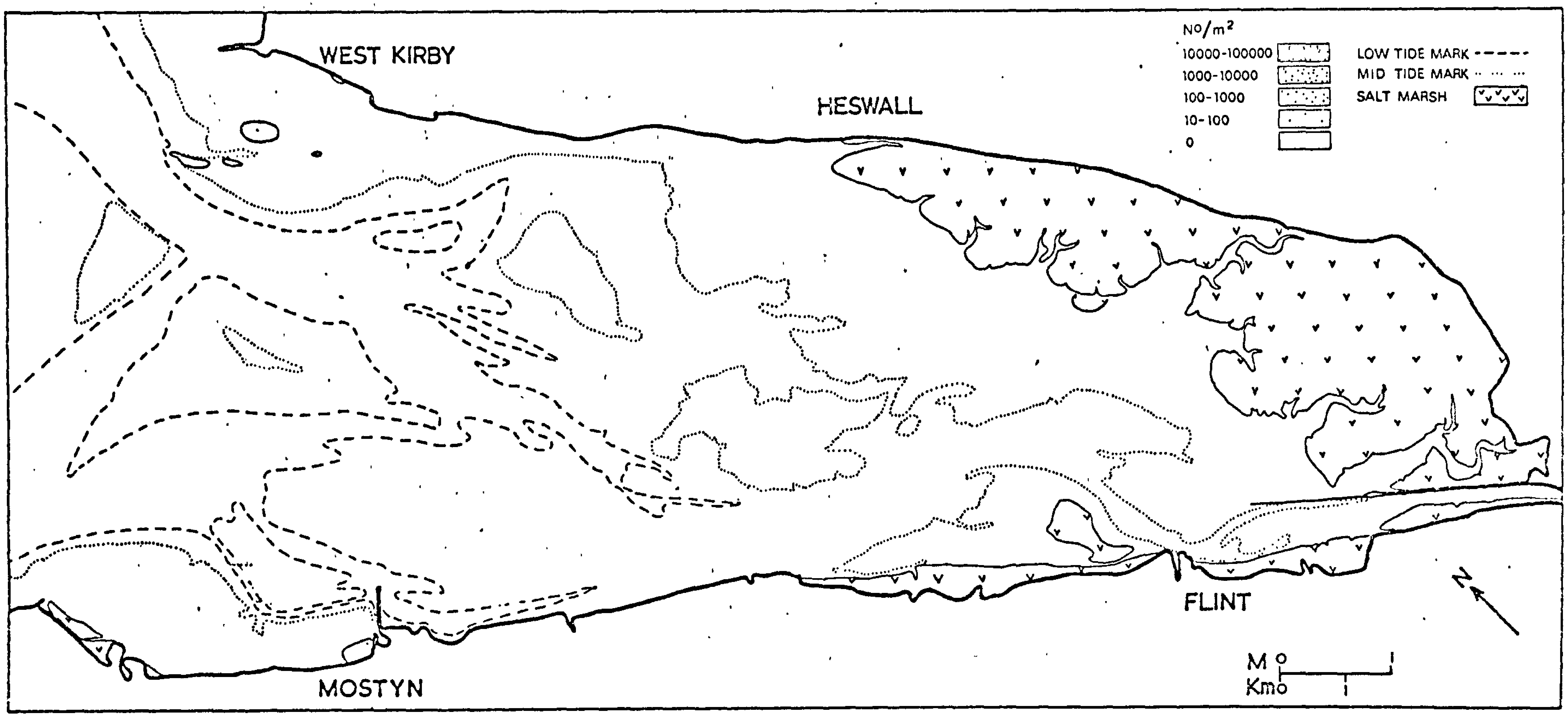
Map 233. Density distribution of _Carcinus maenas_ in Autumn 1975.



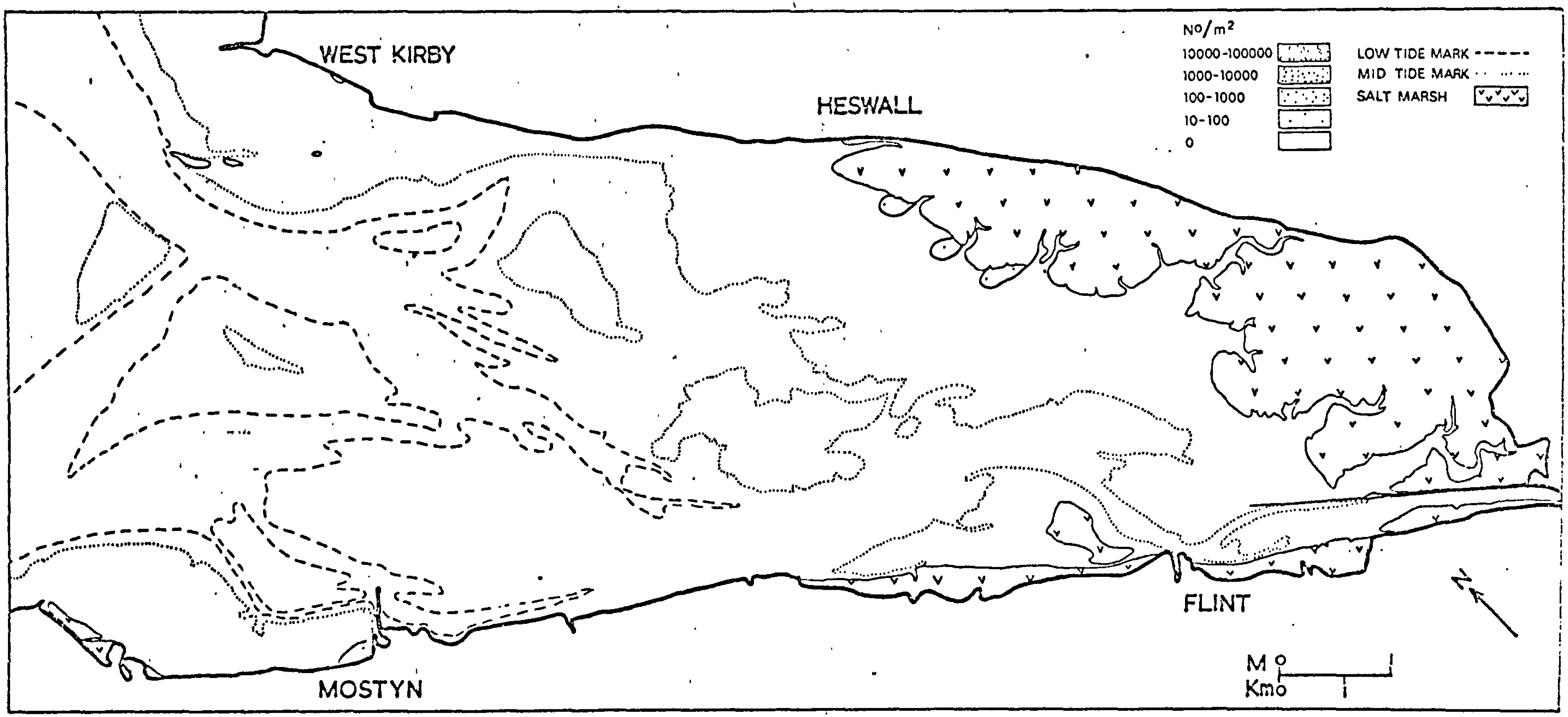
Map 234. Density distribution of Carcinus maenas in Spring 1976.



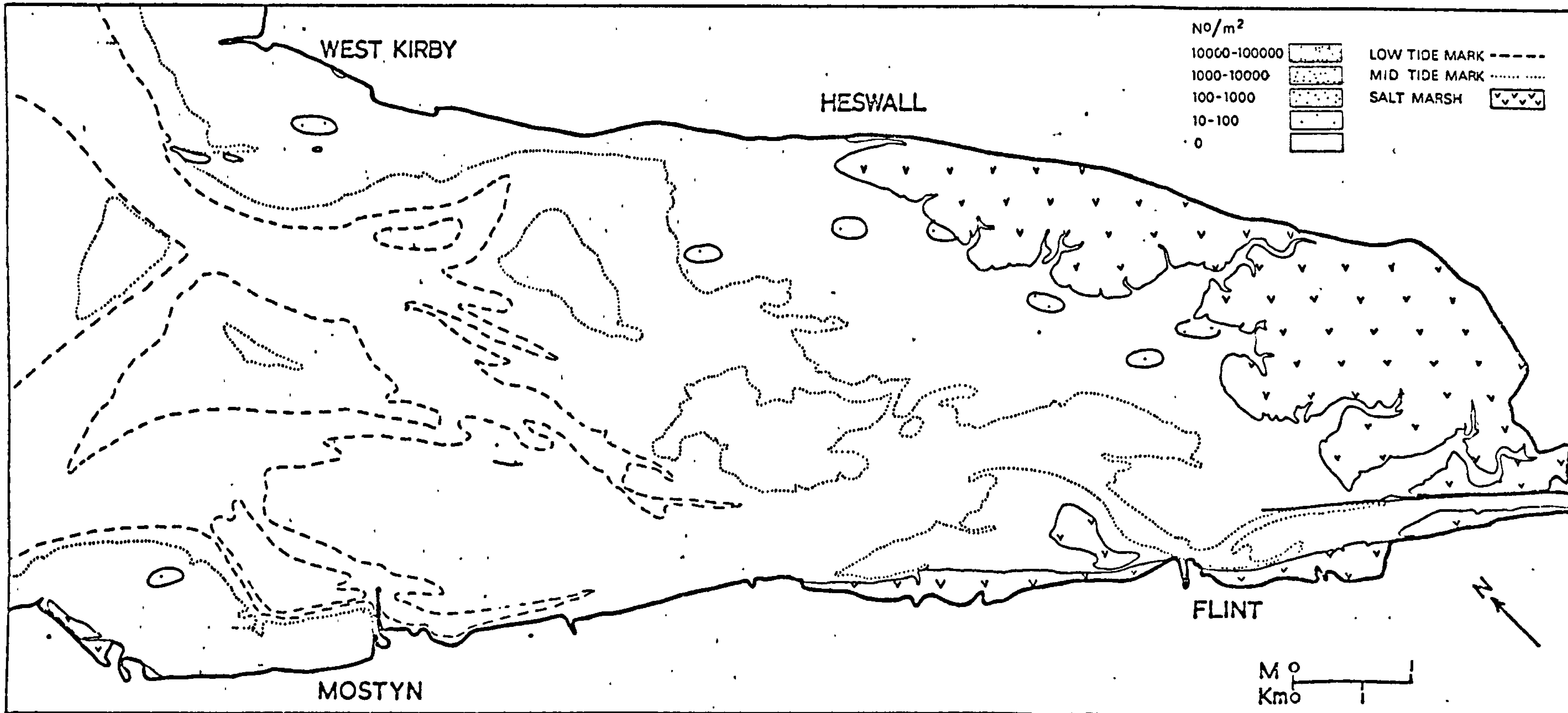
Map 235. Density distribution of <u>Carcinus maenas</u> in Autumn 1976.



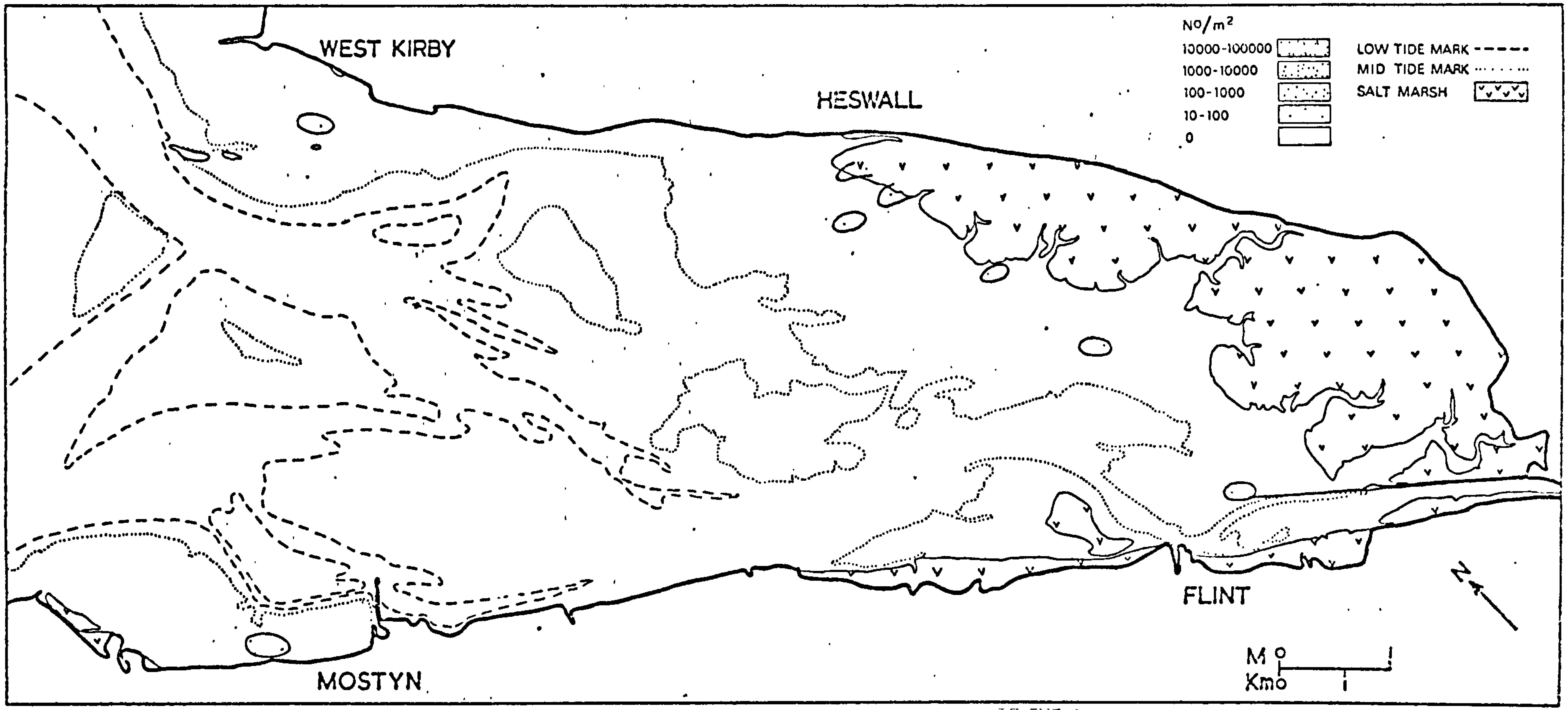
Map 236. Density distribution of Diptera larvae in Autumn 1971.



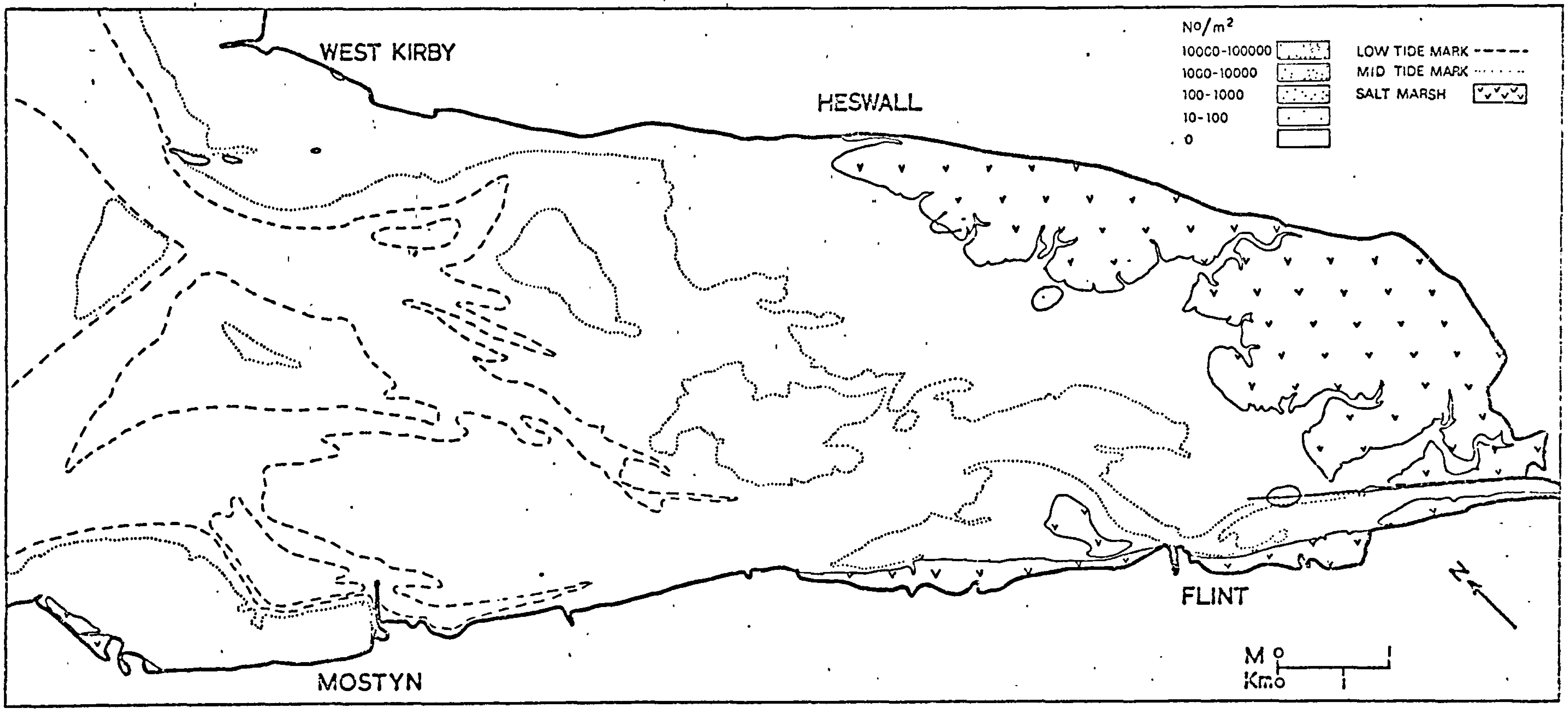
Map 237. Density distribution of Diptera larvae in Spring 1972.



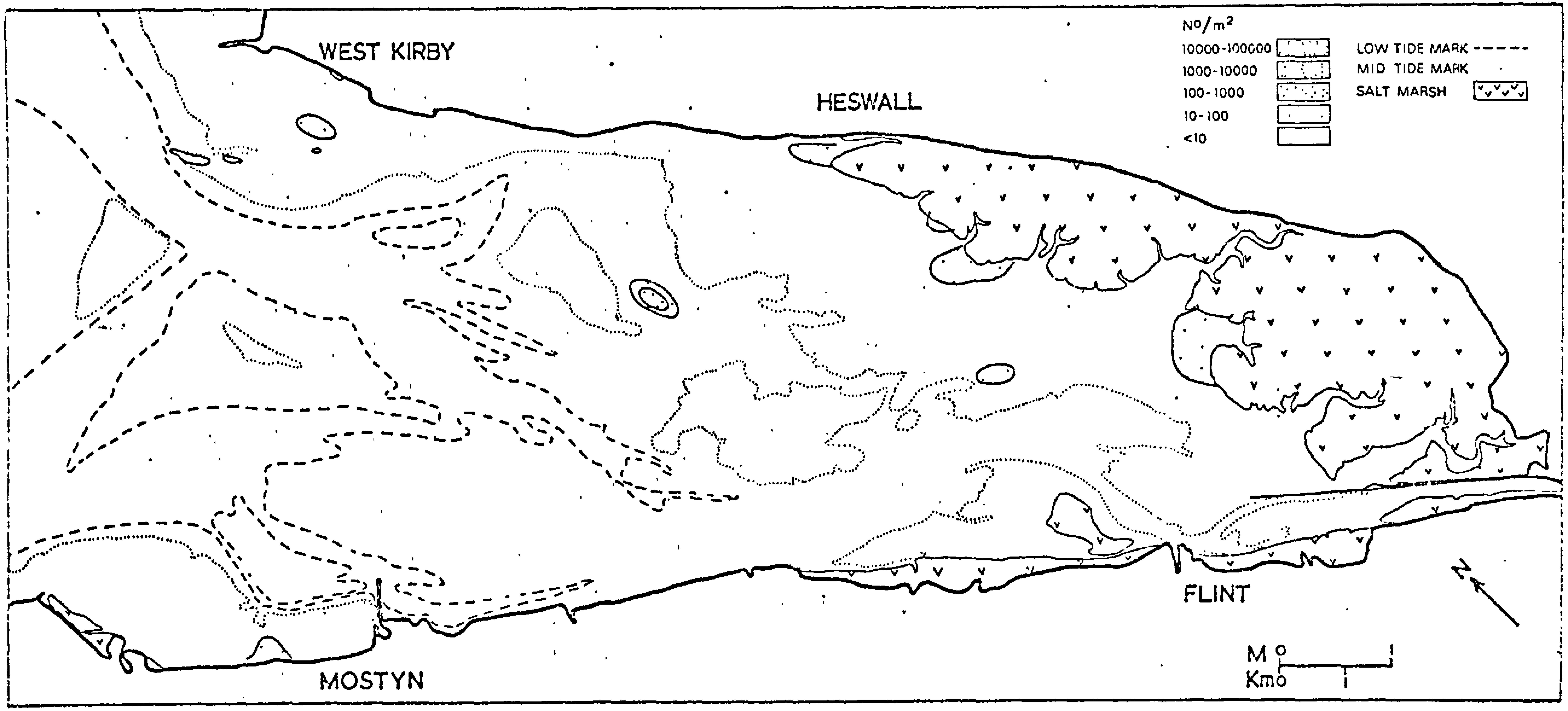
Map 238. Density distribution of Diptera larvae in Spring 1973.



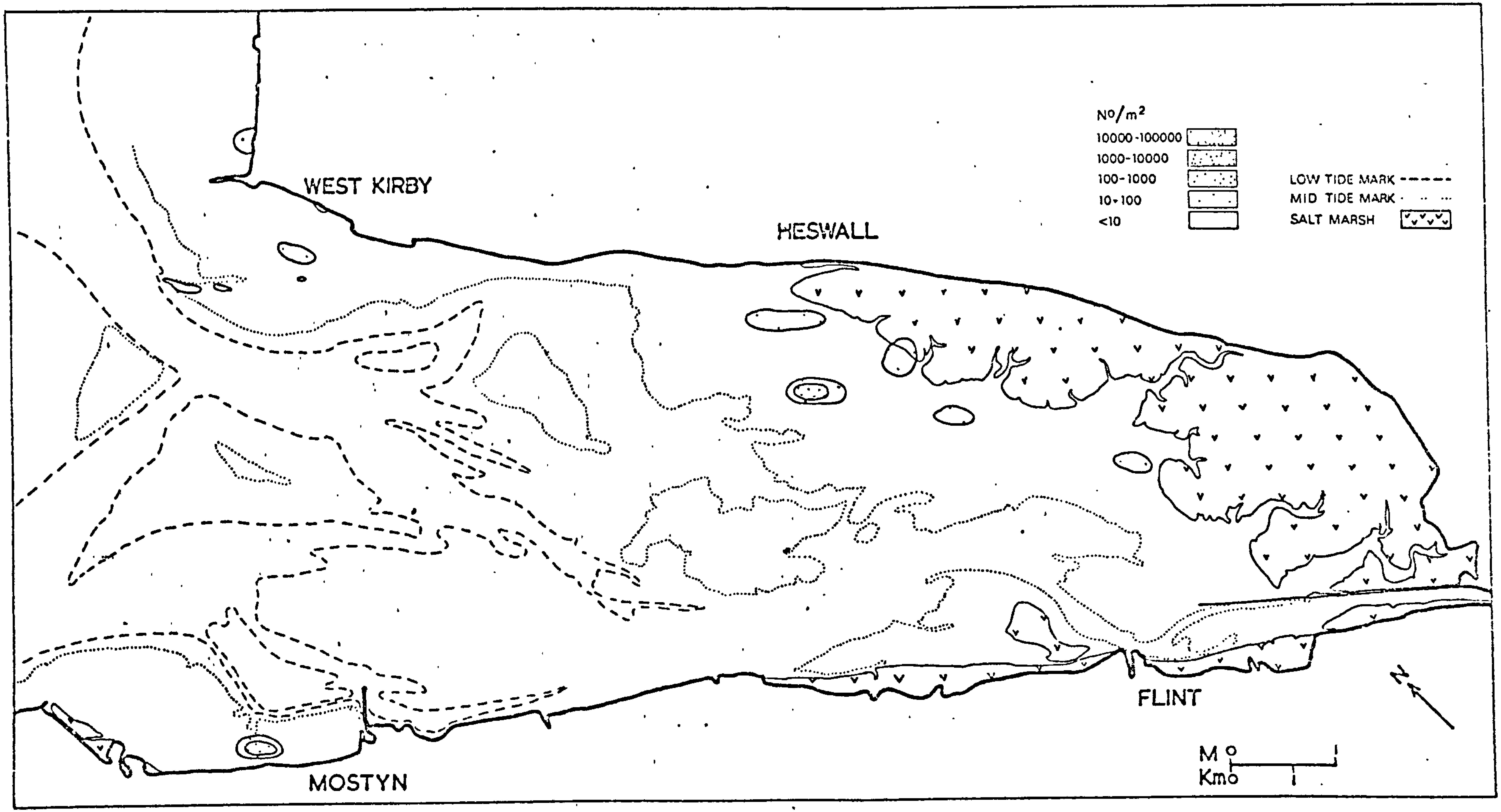
Map 239. Density distribution of Diptera larvae in Spring 1974.



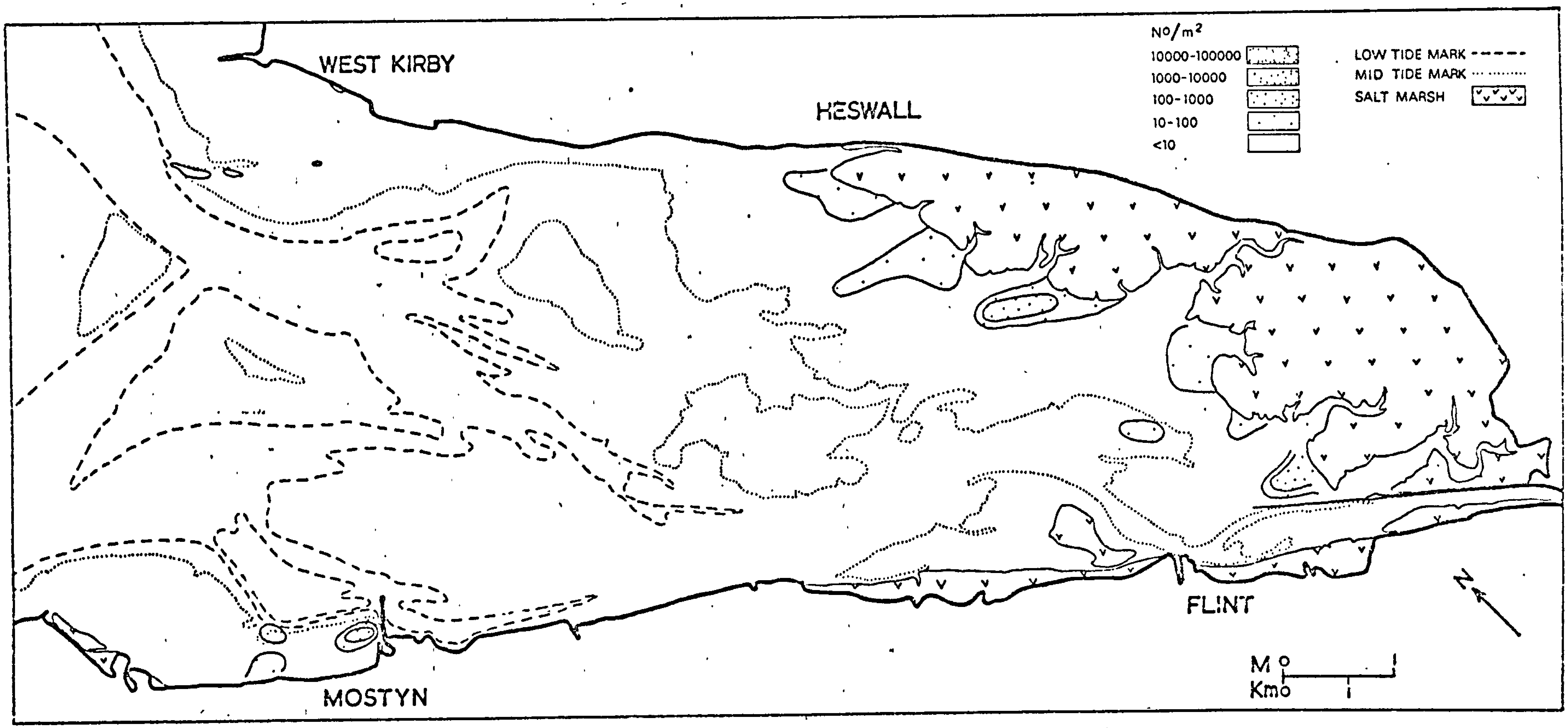
Map 240. Density distribution of Diptera larvae in Spring 1975.



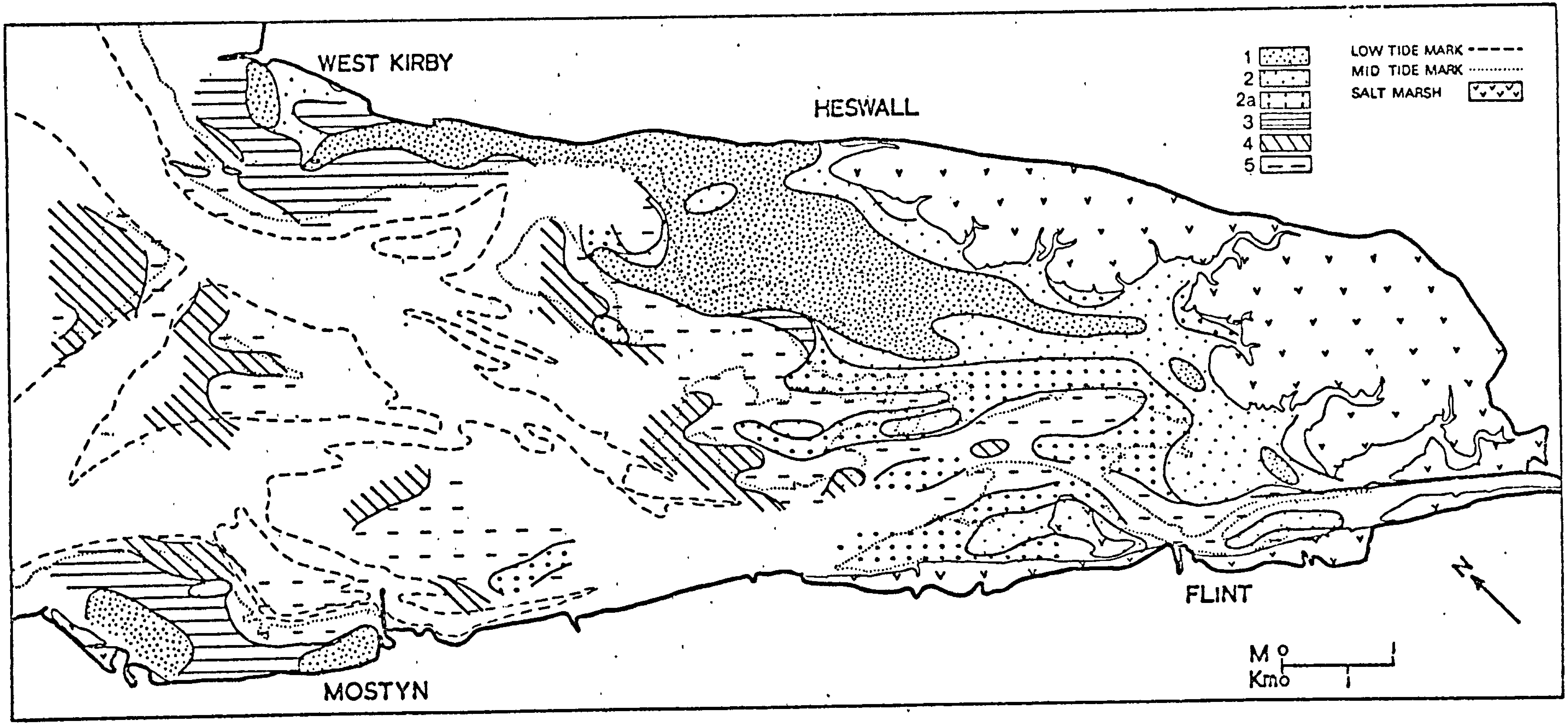
Map 241. Density distribution of Diptera larvae in Autumn 1975.



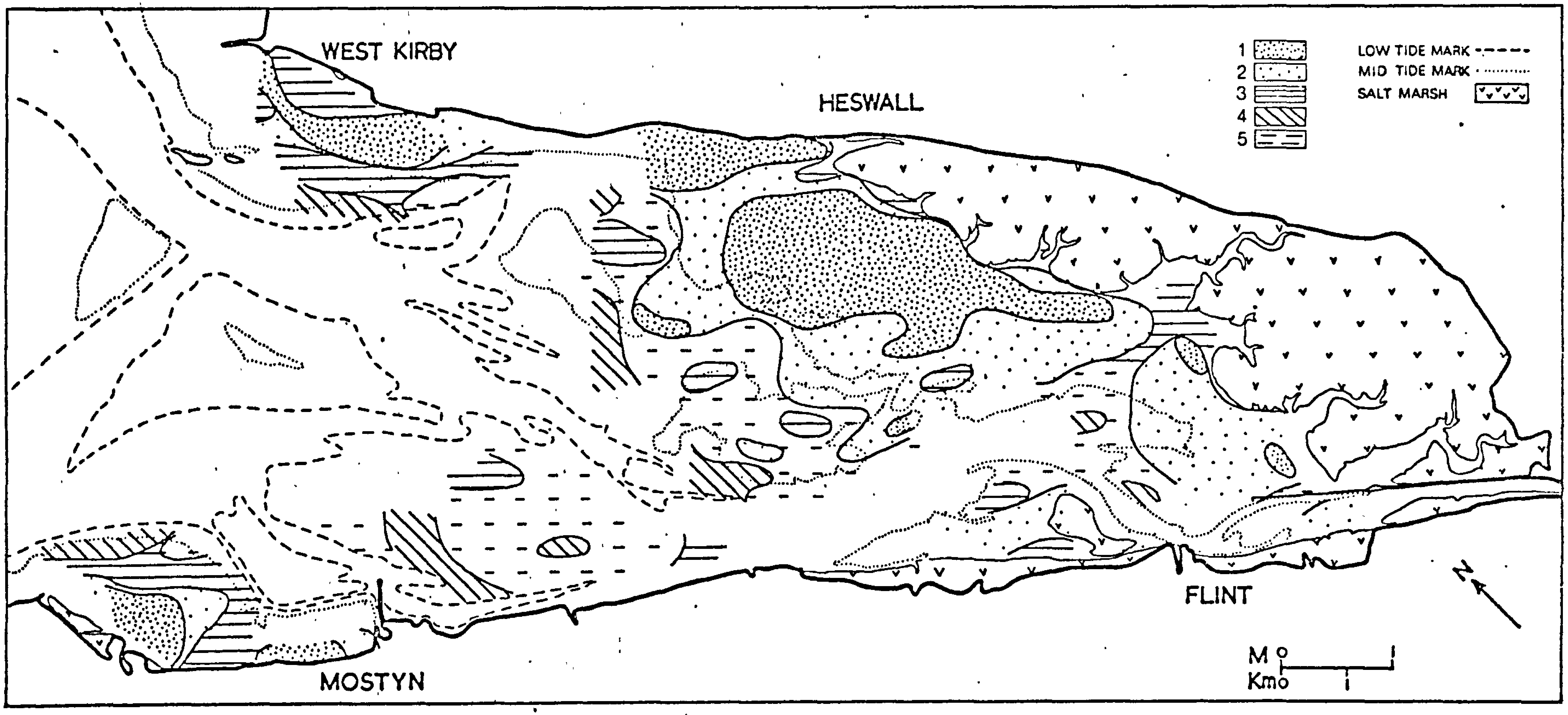
Map 242. Density distribution of Diptera larvae in Spring 1976.



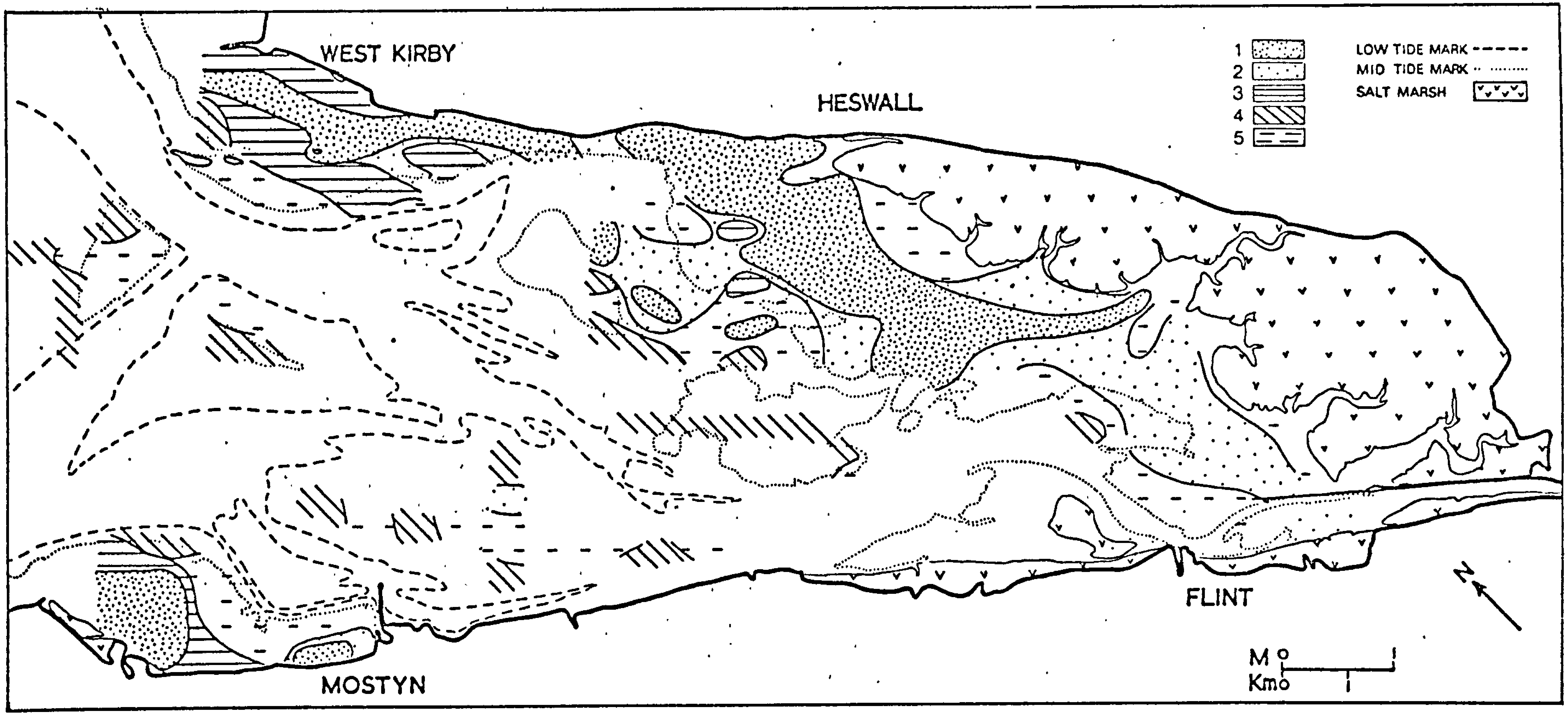
Map 243. Density distribution of Diptera larvae in Autumn 1976.



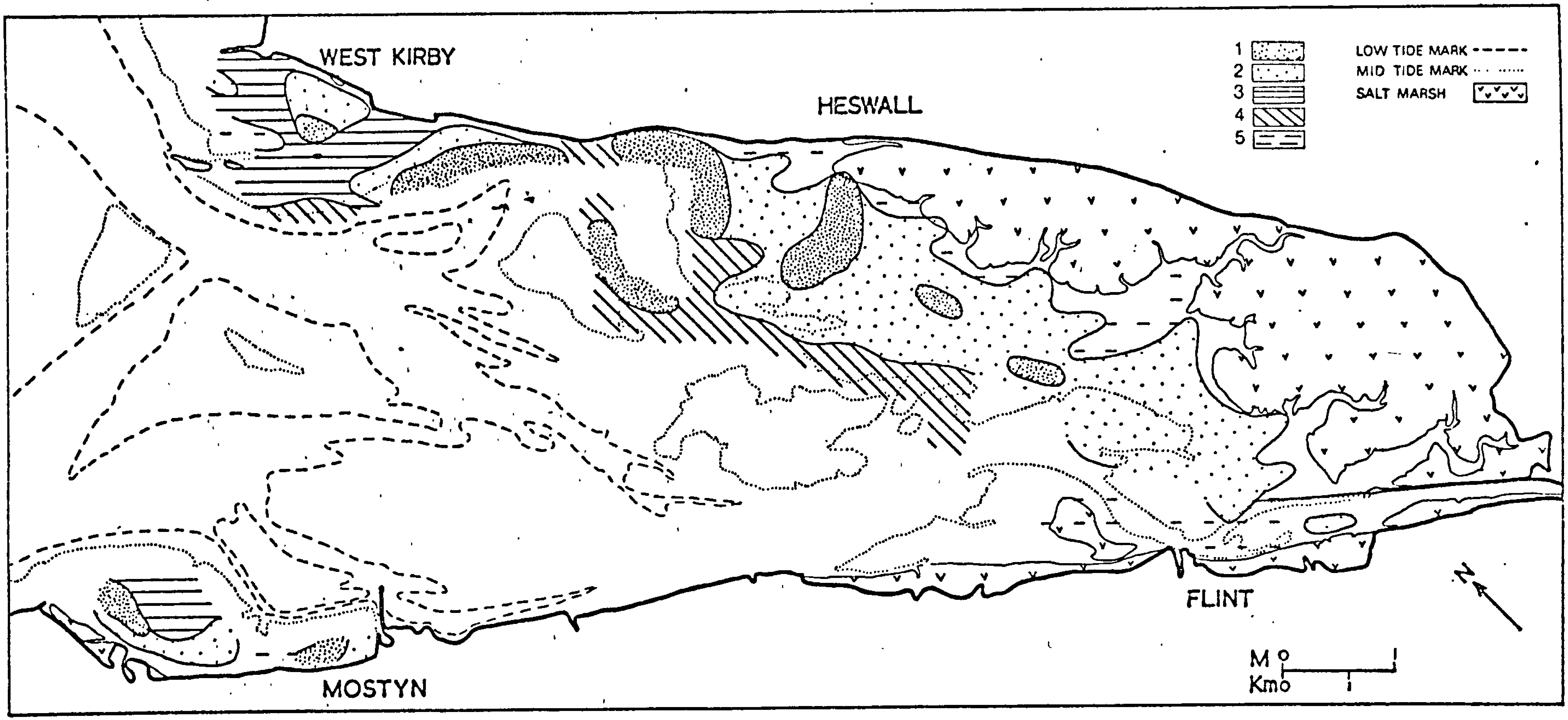
Map 244. Distribution of Normal Association Analysis Groups in Autumn 1971.



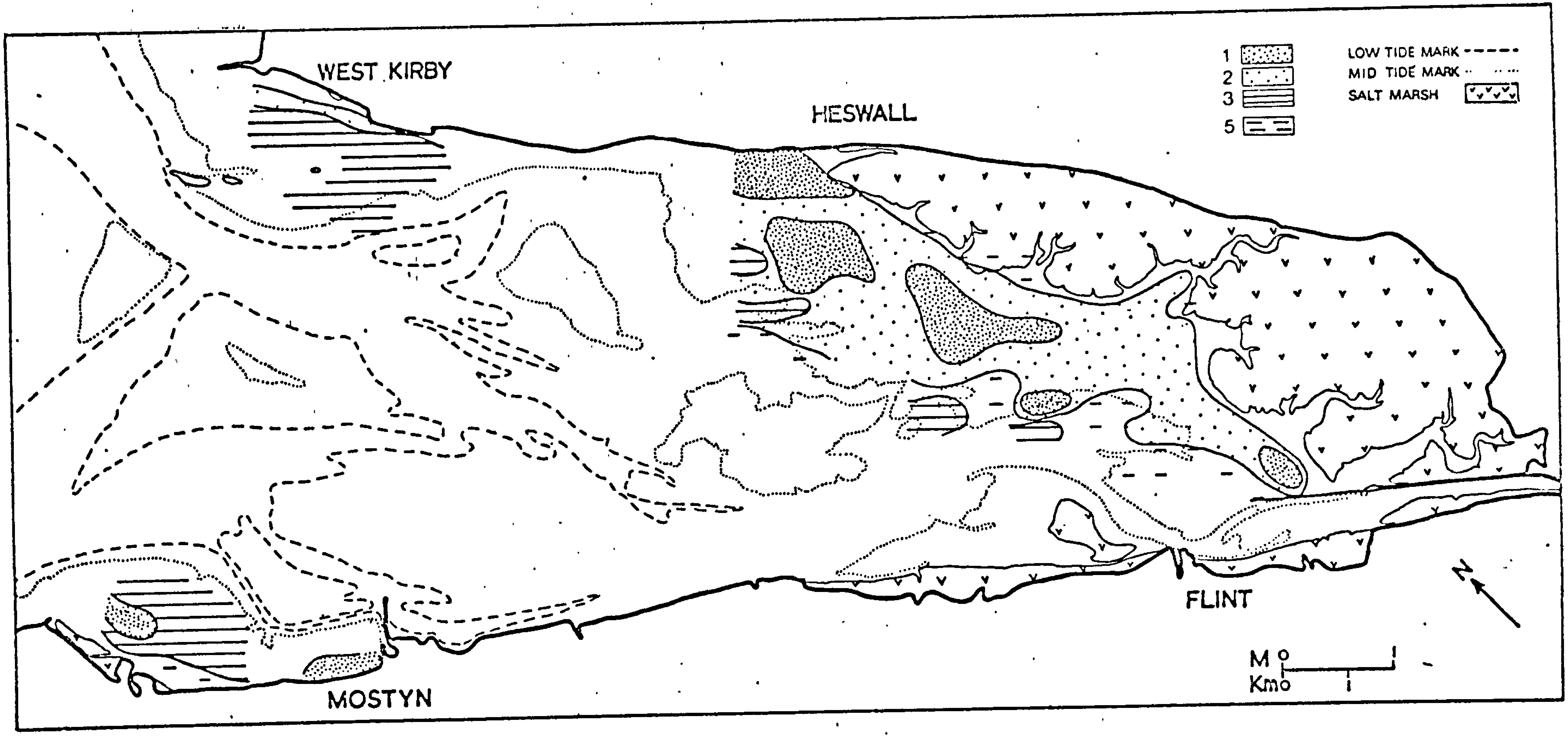
Map 245. Distribution of Normal Association Analysis Groups in Spring 1972.



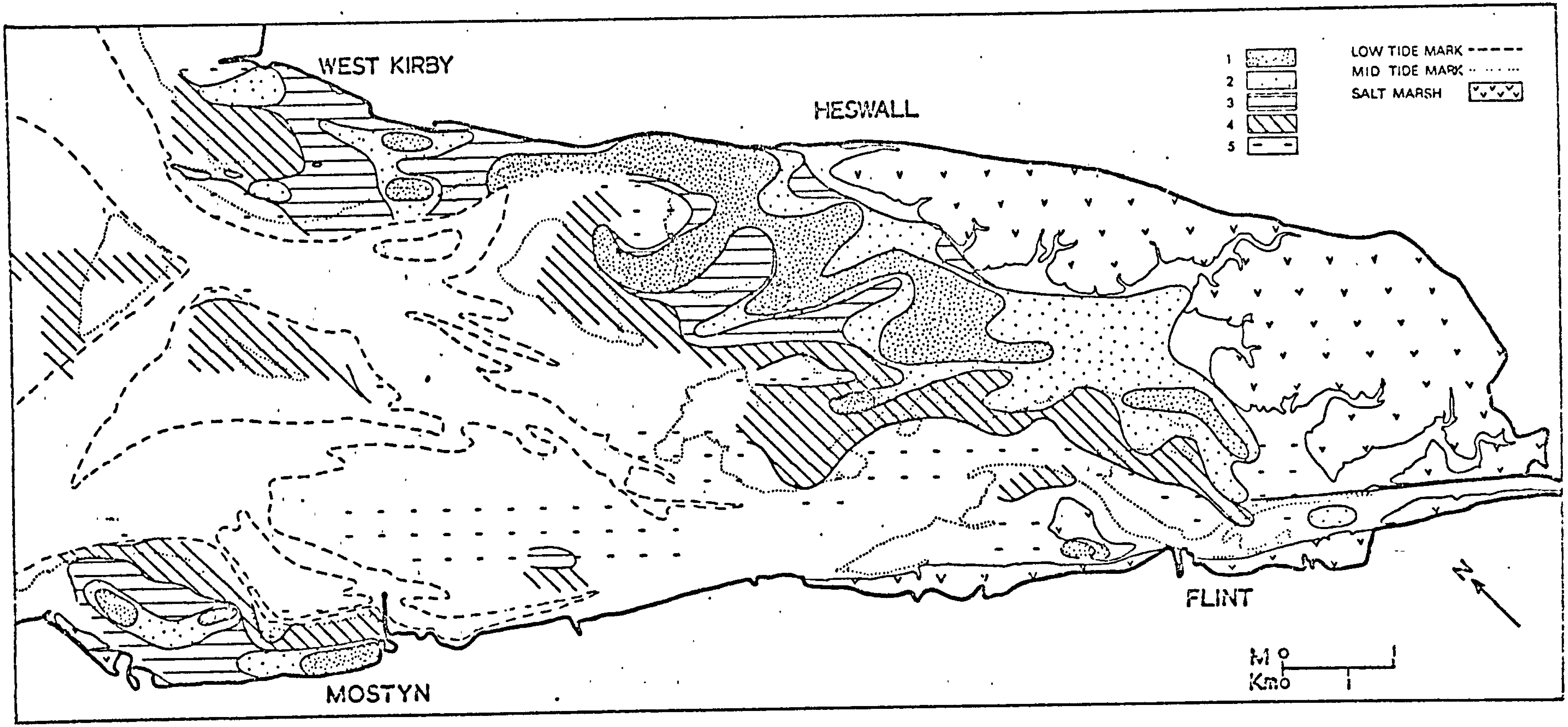
Map 246. Distribution of Normal Association Analysis Groups in Spring 1973.



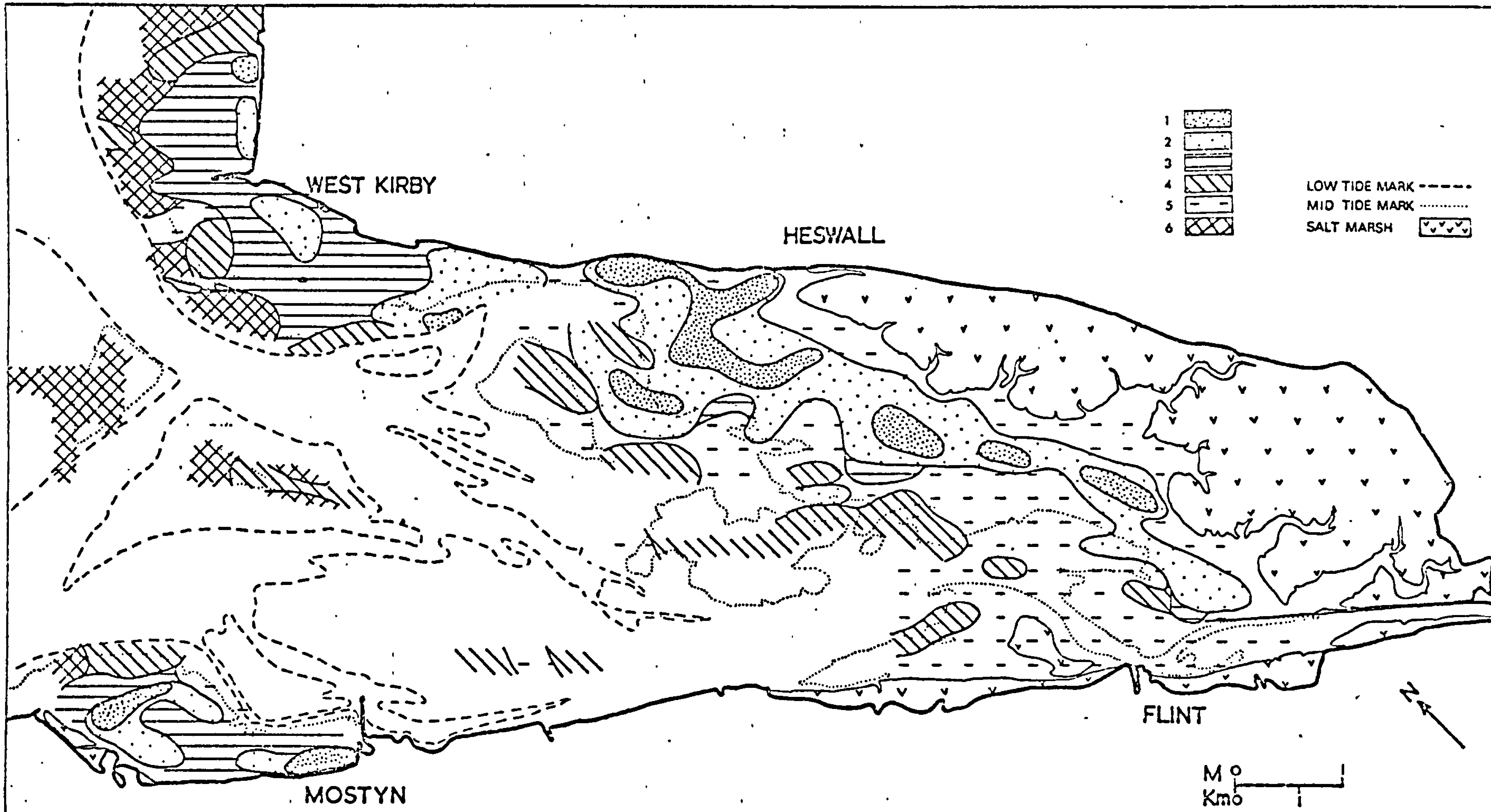
Map 247. Distribution of Normal Association Analysis Groups in Spring 1974.



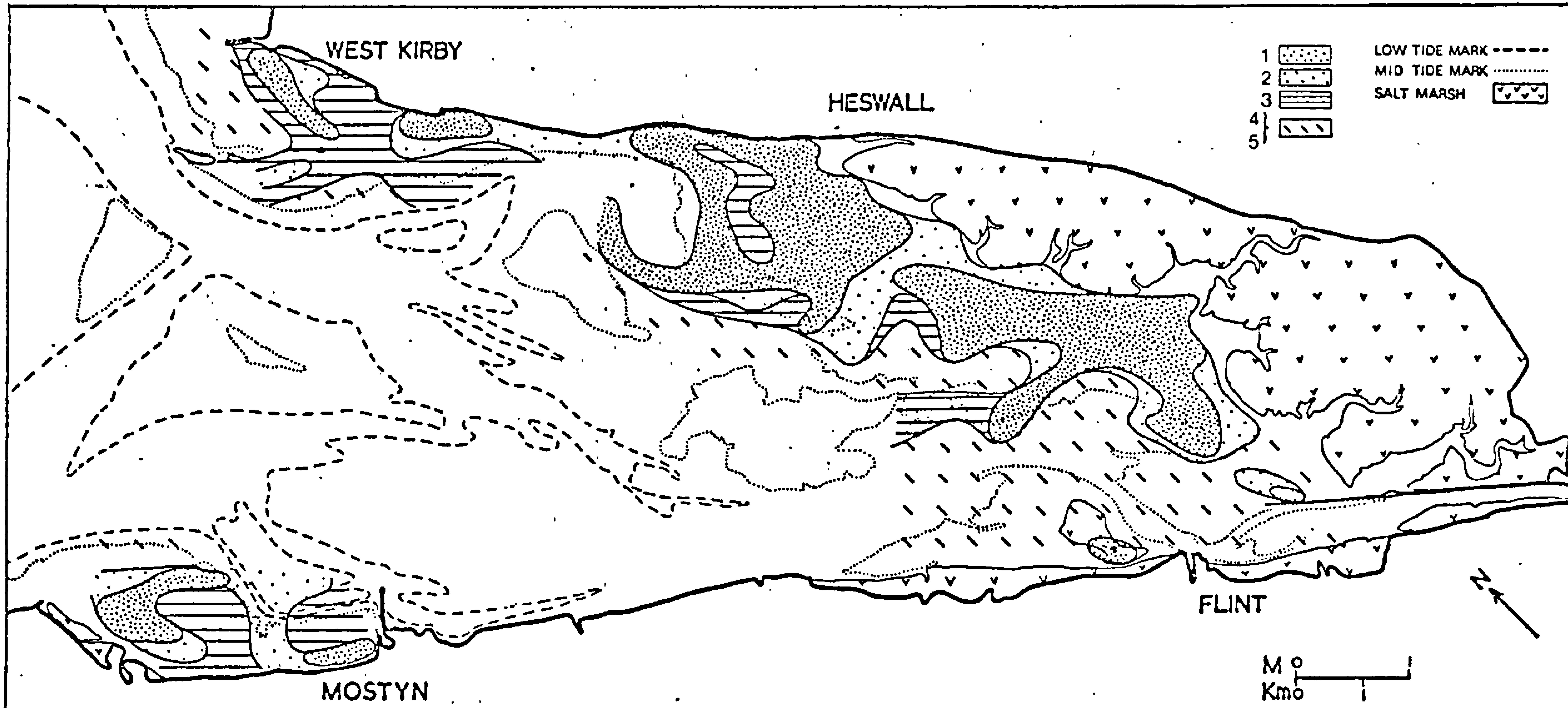
Map 248. Distribution of Normal Association Analysis Groups in Spring 1975.



Map 249. Distribution of Normal Association Analysis Groups for Autumn 1975.



Map 250. Distribution of Normal Association Analysis Groups in Spring 1976.



Map 251. Distribution of Normal Association Analysis groups in Autumn 1976.