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SPATFALL AND RECRUITMENT OF MUSSELS *(MYTILUS EDULIS)* AND COCKLES *(CERASTODERMA EDULE)* ON DIFFERENT LOCATIONS ALONG THE EUROPEAN COAST

by

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Spatfall and recruitment of mussels (*Mytilus edulis*) and cockles (*Cerastoderma edule*) on different locations along the European coast. Results of the first of two workshops, sponsored by the C. E. C.

by

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Abstract

The paper describes the state of the art concerning spatfall and recruitment of mussels and cockles and research activities in this field, under way in the countries which participated in the workshop. A summary of the working papers presented at the workshop is given, split up in three themes: spatfall and recruitment, mortality of spat and methods for assessment of spat and spawning stocks. There were 21 participants from 5 countries. In all countries, except Spain, recruitment of mussels and cockles had been poor since 1990. There were two contributions presenting evidence that recruitment success of mussels and cockles, and also of other bivalves, is favoured by cold preceding winters and decreases after mild preceding winters. A possible cause, or one of the causes, might be delayed arrival on the tidal flats of predators, such as crabs and brown shrimps, after cold winters, which allows the spat to reach a larger size before being confronted with these predators. Evidence for this causality was presented. Further, participants presented their methods for assessment of stocks of spat and adults. In many countries, assessments in large areas appeared to pose capacity problems. Stock assessments, however, are considered indispensable if the variations in spatfall and recruitment are to be studied

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1. INTRODUCTION

This paper is an account of contributions and discussions, produced during a two-day workshop on relations between spatfall and recruitment and environmental parameters in a number of European countries. The workshop was the first of two, sponsored as a Coordination Action in the FAR- programme of the Commission of European Communities.

Three successive years of failing spatfall and recruitment of mussels (*Mytilus edulis)* and cockles (*Cerastoderma edule*) are causing serious trouble for mussel growers and mussel and cockle fishermen in a number of European countries. In 1991 and 1992, substantial production losses occurred. In addition to this, negative side-effects are showing, like food depletion in foraging areas for migrating or over-wintering birds, leading to an increased mortality among eider ducks (*Somateria mollissima*) and oystercatchers (*Haematopus ostralegus*). International transports of mussel seed, necessary to satisfy the demand, increase the risk of transfer of non-indigenous parasites, pathogens and other organisms. The lack of cockle and mussel spat on its present widespread scale is, as far as known, occurring for the first time in Europe. In the Netherlands, and also in the other coastal countries, scarcity of mussel and cockle seed is increasing the level of wholesale and consumer prices of mussels and cockles. The scarcity of the product and the high prices lead to financial problems for growers, traders and retailers.

If the outcome of these workshops can lead to a better understanding of the underlying causes of variations in spatfall and recruitment, it will contribute to a better management of seed collecting for aquaculture and of cockle and mussel fisheries. This can result in a more balanced use of these coastal resources and may have a positive effect on the European shellfish market, where large oscillations prevail and demand is gradually increasing.

Apart from contributions and discussions on reproduction, spatfall and recruitment mechanisms and the possible influence of environmental and climatological factors, the assessment of stocks of spat and spawning stocks was discussed. Methods used and tried out in the different countries were compared, the results of the discussions are dealt with in this report.

2 ATTENDANCE OF THE WORKSHOP

Denmark: Per Sand-Kristensen Institute for Fishery and Marine Research, Charlottenlund Slot, 2920, Charlottenlund.

France: Jean Prou, IFREMER, BP 133, 17390 La Tremblade, Marie-José Dardignac, IFREMER, Place du séminaire 7, B.P. 7, 17137, L' Houmeau.

Netherlands : Renger Dijkema (Chairman), Jeanet Allewijn, (support), Marnix van Stralen, Joke Kesteloo, Harry de Jong, Cora Brand, Gerrit van de Kamp., Netherlands Institute for Fisheries Research (RIVO-DLO), PB 77, 4400 AB Yerseke. Norbert Dankers and Kees de Vooys, Institute for Forestry and Nature Research (IBN-DLO), PB 167, 1790 AD Den Burg. Jan J. Beukema, Netherlands Institute for Sea Research (NIOZ), POB 59\1790 AD Den Burg, Jaap de Vlas, Ministry of Agriculture, Nature Management and Fishery, PB 2003, 8901 JA Leeuwarden.

Spain: Jorge Caceres Martinez, Instituto de Investigaciones Mariñas, Eduardo Cabello 6, 36208 Vigo. José Fuentes, José Molares and Antonio Villalba, Centro de investigaciones mariñas, Apartado 208, Vilaxoan, 36600 Vilagarcia de Arousa (Pontevedra).

Great Britain: Peter Dare and Peter Walker, MAFF Fisheries Laboratory, Lowestoft, Suffolk NR33 0HT.

3. STATE OF THE ART IN THE PARTICIPATING COUNTRIES

3.1 The Netherlands

The Netherlands Institute for Fishery Research (RIVO-DLO) studies yearclass strength and biomass of mussels and cockles in the Wadden Sea and the Oosterschelde and Westerschelde estuaries. The Netherlands Institute for Sea Research (NIOZ) at Texel studies long-term developments in benthos communities on tidal flats in the Wadden Sea, in which also yearclass strength, mortality and predator densities are taken into account, as well as environmental factors. Settlement of mussels is monitored on test collectors and larval densities. Relations between bivalve egg quality and water temperature during winter are studied. Spatfall of mussels in the Netherlands was very poor in 1989 and 1990. Failing recruitment of mussels during several years had for the last time occurred in 1954. Adult mussel stocks, wild as well as cultured, were minimal in the early spring of 1990, as intertidal seedbeds had been swept away by storms in the previous winter and cultivation plots were almost harvested empty by the growers. Eider ducks (*Somateria mollissima*) further consumed a considerable part of the stock on culture plots and the remaining wild banks. Despite the low spawning stock, reasonable mussel settlement was reported in 1991. A part of this, in one case documented, may have originated from autumn spawning in 1990. The adult mussel stock size in the Wadden Sea was minimal again in early spring 1992. Nevertheless, reasonable quantities of mussel spat were reported to have settled in the subtidal area in the western part of the Wadden Sea in June 1992.

Recruitment of cockles was minimal from 1989 to 1991 in both the Wadden Sea and the Oosterschelde. Despite the very low adult cockle stock, a relatively good late settlement occurred in autumn 1990 in both areas, which will recruit by autumn 1992. In the offshore area also a good spatfall occurred in 1991, which also will recruit in autumn 1992. Also in the summer of 1992, fair amounts of spat are reported. In both 1991 and 1992 the spawning stocks in all areas were very low.

3.2 Denmark

In Denmark, mussel recruitment has been poor for the last four years. A devastating ice winter occurred in 1986 / 1987. In 1987, very rich spatfall occurred in the northern part of the Wadden Sea. In the Limfjord spatfall occurs regularly every year. Cockle stocks are large, yearclass 1987 is highly dominant. Densities are 5 - 7 $kg.m^2$. The Danish Institute for Fishery and Marine Research has started to study mussel stocks in the Wadden Sea in 1986. Also cockle stocks are inventarised on a limited scale.

3.3 Spain

Most (70%) of the seed for the Spanish rope culture of mussels is scraped from intertidal rocks. This is considered risky and inefficient. There is, however, no lack of recruitment. Methods are sought to collect seed in more efficient ways, for instance on ropes. Even hatcheries are considered to be of potential interest. There is no wild mussel population, only cultured stock. Since the last 2 years, research in gametogenesis and spatfall and recruitment by the two participating institutes is oriented on study of early settlement and development of mussel spat in relation to depth and environmental factors on artificial collectors (ropes) and natural rocks.

3.4 United Kingdom

The situation in different parts of the country is not similar. Adult cockle stocks in the Wash have been low since 1986. This seems to be the only area with a long period of bad recruitment. A stock in Burry Inlet (South Wales) is low due to failing recruitment in 1990. Older and younger yearclasses, however, are of average strength. There is little research done on wild populations and spatfall of mussels. Mussel stocks in the UK have been very low since a decline started in 1982, despite a good spatfall (the last) in 1986.

3.5 France

In the Pertuis Breton (Charente Maritime, Atlantic coast), mussels are cultivated on poles (bouchots). Seed is collected on coconut-fiber ropes. Concentrations of mussel larvae are monitored there as they can be a threat to oyster spat collecting. Since 1979, IFREMER follows mussel recruitment in the Marennes-

Oléron basin. Development of mussel larvae, settlement: time, importance, whether or not remaining fixed on the ropes and differences with recruitment on long-lines are studied. Spatfall on test ropes normally yields 7000 - 10 000 spat.m^{-1}. In 1982 this decreased until 700 spat and in 1989 - 1991 until between 1500 and 2200 spat.m^{-1}. Recruitment failure of the last 3 years has reduced cultivated mussel biomass. Growth rate of the cultured mussels and oysters was also low in 1991, for which low river discharge (by draught) was blamed. In 1989 and 1990, climatic factors were thought to be the cause of poor spatfall. In 1991 no explanation could be found.

In the Seine bay, the research organisation GEMEL reported poor spatfall of cockles. during the last 3 years. This was attributed to a succession of mild winters, which caused loss of condition in the parent organisms through depletion of glycogen reserves.

4 SPATFALL AND RECRUITMENT, A SUMMARY OF CONTRIBUTIONS BY THE PARTICIPANTS

4.1 Spain

In Spain, spatfall of *Mytilus galloprovincialis* is studied in 1990 and 1991 by the Centro de Investigaciones Mariñas in Pontevedra, Spain (Fuentes and co-workers). In the Ria de Arosa (Fig. 1), the influence of the locality, height in the tidal zone and depth are studied on artificial collectors in the tidal zone and suspended subtidally. Results showed a similar pattern of settlement in both intertidal and subtidal collectors. Settlement starts in April and ends in October. Two peaks of settlement occur, one in May-June, the other in August- September (Fig 2). Settlement was more intensive in the outer zones of the Ria than in the inner area (Fig 3). Differences in settlement intensity between four different heights in the tidal zone and two heights above the low water mark could not be demonstrated.

Gametogenesis was studied in 1988 and 1989 on mussels, hung from culture rafts in different areas of the Ria. Results of one locality are represented in fig 4. From January 1989 to June 1989, a period of active spawning took place. From January to March, the mussels were mostly ripe with a moderate percentage of early spawning and re-developing individuals. The first great peak of spawning occurred between March and April. In April, no ripe mussels were found and gonads of most mussels were found re-developing for the next spawning. By May, the mussels were either ripe (40%) or finishing the re-developing process (60%). The second, large spawning peak occurred between May and June. After June, few mussels re-developed their gonads and became ripe, but most of them reabsorbed their gonads to the resting stage (Fig 4).

4.2 The Netherlands

At the Netherlands Institute for Sea Research (NIOZ), spatfall of *Mytilus edulis, Cerastoderma. edule, Mya arenaria* and *Macoma balthica* is studied by J. J. Beukema. He compared spatfall during successive summers between 1969 and 1990. (Beukema, 1982), and found synchronisation in spatfall intensity between the three species (Fig 5a, b, c, d). His (preliminary) results show a relation between spatfall intensity of mussels and cockles and low and high water temperatures in preceding January-March. (Fig 5c, d).

At the same institute, C. de Vooys studies intensity of settlement of metamorphosing larvae of *M.edulis* as well as concentrations of larvae in the water near Texel and spatfall intensity on "petticoat gauze", in the period from 1979 - present.

J. de Vlas (Ministry of Agriculture, Nature management and Fisheries), gave ratings from 0 - 4 (0 = no recruitment, 4 = abundant) to the recruitment success of mussel spat, which he derived from the quantities of seed mussels, fished up by Dutch mussel growers and noted down qualitatively in the reports of fishery inspectors. He compared the "recruitment index" thus obtained, with the mean water temperatures in January and February. The results are shown in fig 6 and 9, demonstrating an inverse relationship between recruitment intensity and the mean water temperature in January - February. He did not find a correlation with mean water temperature in March. Spatfall on intertidal flats in the eastern section and on subtidal beds in the western section of the Wadden Sea did not show significant differences (fig 9).

4.3 United Kingdom

P. J. Dare (Ministry of Agriculture, Fisheries and Food, Lowestoft) presented preliminary results of an analysis of data on stock size of *M. edulis* and *C. edule* in the Wash over the last 95 years, as recorded in the annual reports of the Sea Fishery Committee.

For cockles, a strongly cyclical pattern of abundance could be demonstrated (fig. 7a), with probably 11 cycles during the period at more or less regular intervals of 7 - 10 years between peaks. This figure also indicates the occurrence of good/very good spatfall years (assessed in summer or autumn) and of notable winter mortalities from storms or ice. The present low adult stock abundance has now continued for 6 years (since 1986); previous troughs in the cycle lasted up to 4 successive years. The frequency of cockle spatfalls of different magnitude on this ordinal scale followed a log-normal distribution (fig 7b), with light or moderate spatfalls (orders 1 + 2) predominating and failures being more frequent than heavy spatfalls (orders 3 + 4). No clear relationship is shown between the indices of spawning stock size and those of spatfall magnitude (Fig. 7c). However, several large spatfalls were generated by very small spawning stocks after high mortality from severe cold in the preceding winter.

For *M. edulis,* estimates of area and landings are known from 1920 - 1955 and again since 1982. Wide fluctuations occurred but no cyclical pattern is evident. High stock levels did not follow from heavy spatfalls because, as with cockles, winter storm losses were significant in some years. Since 1982, stocks have declined to a very low point despite a good spatfall in 1986. This may in large part have resulted from over-exploitation. The long-term records of mussel spatfall and stock size indices (fig. 8) show patterns almost identical with those for Wash cockles. Spatfall magnitude typically is low (Fig. 8a) and again the ordinal ranking suggests no relationship between adult stock size and subsequent spatfall abundance (Fig 8b). As with cockles, several heavy mussel settlements were recorded from low spawning stock levels, after very cold winters.

Preliminary modelling of likely larval dispersal pathways in the Southern Bight of the North Sea, using the NORSWAP North Sea water following model, indicates that Wash stocks should best be regarded as discrete and self-sustaining. Larval exchanges between Wash and Thames Estuary, or between English and Dutch populations, should not be expected.

5 PREDATION ON SPAT

5.1 Denmark

5.1.1 Wadden Sea

P. Sand-Kristensen (Danish Institute for Fisheries and Marine Research) presented two working papers with information on possible predation on mussels and cockles. Crab (*Carcinus maenas*) abundance was studied by means of captures in modified lobster creels and by counting numbers in the dredges of mussel fishermen off the island of Skallingen (Danish Wadden Sea). The number of crabs found was 0 - 1 per 3 m^2. This number is in accordance with findings by Munch-Petersen et al. (1982) in the Kattegat area, who found 0.001 - 5 crabs per m^2. The estimated predation by crabs in the Danish Wadden Sea was about 480 tons per month. Predation by the 3.4 - 12.1 million eider ducks (*Somateria mollissima*) per year in the Danish Wadden Sea was estimated to be 6,000 - 20,000 tons per year, that by other birds 5,000 tons (Ministry of Fisheries, 1987).
Predation on mussel and cockle spat by the brown shrimp (*Crangon crangon*) was suggested by an observation in "Jørgens Lo" (Danish Wadden Sea) in the summer of 1988. Very high densities of shrimps (around 400.m^{-2}), were observed feeding very actively in a tidal flat area on approximately 1000 m^2, at daytime. No quantitative information is available. *Crangon crangon* is an abundant species in the Danish Wadden Sea. Annual shrimp landings between

1980 and 1991 lie between 800 and 2000 tons. Around 20 fishing ships are active.

5.1.2 Great Belt area

In Great Belt area (Baltic region of Denmark), eiders and starfish are reported to consume up to 40% of the total mussel biomass per year. The abundance of starfish (*Asterias rubens*) found was one per m^2. The estimated annual consumption in this area was 7,500 tonnes by eiders and 4,500 tonnes by starfish. It was concluded that predation by crabs plays a minor role in relation with predation by starfish and eiders, but crabs are supposed to predate on juvenile stages of mussels. Eider density was 3 million "eider days" per year, with an estimated daily consumption of 2.5 kg mussels. No research has been done in this field.

5.2 The Netherlands

5.2.1 Predation by *Crangon crangon and Carcinus maenas*

Beukema (1992a) sampled juvenile shrimps (*Crangon crangon*) on a tidal flat in the western Dutch Wadden Sea between 1983 and 1991. High densities of juvenile shrimps (5 - 25 mm) were found at low tide in late spring, summer and early autumn. After mild winters maximal densities were found in June, after cold winters in July. Shrimp biomass on the tidal flats was much lower after cold than after mild winters. Shrimps have been found to consume recently-settled *Macoma balthica* (Keus, 1986). Mattila et al. (1990) concluded that shrimp predation seriously reduces densities of *M. balthica* spat. For this reason, cold winters seem to favour recruitment of *M. balthica* via lower shrimp predation. Beukema (1992b) observed high densities of *M. balthica* spat in August on tidal flats in the western Wadden Sea in years starting with a cold winter, whereas spat densities after very mild winters were low. Shore crabs (*Carcinus maenas*) in the Wadden Sea were found to respond in the same way to cold and mild winters as *C. crangon* (Beukema, 1991). The delay in arrival of the juveniles on the tidal flats after cold winters in this species appeared to be even longer than in shrimps (Fig.8).

6 ASSESSMENT METHODS OF JUVENILE AND PARENT STOCKS

6.1 The Netherlands

In the Netherlands, the last few years an increased demand exists for information on size, distribution and composition of cockle and mussel stocks in the coastal waters. This demand comes from both fishery management and nature management authorities, which have to regulate the fisheries in accordance with fishery regulations and nature management policy. This has been stimulated after both the Wadden Sea and the Oosterschelde were given the status of nature reserves a couple of years ago.

6.1.1 Cockles

Stock assessments of macrobenthos, especially in large areas, may pose considerable problems, not only concerning methods and equipment to be used, but particularly in terms of capacity and manpower. Since 1990, the Netherlands Institute for Fisheries Research (RIVO-DLO) carries out stock assessments of cockles in the Dutch part of the Wadden sea, the Oosterschelde and the Westerschelde. The aim is to provide a global figure of size and composition of the cockle stocks in large sections of the fishery areas. This stock assessment is too global to describe single cockle beds. Bottom samples are taken according to pre-established grids. The "mesh width" of these grids is not based on scientific desirability but is merely restricted by the amount of manpower and material available during a period of 3 - 4 weeks in May, within which the assessment has to be made. In the Wadden Sea, the transects of the grid are 2180 m (2') apart, in the Oosterschelde and the Westerschelde 571 m (1'). The distance between two stations in a transect is 463 m (0.25 '). In the Wadden Sea 1561 sampling stations are used, in the Oosterschelde 440 and 319 in the Westerschelde. Fig 11 shows the grid, used in the Wadden Sea. Eight inspection ships, five from the fisheries inspection and three from the nature management inspection service participate, six in the Wadden Sea and two in the Oosterschelde and the Westerschelde. They follow the transects with aid of portable radio-navigating equipment, using DECCA® lines. At each station, 3 samples are taken with an especially designed scooping device (M.R. van Stralen, in prep.). These devices, attached to wooden poles, are operated from small dinghies with outboard engines. They can take undisturbed, rectangular samples of 0.03 m^2 and 8 cm deep from the bottom in water until 1 m below MLWS. *C. edule, M.edulis* and *M. balthica* in the samples are counted and weighed and their age is determined. Fig 9 gives an example of the distribution of fishable cockles in the Dutch Wadden Sea in 1992. The smallest dots represent sampling stations where no cockles were found

The 15 combined Dutch mechanical cockle fishing firms each summer make a coordinated inventarisation of the fishable cockle stock and cockle seed. This assessment is aimed at inventarising the size of the stock and localising beds of fishable cockles and spat, in order to make a planning of the fishery. A small number of selected ships are sent out to the different fishing areas, inventarising the beds on foot and with the dredge. The pattern of searching during these surveys is not according to a grid or at random, but is largely based on knowledge of traditional seed beds. The results therefore yield not more than an impression, but nevertheless provide useful information on spatfall. In 1991 an extra inventarisation of recently-settled spat was made following the same method. Our department incidentally verified the outcome of this survey. The resulting map of cockle seed beds is shown in fig. 12

6.1.2 Mussel seed

In 1992, for the first time, an assessment was made of the stock of 0-group mussel seed in the Wadden Sea. This survey was financed by the mussel growing industry, which needed a quantitative estimate of the stock and its distribution. In the previous years, the industry itself inventarised the mussel seed stocks every year, using conventional dredges. The resulting information had a qualitative nature, as methods were far from standardised and the fishing efficiency of a 1.9 m wide, commercial mussel dredge is highly variable with sediment nature. The survey had to be made in the subtidal area. With this aim, a conventional cockle dredger was chartered, of which one of the two suction dredges was modified (Van Stralen, in prep.). These 1 m wide dredges have a pression nozzle, whirling up the molluscs in front of an obliquely positioned, about 4 cm deep blade. The catch is suctioned aboard. The fishing blade of this modified version had been narrowed until a cutting width of 20 cm. A metering wheel was attached to he dredge to measure the exact distance sampled. Sampling was done in a partially stratified manner, after a preceding qualitative prospection by fishery inspectors with 1 m wide conventional dredges. On the locations where mussels beds had been located, hauls of 150 m were made in a grid with a distance between transects of 500 m. Radio-positioning was done with aid of the very accurate local "Syledis®" chain. The tracks were plotted with aid of the computer software "MacSea®". The "catch", suctioned aboard from the dredge, was measured volumetrically and sampled. As the pipes of a suction dredge do not sustain a greater length than about 15 m, this sampling method is limited to water until 10 m deep.

In deeper areas, a home-developed towed sampling device is used (Van Stralen, in prep.). This device, in some respects comparable with the "Burnham dredge", described by Howard (1976), consists of a rectangular steel mesh cage on a sleigh, towed behind the ship. It is equipped with a cutting blade of 10 cm wide, the cutting depth of which can be adjusted. The material sampled is collected in the mesh cage of the device, which is closed with a lid. The dredge is equipped with a metering wheel. Mussel seed and cockles in the samples were sub-sampled, counted and measured. An example of a resulting distribution map of the seed mussel stock is shown in fig. 13.

6.2 United Kingdom

Qualitative or (semi) quantitative information of cockle stocks in the Wash is available since 1894. Cockle stocks in the Wash and in Burry Inlet, (south Wales), are regularly sampled since 1980 by MAFF, and in the Thames from 1987 - present by the local fishery authority. Since 1991, a more detailed monitoring program of cockle recruitment is carried out in the Wash. The assessments in Burry Inlet are mostly carried out on foot, using transects 400 m apart with sampling stations every 50 m along the transect. The transects are compass-oriented, distances measured by pacing. Samples are taken using a 0.1 m^2 quadrat, driven into the bottom. Cockles taken are counted, weighed, measured and aged. Plotting and contouring is done with aid of the "Surfer®" computer package (P. walker, pers. comm.).

A rapid survey method of mussel biomass was described by Walker & Nicholson (1986). They determined the surface area and position of mussel beds with compass bearings and planimetry. To determine the coverage of the bed with mussels, they then placed a zig-zag of 100 m long straight line transects over the bed. Samples were taken at the end of each transect with a 0.1 m^2 quadrat, the biomass was determined by a combination of visual determination of the percentage of live mussels in the sample and weighing of minimally eight collected, mixed subsamples.

Because surveys on foot take too much time and effort, Walker et al (1990) tried aerial photography to estimate the area and the proportional mussel cover of an intertidal bed in the Wash. They took stereo photographs from altitudes of 500 - 800 m within 1.5 m of low tide. Image analysis with the GEMS 33/3 system was used to determine the surface area within a certain range of "greyness" on the photograph. The method was compared with survey on foot: triangulation with compass and radio-positioning with a navigator using DECCA® lines. They concluded that, with a young mussel bed, showing sufficient contrast, aerial photography was a suitable assessment method. Older beds, however, made poor contrast targets, due to differences in shell dryness, debris, silt cover and fouling.

6.3 Denmark

Munch-Petersen and Kristensen (1989), who also faced the requirement to survey very large areas in the Danish Wadden Sea with minimal resources in a short period, also experimented with aerial photography to assess mussel beds. They applied image analysis, using the system EBBA® with EA-SI/PACE software. They concluded that also with this method, field surveys are necessary when information on population and size structure is desired. They did not succeed in obtaining a convincing relationship between color value or "grey levels" of the beds on the photographs and biomass. However, they state that it is likely that this relationship can be established in the future. As regards costs, they concluded that, if processing and analysis of the photographs has to be carried out externally, photography and subsequent analysis of an area of 5 km^2 was about as expensive as having in the field two men for three days, including transport. Aerial photography would only be feasible when an institution should dispose of own trained personnel and equipment.

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8 FIGURES

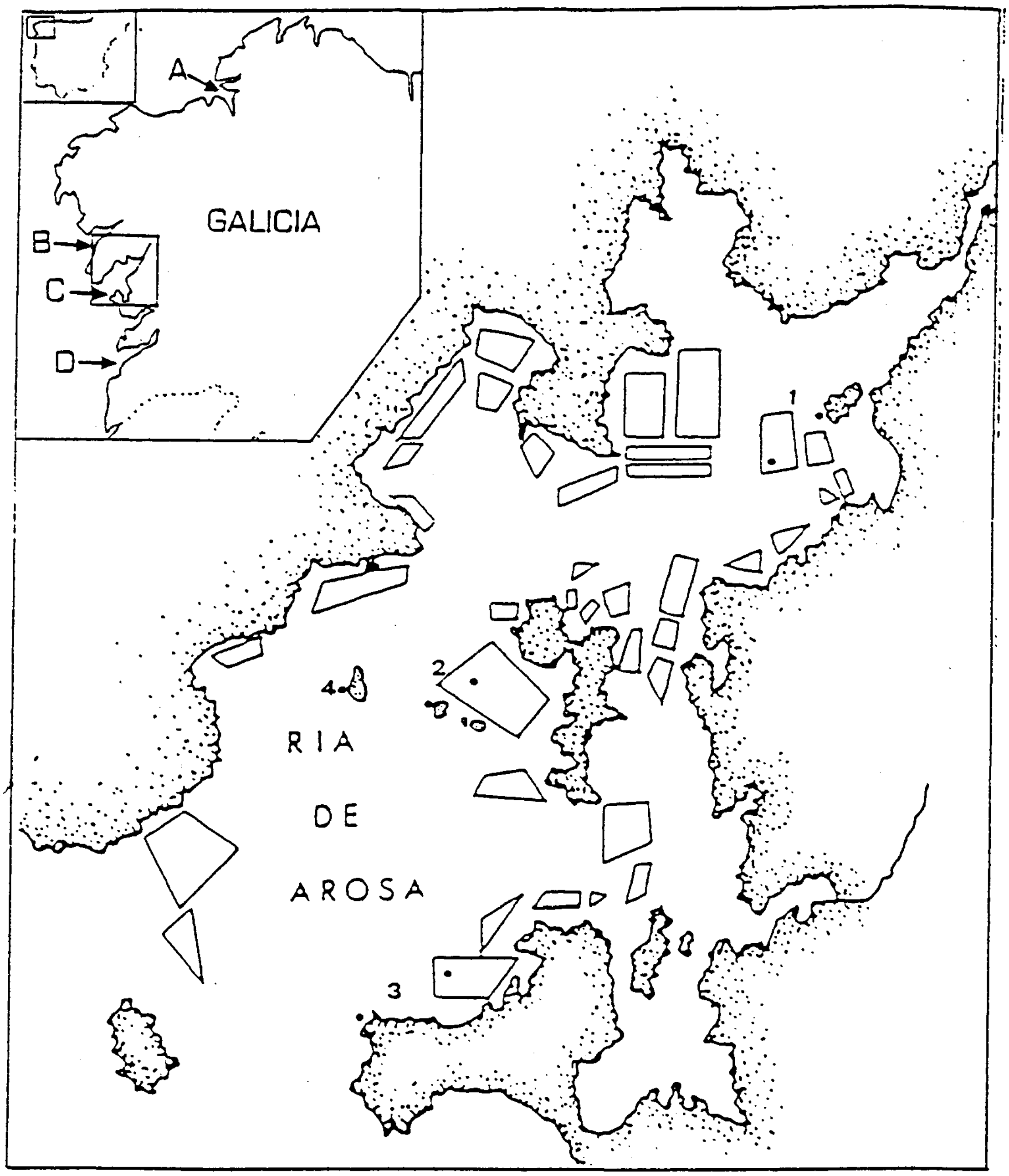


Fig. 1: Map of Galícia and Ria de Arosa (NW Spain), showing localities where gonad cycle (arrows) and early settlement (dots) were studied. Dots inside polygons indicate subtidally suspended collectors and dots outside polygons indicate intertidal collectors. Polygones indicate the areas in the Ría, occupied by mussel rafts (After Fuentes et al.).

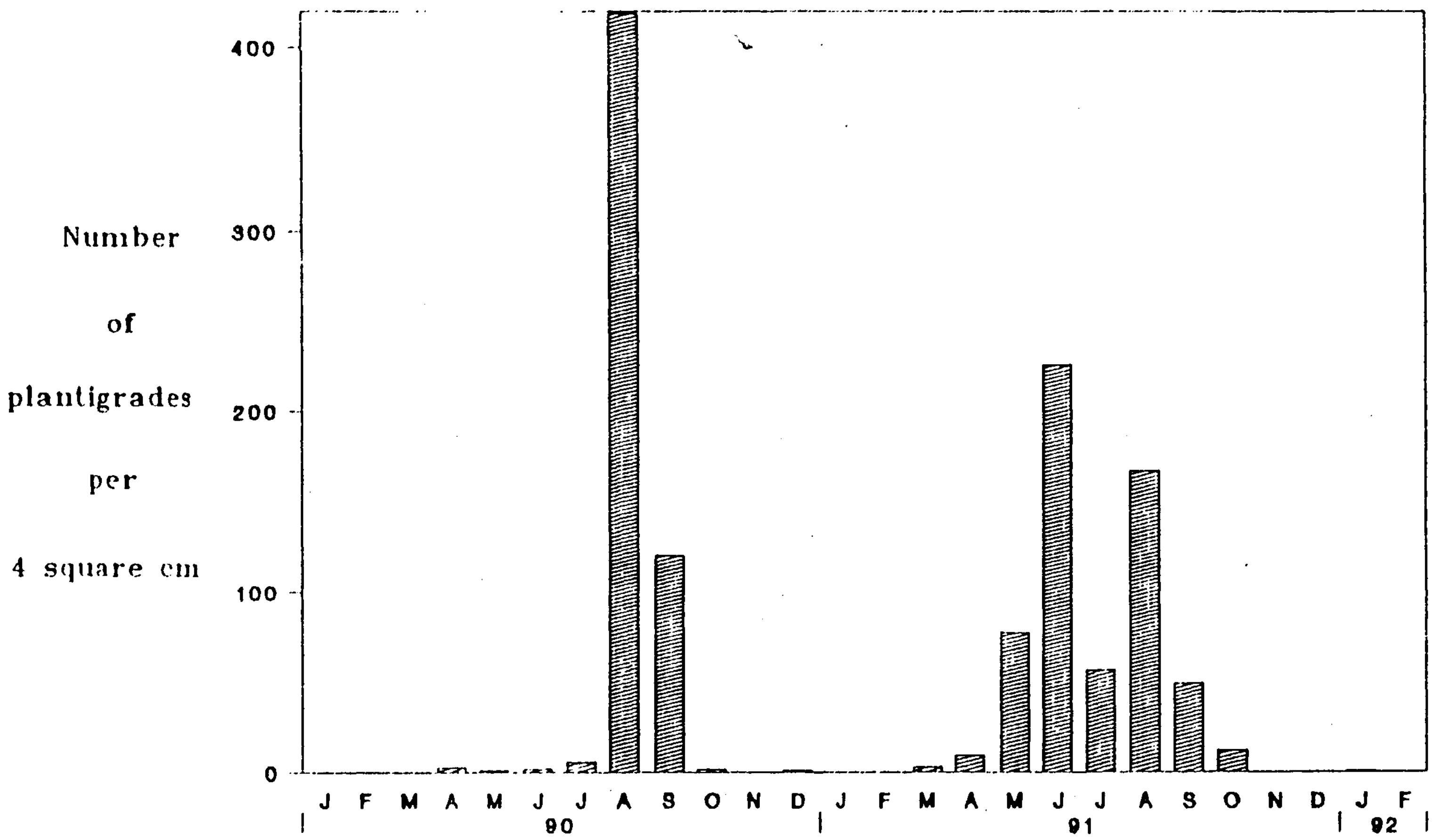


Fig. 2 Early settlement (number of plantigrades per four square cm) on intertidal experimental colectors during 1990 and 1991 in the zone 4 of the Ría de Arosa.

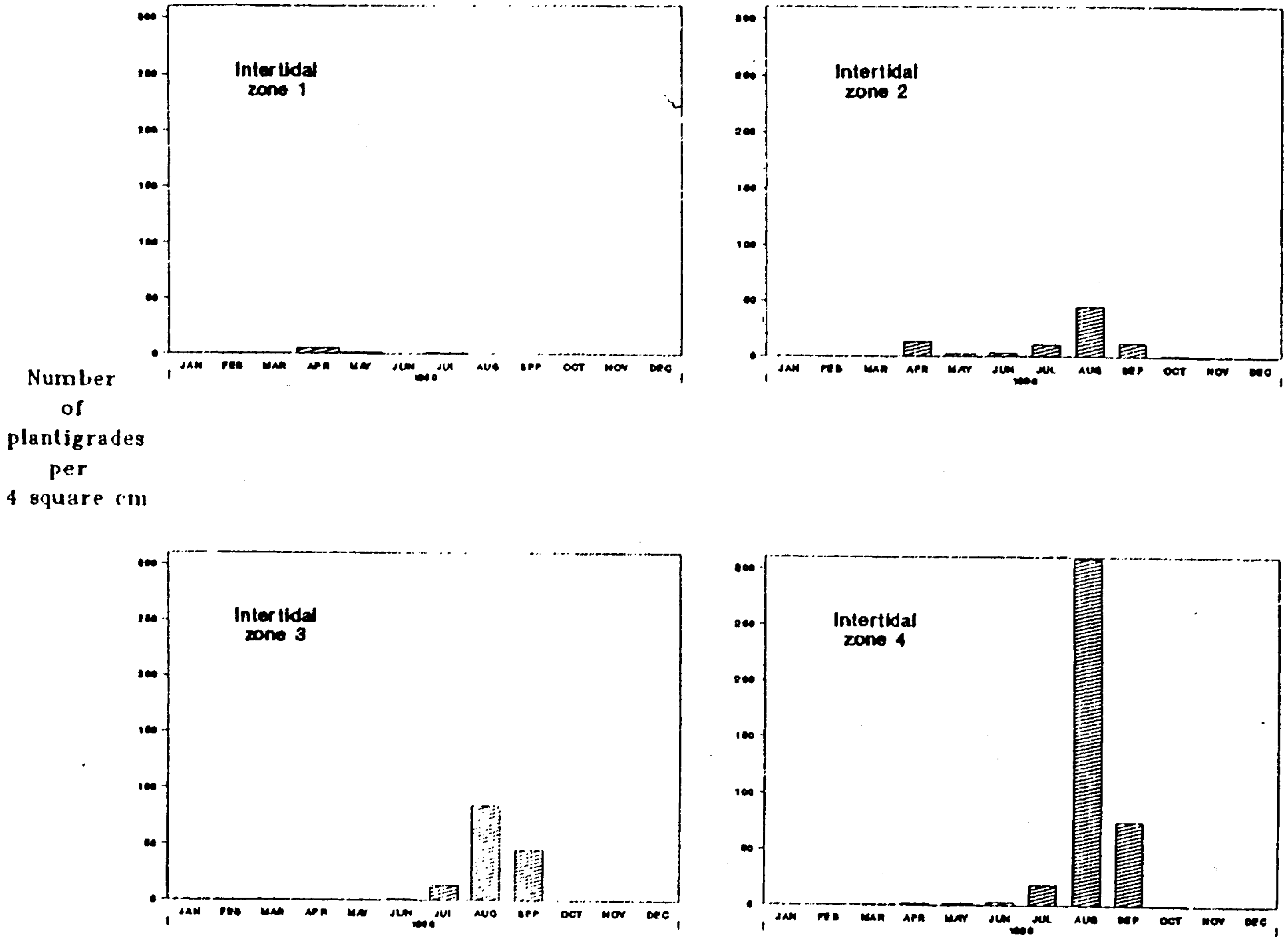


Fig. 3: Early settlement (number of plantigrades per four square cm) on intertidal experimental colectors during 1990, in four zones of the Ría de Arosa.

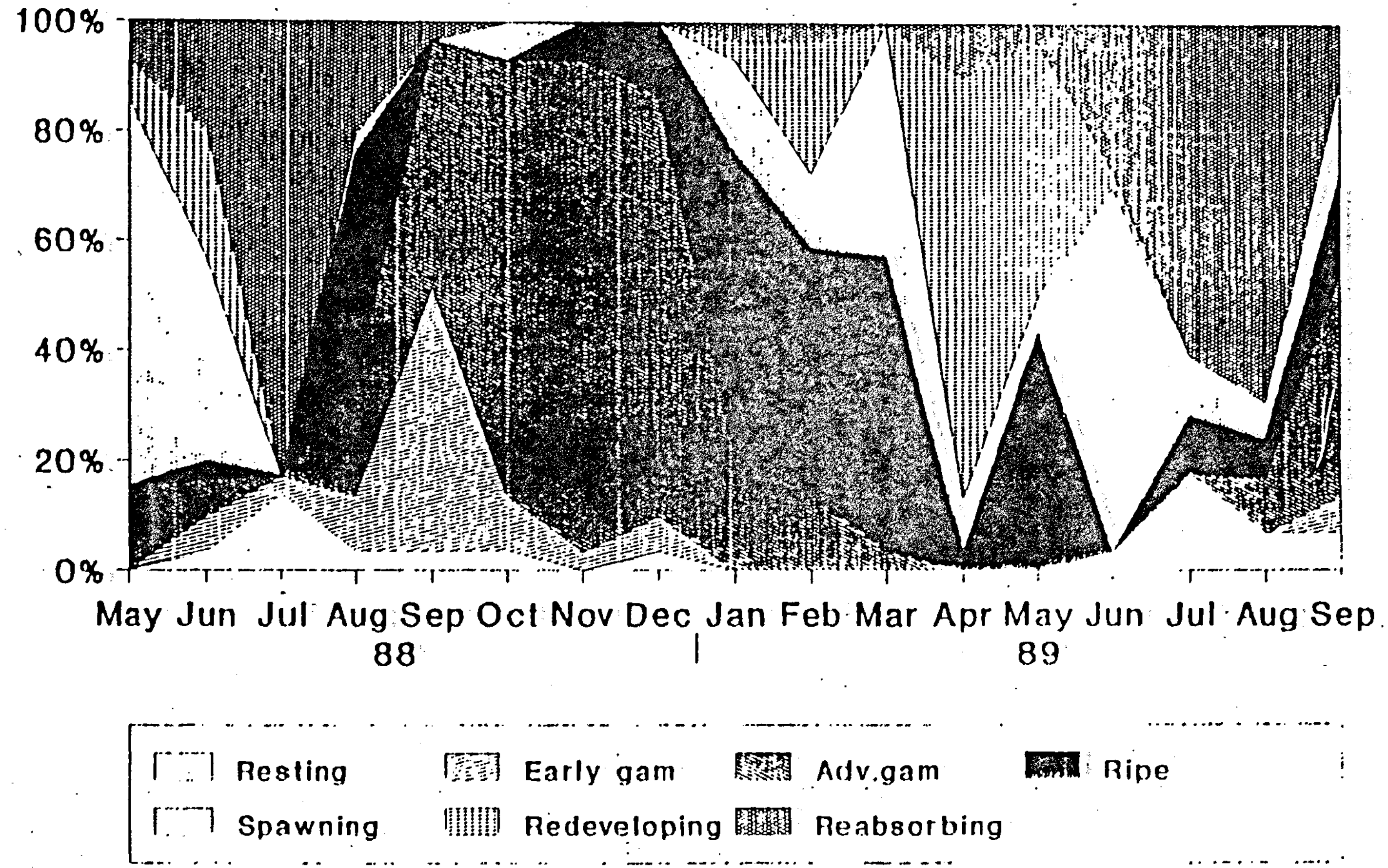


Fig. 4: Percentages of mussels distributed among each category of gonad condition, every month, throghout the period of culture. The data come from the mussels sampled from the zone 1 of the Ría de Arosa.

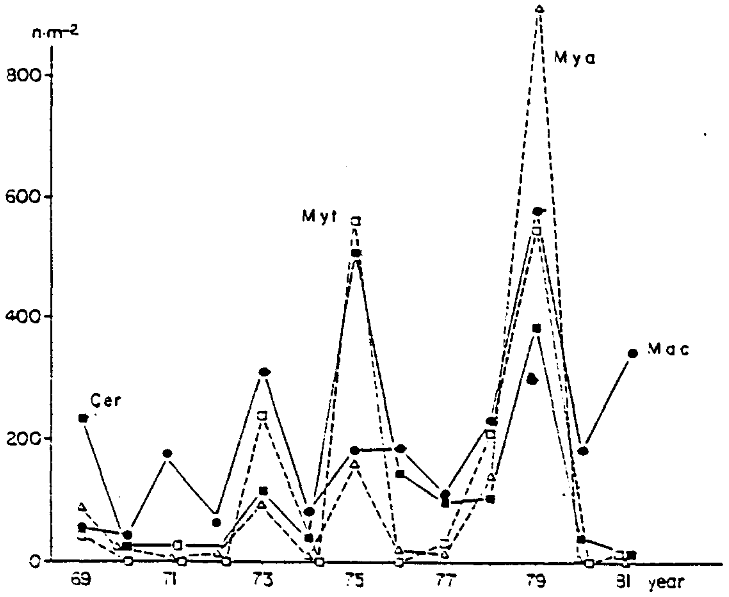


Fig 5a. Numbers of spat (young-of-the-year) as observed on Balgzand (averages from 15 sampling places; $n \cdot m^{-2}$) during 13 successive summers for 4 bivalve species: *Macoma balthica* (●), *Cerastoderma edule* (■), *Mya arenaria* (△) and *Mytilus edulis* (□).

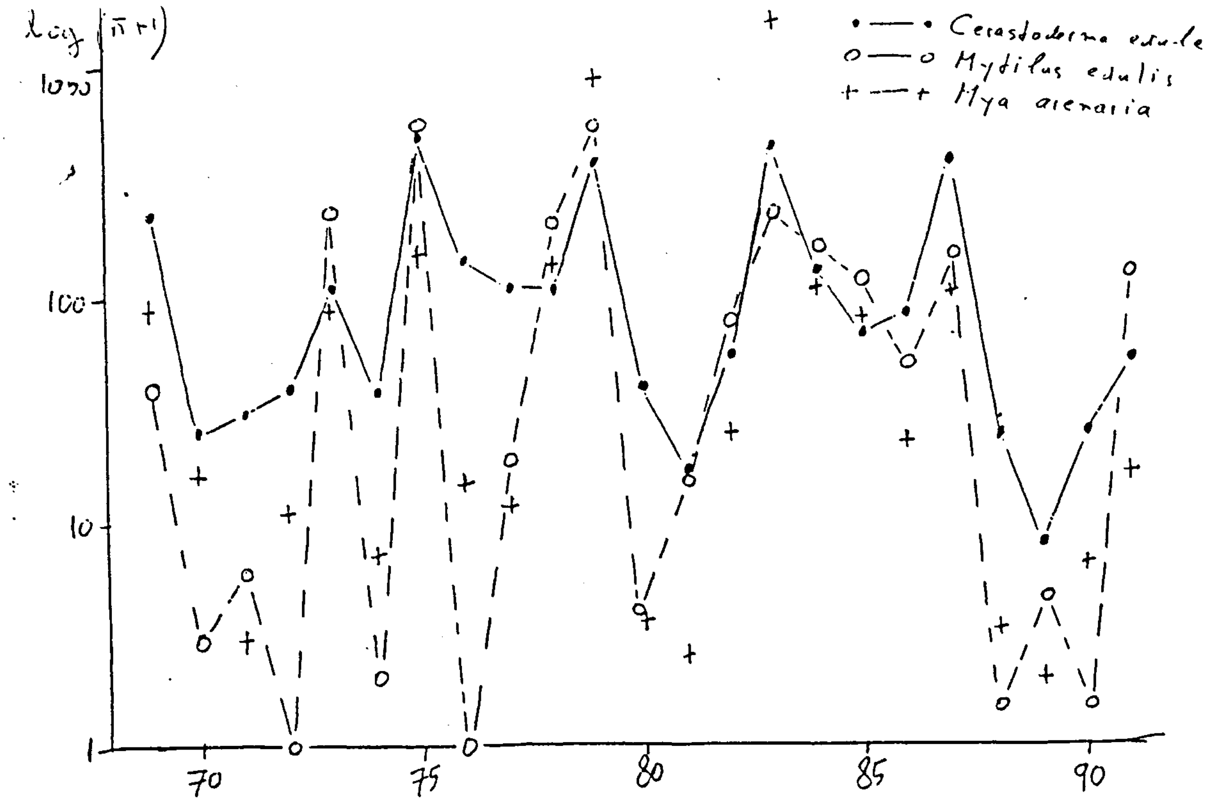


Fig 5b. Year to year variation in spatfall (0-year animals in august) on Balgzand in 3 bivalve species: mussels, cockles and gaper calms (Mya arenaria) Log scale of densities.m^{-2}. Note the synchronisation of the three species, probably caused by similar responses to the character of the foregoing winter (see also Beukema, 1982). After Beukema.

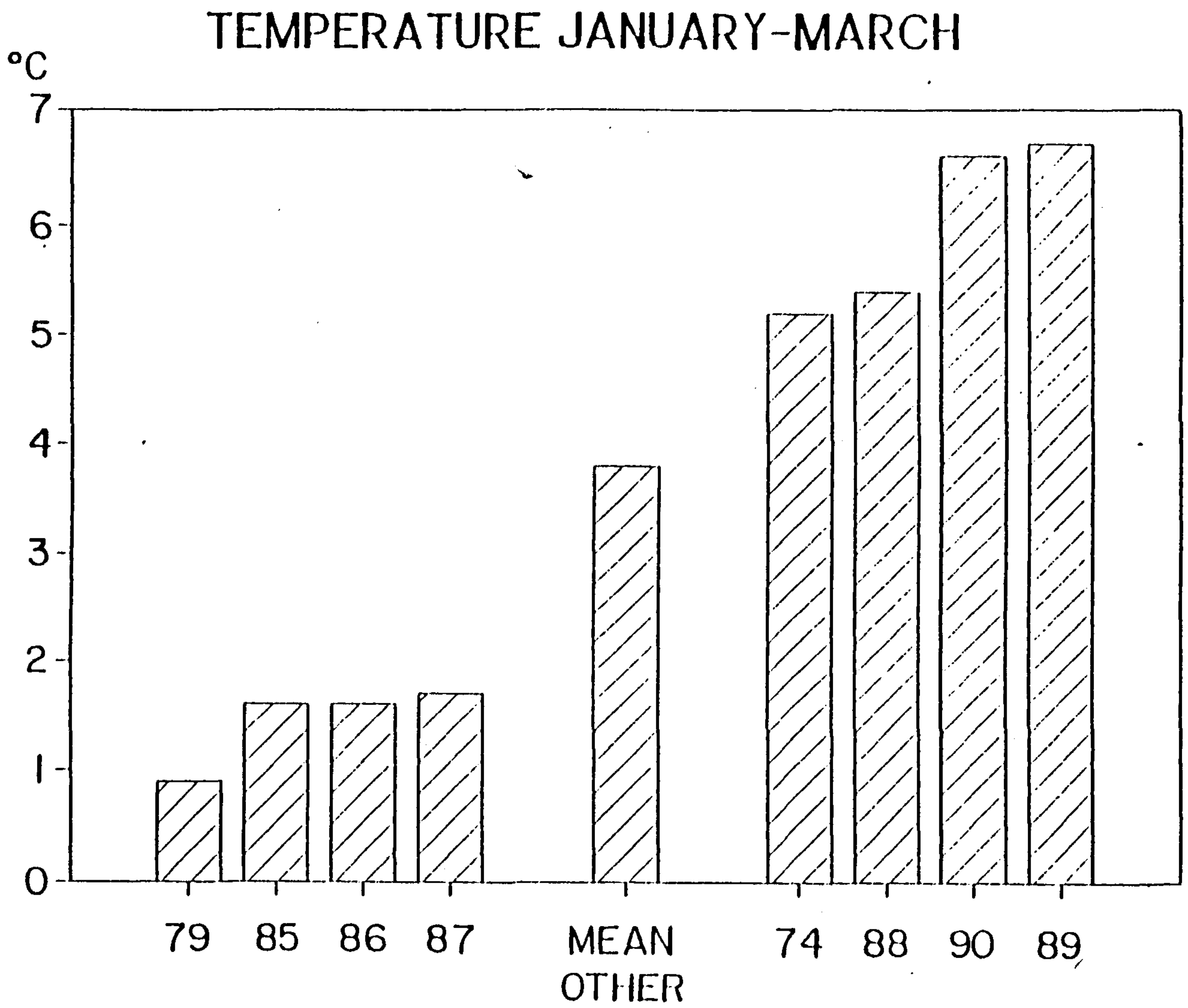
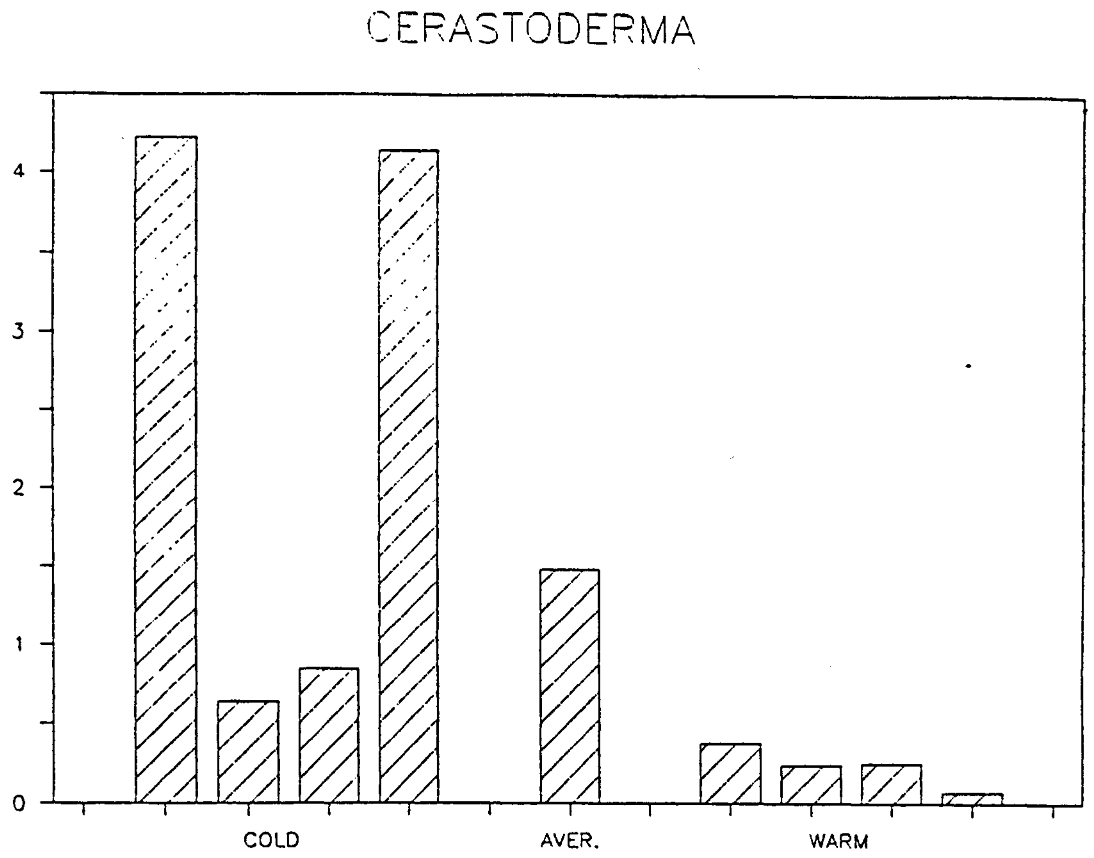


Fig.5c. Winter temperatures of the sea water near Den Helder in the coldest and the mildest winters of the period of observations of bivalve recruitment (1969 - 1991) After Beukema.



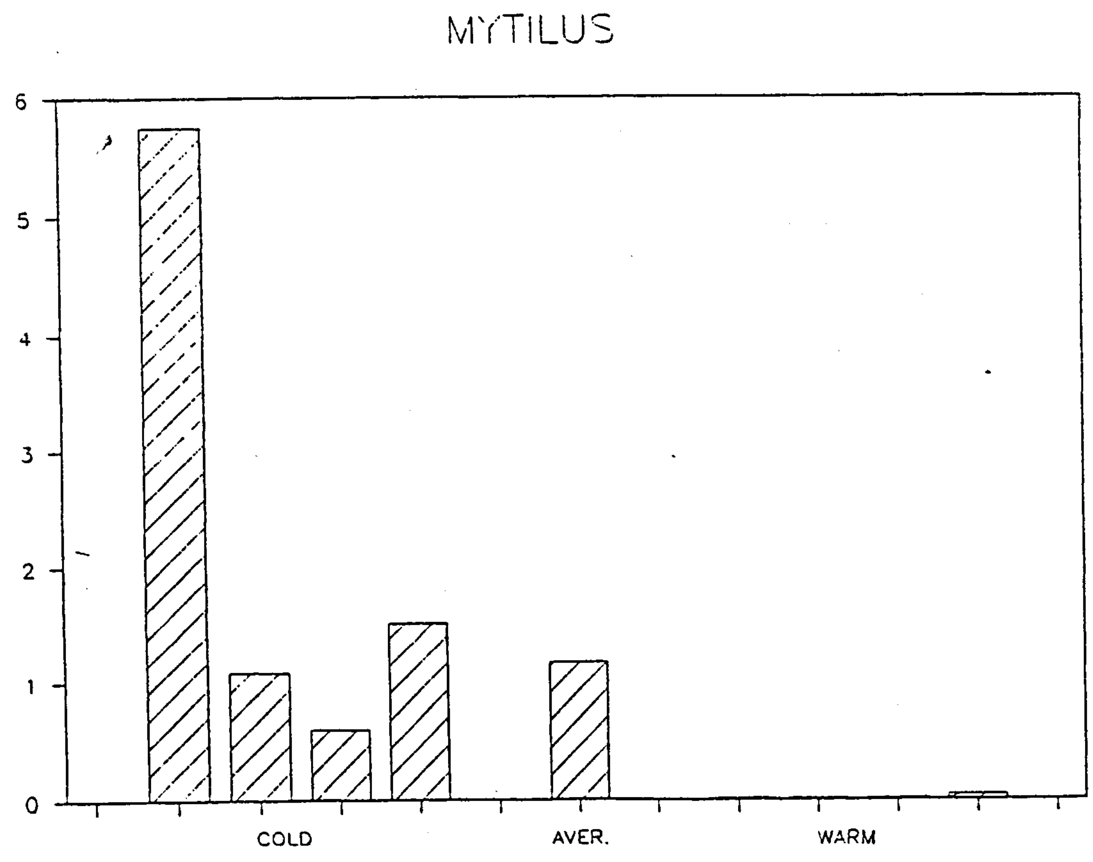


Fig 5d. Abundance of mussel and cockle spat in august of the same years as in fig. 5 c. After the mildest winters the abundance is always less than after the colder winters In: Beukema (1992). Neth Journ Sea Research 30 (in prep.)

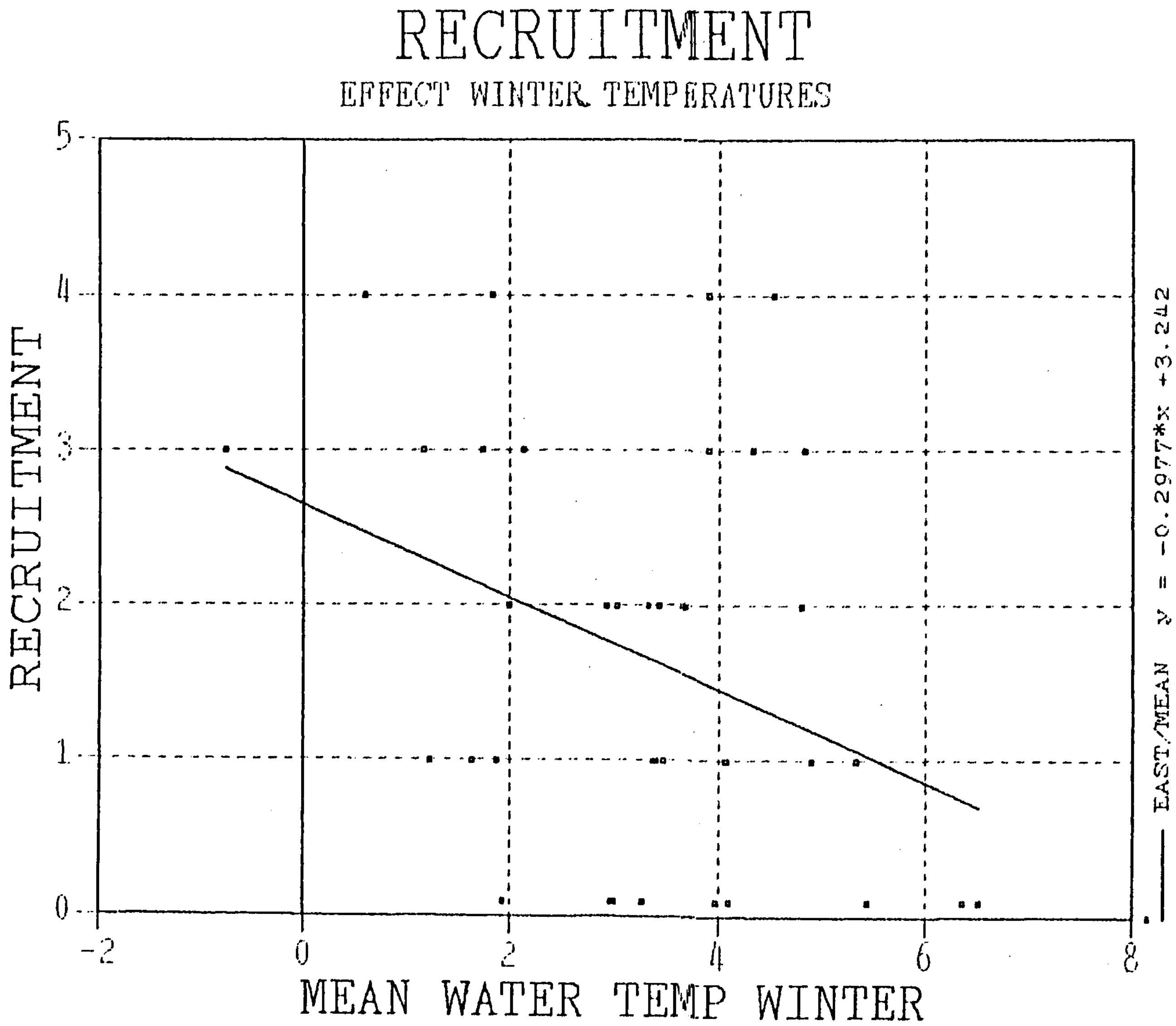


Fig 6 Relation between the recruitment index (0 - 4) of mussel spat and the mean water temperature in [illegible]uary-february in the Dutch Wadden Sea, period 19[illegible] - 1990. After J. de Vlas.

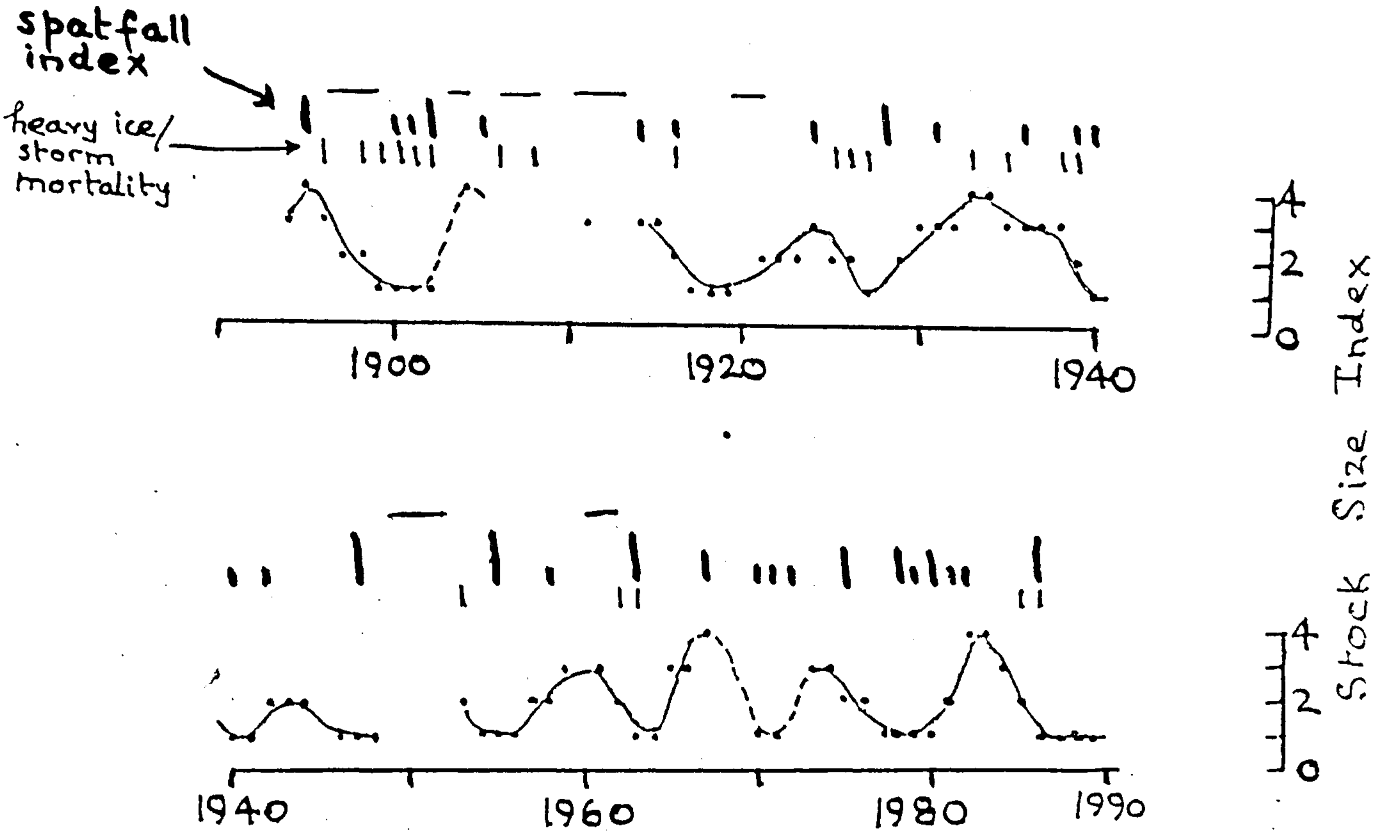


Fig 7a Fluctuations in the abundance of fishable cockles in the Wash during 1894 to 1990, expressed by an ordinal scale. Vertical bars show (upper row) years of average or above-average spatfalls, and (lower row) winters of high storm or frost mortality. Horizontal bars denote periods with gaps in information. (After P.J. Dare)

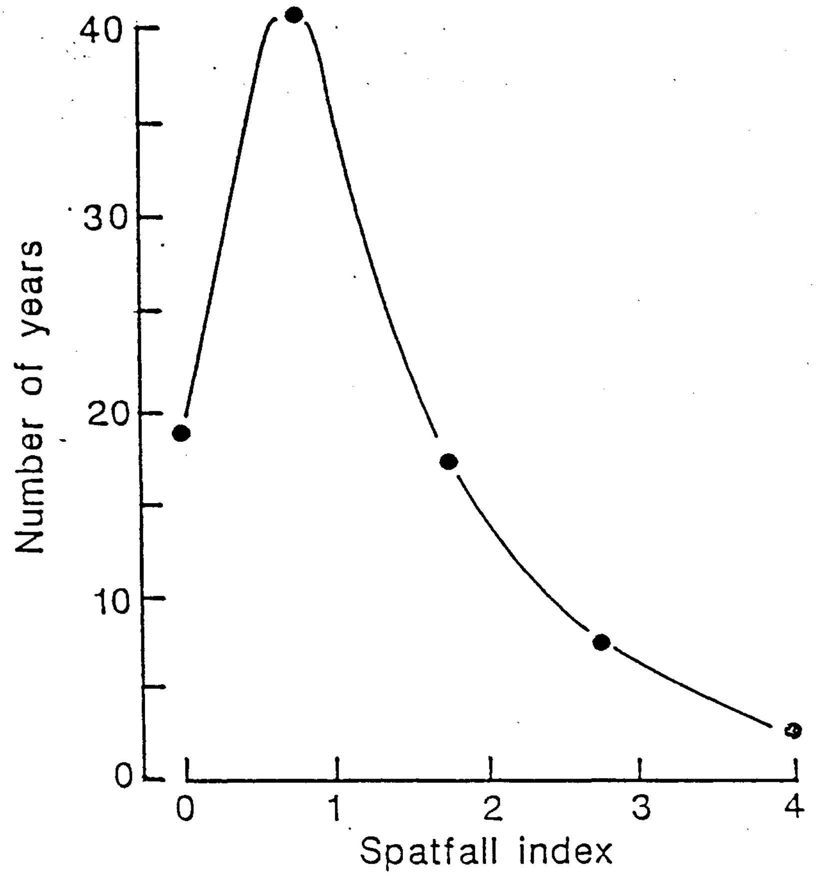


Fig 7b Frequency of occurrence in the Wash (1894-1990) of cockle spatfalls of different magnitudes; the indices are expressed by an ordinal scale. (After P.J. Dare)

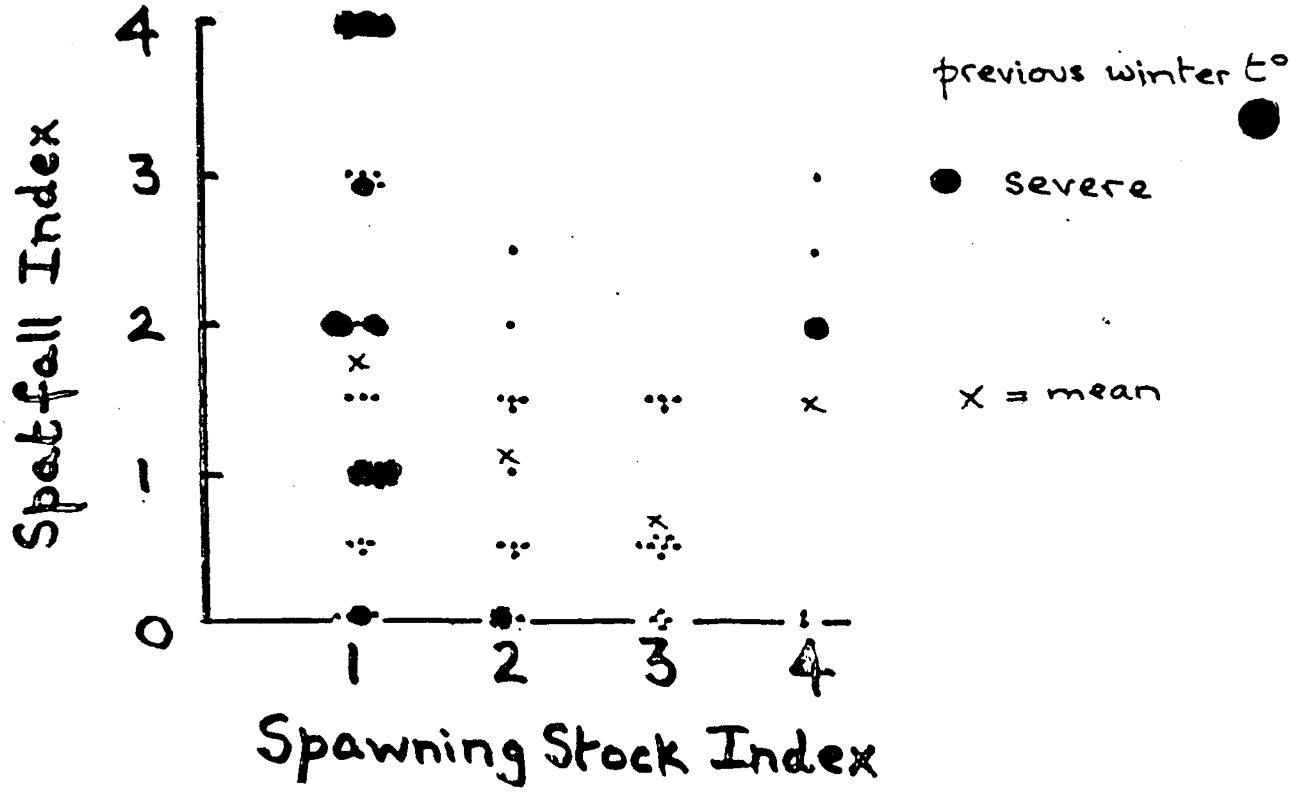


Fig 7c Scattergram relating indices of cockle spawning stock size to subsequent spatfall magnitude for the Wash, 1894-1990. Years with very cold winters are indicated. x = mean index values. (After P.J. Dare)

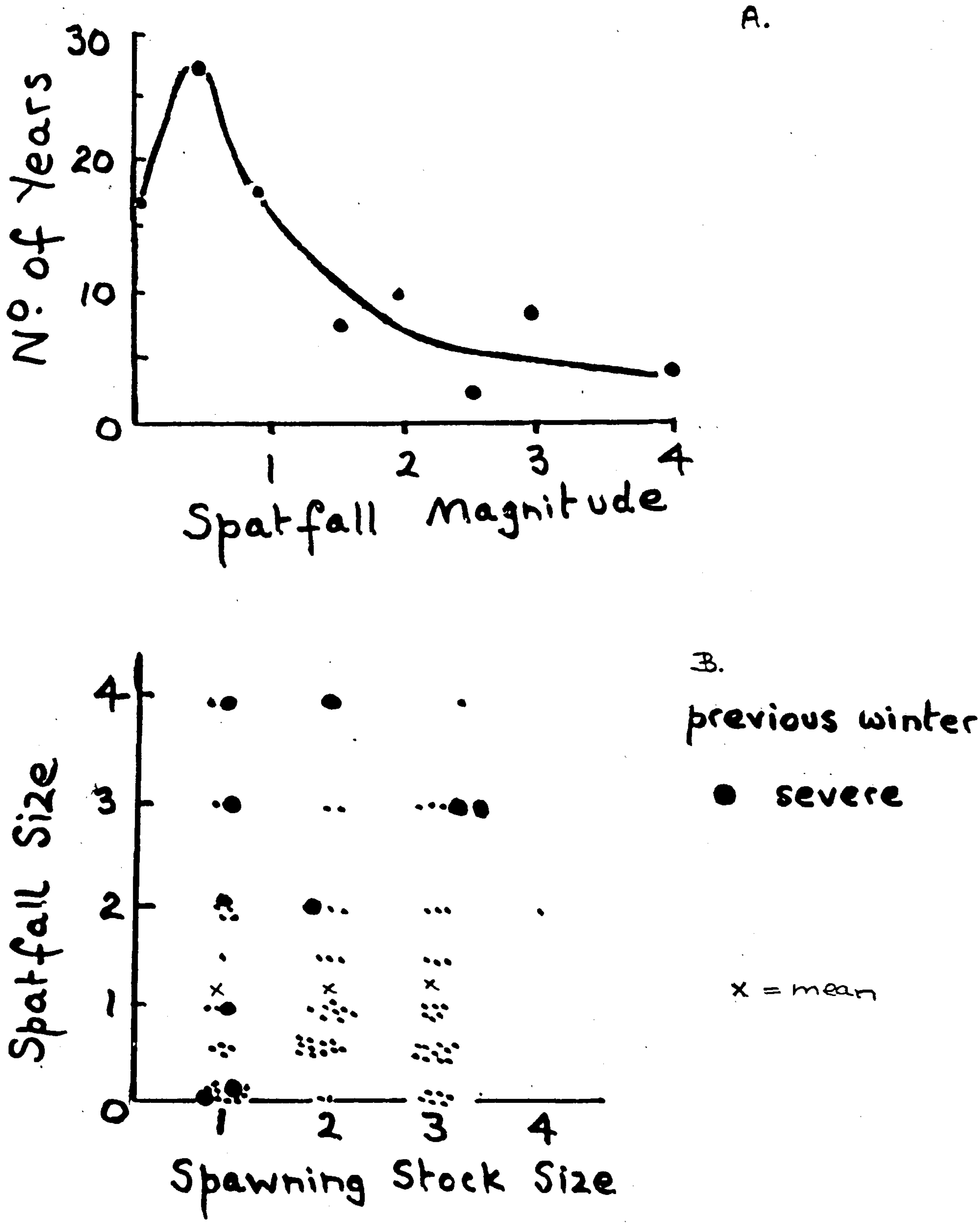
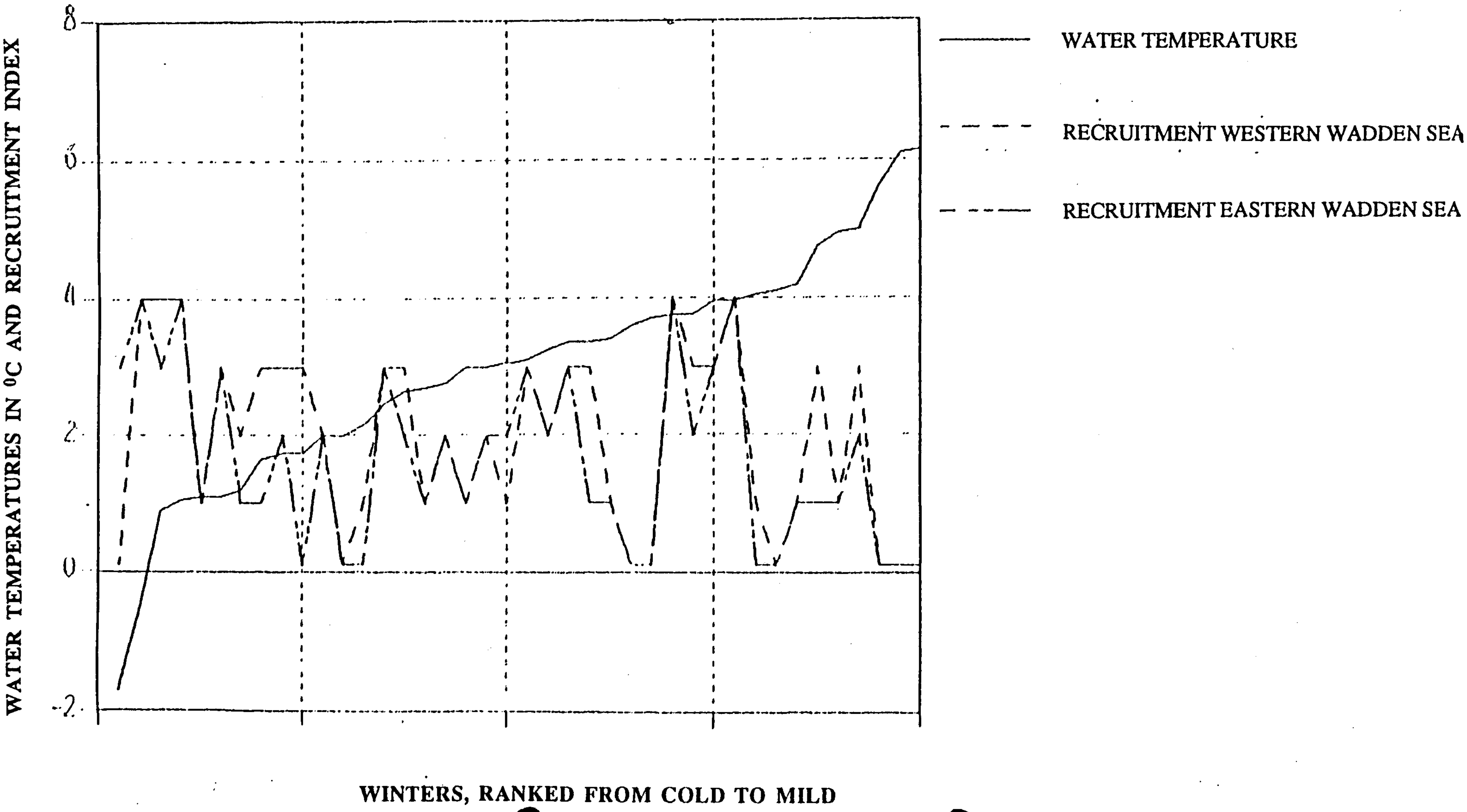


Fig. 8: (A) Frequency of occurrence in the Wash (1894-1990) of mussel spatfalls of different magnitudes; abundance indices are expressed by an ordinal scale.

(B) Scattergram relating indices of mussel spawning stock size to subsequent spatfall magnitude in the Wash, 1894-1990. Years with very cold winters are indicated. x = mean index values.

Fig. 9: Recruitment indices of mussel spat in relation with mean water temperature in january-february. The winters are ranked from mild to warm on the x-axis (solid line). The y-axis gives the recruitment index in the western (dashed line) and the eastern section (interrupted line) of the Wadden Sea (After J. De Vlas, working paper).



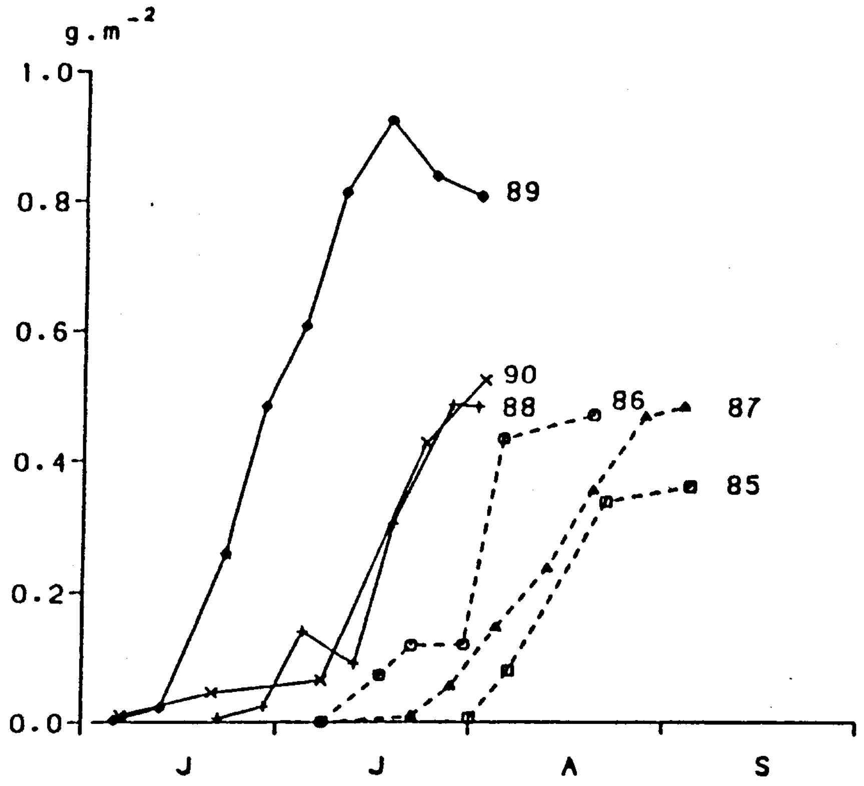


Fig. 10: Development of the biomass of juvenile shore crabs (Carcinus maenas) on Balgzand after mild ('88, '89, '90) and cold ('85, '86, '87) winters. They appear earlier and tend to be more abundant after mild winters. Young stages of bivalves are less retarded after cold winters and thus escape for the greater part from predation by juvenile shore crabs. (After Beukema, 1991).

Fig. 11: Example of the sampling grid method used by RIVO-DLO during annual assessments of bivalve stocks in the western section of the Dutch Wadden Sea. Each small dot represents one sampling station, larger dots show different population densities of cockles.

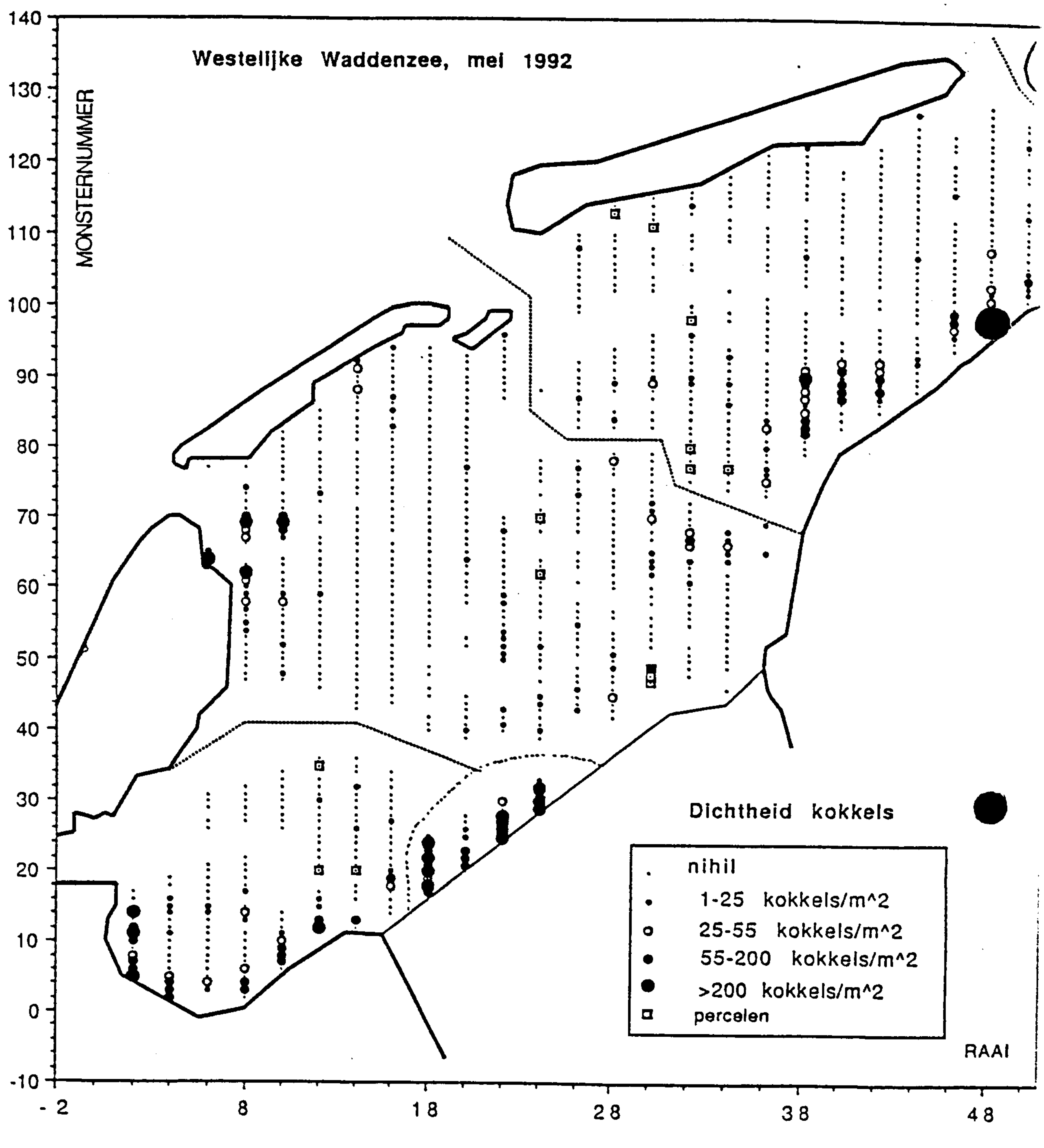
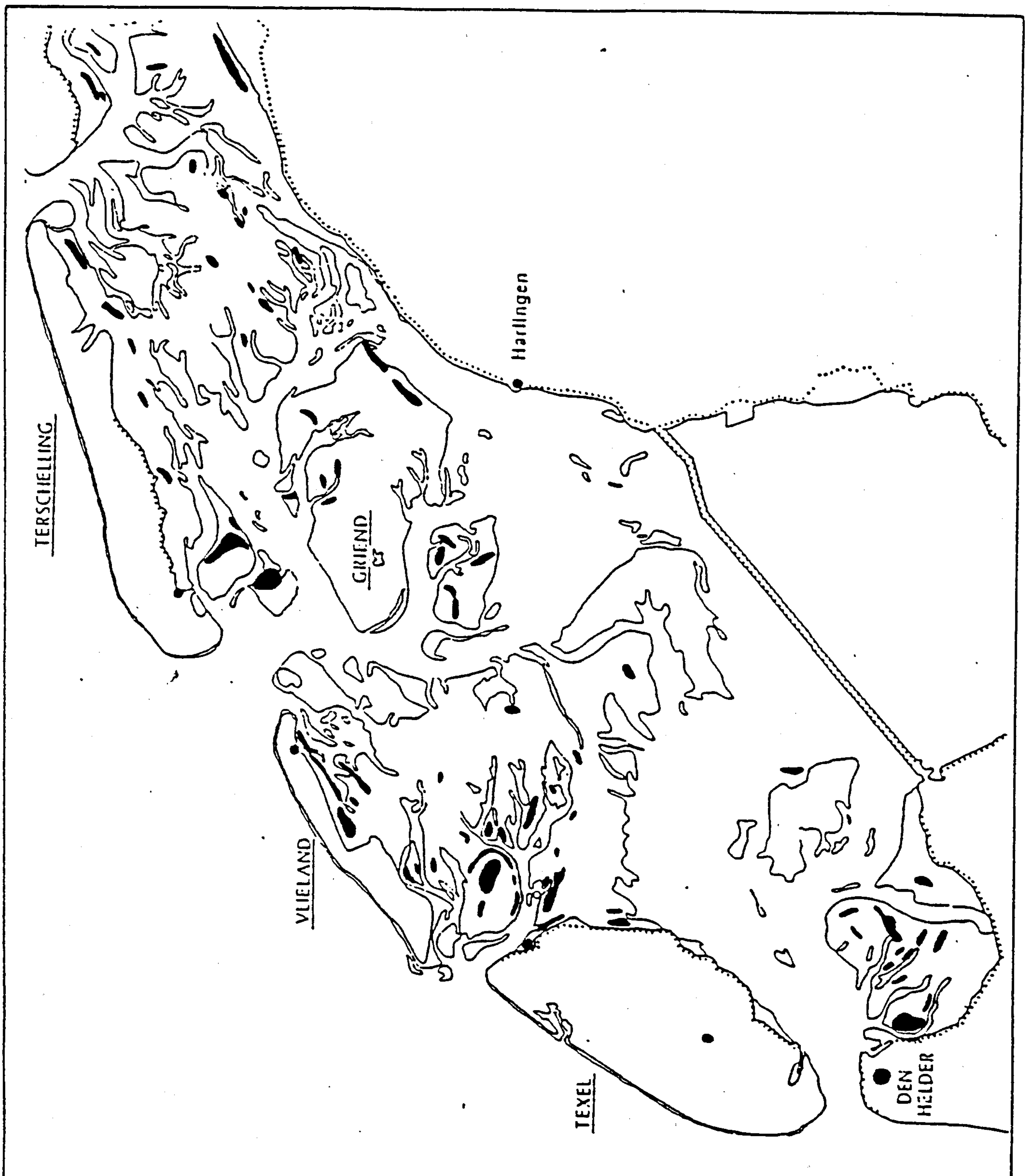


Fig.12: Position of beds with cockle spat in the Dutch western Wadden Sea in august 1991, as reported during organised search actions by cockle fishermen.



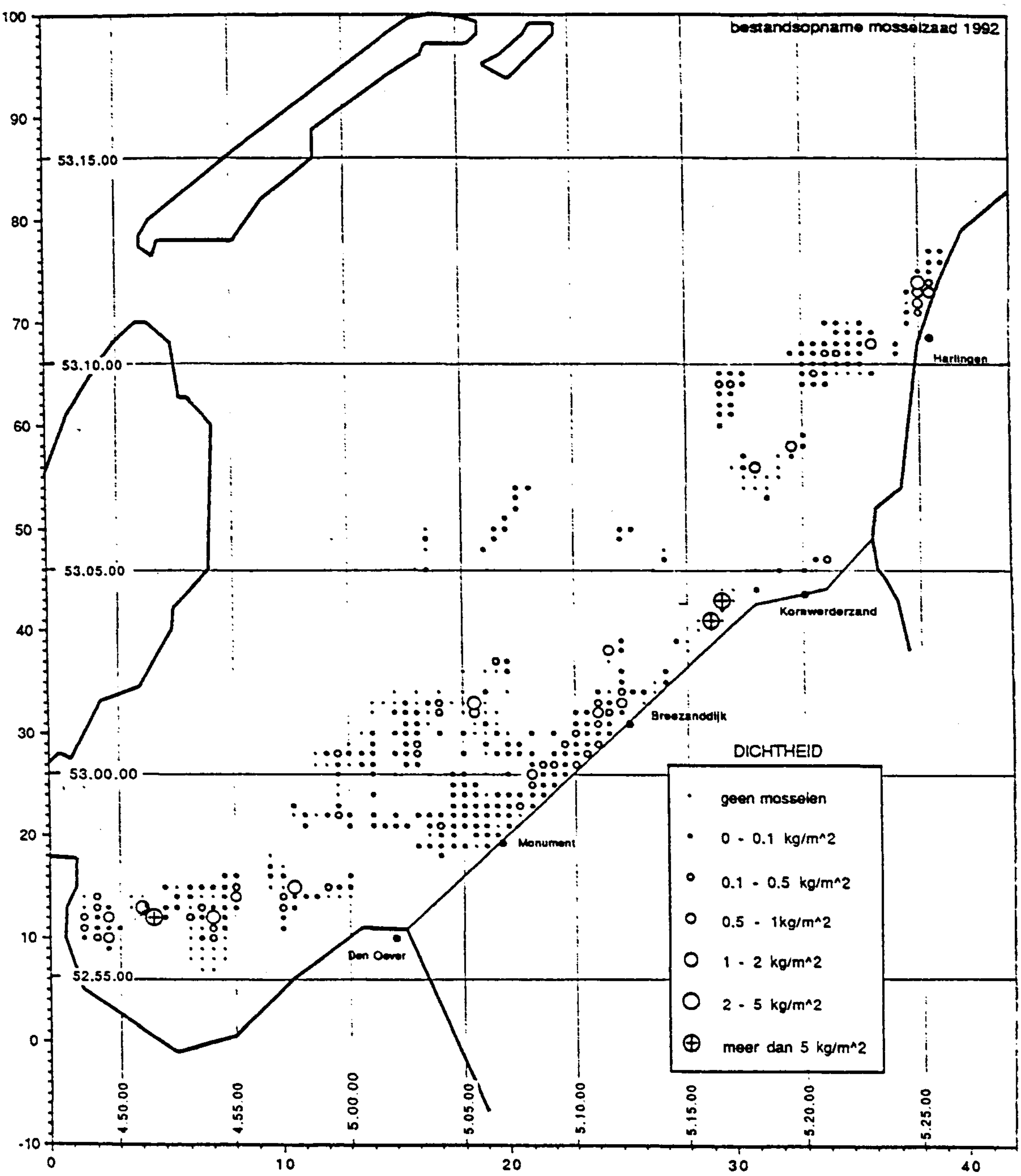


Fig. 13: Example of the results of a stock assessment of one year old mussel seed in the western Dutch Wadden Sea in May 1992. The smallest dots indicate sampling stations without mussels, Larger dots indicate density classes in kg/m^2 . Latitude is indicated in the grid.