INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

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SPATFALL AND RECRUITMENT OF MUSSELS (*Mytilus edulis*) AND COCKLES (*Cerastoderma edule*) ON DIFFERENT LOCATIONS ALONG THE EUROPEAN COAST

Report of the second of two workshops

by

Renger Dijkema
Netherlands Institute for Fisheries Research
P.O. Box 77, 4400 AB Yerseke
The Netherlands

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SPATFALL AND RECRUITMENT OF MUSSELS (*Mytilus edulis* L) AND COCKLES (*Cerastoderma edule* (L) ON DIFFERENT LOCATIONS ALONG THE EUROPEAN COAST.

Results of the second of two workshops on this topic, sponsored by the FAR- programme of European Community.

by

Renger Dijkema

Netherlands Institute for Fisheries Research
P.O. box 77, NL 4400 AB Yerseke
The Netherlands

(Mytilus edulis)
(Cerastoderma edule)

Abstract

Different intensities of the 1992 spatfalls of mussels and cockles were reported in the participating countries, no links with external factors like winter temperature or precipitation were observed. Overview maps of Europe show the reported recruitment success of mussels and cockles in the different countries. Since 1992, research activities in the field of spatfall and recruitment have increased in most of the participating countries, and at present about 9 research and monitoring programmes are under way, concerning subjects like larval densities and settlement, spat condition and survival and recruit stock monitoring. In this report, summaries of the contributions of the participants are represented, Discussions dealt, among other subjects, with the effectivity of artificial mussel spat collectors for monitoring purposes, primary and secondary settlement of mussel larvae, as well as monitoring techniques for recruits and parent stocks. As the interest in spatfall, settlement and recruitment of bivalves is growing and a number of studies are still in development, the wish was expressed by the participants to find a way of continuing these workshops. The present, relatively cheap form of short workshops, held in an institute at a central location, is considered very effective to standardise methods, to share experiences and to improve European coordination between researchers.

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1 INTRODUCTION

This paper is an account of contributions and discussions produced during a two-day workshop on spatfall and recruitment of mussels and cockles It was the second of two workshops on relations between spatfall and recruitment and environmental parameters in Europe. Both workshops were sponsored as a Coordination Action in the FAR-programme of the Commission of European Communities. This paper has to be read in combination with ICES paper C.M. 1992/K:45, which contains the report of the first workshop of the same name, held in March 1992, (Dijkema, 1992).

The workshop was, like the first one, held in Yerseke, the Netherlands, on 11 and 12 of March, 1993. It was attended by 20 participants from 6 countries: Spain, France, the UK, the Netherlands, Germany and Denmark.

The problems with failing recruitment of especially mussels appeared in some cases to have decreased after new, successful settlements. The participants reported on a number of studies, already under way or recently undertaken, especially in the field of the monitoring of spatfall on artificial collectors and of condition and survival of spat. The subject of the monitoring of settlement by means of test collectors appeared to be of wide interest and was extensively discussed.

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.
Germany: Maarten Ruth, Matthias Seaman and Andrea Pulfrich, Institut für Meersekunde an der Universität von Kiel, Dusternbrooker Weg 20, Kiel. Rudi Meixner and Thomas Neudecker, Bundesforschungsanstalt für Fischerei - Institut für Seefischerei, Palmaille 9, D-2000 Hamburg 50.
Netherlands : Renger Dijkema (Chairman), Jeanet Allewijn, (support), Marnix van Stralen, Joke Kesteloo, Cora Brand, Netherlands Institute for Fisheries Research (RIVO-DLO), PB 77, 4400 AB Yerseke. Cees de Vooys, Institute for Forestry and Nature Research (IBN-DLO), PB 167, 1790 AD Den Burg. Pieter Honkoop, Netherlands Institute for Sea Research (NIOZ), POB 59\1790 AD Den Burg, Daan Bos, & Jon Coosen Ministry of Transport and Public Works, Tidal Waters Division, PB 8039, 4330 EA Middelburg. Jan Bol, Irislaan 13, Yerseke.
Spain: Jorge Caceres Martinez, Instituto de Investigaciones Mariñas, Eduardo Cabello 6, 36208 Vigo.
Great Britain: Peter Dare and Peter Walker, Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Lowestoft, Suffolk NR33 0HT, England

3 STATE OF THE ART IN THE PARTICIPATING COUNTRIES

3.1 Recruitment

The intensity of settlement and recruitment appeared to vary considerably between countries and also, within some countries, between regions. No apparent relation could be found with environmental factors like mild or strong winters, water temperatures, precipitation or river discharge. In the maps of figure 16, an impression is given of the recruitment success in 1991 and 1992 of mussels and cockles in the most important regions in western Europe where these are exploited. The categories: "good", "medium" and "bad" are subjective and based on impressions, given by the participants and other scientists working in these areas. The maps give too general a view to base conclusions on. The considerable variability between regions, without an obvious pattern, however, is interesting. An exercise like this should be repeated during a number of years in order to be meaningful. The following information was contributed by the participants:

<u>Denmark</u>
Recruitment of mussels in the Wadden Sea has been poor during the last four years. The last rich spatfall occurred in 1987. Mussel recruitment in the Limfjord, as far as observed., is good every year. Recruitment of cockles has been good and there are large stocks present in the Danish Wadden Sea.

<u>Germany</u>
No statistical data on spatfall and recruitment were available. A relation is presumed between mussel landings and numbers of frost days during winter.

<u>France</u>
On the mussel ropes used to collect spat for the "bouchot" cultures along the French Atlantic coast, little or no spatfall has been reported for the last 3 years, which causes difficulties for the mussel growers. There were no data available on recruitment of cockles.

<u>Great Britain</u>
Molluscan stocks are studied by MAFF and local fisheries authorities. Mussel stocks are still low in the U.K., the last good recruitment has occurred in 1986. Recruitment of cockles is highly variable over the country without any explanation for the differences.

<u>The Netherlands</u>
the Netherlands Institute for Fisheries Research (RIVO-DLO) follows recruitment of mussels and cockles, the Netherlands Institute for Sea Research (NIOZ) studies recruitment and production of benthos on a tidal flat in the Wadden Sea. Recruitment of mussels in the Wadden Sea was poor in 1989 and 1990, a little

better in 1991 and good again in 1992, despite a very mild winter. This 1992 yearclass was produced by an extremely low parent stock which had been decimated by storms, predation by Eider ducks and fishery. Spatfall only occurred in the subtidal zone. In October 1992, the stock was 150,000 tonnes (fresh weight). Heavy storms swept away most of the stock thst had remained after the seed fishery in October. In the Oosterschelde, no spatfall of significance had been recorded since 1986. Spatfall 1993 appeared to be good in the western half of the Wadden Sea in July 1993. This is, however, too early do justify conclusions on recruitment. Mussel seed surveys are made yearly in April.

Recruitment of cockles was low in 1989, good in 1990 and low to moderate in 1991. Recruitment in 1992 appears to be better, although assessment results are not known yet. More than half of the cockle production in 1992 was dredged in the subtidal zone of the North Sea coast in the Zeeland delta area.

Spisula subtruncata (Da Costa) developed to a regular target species for the bivalve dredging industry, after, since 1986, incidental small catches were landed. In 1992-1993, 7,000 - 15,000 tons fresh weight were dredged at the seaward sides of the Wadden Sea islands and in the southern delta. Information on the stocks is still scarce. Large but rather short-lived stocks appear to be present all along the Dutch coast, at depths of 10 - 25 m. Most of the beds probably had an age of 1,5 - 3 years in January of 1993. It is endeavoured to carry out regular surveys on this species, as these stocks may constitute an important and hitherto unstudied link in the food web, particularly where grazing on phytoplankton and food supply of bivalve-eating seabirds are concerned.

<u>Spain</u>
Spatfall and recruitment are studied by several research institutions. the Instituto de Investigaciones Marinas studies spatfall in the Galician Rias. There are two peaks: one in May and one in August-September. Spatfall appeared to be more intensive in the outer area than within the Rias.

3.2 Survival of spat

In Denmark, predation by shore crabs was reported on juvenile mussels up to a shell length of 15 mm. Consumption of mussels by Eider ducks in the Netherlands, Germany and Denmark combined, was estimated at 60,000 tons fresh weight per year. In Germany, herring gulls (*Larus argentatus*) are mentioned as a serious mortality factor on intertidal mussel beds.

4 SUMMARIES OF THE WORKING PAPERS PRESENTED BY THE PARTICIPANTS.

4.1 Monitoring mussel spat abundance in the Wash using artificial collectors

P. Walker and P.J. Dare, MAFF, England

4.1.1 Introduction, materials and methods

In 1983, the Eastern Sea Fisheries Committee (ESFC), managers of the Wash mussel stocks, expressed concern at the low stock levels of fishable mussels. A low-budget exercise was initiated using artificial spat collectors combined with a foot survey of spat and adult stocks on the ground. Two sites were selected, close to the extreme water of spring tides at Thief and Toft Sands. The spat collectors consisted of 0.5 m lengths of 10 mm diameter polypropylene carrier rope into which were inserted transversely 15 cm long tufts of split-film polypropylene (SPF)rope at 10 cm intervals. Each tuft was frayed and combed to produce a 5 cm wide brush. At each site, four collectors were mounted on a tubular steel frame at a height of 0.5 m above the substrate (Dare et al., 1983). The number of spat in each sample was counted using a low-powered zoom microscope (x3-x10 magnification). From 1983-1987, five monthly samples were collected between April and September. Destroying of the collectors by mussel dredgers formed a serious problem, leading to the ending of the project.

4.1.2 Results

1 *Seasonal pattern of settlement*

Figure 1 A and B show clear seasonality which is consistent between the two sites, with peak abundance in June-July each year.

2 *Annual variation*

At the period of peak settlement, variation in abundance between years exceeded 2 orders of magnitude: 500-61,000 spat per (0.5 m) collector at the Toft site and 300-27,000 at the Thief site.

3 *Length of distribution of the spat.*

Mytilus spat may be separated into primary (<0.5 mm) and secondary(>0.5 mm) stage plantigrades. In most months, almost all settlement was by secondaries. Table 1 shows the variability of primary stage abundance in collector catches during the peak settlement months of June-July in two years (1986 and 1987).

Figure 2 shows the size distribution of the spat which settled on the Toft and Thief collectors during July 1986. The distribution is quite different with the Toft sample consisting of 70% primaries, with secondaries mainly below 1 mm. At the

Thief site, primaries made up only 0.5% of that month's settlement, while secondary spat were larger and ranged up to 4 mm.
Fig. 3 shows the size distribution of spat from a collector retrieved from the Thief Sand on 12 October 1987 after a deployment of 112 months. The spat here were all secondaries but the low model length (1 mm suggests an autumn spawning) may have occurred.

4 *Relationship of collector catches to stock and to ground settlement.*
Table 2 summarises the 1987-'89 data, and shows winter air temperature anomalities prior to spawning. Despite the short time series, use of crude indices, and gaps in collector data, several possible relationships are hinted at:

(i) collector catches
-do not always appear to reflect relative abundance of ground settlement, perhaps because of the varying numbers of the migratory primary phase attracted to these filamentous collectors.
-are not related to spawning stock.

(ii) Moderate or good ground spatfalls (n=4)
-seem more likely (3 of 4) after a cold/very cold February.
-can occur in years of\ low spawning stock (3 of 4).

(iii) zero spatfall years (n=5) seem more likely (4 of 5) following average/warm winters in conjunction with low spawning stocks.

4.1.3 conclusions

There does not appear to be a simple stock-recruitment relationship. Spat are present in Wash waters every year, but their variable abundance seems to be related more to physical factors (winter temperature and dispersal/retention) than to spawning stock levels alone. One can only speculate about possible mechanisms.

Exploratory application of the NORSWAP hydrographic model has indicated that the Wash is probably a semi-closed system, with annually variable losses of Wash larvae to sea but no significant input of mussel (or cockle) larvae from other North Sea populations.

A collector study can provide useful information, but needs considerable long-term commitment of effort in terms of manpower and vessel time.

4.1.4 Reference

Dare, P. J., Edwards, D.B., and Davies, G. (1983). Experimental collection and handling of spat mussels (*Mytilus edulis* L.) on ropes for intertidal cultivation. Fish. Res. Tech. Rep. MAFF Direct.Fish.Res., Lowestoft, (74), 23 pp.

4.2 Larval abundances and artificial spat collecting observations in the Dutch Wadden Sea

C.G.N. de Vooys
Inst. of Sea Research (NIOZ),
Neth. Inst. of Forestry and Nature Research (IBN-DLO)

For a large number of years, mussel larvae and metamorphosing larvae have been studied in the western Dutch Wadden Sea. Nearly all larvae and spat originate from cultivated mussels, reared on plots along channels at a depth of 3-10 m. Larvae are counted in water samples of 100 l, and filtered through plankton gauze. The samples were taken from the jetty of NIOZ on the island of Texel next to the Marsdiep, (Figure 4, see arrow), which has a depth of 10-20 m. Metamorphosing larvae were collected on petticoat gauze, stretched on a frame, which was hung from the jetty. Both free and metamorphosing larvae were sampled two times a week. Since I am working on contracts on other subjects at NIOZ, not all samples could be counted and analysed. At the moment, three years of observations of mussel larvae have been counted: 1981, 1982 and 1992, at least for the most important spawning time in April and May.

From the results, a pattern became visible. In April only in 1982, a larval peak is visible; on the contrary in May each year, a large peak shows. Probably, spawning of large numbers of mussels together could be triggered by a rise in water temperature in a short time. Even a preliminary analysis between the time in which the peaks occur and the previous increase of the surface water temperature at the NIOZ jetty gives an indication that this might be true. Unfortunately, local water temperatures near the main cultivation areas of mussels are not available. However, values of solar radiation and wind force and direction from the meteorological station near Den Helder could be used for analysis. Also, interactions between the daily heat balance and the shifts of the tidal cycle give a deviation from the daily water temperature in the Western Dutch Wadden Sea which could give an additional "heat shock".

For a statistical analysis of the results, at least 4 - 5 years of observations are necessary. This summer, I want to make a start with s method to monitor the occurrence of spatfall with time. Substrates will be presented to the spat which are as natural as possible, and, besides, identical. For this purpose, a transparent and elastic mould of silicone material is made of natural aggregates of barnacles. From this mould, casts are made with polyester (styrene), which gives a surface resembling that of barnacles. The casts will be hung from the jetty into the water column and will be changed two times a week.

4.3 Settlement of mussels *Mytilus galloprovincialis* on an exposed rocky shore in Ría de Vigo, NW Spain.

Jorge Cáceres-Martínez, José Antonio F. Robledo, Antonio Figueras
Instituto de Investigaciones Marinas CSIC,
Eduardo Cabello, 6, E-36208 ,Vigo
Spain

Abstract of a paper, acepted for publication in the Marine Ecology Progress series.

The blue mussels *Mytilus galloprovincialis* is the most important species in marine aquaculture in Spain, especially in Galicia (NW Spain), where production has been estimated at 200,000 tonnes per year, placing the country as the biggest producer of mussels in the world (Figueras 1989, Pérez Camacho et al., 1991). The culture is carried out in protected areas, Ria's, and the culture method uses ropes, suspended from rafts. The mussel farming industry of the Galician region requires that 60-70% of its seed supply is taken from rocky shore areas.
There are almost no quantitative data for a recruitment and settlement pattern of the mussel seed. The study was carried out on the exposed rocky shore located at Cabo Horne on the oceanic side of the Ria de Vigo. Twelve seed collectors made of nylon ropes, similar to those used by the local mussel farmers, of 35 cm length and 2 cm diameter (225 cm^2) were placed in two stainless steel structures, placed just above LWS level. Monthly samples were taken between March 1991 and February 1992, changing one rope. Spat were scraped off, counted and measured. Primary spat was separated, considering mussels with shell lengths from 0.250 - 0.470 mm according to Rees 1954, Bayne, 1956 and Widdows, 1991. This group was considered as 0.500 mm.

The total numbers of mussels from the rope collectors are shown in figure 5. Settlement peaked from May to September and remained low throughout the other months but with a light increase in November. The contribution of the primary spat was mainly in June at the start of the settlement season. Length frequency distributions of the mussels, obtained from the rope collectors, are shown in figure 6 A and B. Primary settlers occurred throughout the study period. An important increase occurred in May, although with low numbers of mussels. In June, the secondary stage (length class > 0.500 mm) became more frequent as the total numbers of mussels increased. From this month there was a progressive occurrence of the longer length classes. In samples obtained from the adult bed (Fig. 6 B), the primary spat also appeared throughout the study period.

The year-round presence of primary spat and their abundance in May and June reflects the presence of spawning mussels throughout the year and the occurrence of a major spawning period during the spring. The observed settlement pattern indicates the direct settlement of larvae from the plankton onto the adult beds and an immigration of mussels previously settled on other substrates. The strong increase of the number of secondary settlers within one

month can probably be explained by the immigration of primary settlers and the fast growth of primary settlers during a warm period. The scarcety of the length classes <2.860 mm suggests that the majority of young post-larvae able to drift occur under this shell length (Sigurdson et el., 1976, Blok and Tan Maas, 1977). The presence of primary settlers (<0.500 mm) on the adult beds detected in this study indicates a direct settlement from the plankton without a previous phase of growth on another substrate. The settlement pattern found in the Ria de Vigo could be explained by the possible genotypic differences between the two mussel species and the differential mortality as suggested by McGrath et al. (1988). In addition, the difference between the settlement patterns could also be a response to the ecological and environmental conditions that occurred on the Galician rocky shores.

For literature references the reader is referred to the article.

4.4 The influence of winter temperatures on the reproductive success of the marine bivalves *Macoma balthica, Cerastoderma edule* and *Mytilus edulis.*

An introduction.

Pieter Honkoop
Netherlands Institute for Sea Research (NIOZ)
Coastal Systems department

4.4.1 Introduction

Annual observations since the year 1969 by Beukema on macrozoobenthos at tidal flats at the Balgzand in the westernmost part of the Dutch Wadden Sea (Figure 4) indicate the influences of winter temperatures (mean temperature of the Wadden Sea water in January, February and March) on the abundance of many species in the spring and summer of the same year.
It appears that juveniles of some bivalve species are more abundant in summers following a severe winter than after a mild winter. The most important species are the cockle *Cerastoderma edule*, the blue mussel *Mytilus edulis,* the Baltic clam *Macoma baltica* and the gaper clam *Mya arenaria.* These species are the most important ones because they have a high relative biomass and failure of their recruitment could have negative consequences for animals higher in the food chain. Another reason for the importance of two of the species is that the cockle and the blue mussel are heavily fished and a failing recruitment will also have economic consequences.
A low recruitment was observed after the mildest winters of the last decades (1974, 1988 - 1990). The mean water temperature in these winters was about 6 °C. After cold winters (1979, 1985 - 1987, mean water temperature of 1,8 °C), there was an above-mean recruitment.

To explain these results, there are two hypotheses:

1. After a warm winter predators will appear earlier and in greater abundance on the flats than after a cold winter. Their appearance on the tidal flats coincides with the settlement of the bivalve larvae. The size of the larvae is so small that they are suitable food for their predators such as juvenile shore crabs, *Carcinus maenas*, and shrimps, *Crangon crangon*.

2. The metabolism of the bivalves is at a higher level during a mild winter than during a severe winter. The consequence is that the food supply to the gonads will decrease and the eggs will be smaller and less vital after a warm winter.

Consequences of the second hypothesis could be:

1. -an abnormal cleavage of the first stages after fertilization,
2. -abnormal trochophore larvae,
3. -an abnormal prodissoconch I (first larval shell) and
4. -a lower growth rate of the larvae.

Maybe, both hypotheses are true and either of them can explain a part of the poor recruitment after a mild winter. In our investigations we want to study the question in how far the second hypothesis is true.

So the main question is:
Do high winter temperatures negatively affect the vitality of the eggs and the survival of the larvae during the first days of their life?

To investigate the effects of winter temperatures on the reproduction on a lab-scale, we need 3 groups of animals which are kept at different temperatures during the winter, viz. at the normal seawater temperature, at temperatures 2°C higher, and at temperatures 2°C lower. From the different groups the glycogen content, the condition factor (the weight of the soft parts at a standard length) and the gonadal development during the winter will be assessed. In the spawning season the gametes will be counted, the diameter of the eggs observed,and the larval survival and the quantity of deformed larvae estimated.
We also want to assess some biochemical parameters in the eggs and larvae such as protein-, lipid-, glycogen- and carbohydrate content.

4.4.2 Preliminary results

Last year (spring 1992) we started our experiments. This was in fact too late, as the winter was almost over, but the experience with our experimental set up was useful. We measured the condition of the animals and the egg diameters. The warmest winter temperature resulted in the worst conditions and the smallest eggs for all species. The condition of the mussel and the Baltic clam were maximal after the simulated cold winter and the best condition of the cockle was observed after a simulated mean winter. The diameter of the eggs followed this trend. We do not know the survival of the larvae of the different groups yet. This year, the above mentioned parameters will be estimated for the animals kept under lab conditions at three temperature levels, and for animals in the field. A detailed description of the amount of gonadal tissue will be made, and the amount of eggs of the three species will be assessed. We also want to know how normal larval development will take place, in order to be able to recognize deformed embryos.

4.5 Recruitment of mussels in the Pertuis Breton (France) in these last years. A preliminary analysis of the influence of temperature and sunshine.

J. Prou and M. J. Dardignac.

IFREMER, La Tremblade and Le Houmeau, France.

4.5.1 Introduction

Since 1979, the IFREMER Laboratory follows mussel recruitment in the Pertuis Breton. Gametogenesis generally begins in September or October and ends in December. Spawning may begin in February and continues up to the end of April, but it usually occurs in the second fortnight of March. The most important settlement generally runs after the middle of May up to the middle of June.

During the study period, four years are noticeable by lack of settlement: 1982, 1989, 1990 and 1991 (Figure. 7). This failure throughout these last years resulted in breakdown of the cultivated biomass (Figure. 8).

4.5.2 Temperature

In order to test temperature effect on recruitment, the number of spat per meter of coconut rope is considered as an index of annual spatfall success. Air temperature is chosen as the independent variable because of its good agreement with water temperature in shallow bays.

Correlations between spat numbers and weekly temperatures show a negative effect of temperature on spat numbers (Figure 9). This result is corroborated by the distribution of these correlation coefficients compared to a normal distribution. It clearly shows the negative effect of temperature.

The day-degrees method was applied here for molluscs. For instance, the date of spawning of *Crassostrea. gigas* showed good agreement between the sum of temperature above a minimum and over the period of gametogenesis until spawning. Correlations were calculated between spat number and all combinations of cumulative temperatures between the supposed beginning of gametogenesis (October) and spatfall (June).

The three isolated periods in which correlations were highest are (Table 3 A):

Second week of October	-	third week of January
Third week of February	-	first week of March
Second week of May	-	first week of June

Each of these periods shows strong correlations with spat number.

A multilinear model to predict spatfall success explained 91% of the variance of the dependent variable:

$$SS \quad = \quad -98.9 \sum_{oct2}^{Jan3} T^{\bullet} \; - 131.2 \sum_{Feb3}^{Mar1} T^{\bullet} \; - 357.4 \sum_{May2}^{Jun1} T^{\bullet} + 43413$$

This high value clearly shows the negative effect of cumulated temperature expressed as a maximum temperature which could not be exceeded.

Furthermore, strong correlations between cumulated temperatures show that only one period has to be taken into account for explaining spatfalls (Table 3 B).

4.5.3 Sunshine

Let us remember that in the Pertuis Breton the mussel seed is collected on coco-fiber ropes which are out of water during the low waters of spring tide (Fig. 10). The seed is known to be very weak just as it sets on the rope. If, at this moment, a spring tide getting the ropes out of the water, coincides with very sunny weather, seed can die. Table 4 gives the monthly averages of sunshine in May since 1979. It shows a very important sunshine in May 1989 and May 1990. The same occurs in 1992, when the recruitment was normal and, on the contrary, sunshine was normal in 1991 when the recruitment was deficient.

However, looking in details at these two years, we can observe that:

-In 1991, if the average of sunshine in May was near the standard, it appears that it was in excess between the 18th and the 30th of the month (Fig 11). In addition, the last days of May coincided with spring tides and, if seed has settled at this moment, it can have died.

-In 1992, we have watched for the larvae, so we know that settlement began after the 19th of May. But, at that moment, if sunshine was important, it was neap tide and ropes did not get out of the water.

4.5.4 Conclusions

It has been shown that temperature is inversely related to spatfall success. Between October and June, three periods seem to be of special importance, but only one of them has to be chosen. Further research has to be made for making this choice.

On the other hand, owing to the technique used in Pertuis Breton, an important sunshine coinciding with a spring tide just as seed is setting on the ropes, appears to be a major factor in spatfall success. This hypothesis is strengthened by the fact that, during the period of study, a recruitment failure was not observed on the longlines, where ropes are never out of the water.

4.6 Spatfalls of cockles and mussels in the Wash in relation to preceding winter temperatures and possible effects of spring wind regimes upon larval dispersal: a preliminary analysis.

P.J. Dare and P. Walker,
MAFF,
Lowestoft, England

4.6.1 Introduction

At the first workshop, a preliminary analysis was presented of a long time series of spatfall and stock abundance indices for both *Cerastoderma edule* and *Mytilus edulis* in the Wash, eastern England (Dare, in ICES report of Dijkema, 1992). The frequency of occurrence of spatfalls of different magnitudes was discussed mainly in relation to spawning stock abundance (i.e. biomass) indices. No strong stock-recruitment relationship was evident from the aggregated data for either species, though a possible association of very cold winters with subsequent large spatfalls was indicated, paralleling a more striking correlation shown by Wadden Sea populations.

The present paper outlines a further, limited exploration of the Wash information for the years 1920 - 1990. In particular, we examine the extent to which spatfalls of the two species may be linked to (a) spawning stock biomass (SSB) index, and (b) climatic factors during the periods of gametogenesis (winter) and larval drift (spring).

4.6.2 Methods

(i) Climatic data:

Monthly averages of air and sea temperatures were available for an open coast situation (Skegnes) just outside the north entrance to the Wash (Figure 12). As the sea temperature record spanned only 14 years (1966-79), values for winter

(January and February) prior to 1966 were estimated from the regression of sea on air temperature:

$$t_{sea} = 0.5368t_{air} + 2.2212 \ (r=0.8030)$$

A comparison of the mean air temperatures at Skegness with those at two inland sites just south of the main Wash shellfish stocks showed only a small (<0.50°C) difference. It was assumed therefore that mean sea temperature in the southern Wash at high water would be less than 0.5 °C cooler than at Skegness.

Temperature data are expressed as departures (+ve of -ve anomalies) from the long-term mean at Skegness. Winters were than ranked in decreasing order of warmth and divided in three sea temperature bands: "warm", "normal" and "cold". Monthly mean wind velocities were calculated for each direction.

(ii) biological data
SBB indices were grouped into two classes: (a) "low" (inadequate to support a fishery), and (b) "medium-high" = capable of supporting a fishery. Spatfall indices were classed as: (a) "low" (including failures), (b) "medium", or (c): "high" abundance; the last categories would sustain fisheries.

Pathways of likely larval dispersion from (or into) the Wash were explored using the North Sea hydrographic model NORSWAP (Backhaus, 1985; Darby and Durance, 1989).

4.6.3 Results

As only primary statistical analyses have been performed on the data, the observations and interpretations given here are necessarily provisional.

The co-occurrence of spatfall was examined for 68 of the years between 1923 and 1992 (table 5). There was marked synchronicity between species for years of low spatfall. with a ~70% coincidence (31 of 42 for mussels, 31 of 47 for cockles). However, there was little tendency for medium or high spatfalls of the two species to occur together.

The frequencies of occurrence of low, medium and high spatfalls in relation to SSB indices and to preceding winter sea temperature anomalies are summarised for 55 years of cockle records (Figure 13) and for 63 years of mussel data (Figure 14). For each species, the data were analysed by a 3-way contingency table of the frequency of different levels of SSB, temperature and recruitment. However, as the frequencies in several of the cells were small, the analysis was repeated for each 2-way comparison, i.e. recruitment v. SSB. and recruitment v. temperature (Table 6).

(i) *Cerastoderma edule*
Low, or zero, cockle spatfalls occurred in 55% of the years and appeared to be related inversely to size of SSB. Recruitment appeared to be related to SSB, though not to winter temperature (Table e 6). However, the greater prevalence of high spatfalls at low SSB than with high SSB did indicate some association with cold preceding winters. In such years, notably 1947, 1955, 1963 and 1986, previously high cockle stocks experienced great frost mortalities, but the few survivors generated large spatfalls.

(ii) *Mytilus edulis*
Unlike cockles, poor spatfalls in mussels were twice as frequent (43 : 20 years) as medium and high spatfalls, and they were equally prevalent (68%) whether SSB was low (13 of 19 years) or medium/high (30/44).

Fig. 12 shows the average pattern of dispersal of larvae predicted by the NORSWAP model, outside the Wash, for the period April-June, based on a 20-day pelagic phase. Dispersal of larvae, "escaping" from the Wash would appear to be limited. Retention of larvae in the Wash might depend on annual wind force variations. A problem appeared to be a lack of data on timing of the larval phase each year. For he Wash, possibilities of recruitment by larval immigration from the small spawning populations to the north, appear to be at best restricted or sporadic. Similar modelling for other Southern Bight estuaries in England and the Netherlands indicate that larval exchanges between major stocks are unlikely.

4.6.4 Discussion and conclusions

In the Wash, the influence of SSB abundance and winter temperature upon spatfall success differs between cockles and mussels. In cockles, spat abundance apparently was related inversely to size of adult stock rather than to winter temperature per se. Cold winters appear to enhance the likelihood of high spatfall by removing most of the older year-classes that would otherwise compete with spat for space, food and other resources.

In Wash mussels, good spatfalls were less frequent than those of cockles, and tended to be related positively to both medium/high SSB levels and to cold winters. Interactions between mussel spat and adults are known to be more complex and variable than in cockles; indeed, density dependent effects can be diametrically opposite - as when adult mussels are outcompeted, smothered and killed by high densities of spat settling onto mature beds.

The direct effect of very cold winters is mediated in different ways in the two species. The *Mytilus* is more cold-hardy than *Cerastoderma*, except when ice-scouring is concerned.

For fisheries management purposes in the UK, the larval modelling results show that the Thames and Wash stocks of both cockles and mussels should be regarded as discrete, self-sustaining management units.

4.6.5 References

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4.7 Research into parental stock, larval abundance and spatfall of mussels in the German Wadden Sea

By Maarten Ruth
Institute for Sea Research
Kiel, Germany

4.7.1 Introduction

The project is part of an integrated multidisciplinary ecosystem research program funded by federal and state authorities. It was started in 1989 and ends at the end of 1994. The project focuses on the population dynamics of, and fishery for, cockles and mussels in the national park area (Elbe estuary to Danish border Figure 15). The final aim is to develop fishery and nature management measures.

4.7.2 Methods

Each year, all intertidal and subtidal beds are inventarised and abundance, length distribution and condition of the mussels are measured. At intervals of 2-3 weeks in summer and 4-6 weeks in winter, numbers of mussel larvae (>150 µm) in the surface layer of the outer part of three main tidal inlets are sampled with a baby bongo net and counted. Primary settlement is measured on natural substrate and on artificial collectors in the intertidal and subtidal region. Condition and gonad development of mussels are investigated on two intertidal and one subtidal bed.

In the laboratory, the influence of nutrition and the contents of inorganic seston in the water on the larval development are investigated. It will be tried to apply the DNA/RNA ratio method to determine the nutritional status of larvae in the field in the first days after primary settlement.

4.7.3 Results

The last extraordinarily strong recruitment in all areas of the Schleswig-Holstein Wadden Sea occurred after a sequence of three cold winters, in late summer 1987. In 1988 and 1989, recruitment failed almost completely. In July 1990, an extraordinarily strong recruitment occurred in the subtidal area after a very mild, though stormy, winter followed by a moderate recruitment on intertidal beds in autumn. In 1991, recruitment in the subtidal region was concentrated in May and in July. During spring and early summer, intertidal recruitment was more or less continuous. In the autumn of 1991, a rather strong recruitment occurred, leading to recovery of old and formation of new mussel beds. In 1992, recruitment began in February on the sub- and intertidal beds, but remained weak throughout the year. This recruitment failure coincided with low phytoplankton levels during the -long and warm- summer, which were ascribed to low precipitation and river runoff during that period.

4.7.4 Conclusions:

From the comparison of the temporal and spatial pattern of recruitment with similar data from other parts of the Wadden Sea, the following conclusions can be drawn:

Recruitment is a regional phenomenon (note the strong recruitment in the Dutch WS in 1992, compared to the failure in Schleswig Holstein; in 1990, it was quite the other way around). Cold winters normally affect the entire WS.

Cold winters can be followed by strong recruitment, but strong recruitment can also happen without preceding extreme winter conditions.

Although no calculations have been made yet, there seems to be no correlation between larval densities in the water and spawning success. Recruitment seems to be independent of parental stock size and spawning success. Predation on the planktonic stages of *Mytilus* seems to be negligible in years with excellent conditions for primary settlement.

The limiting factors are unclear up to now. They may vary from case to case. Predation can be the main limiting factor in some situations, but lack of food or lack of adequate primary or secondary settlement substrate can play the same role.

4.8 A review of literature on the influence on recruitment success by predation on spat

Per Sand Kristensen
Institute for Fishery and Marine Research
Charlottenlund
Denmark

4.8.1 review

André and Rosenberg (1991) suggested that predation on settling larvae is an important mechanism invoked to explain inhibition of settlement by established adult suspension feeders (Figure 17) (Thorson., 1950, Woodin, 1976). Field observations and laboratory experiments (review in Young & Chia, 1987) suggest that a great potential exists for direct predation by adult suspension feeders on settling larvae.

On the other hand, Reise (1985) suggested that a high survival of juvenile cockles could occur due to the absence of surface-feeding omnivores and small epibenthic predators. Predator exclosure experiments (Reise, 1978, 1979, 1980), laboratory experiments (Jensen & Jensen, 1985) and stomach contents analysis (Pihl & Rosenberg, 1984, Pihl, 1985) have shown that a guild of mobile epibenthic predators, mainly juveniles of *Carcinus maenas*, *Crangon crangon* and *Pleuronectes platessa* prey heavily on newly settled larvae and juveniles of *Cerastoderma edule* (Figure 18). After strong winters, immigration of predators to the study area was delayed by 1-2 months (Pihl and Rosenberg, 1982). The population dynamics of *Cerstoderma edule* and *Mya arenaria* is to a large extent controlled by the timing of the reproduction of these bivalves and their predators, as was also pointed out by Beukema (1992).

The encounter rate between settling larvae and suspension feeding benthic predators will vary with patch size (Peterson, 1982, Ertman & Jumars, 1988) adult density and movements of the larvae (Buttmann, 1987). In case of a rich spatfall, recruitment success is little influenced by predation. When spatfall is poor, however, its success depends strongly on the abundance, timing and size of predators.

4.8.2 Literature

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Table 1. Percentage of primary spat (smaller than 0.5 mm shell length) on spat collectors at Thief and Toft Sands in June and July 1986 and 1987. Number in brackets ( ) is the mean number of spat per collector.

	1986		1987	
	June	July	June	July
Site				
Thief	7.7 (897)	0.5 (3381)	18.1 (312)	4.1 (225)
Toft	10.9 (593)	70.6 (1298)	7.7 (501)	0.3 (378)

Table 2. Data on Wash mussel spat collector catches in relation to spawning stock and spatfall indices, 1978-1989.

	Spawning stock index	Peak monthly spat catch on collectors (n/0.5m)		Spatfall index on ground	Winter air temperature anomaly (°C) at Skegness		
		Tofts	Thief		January	February	January+ February
1978	**	61 500		**	-0.2	-0.6	-0.4
1979	*	37 000		**	-2.9	-2.0	-2.4
1980	*			**	-0.5	+1.7	+0.6
1981	*			*	+0.8	-0.4	+0.2
1982	*			0	-0.1	+1.0	+0.4
1983	*	27 000	27 000	*	+3.1	-1.0	+1.0
1984	*	950	1 500	0	+0.1	0.0	0.0
1985	*		200	0	-4.0	-1.1	-2.5
1986	*	1 200	3 500	**	+0.1	-3.7	-1.8
1987	*	500	300	*	-1.7	+0.2	-0.7
1988	**			0	+1.7	+1.3	+1.5
1989	*			0	+2.3	+2.1	+2.2

Notes:

1. Mussel indices based on ESFJC/MAFF records of general abundance: 0 = nil, * = low abundance, ** = moderate abundance, *** = high abundance.

2. Collector data: blanks = site not monitored.

3. The high catches of 1978, 1979, 1983 and 1986 comprised many primary stage plantigrades (> 50% in 1983 and 1986).

Table 3: Correlations between temperature and spat number (A) and correlation matrix between cumulated temperatures. The choice of one period could be based on further knowledge (B).

A)

Cumulated temperature over		R Correlation with spat number
Oct. 2	Janv 3	- 0,88
Feb. 3	Mar 1	- 0,84
May 2	June 1	- 0,92

B)

	Oct. 2 - Jan. 3	Feb. 3 - Mar. 1	May 2 - June 1
Oct. 2 – Jan. 3	1		
Feb. 3 – Mar. 1	0,77	1	
May 2 – June 1	0,82	0,78	1

Table 4. Monthly averages of temperature, rain and sunshine in May since 1979.

ANNEE	TEMPERATURE	PLUVIOMETRIE	ENSOLEILLEMENT
1979	- 1.4	+ 118 %	- 15 %
1980	- 1.1	- 24 %	- 22 %
1981	- 0.8	+ 164 %	- 44 %
1982	0	- 33 %	- 15 %
1985	- 0.8	+ 111 %	- 10 %
1987	- 0.9	- 51 %	+ 19 %
1989	+ 4.0	- 79 %	+ 44 %
1990	+ 3.3	- 37 %	27 %
1991	+ 2.0	+ 3 %	0
1992	+ 2.7	- 52 %	+29 %

Table 5. The number of years in which cockle and mussel spatfalls of similar magnitude coincided in the Wash during 1923-92.

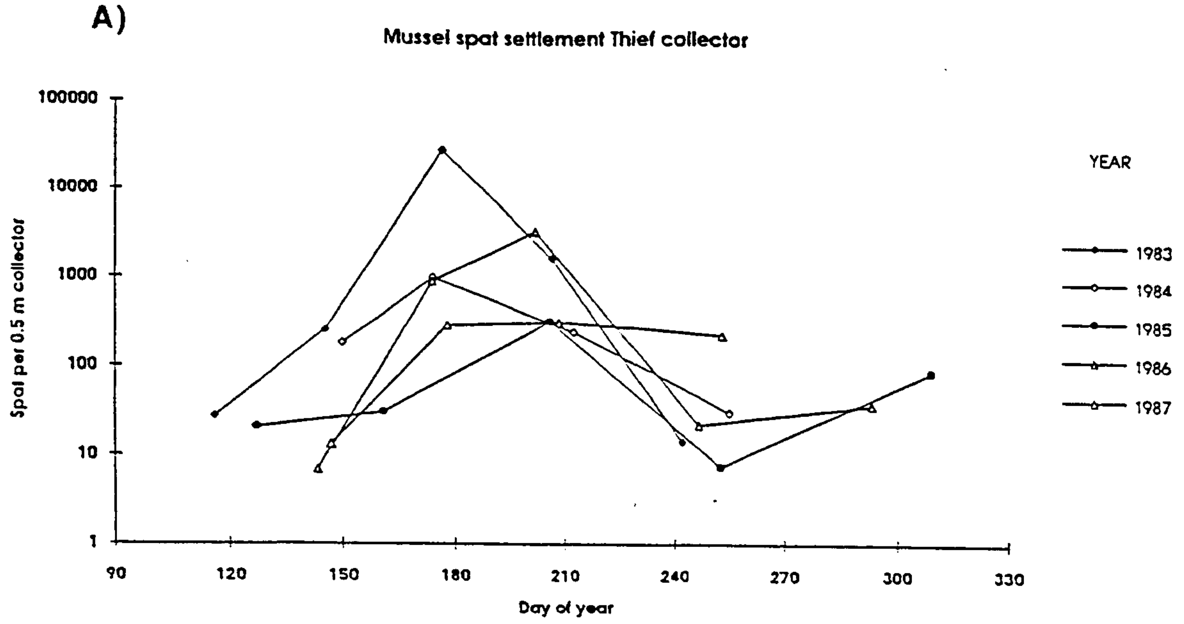
Mussel/ Cockle	LOW	MEDIUM	HIGH	TOTALS
Low	31	10	1	42 (62%)
Medium	13	3	1	17 (25%)
High	3	3	3	9 (13%)
Totals	47 (69%)	16 (24%)	5 (7%)	68

Table 6. A 2-way contingency table analysis of the effect of spawning stock biomass (SSB) and preceding winter sea temperature upon recruitment in Wash cockles and mussels

			Recruitment low	Recruitment medium	Recruitment high	
Cockles	SSB	low	8	6	8	
		medium + high	22`	9	2	χ^2=9.04*
	Temp	warm	10	3	4	
		normal	12	7	1	
		cold	8	5	5	χ^2=5.30^{ns}
Mussels	SSB	low	13	5	1	
		medium +high	30	9	5	χ^2=0.78^{ns}
	Temp	warm	19	2	0	
		normal	15	5	3	
		cold	9	7	3	χ^2=11.2*

Footnote: The 3 sea temperature bands correspond to anomalies from long-term means as follows:
warm = >0.5°C positive anomaly,
cold = exceeding -0.5°C negative anomaly,
normal = within ± 0.5°C of mean.

A)



B)

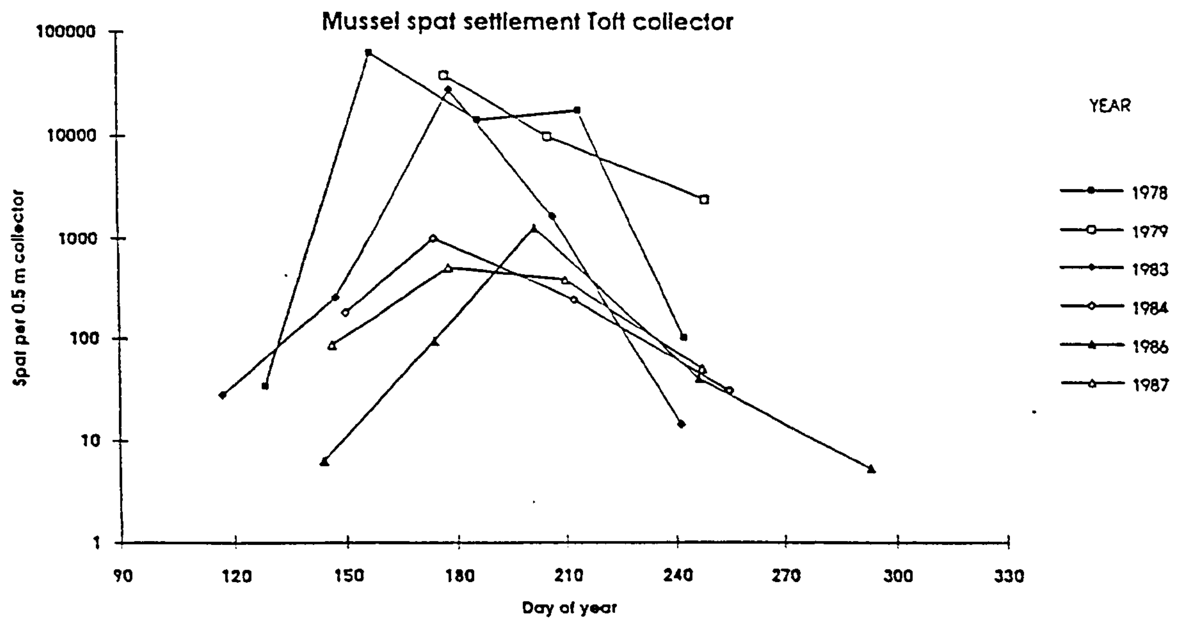
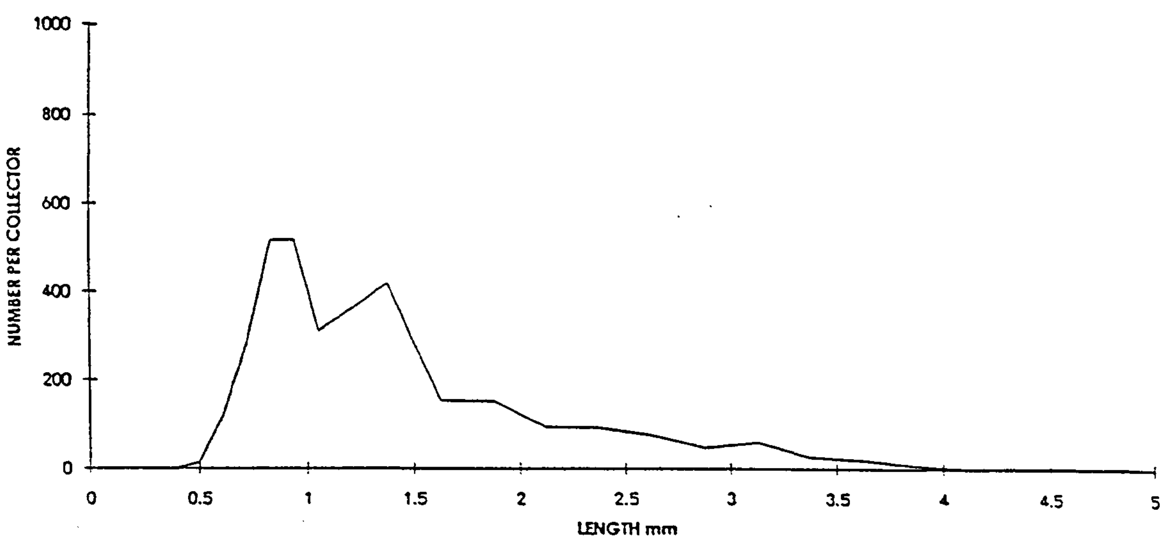


Figure 1. Seasonal and annual variation of mussel spat on 0.5 m SFP collectors from two sites in the Wash. A) Thief Sand , 1978-1987. B) Toft Sand, 1983-1987.

A)



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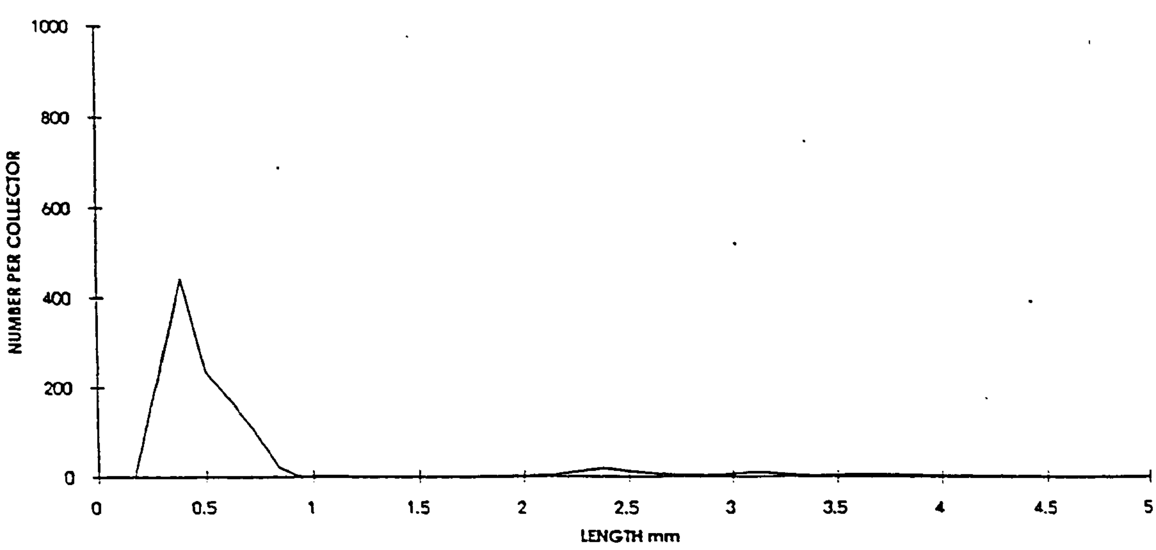


Figure 2. Size distrubution of mussel spat from SFP collectors deployed in the Wash, July-early August 1986 on: A) Thief Sand and B) Toft Sand.

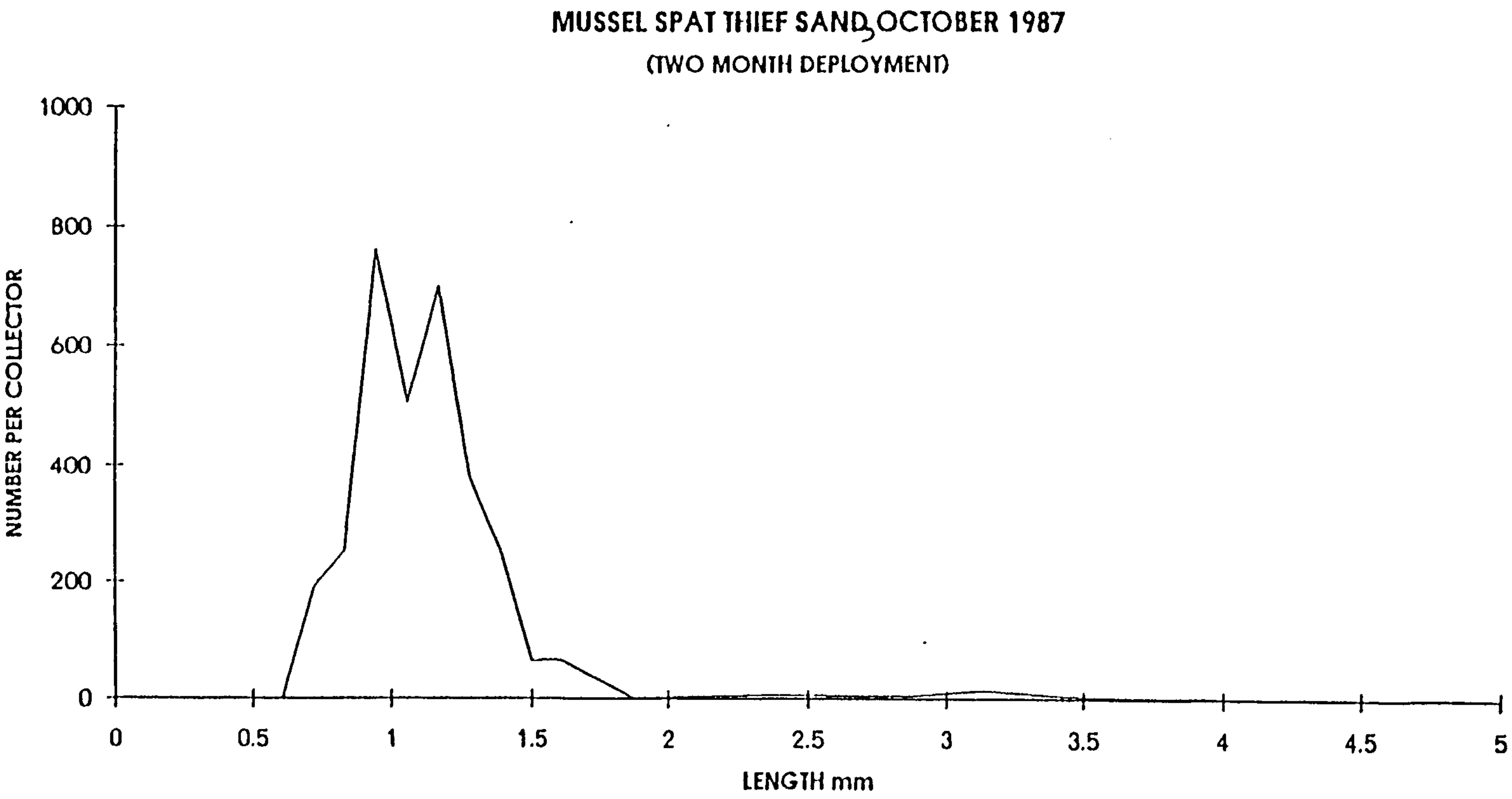


Figure 3. Size distribution of mussel spat from an SFP collector deployed for 2 months on Thief Sand, during September-October 1987.

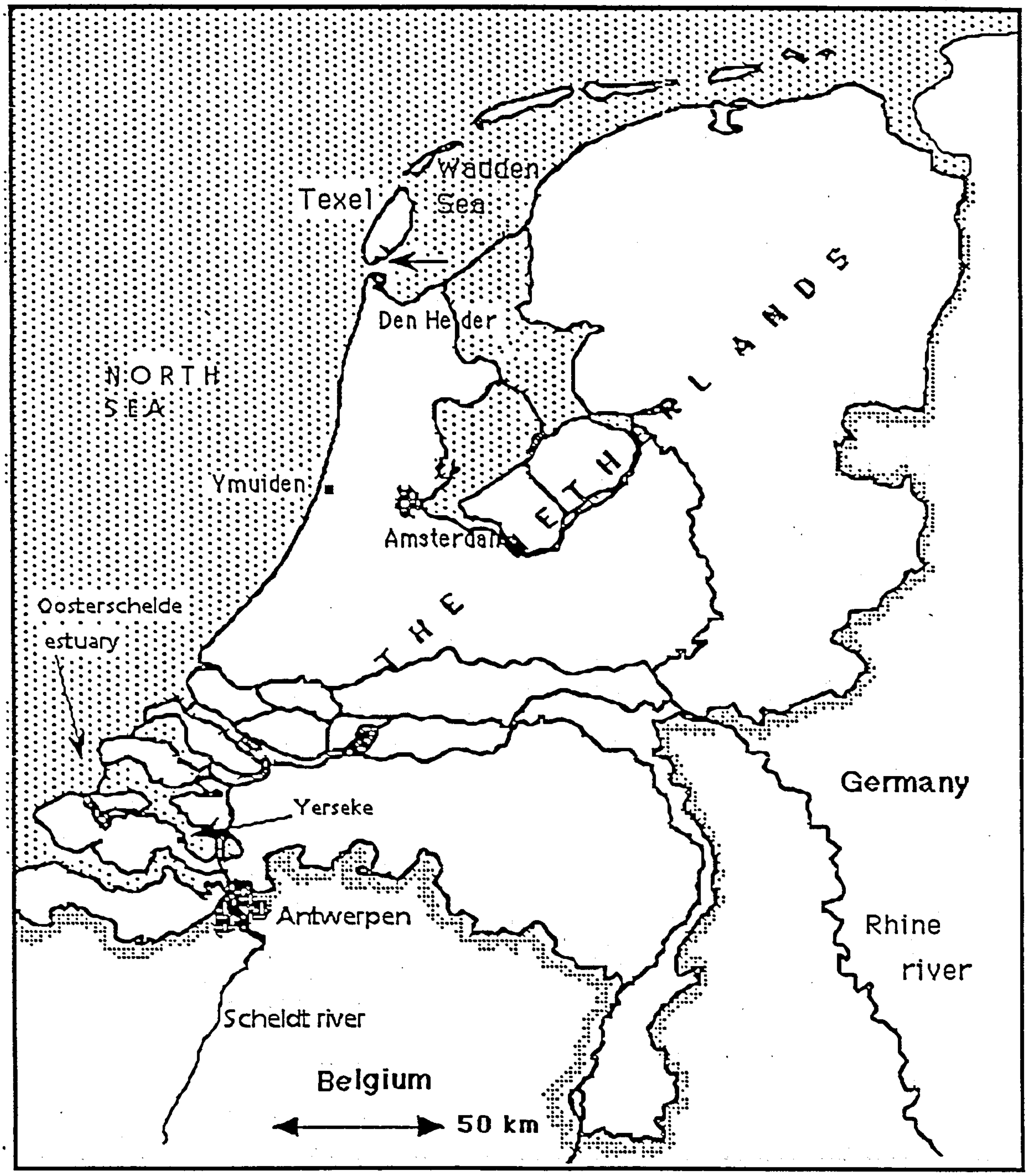


Figure 4. The Netherlands with sampling point NIOZ/RIN. (Arrow)

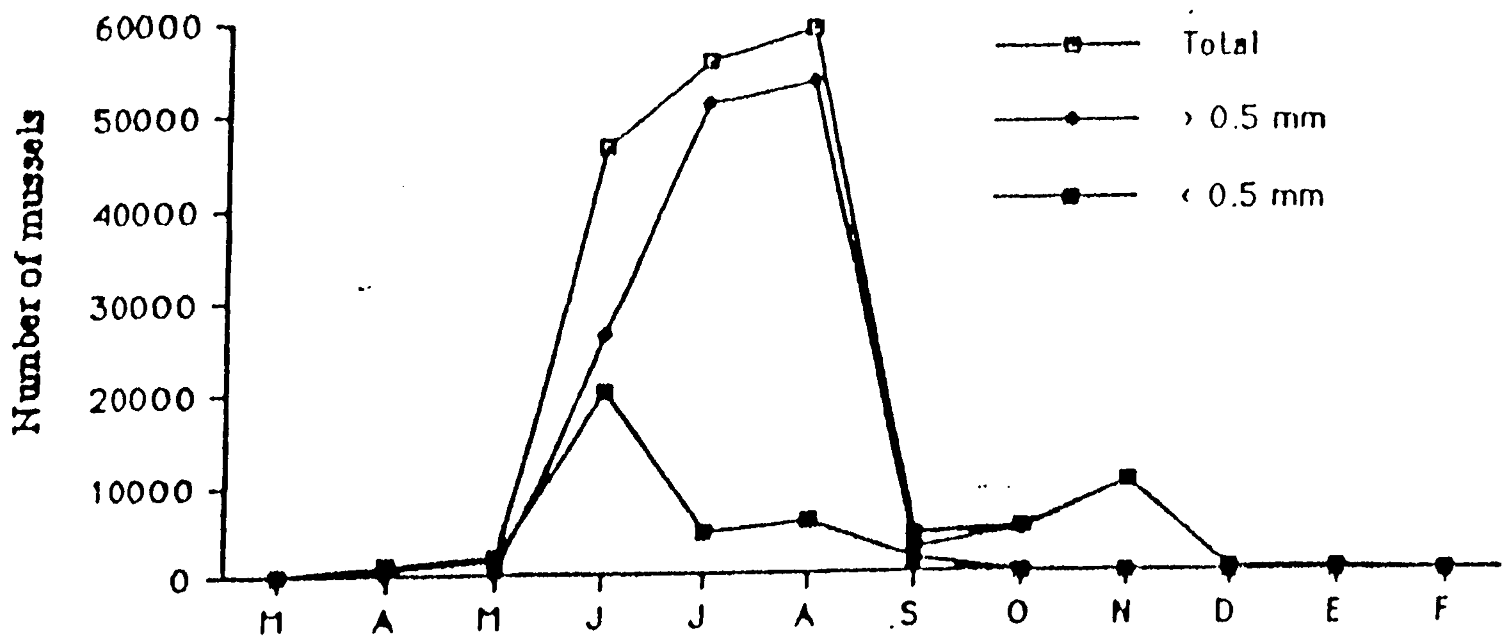


Figure 5. *Mytilus galloprovincialis* . Monthly catches of primary (< 0.5 mm) and secondary (> 0.5 mm) stage mussel spat on rope collectors in Cabo Home, Ria de Vigo, during 1991-1992.

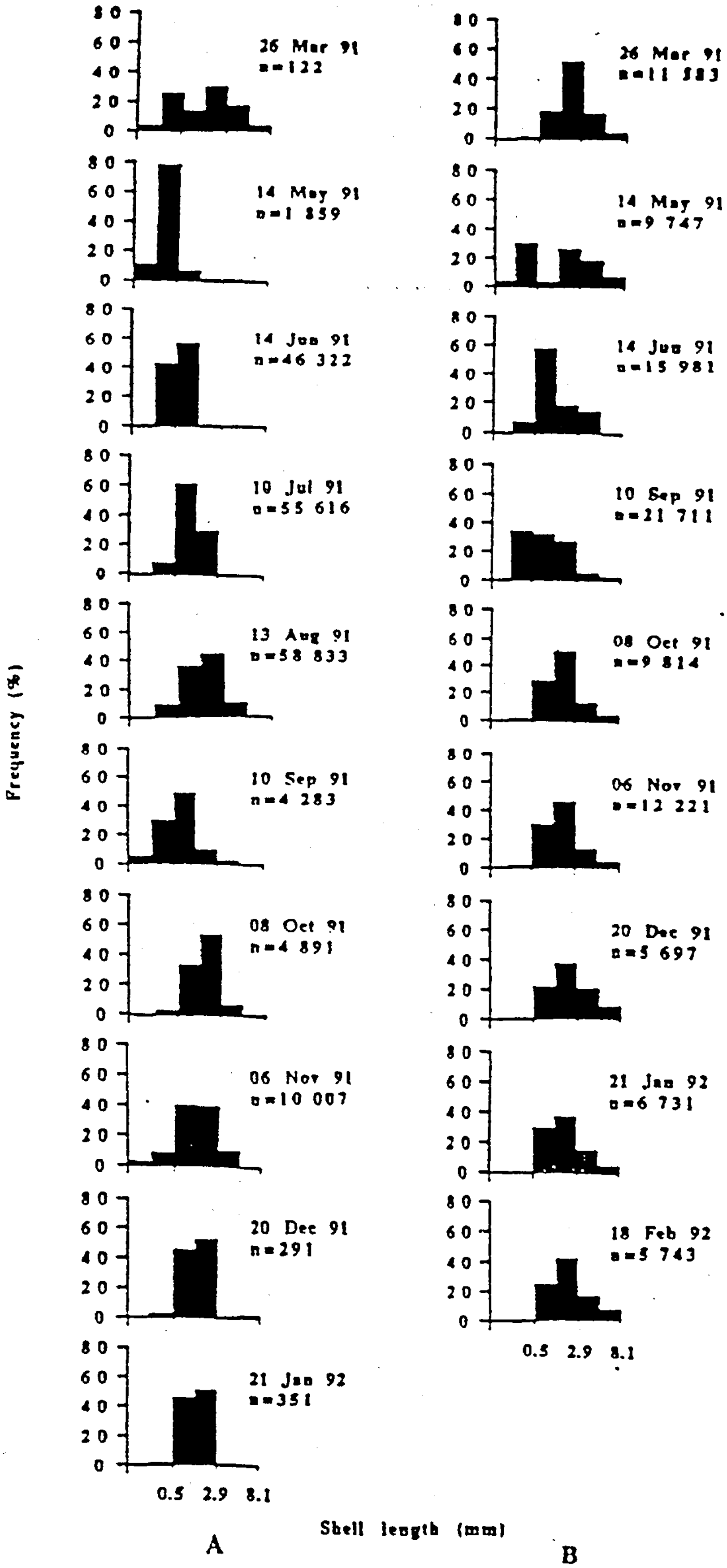


Figure 6. *Mytilus galloprovincialis*. Frequencies of 6 length classes (0.250-0.350, 0.351-0.470, 0.471-1.500, 1.501-2.900, 2.901-5.599 and 5.600-8.100 mm) of mussel spat settled each sampling period on: A) rope collectors and B) adult beds in Cabo Home, Ria de Vigo.

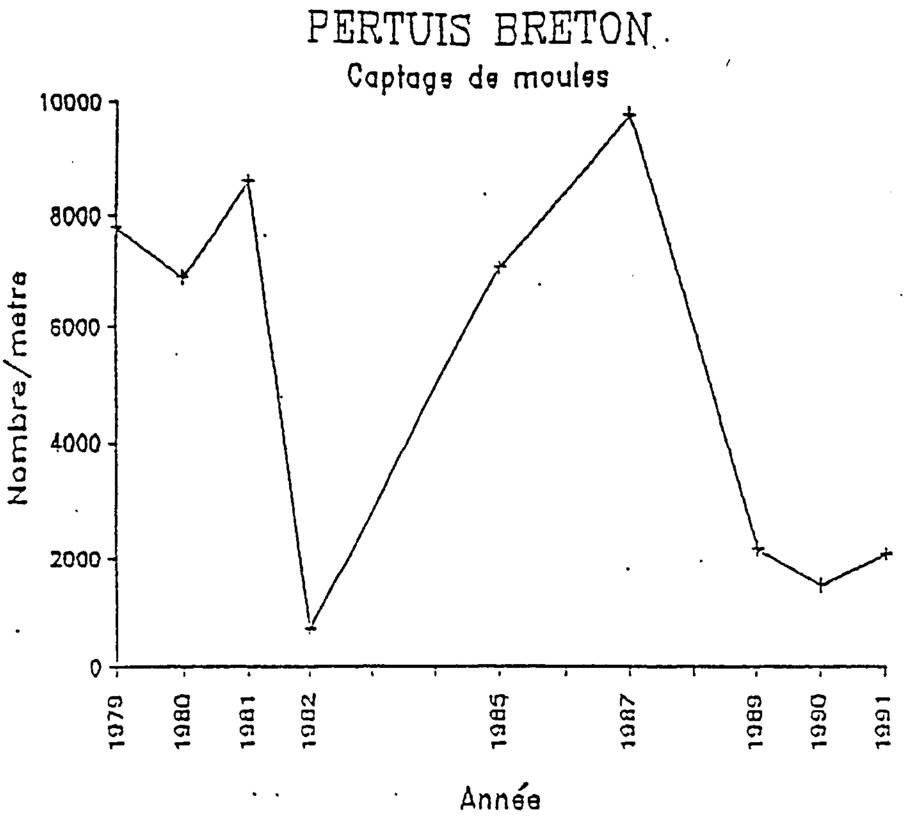


Figure 7. Recruitment of mussels since 1979 in the Pertuis Breton (number of spat per meter of rope).

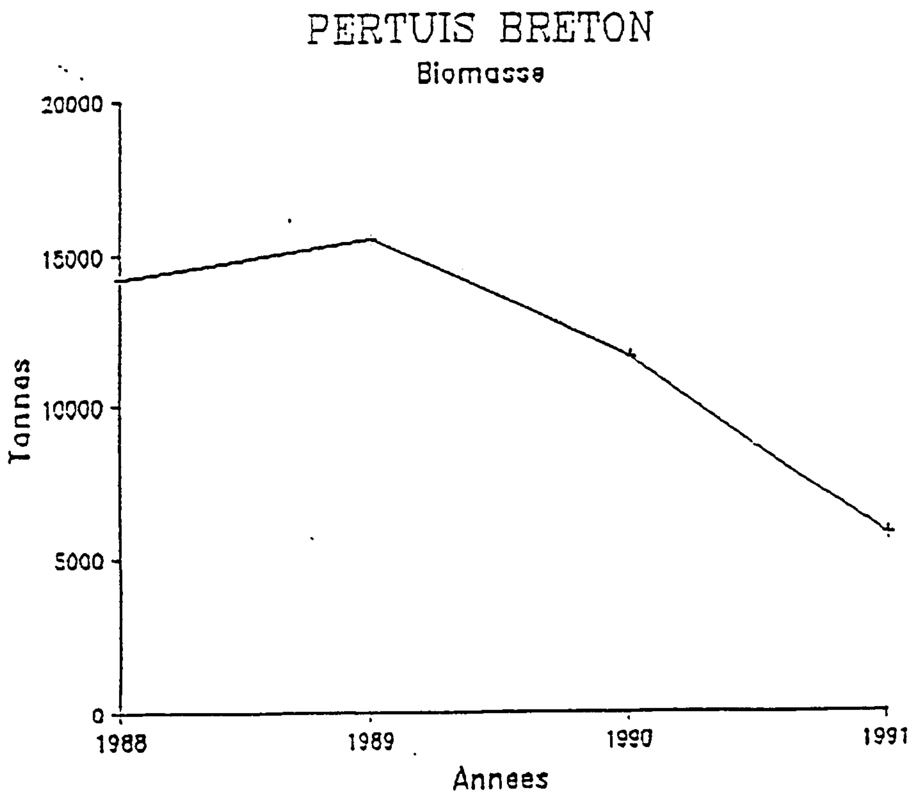


Figure 8. Biomass of mussels cultivated in the Pertuis Breton.

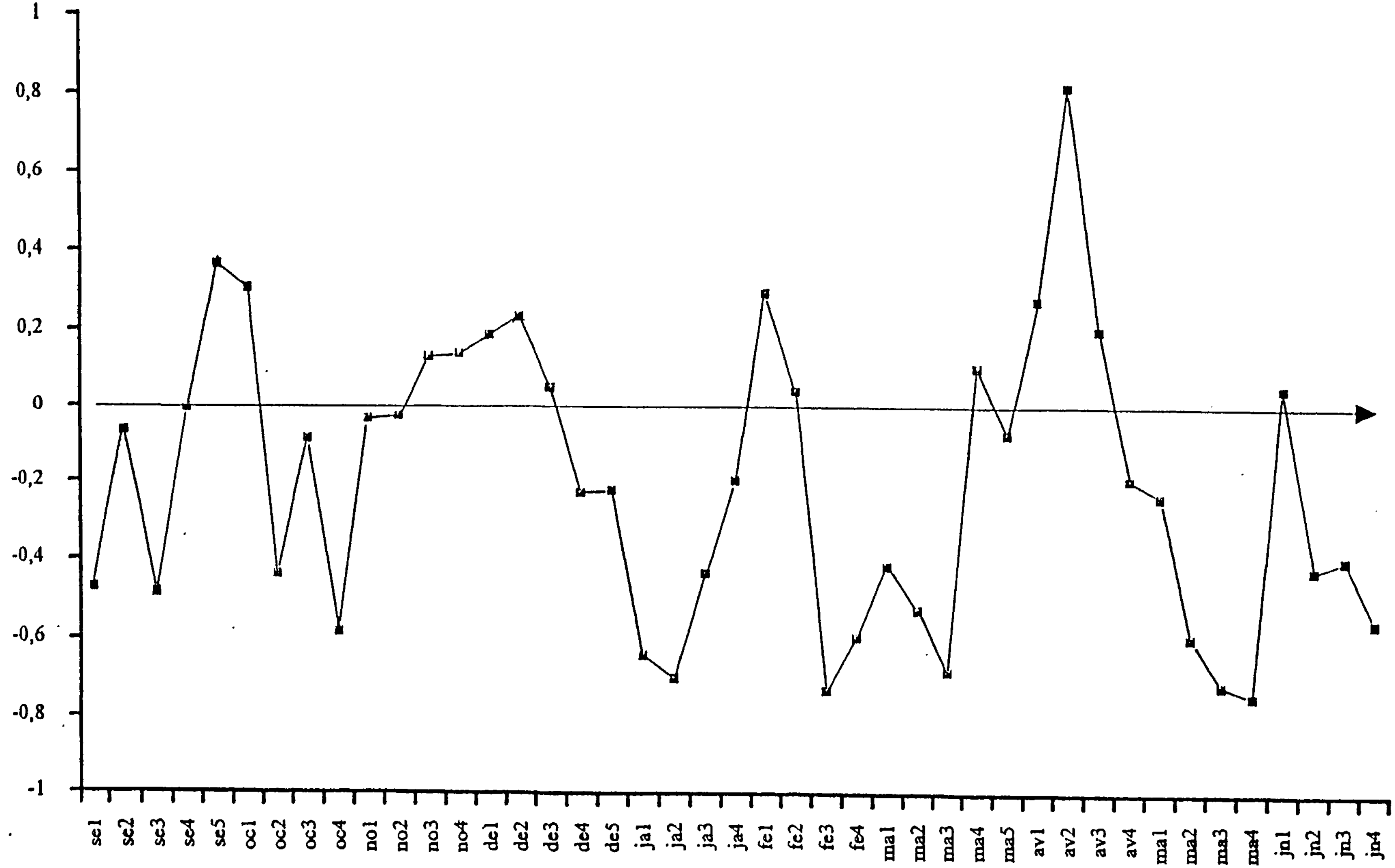


Figure 9. Correlation between spat number and weekly temperatures.

Figure 10. In the Pertuis Breton spat of mussels is collected on ropes.

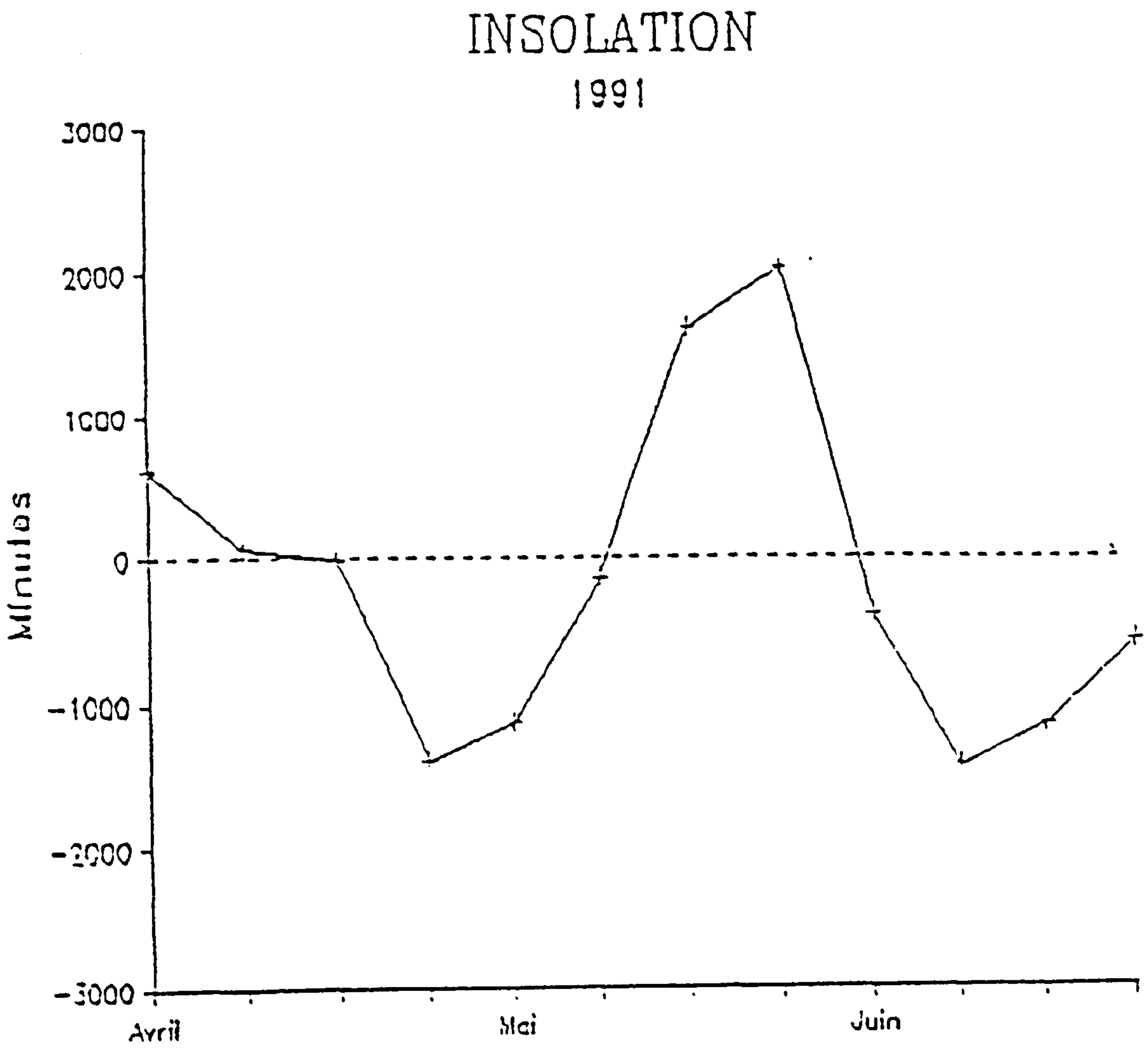


Figure 11. Sunshine in May 1991.

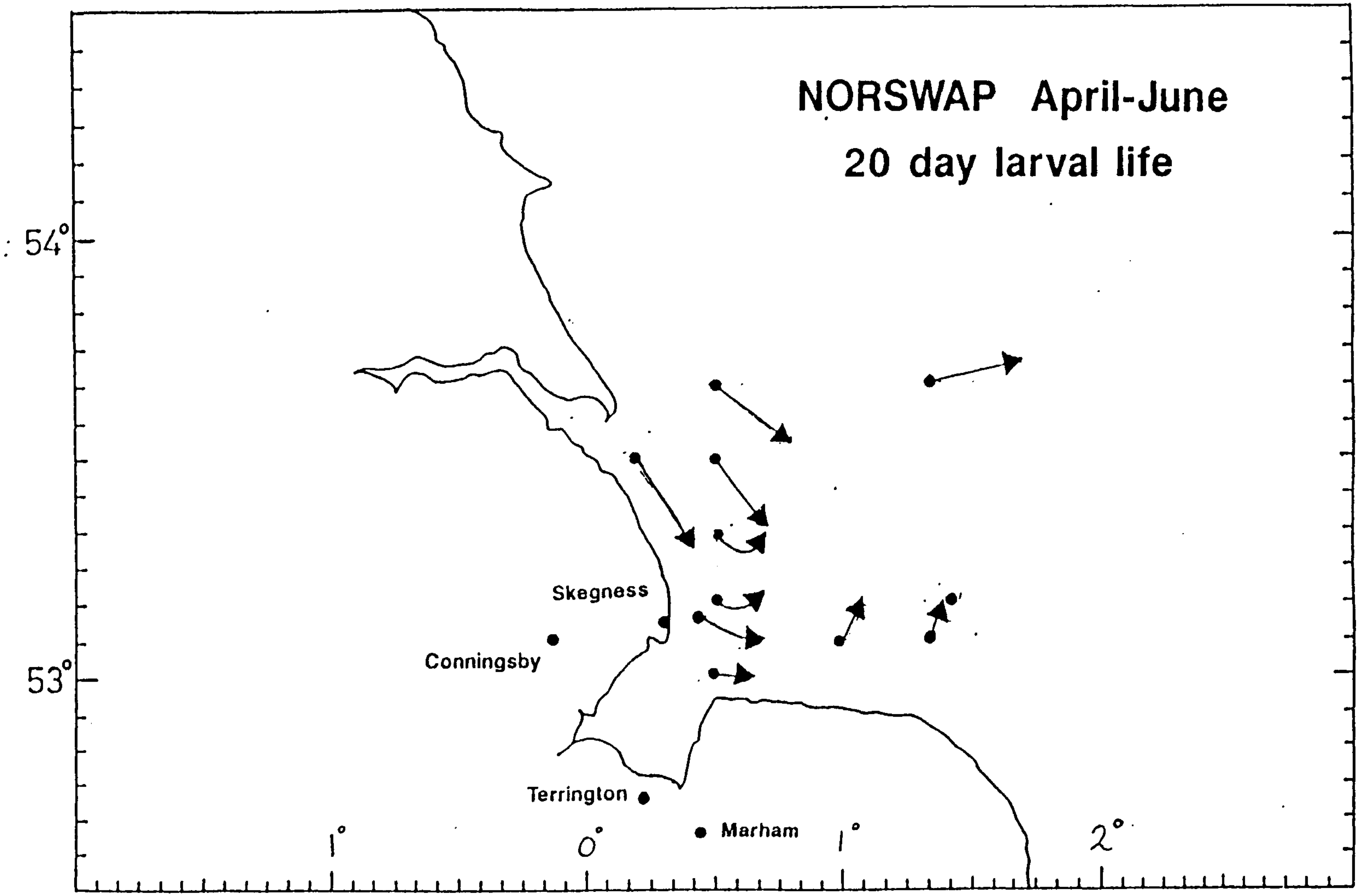


Figure 12. Dispersal pathways predicted by NORSWAP hydrographic model for bivalve larvae outside the Wash, calculated for a 20-day pelagic phase during april to June. (circles denote relaese points; arrows show length and direction of movements).

Figure 13. Frequency of different magnitudes of cockle spatfalls in the Wash for 55 years between 1920 and 1990, expressed in relation to (a) spawning stock (SSB) size, and (b) winter sea temperature anomalies in January-February. (Spatfall indices: O/L= zero or low; M=medium; H=high).

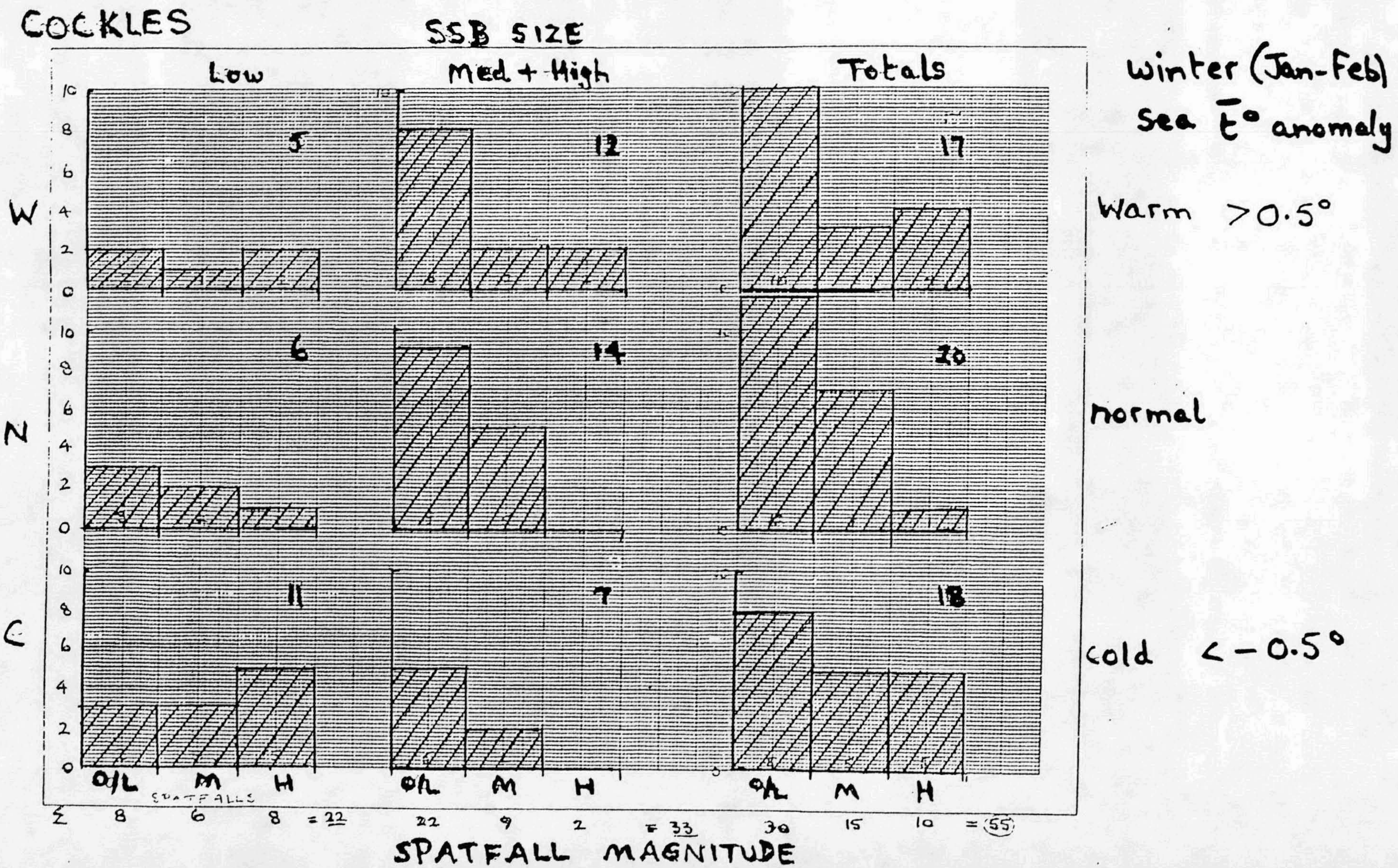
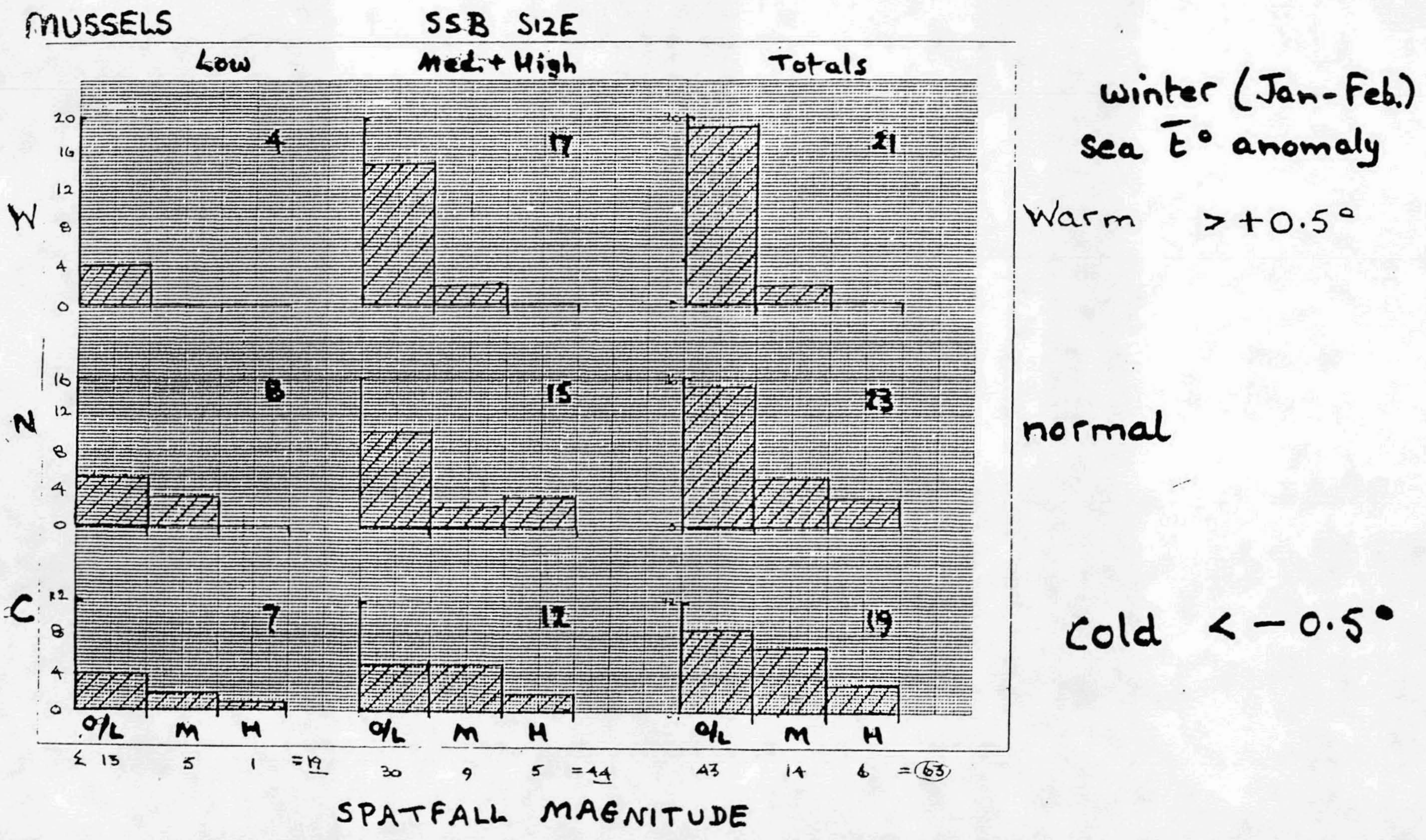


Figure 14. Frequency of different magnitudes of mussel spatfalls in the Wash for 63 years between 1920 and 1990, expressed in relation to (a) spawning stock (SSB) size, and (b) winter sea temperature anomalies in January-February.



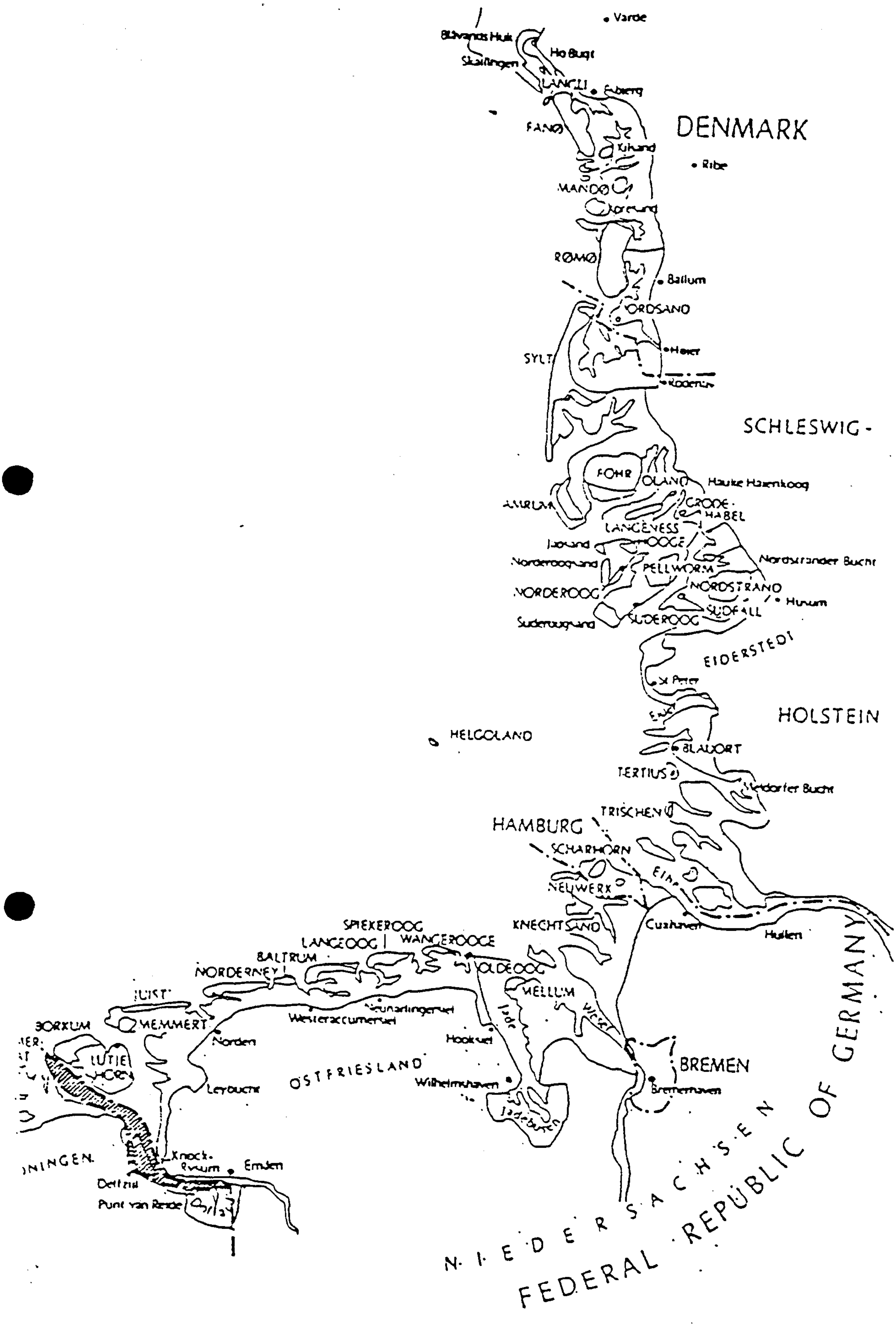
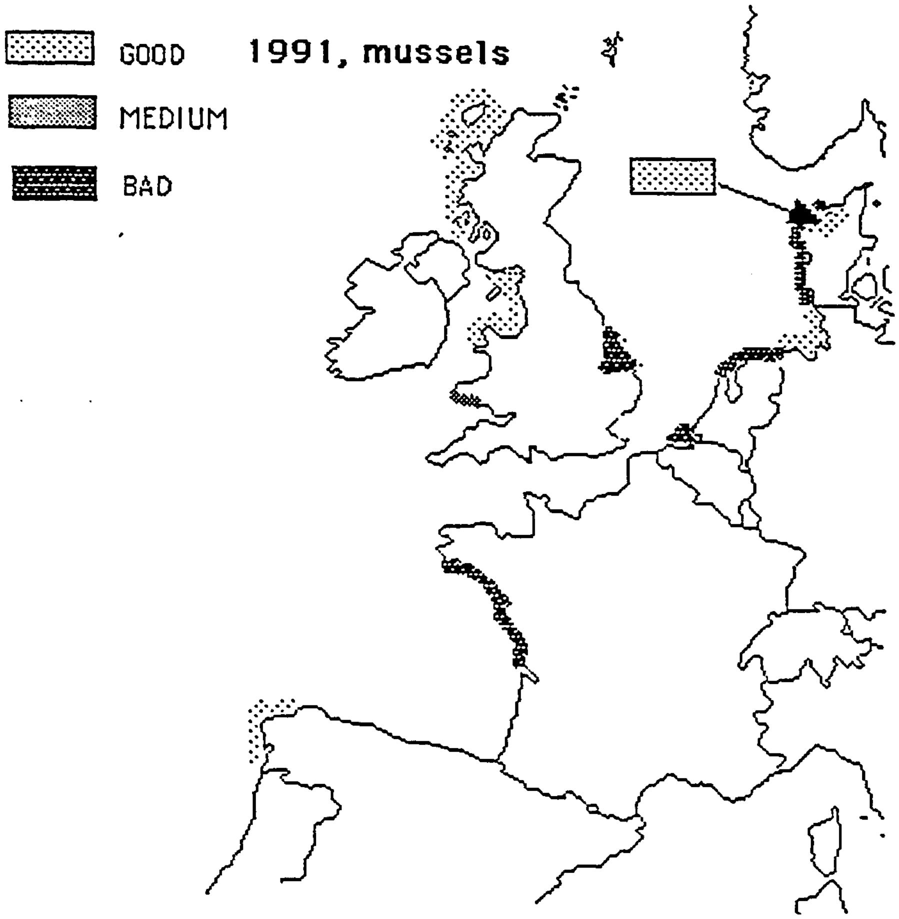


Figure 15. German Wadden Sea.



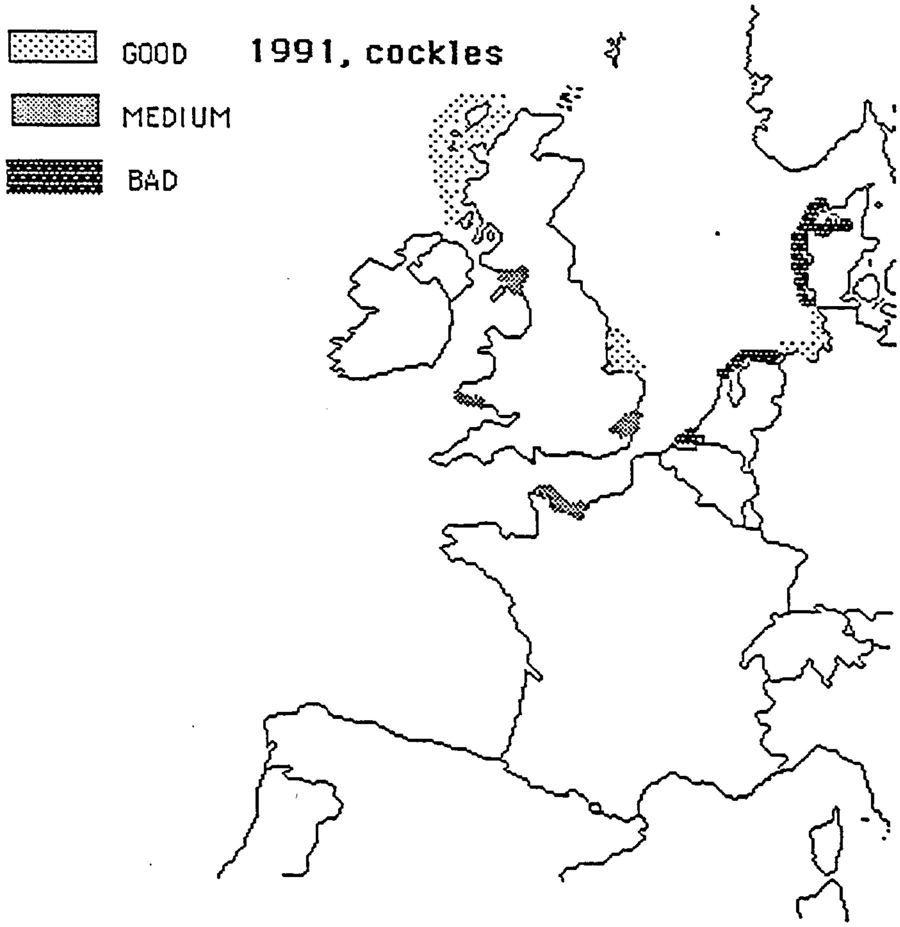
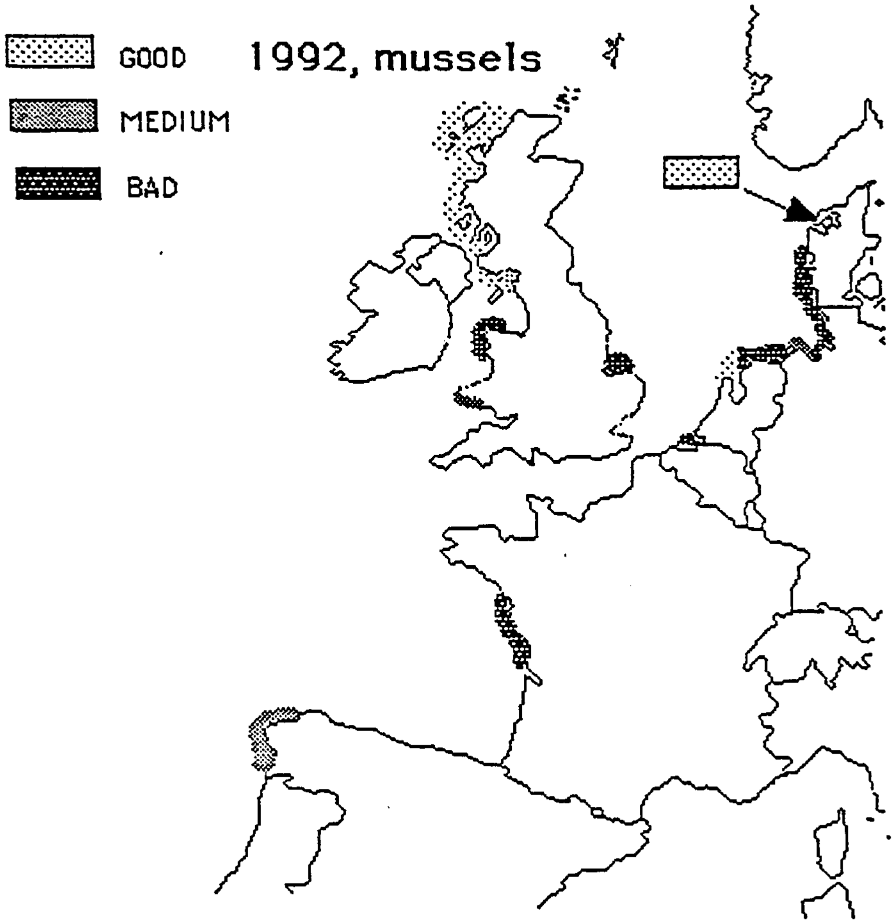
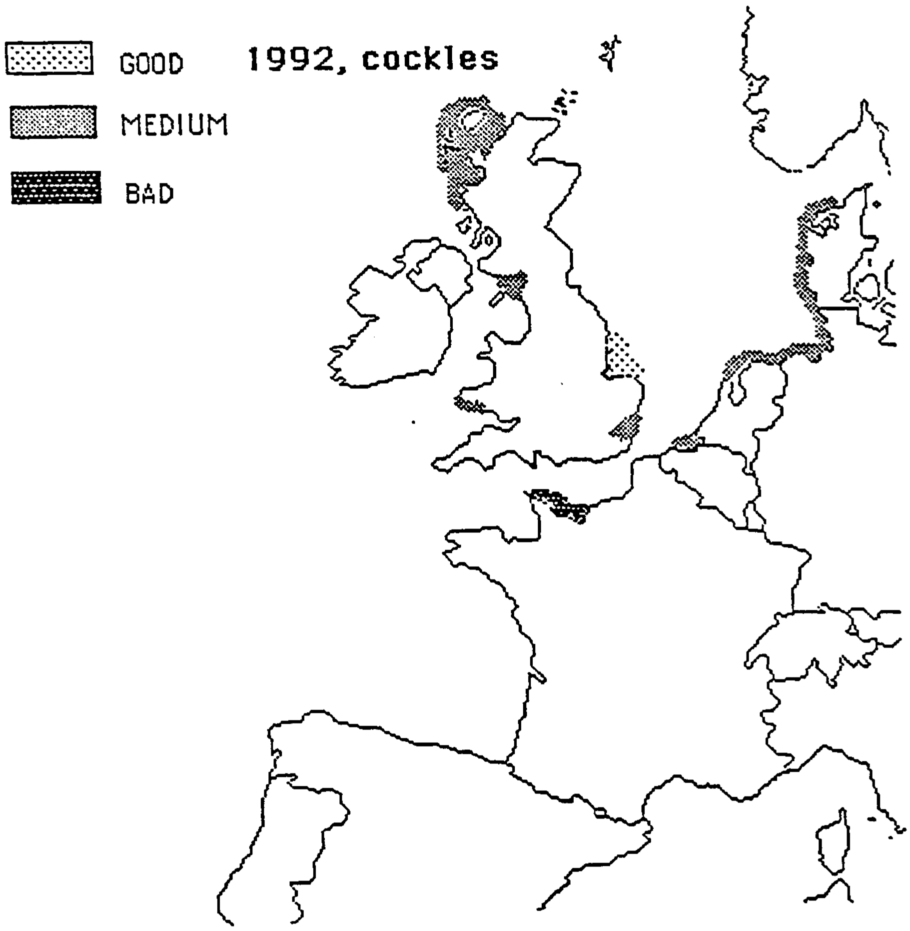


Figure 16 Survey maps of western Europe showing recruitment success of mussels and cockles in 1991 and 1992, according to estimates by local reseachers.


GOOD
MEDIUM
BAD
1992, mussels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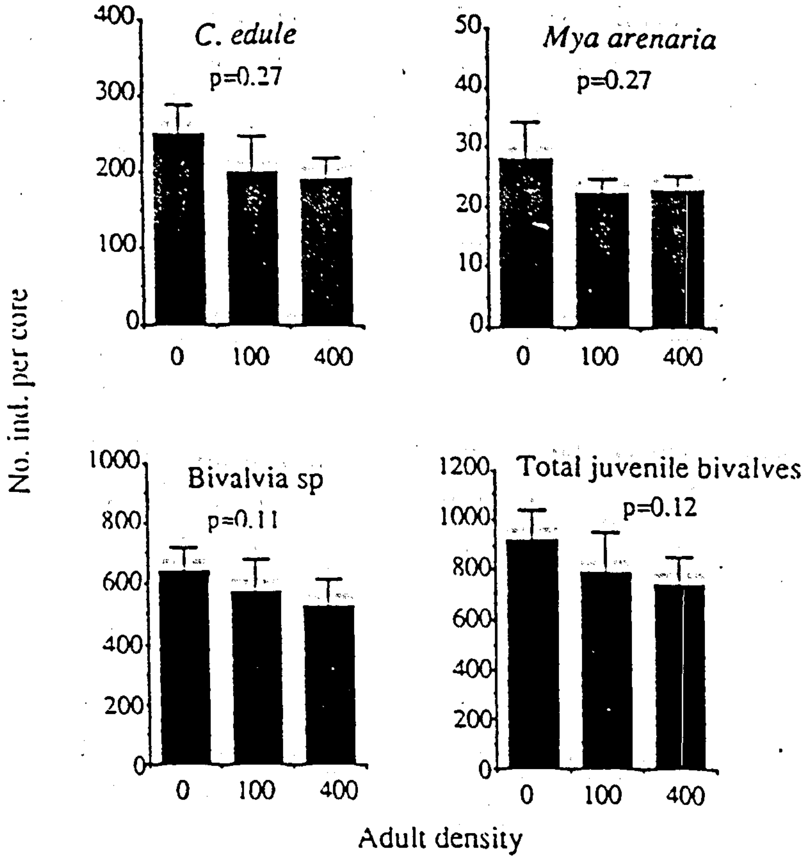
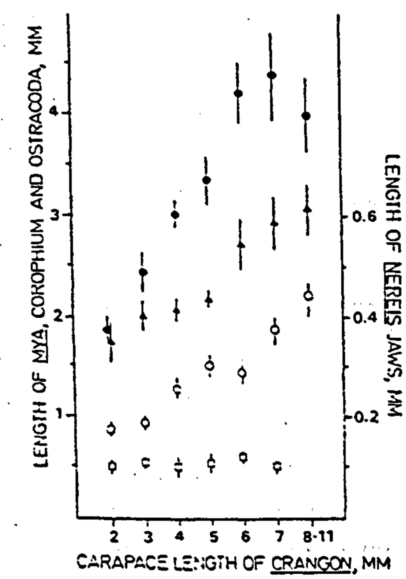


Figure 17: Mean densities (± SE) of newly settled bivalves in experimental plots with 0, 100 and 400 adult *Mya arenaria* m-2 on 19 june 1989, p-values indicate the probability for no difference among treatments (from: André & Rosenberg, 1991).



Crangon crangon. Body size in relation to size (mean and S. E.) of 4 dominant food items: *Nereis* spp. (▲). *Mya arenaria* (C). *Corophium volutator* (●) and Ostracoda (□)

Figure 18: Crangon crangon. Body size in relation to size (mean and S.E.) of 4 dominant foor items. (From: Pihl & Rosenberg, 1984).