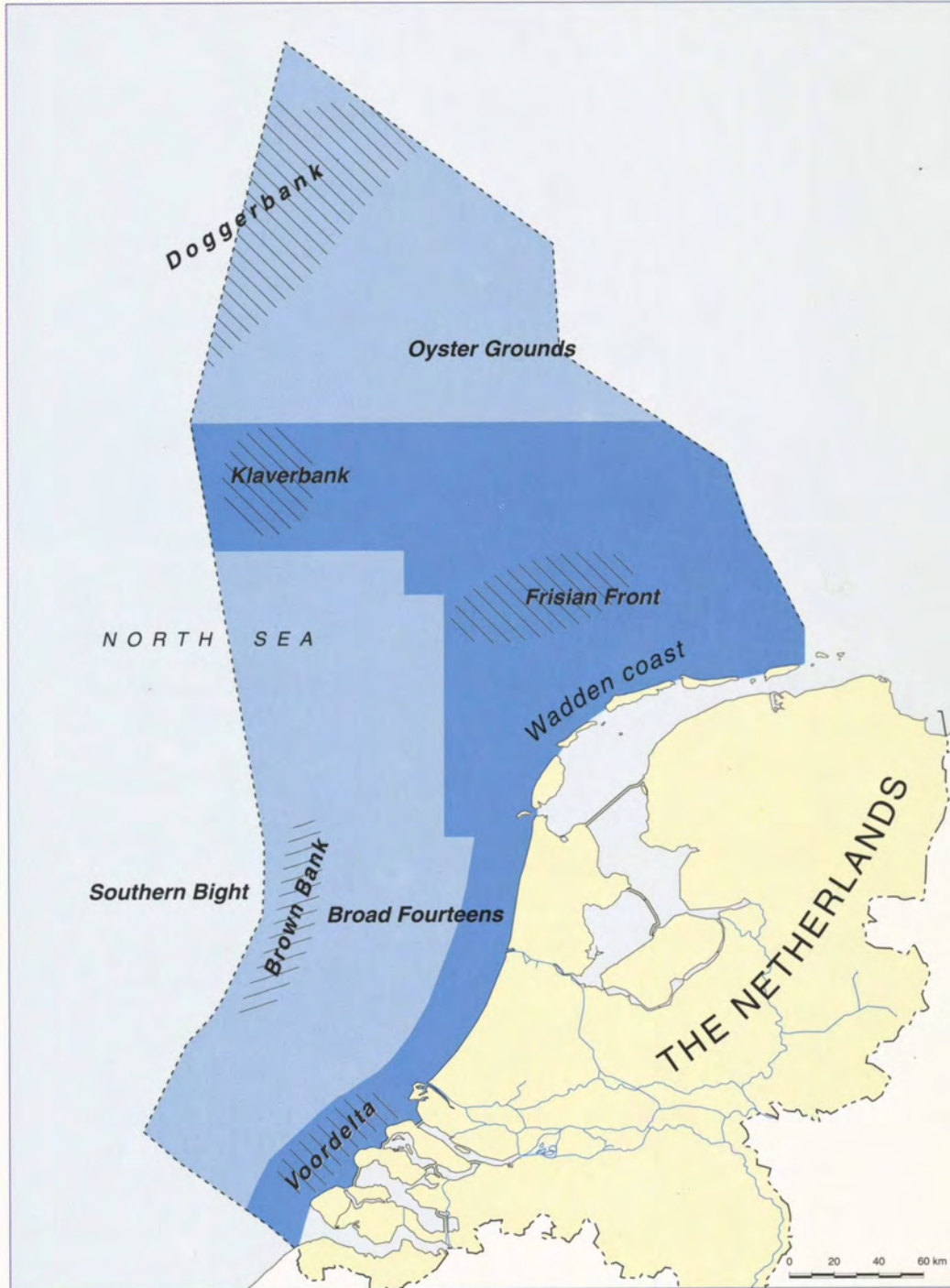
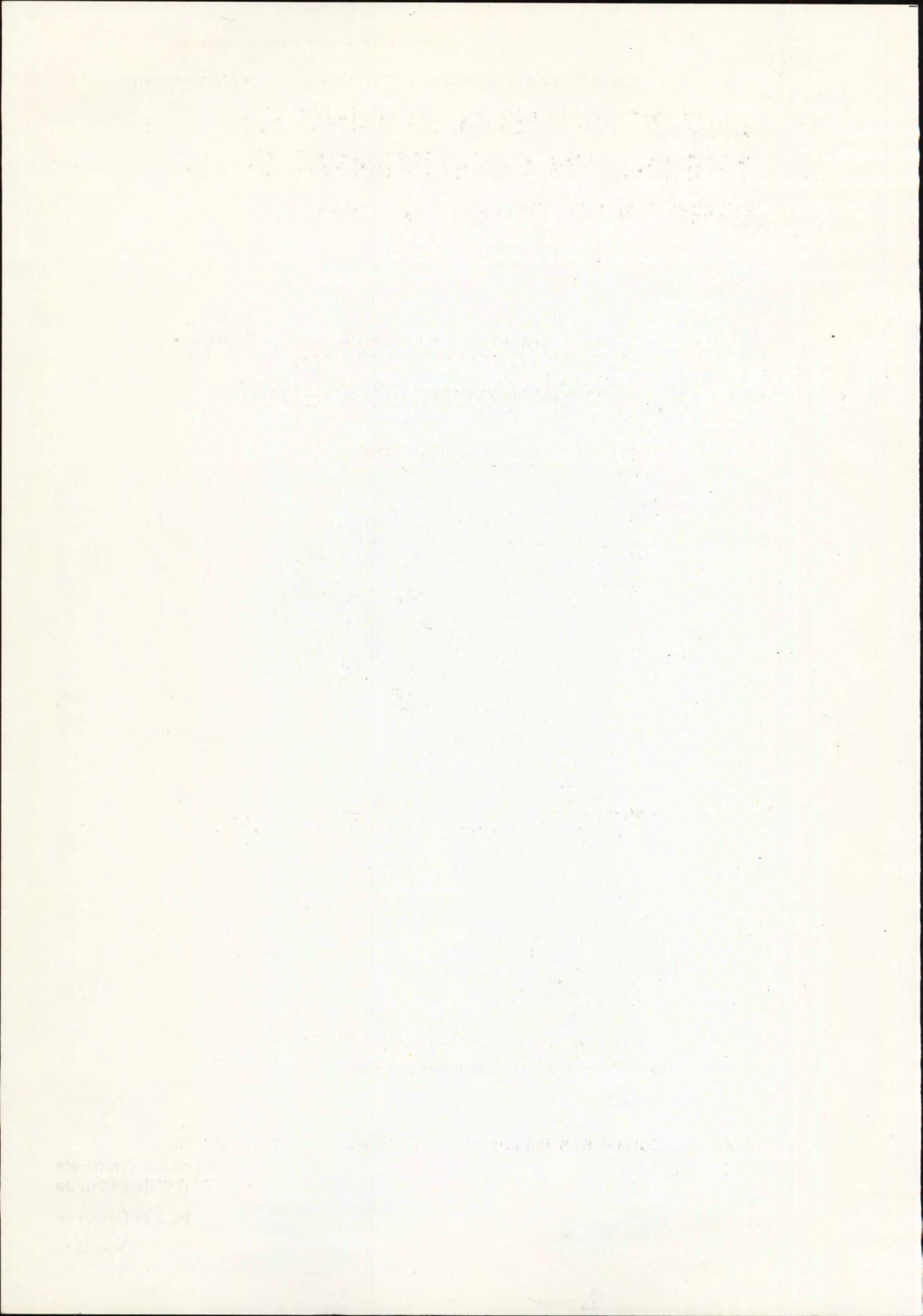


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# ENVIRONMENTAL ZONING OF THE DUTCH CONTINENTAL SHELF BASED ON ECOSYSTEM FEATURES



Reference Document of the North Sea Water System Managementplan  
1991 - 1995





26 April 1993

# Environmental Zoning of the Dutch Continental Shelf

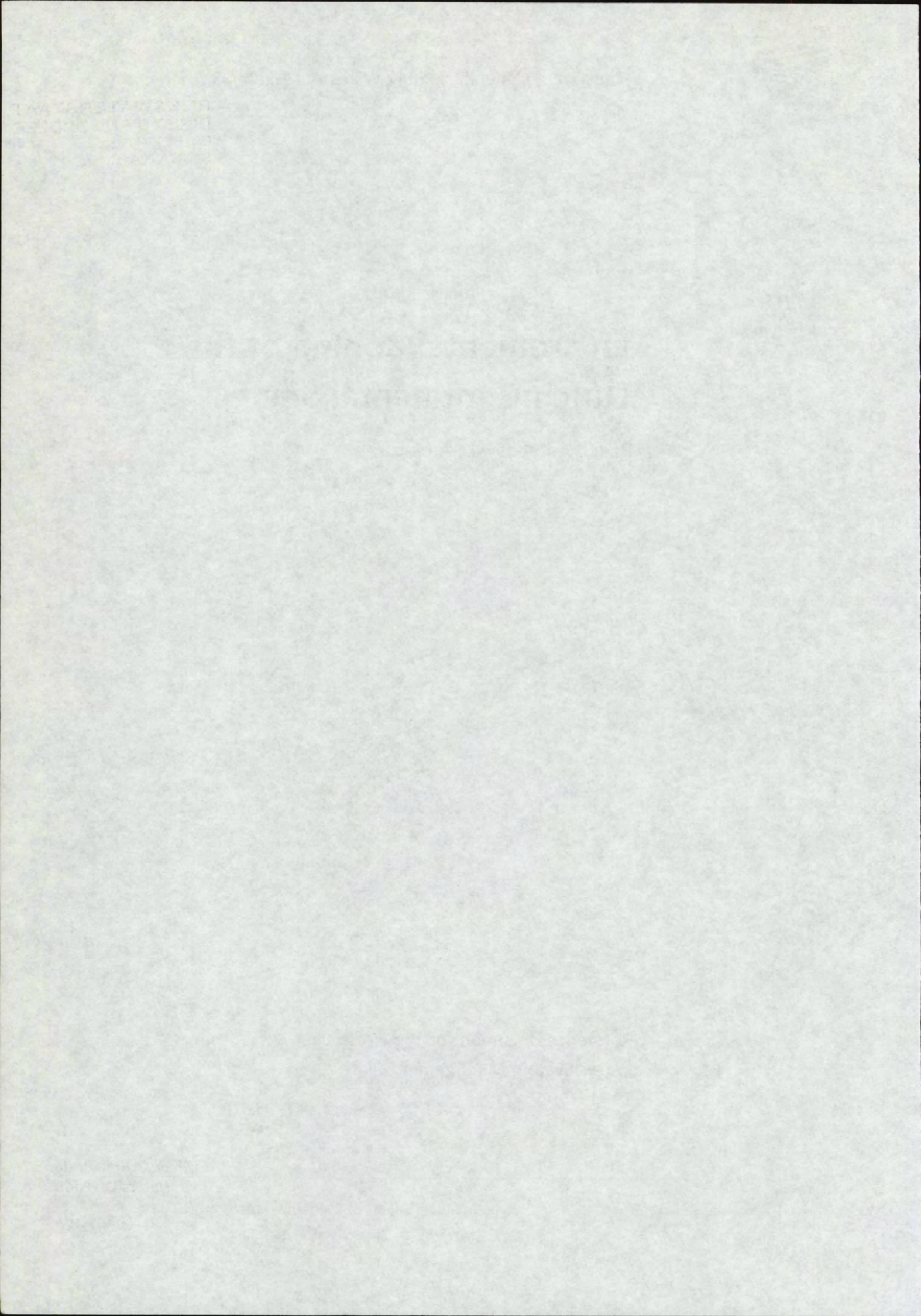
Based on ecosystem features

Reference document of the North Sea  
Water System Management Plan  
1991-1995

North Sea Directorate  
Tidal Waters Division

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## Summary

The North Sea Water System Management Plan 1991-1995 (NSWSMP) developed a strategy by which to establish the North Sea Target Situation as presented in the Third National Policy Document on Water. An essential component of this strategy, aimed at sustainable development of the North Sea ecosystem, is an area-orientated protection, conceptualised in spatial zoning. This provides realistic and differentiated environmental zoning as proposed by the North Sea Water Quality Management Plan 1986-1990. The area-orientated objective with regard to the Environmental Zone is defined in the NSWSMP as:

**An area for which, by implementation of stricter regulations for contamination and disturbance by certain human uses of the marine environment, a special level of protection is offered, in order to contribute to the protection, recovery and development of the entire North Sea ecosystem.**

This document presents, based on the results of the MILZON-project, the underlying motivation of the Environmental Zone as presented in the NSWSMP. It should be noted that the results of the Protected Area Project of the Dutch Ministry of Fisheries, Nature and Agriculture (NBP 22) have explicitly contributed to the establishment of the boundaries of the Environmental Zone.

In 1987, the MILZON-project was initiated with the objective:

**'to develop a better understanding of the spatial and temporal distribution of structural and functional North Sea ecosystem characteristics, and the influence of actual or potential human uses of the marine environment, in order to distinguish areas of different ecological value and/or vulnerability.'**

Within the project, an inventory of biotic and abiotic ecosystem characteristics was carried out. A classification of ecosystem feature priority was developed by means of a matrix coupling seven different types of human use of the marine environment to their various features. This revealed that benthic fauna is a key parameter in the discrimination between different areas when considering the regulation of human activities. The reasons for this are that specific benthic communities are restricted to particular areas, since benthos does not migrate, and that most human uses of the marine environment influence the sea-bed and its fauna to a greater or lesser degree. Sampling programs on the Dutch Continental Shelf during 1987-1989 generated additional information on the spatial distribution of benthos. Furthermore, new information (1985-1990) on the spatial distribution of plankton, fishes, seabirds, coastal birds and marine mammals has recently been collected. Abiotic system characteristics, such as data on sediment composition of the Dutch North Sea Continental Shelf (DCS) and levels of some contaminants in the benthic sediment have also been taken into account. The results of the inventory of structural ecosystem characteristics are depicted in a series of abiotic, biotic and ecological maps representing the present condition of the DCS. Earlier studies revealed that the silt content of sediment is a major prerequisite for the distribution of benthic communities. The spatial distribution of macrobenthos communities, which is based on differences in diversity, biomass and density, is the starting point for spatial zoning. Nine, ecologically more or less homogeneous, subareas could be distinguished on the DCS: the Voordelta area, the western Dutch coast, the northern Wadden coast, the Frisian Front area, the Klaver Bank, the Oystergrounds area, the Dogger Bank, the Broad Fourteens area and the Brown Bank.

The (potential) ecological values present in these areas have been defined according to the following criteria. High ecological values are accorded to areas with a characteristic benthic community or areas which possess the ability to develop such communities. Furthermore, the function of an area for fishes, seabirds, coastal birds and marine mammals is considered. For fish, the presence of spawning grounds and nursery grounds is essential for sustainable development. For birds, resting and foraging areas and migration routes are a requirement. The presence of marine mammals contributes to the ecological value of an area.

On the DCS the Voordelta, the western Dutch coast, the Wadden coast, the Frisian Front area and the Klaver Bank have the highest (potential) ecological value. Due to its high degree of pollution the western Dutch coast scores relatively low, but after biological recovery a potential development towards an ecologically valuable area is foreseen. The Oystergrounds and the Broad Fourteens also score lower but are essential to the facilitation of migration. Combining (parts of) different subareas having the highest ecological value with the principle of free migration results in the Environmental Zone.

The exact boundary of the Environmental Zone in its shallow, sandy part is the isobath of NAP-20 m for the coastal zone and the Wadden coast. The deeper part, lying adjacent to the coastal zone, contains the Frisian Front area, parts of the silty Oystergrounds and the gravel deposits of the Klaver Bank. The special protection level in this Environmental Zone provides an optimal guarantee for the sustainable development of a stable and diverse ecosystem on the DCS.

Within the Environmental Zone so-called Protected Areas, as proposed in the NBP 22-project, will be established. For these areas a specific level of protection will be applied.

## 1 Introduction

### 1.1 The background to Environmental Zoning

The Dutch North Sea Water Quality Plan (NSWQP) of 1986 expresses the intention of arriving at a realistic and differentiated zoning system with regard to ecological values and human uses. The Dutch North Sea Policy Harmonization Plan 1989-1992 (NSPHP) of 1988 gives zoning as the starting point for the development of balanced use. This document also notes that the spatial differentiation of environmental directives for various user functions is to be preferred above the creation of protected areas.

The Third Dutch National Policy Document on Water (NPD3) of 1989 describes the current ecological condition of the coastal zone of the Dutch Continental Shelf (DCS) by means of the Marine Water 'AMOEBE' (General Method for Ecological Description, ten Brink 1989a). A target situation of sustainable development in the Dutch water system is also described. Strategies by which the target situation may be achieved are derived from a number of policy avenues. Besides the accelerated reduction of pollution it is considered necessary to take action in two additional ways: the redesign of water systems and regulation of their human use.

With regard to the North Sea there indeed exists a large discrepancy between the target situation and the current condition. The target situation is described as follows in the NPD3: 'The North Sea is [to be] characterized by the coexistence of a broad variety of human activities. Evidence of eutrophication is slight. The fish population is healthy; catches of several fish species are considerably higher than at present. The extraction of oil, gas and sand is subject to satisfactory environmental and safety regulations. The clean coast attracts tourists. Seals, porpoises and dolphins are regularly seen. The bird populations are stable and diverse.' In the North Sea Water System Management Plan (NSWSMP) of 1991 the following is added: 'The North Sea is [to be] characterized by a stable and diverse benthic life.' The NSWSMP states that the target situation is to be achieved by 2010.

The current state of the North Sea can be ascertained using the AMOEBE method (ten Brink 1989a). It demonstrates that human influence on the Dutch marine water system is considerable: the reference conditions of 1930, assumed to be practically undisturbed, differs markedly from the current ( $\pm$ 1985) situation. There has been, for example, a shift in dominance from long-lived species towards short-lived species (ten Brink 1989a, 1989b).

The discrepancy between the target situation and the current condition is not the result of pollution alone and therefore this water system too calls for a number of policy avenues. Sustainable use of the North Sea would benefit not only from pollution reduction but also from the regulation of its other uses.

One way of establishing this is by means of spatial or temporal zoning. This method is considered indispensable from the management point of view. Zoning offers a way of formulating differentiated levels of protection for various separate areas or periods in time, thereby establishing a regulated, multifunctional and sustainable use. It is in line with the findings of the Brundtland Report of 1987 and the Dutch National Environmental Policy Plan of 1989. General 'protection levels' for the entire North Sea could be supplemented by a special protection level for a so-called 'environmental zone'. Within this environmental zone more specific protection measures could also be taken. The protection level itself would take the form of a package of measures (demands, licences, bans) with regard to the various user functions.

## 1.2 Objectives

In 1987 the North Sea Directorate and the Tidal Waters Division of the Department of Public Works launched the North Sea Environmental Zoning, or 'MILZON', project (Zevenboom & Leewis 1987, Leewis & Zevenboom 1989). The intention was to meet the need foreseen for a spatial or temporal zoning of the North Sea.

The objectives of the MILZON project are:

**'To obtain insights into the spatial and temporal distribution of structural and functional North Sea ecosystem features and to distinguish the areas of greatest ecological value for, and/or vulnerability to, actual or potential human uses.'**

The project has concentrated on the spatial distribution of ecosystem features in the Dutch part of the North Sea Continental Shelf (DCS).

A tentative analysis of the influence on the ecosystem of human user functions is carried out by drawing up a matrix of relationships between human use functions and ecosystem features in terms of the vulnerability of the system.

The operational objectives of this document are thus formulated as follows:

**'To show the spatial distribution of those structural ecosystem features that are indicative of the ecological value of the DCS and which have a relationship with human use; the delineation of areas (an Environmental Zone) within the DCS on the basis of these features.'**

Another project has already been formulated to succeed MILZON: MILZON-2. This project anticipates the designation of an Environmental Zone, and its objectives are:

- the specification of enforceable and effective human-use measures by which the different protection levels in the various areas can be achieved. Use will be made of the MILZON relational matrix and also of the future results of the risk-analysis project 'Referee Amoebe Mans' (RAM);
- monitoring (both spatially and in time), analysing, and presenting ecosystem features in the course of testing the efficacy of such environmental zoning and the corresponding levels of protection. The ecosystem features and the indicator species of the North Sea AMOEBE now in development will function as yardsticks in:
  - detecting trends over time;
  - establishing whether stated objectives and target levels have been attained.

In this way a contribution will be made to the foreseen evaluation of the Environmental Zone at the end of the NSWSMP-period.

## 1.3 Approach

The starting-point has been a description of the DCS in terms of its physical and chemical characteristics (Chapter 2). To a great extent these determine the type of ecosystem.

Next an inventory has been made of the biotic features of populations and communities, expressed in terms of density, diversity and biomass. The guiding principle in this description is that of trophic levels (Chapter 3). Study is made of the extent to which these structural characteristics display a spatial variation on the DCS, and in what manner certain areas might play a functional role in the survival of a given species (eg spawning grounds, nurseries, migration routes and foraging areas).

In Chapter 4 the relationship between ecosystem elements and human uses is examined and an assessment made of actual and potential effects of various human uses on the ecosystem. Criteria for the evaluation in ecological terms of various ecosystem features are also formulated. Not only is benthic life useful in describing the spatial differentiation of the ecosystem, it is also a key parameter in establishing the ecological value of the ecosystem as this component also shows a strong relationship with human uses.

Criteria have been formulated by which an ecological evaluation of various ecosystem features can be made. The distinguished areas, differentiated on the basis of their benthic fauna, are assessed in terms of ecological value and are classified.

On the basis of these data an Environmental Zone is delineated (Chapter 5).

Naturally, the areas given the highest ecological value lie within this Zone. However, account has also been taken of migratory routes and of the enforceability of the special level of protection for the Zone: the Zone is therefore a single unbroken area. Potential developments have also been considered. The areas proposed in the 'Nature Policy Plan 22' study report also lie within the Environmental Zone.



## 2 An inventory of the DCS based on its physical and chemical features

The general mapping of ecosystem features has drawn on the most recent possible field research data and literature for both the biotic and abiotic components. The authors have not attempted an exhaustive review and where possible references have been made to more comprehensive descriptions of the North Sea system.

The abiotic components considered are water masses, sediment characteristics and sediment contamination.

### 2.1 Water masses

On the basis of topography (Figure 1a) and residual flows (Figures 1b, 1c), a number of water masses can be distinguished. The DCS water masses, together with their associated sea floors, may be distinguished according to salinity, depth and origins of the water mass.

During the winter the entire DCS is vertically mixed (Figure 1b). Atlantic or Central North Sea waters are stratified in summer (Figure 1c), but Channel waters remain mixed.

Coastal waters exhibit a lower salinity than does open sea and a higher nutrient load because of river influence. The turbulence and waves generated by river currents cause increased turbidity. The water mass directly influenced by river currents is 20 km to 30 km wide.

Tidal currents and wind can generate fronts between areas of well-mixed water masses and water masses showing temperature stratification. The interfaces between the various water masses perform exchanges that can cause strong increases in the total biomass and productivity of a frontal system. This phenomenon has been observed in the Frisian Front area. In the Oystergrounds temperature stratification occurs during summer and during this period oxygen concentrations in the lower, colder layers can fall.

(Source: North Sea atlas 1992; Bergman et al., 1991; Creutzberg, 1985).

### 2.2 Sediments

#### 2.2.1 Geomorphology

Moving away from the shore, water depth increases steadily to a depth of 15 m to 20 m at a distance of 5 km to 10 km. This incline is known as the 'underwater bank'. This coastal line is interrupted by the (erstwhile) river deltas in the south (the Delta Area) and in the north (the Wadden Area). Southern areas of the DCS are characterized by 'sand waves' 1 m to 12 m high and 60 m to 600 m in length. Further away from the coast, such sandbanks may measure 50 km to 100 km in length. On the Brown Bank, old peat material arises. In the Voordelta, just seaward of the Delta Area, high current speeds have created a seascape in which small distances separate deep channels from plateaus uncovered at low tide. In this area, steep gradients describe sediment composition and the exposure of different substrates.

(Source: Van Alphen & Damoiseaux 1988, 1989; data 1976-1984; North Sea atlas 1992)

#### 2.2.2 Sediment type

In general terms, sediment grain size falls from coarse to fine as one moves from south to north. This is accompanied by an increase in depth, from < 30 m in the Southern Bight to > 40 m in the Oystergrounds, and a fall in residual current speeds. The southern North Sea is a relatively shallow transport-area; as depths increase at the Frisian Front, falling current speeds allow

sedimentation of suspended material. Here the sediment is characterized by fine sand with a large silt fraction (Figure 1d).

(Source: Montfrans et al. 1988; data to 1986; Creutzberg et al., 1984; data 1975 to 1983)

***Gravel fraction (> 2 mm)***

The only important gravel area on the Dutch Continental Shelf is to be found in mining sectors E16 and K1, the 'Klaver Bank', which forms part of the Botney Cut area (Figures 1a, 1d). Gravel concentrations vary from < 30% to ca. 80%, and the thickness of the surface layer of gravel varies from 20 cm to 130 cm. The largest gravel deposits are associated with boulder clay outcrops, but not boulder clay plateaus. The gravel is composed of quartz (11%), flint (11%), limestone (27%), crystalline rock (28%) and other components (23%). Smaller gravel deposits can be found on the Texelse Stenen and on the Brown Bank.

(Source: Laban 1982; data 1979 - 1980)

***Sand fraction (median particle size 63  $\mu\text{m}$  - 2 mm)***

In the coastal zone (up to 20 km perpendicular to the coast) the sandy fraction displays an irregular pattern. Along a north-south line, medium-fine sand (median size 250-500  $\mu\text{m}$ ) alternates with fine sand (median 125-250  $\mu\text{m}$ ). Fine and very fine sand (median 63-125  $\mu\text{m}$ ) is found near the outflows of the Nieuwe Waterweg and the North Sea Channel, and north of the islands of Ameland and Schiermonnikoog. Further out to sea in the Southern Bight the sand is coarser, with a median size of > 250  $\mu\text{m}$ . At the Frisian Front and further north the sand fraction has a median size of 125  $\mu\text{m}$ .

(Source: Montfrans et al., 1988; data < 1987)

***Silt fraction (< 63  $\mu\text{m}$ )***

The silt fraction in the coastal zone shows an irregular pattern, though within the 0-10 m depth line the silt fraction is larger than it is further away from the coast. Silt fractions of 3% to 20% occur in a band 10 km wide bordering directly on the coast and north of the islands Vlieland and Ameland.

In the southern North Sea, moving from south to north, the silt fraction increases with increasing depth. Silt fractions of less than 3% predominate in the top 10 cm of the sea-bed in the Southern Bight (Figures 1e, 1f). Sedimentation of fine material and silt occurs in the Frisian Front at about 53°30' N and north of it on the Oystergrounds. In the Frisian Front area the silt fraction is 15% to > 20%. In the Oystergrounds, fine sand is found mixed with a silt fraction of 5% to 10%.

(Source: Creutzberg et al. 1984, 1985; data 1975-1983, Groenewold & van Scheppingen 1987, 1988, 1989; van Scheppingen & Groenewold 1990; data 1987-1989)

### 2.2.3 Sediment contamination

***Heavy metals***

For the heavy metals Cd, As, Zn, Pb, Cu, Cr and Ni occurring in sediments the following broad outline may be given. Riverine inputs of heavy metals (from the Westerschelde, the Rhine delta and the Eems), whether dissolved or bonded to suspended material, cause concentrations in coastal areas much higher than the reference values given by Van Eck et al (1985). In the TiO<sub>2</sub> discharge area in particular, sediment concentrations of zinc, copper, cadmium and lead are much higher than natural background levels (Figure 2a). Concentration levels fall with increasing distance from shore.

(Source: DNZ/WL 1988, in preparation; data 1986-1989)

#### **PCBs**

PCB inputs arise from the Atlantic Ocean, the English Channel, rivers, via atmospheric deposition and from direct discharges. Relatively high concentrations of the congener PCB153, as measured in the 63  $\mu\text{m}$  fraction, have been measured in the coastal area. Peak concentrations can be found in outflows of the Rhine/Maas rivers, the coast of ter Heide (Loswal Noord) and the Vlieland coast (Figure 2b).

(Source: measurements by DNZ 1986-1989, in preparation; Klamer 1989)

#### **Oil**

Both operational and calamitous discharges of oil take place at offshore mining installations and ships (Figure 2c). Offshore mining has a by-product, oil-containing drilling cuttings (OBM), which if spilled contributes to sediment pollution. Most offshore mining installations are found in the Broad Fourteens area. Operational discharges of oil by shipping are frequently observed along the Dutch coast (Figure 2c). Background levels vary from 0.2 mg to 5 mg of oil per kg of dry sediment. Higher values are occasionally measured (up to 15 mg oil kg dry sediment<sup>-1</sup>), depending on sediment type and method of analysis.

In the immediate surroundings of drilling platforms, oil concentrations of 10 g to 100 g per kg dry sediment are found. The distance up to which raised concentrations (> 2 times background levels) can be found vary strongly. It is dependent on the amount of discharged oil (linked to the amount of oil-containing cuttings), the type of well being drilled (single or multiple), the type of cuttings (washed or unwashed), and the local bathymetry and hydrography. On the DCS this distance varies between 2 km (unwashed drill spoil) and 5 km (washed drill spoil).

Because of the slow rate of microbial breakdown of oil, and the redistribution of oil-polluted sediments, oil persists more than six years after drilling has ceased.

The total surface area of the DCS contaminated by oil is estimated as a minimum of 230 km<sup>2</sup> and a maximum of 2800 km<sup>2</sup>.

(Source: Zevenboom et al., 1992; De Jong et al., 1991; data 1985-1991)

### **2.3 Subareas of the DCS based on abiotic features**

The following subareas of the DCS can be distinguished on the basis of sediment composition and water mass (Figure 10a):

#### **1. Coastal zone**

This is composed of three areas: the Voordelta, the North and South Holland coasts, and the Wadden coast.

#### **2. Frisian Front**

In the Frisian Front Channel waters, English coastal waters and Atlantic waters mix. During the summer months a sharp gradient (front) can develop between the mixed and stratified water masses. Because of the sharp fall in current speeds towards more northern waters, sedimentation occurs continuously. Sediment in this area is characterized by high silt levels.

**3. Klaver Bank**

Gravel banks (30 m - 40 m deep) containing 30%-80% of gravel alternating with (medium coarse) sandbanks moving slowly over the gravel according to the prevailing currents.

**4. Oystergrounds**

Sedimentation area in the deepest part of the DCS (40 m - 50 m), with very fine silty sand. Supplied with Atlantic seawater, exhibiting temperature stratification during the summer. Possible reduction of oxygen concentration in the lowest layers during this stratification.

**5. Dogger Bank**

Relatively shallow bank (20 m - 30 m) consisting of fine sand, supplied with Atlantic seawater. Only a small part of the Dogger Bank lies within the DCS.

**6. Broad Fourteens**

Flat, fairly shallow area (20 m - 30 m) with fine to medium-coarse sand forming ripples, supplied with Channel water that remains vertically mixed throughout the year because of tidal movement.

**7. Brown Bank**

Uneven area, with high sandbanks containing peat remains and gravel over a fine sandy bottom in deep water (up to 40 m). Supplied with Channel water that remains vertically mixed.

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### 3 An inventory of the DCS based on its biological ecosystem features

The ecosystem is composed of different trophic levels, each with a characteristic relationship to others in the food web. The distribution of various organisms is therefore not only related to abiotic parameters such as water quality or sediment composition, but is also affected by ecosystem interactions.

Biotic characteristics have been selected from the following groups: phytoplankton, zooplankton, macro- and meiozoobenthos, fish, seabirds and marine mammals. The phytoplankton data were taken from the RWS-projects 'MONO' and 'ALGENBLOEI-EUZOUT'. For the benthic fauna data, use was made of the results of the 1987-1989 MILZON inventory research project on the occurrence and composition of benthic fauna in the western and northern DCS from the coast to the offshore areas ('MILZON-BENTHOS'). Added to this has been information derived from the large-grid North Sea Benthos Survey of 1986 (ICES) and the benthos inventory of the Voordelta area. The Voordelta project carried out intensive sampling of macro- and meiofauna of this area. Use has also been made of research on the Frisian Front. Epifauna - animals living on the seabed or in wrecks - have been included with other macrozoobenthos. Data have been drawn from the literature and from the results of projects undertaken by the Dutch Ministry of Transport, Public Works and Water Management.

As far as zooplankton and fish are concerned, use has been made of data arising from projects in progress and from the literature. The data on seabirds and marine mammals were drawn partly from MILZON.

Finally, data arising from research into the effects of offshore mining activities on the benthos (the MONMIJ project), (potential) gravel extraction on the Klaver Bank (the KLAVERBANK project) and the dumping of titanium dioxide in a designated dumping area, stopped in 1989 (the TIO<sub>2</sub> project), have been included.

#### 3.1 Phytoplankton

##### *Primary production*

Algae (phytoplankton) are the sea's primary producers, since they transform inorganic carbon into organic carbon compounds using the energy of sunlight and the nutrients N, P and Si. Production rates of 1000 mg C.m<sup>-2</sup>.h<sup>-1</sup> (at midday) can be measured during the summer months in the southern DCS (the Frisian Front area), east of England, around the Shetland Islands and north of the German Bight (Figure 3a). During the winter, maximum rates of 100 - 200 mg C m<sup>-2</sup> h<sup>-1</sup> (at midday) are found at the Dogger Bank, the Broad Fourteens area and off the southern Norwegian coast (Figure 3b). Mean annual phytoplankton production over the DCS is about 200 g C.m<sup>-2</sup>.

(Source: Sündermann & Degens, 1989 (ZISCH and TOSCH projects); Rich, 1990; data 1986-1987); NERC field report 1989.

##### *Algal blooms*

During the spring, vigorous algal growth occurs in Dutch coastal waters. Over 90% of these algae are diatoms. From April onwards these algal blooms can be dominated by the foam-forming, non-toxic microflagellate *Phaeocystis pouchetii* (70%-90%), in which algal biomass can increase by a factor of five or ten. Exceptional blooms of this algal species can be related to an excess of nitrogen and phosphorus in coastal waters. In late summer dinoflagellates, including toxic species, may again predominate in coastal areas and offshore in the northern DCS (Figure 3c).

With regard to spatial distribution, diatoms and dinoflagellates are not area-specific. *Phaeocystis pouchetii* occurs mostly in coastal areas, but blooms have also been observed offshore

(Noordwijk 70 km: Figure 3c). Between 1973 and 1985 increasing frequencies and densities of *Phaeocystis pouchetii* blooms in the 'Marsdiep' were observed. The toxic dinoflagellate *Dinophysis acuminata* occurs in the highest densities along the coast (Figure 3c). The toxic *Gyrodinium aureolum* is encountered in the more offshore areas of the DCS, but reasonably high densities have been observed at Goeree-6. Between 1979 and 1990, the seawater surface affected in spring and summer by floating algae lay between 30 and 10,000 km<sup>2</sup>, that is, a maximum of 20% of the sea area of the DCS.

(Source: Cadée & Hegeman, 1986; Kat, 1985; data 1973-1983, Rademaker, 1989, Rademaker & Koeman, 1990, Zevenboom et al. 1989, 1990; data 1988-1989)

### 3.2 Zooplankton

Calanoid copepods form the most important group of herbivorous plankton, making up 80% or more of total zooplankton biomass. In the relatively shallow Southern Bight area of the North Sea, four species of copepods predominate: *Temora longicornis*, *Acartia clausi*, *Centropages haematus* and *Pseudocalanus elongatus*. Copepods graze on the phytoplanktonic population. The growth cycle takes place between April and October. The biomass is greatest in summer, the lowest numbers and biomass (10 to 20 times smaller) occurring in winter (Figures 4a, 4b). An analysis of 13 field trips undertaken in the southern North Sea during 1986-1987 revealed that the summer period was characterized by strong fluctuations in *Temora longicornis* density and biomass. Competition for food would seem to play a regulating role.

(Source: Sündermann & Degens, 1989 (ZISCH and TOSCH projects); data 1986-1987; Daan 1989; data 1984-1985, North Sea Project 1989; data 1988-1989 (interim report), Baars et al. 1990; data 1989).

### 3.3 Zoobenthos

#### 3.3.1 Macrozoobenthos

Macrozoobenthos, attached to sediments, is confined to a limited area and has a life cycle often lasting more than a year, and for these reasons its spatial distribution and population trends in time may be seen as a mirror reflecting all past events. Benthos is characterized by a degree of stability which has its origins in an interconnection between fauna composition and the abiotic environment. The degree of stability is determined, amongst other factors, by the particular developmental stage and the community structure. Communities forming the earliest stages of a succession consist of opportunistic species with short life cycles, rapid reproduction rates and small body size. More stable communities are characterized by large, slow-growing species with slow reproduction rates.

In 1986, the large-grid ICES Synoptic Benthic Mapping project made an inventory of the entire North Sea. Data on macrofauna density and species composition were analyzed with the aid of TWINSPLAN analysis, in which stations were grouped in clusters according to similarities in species density. In the entire North Sea, eight different benthic community types were distinguished, of which five are represented on the DCS (Figure 5a).

	Southern North Sea			Central North Sea	
	Broad Fourteens		Oystergrounds	Dogger Bank	north of Dogger Bank
depth	< 30 m		30 - 50 m	50 - 70 m	> 70 m
cluster	la	lb	IIa	IIb	IIIa
sediment	coarse sand	coarse sand	silt-rich fine sand	fine sand	fine sand
number of species	27 ± 8	29 ± 9	44 ± 9	43 ± 10	54 ± 16
individuals.m <sup>-2</sup>	805 ± 728	873 ± 623	1995 ± 1499	1093 ± 686	1224 ± 1233
biomass g ADW.m <sup>-2</sup>	9.5 ± 9.9	4.3 ± 4.3	12.6 ± 7.5	7.6 ± 6.5	7.4 ± 7.0
Key species	<i>Nephtys spec.</i> <i>Echinocardium cordatum</i>	<i>Aonides</i> <i>Phoxocephalus</i> <i>Pisone</i>	<i>Nucula</i> <i>Callianassa</i> <i>Cheatopterus</i> <i>Amphiura</i>	<i>Ophelia</i> <i>Nephtys</i>	-

Table 1: Diagram of the TWINSPAN classification (Species density data), with abiotic and biotic parameters (mean and standard deviation) of the various communities encountered on the DCS. The species most typical of the community is also given. (Künitzer et al., 1992; Duineveld et al., 1992).

The distribution of these communities is strongly associated with sediment composition and water depth. Table 1 shows the characteristics of the communities relevant for the DCS. The clusters la and lb are found in the coarse sand of the Southern Bight. Species typical of this area include *Nephtys* and *Echinocardium*. These clusters are characterized by low biomass. In the silt-rich fine sand of the Oystergrounds (cluster IIa) a community is found characterized by, amongst others, *Nucula* and *Callianassa*. Average biomass is 13 g ADW.m<sup>-2</sup>. Echinoderms predominate the macrofauna biomass, particularly *Echinocardium cordatum*. It would also appear that as one moves northwards from the Southern Bight species diversity gradually increases.

Detailed information on the composition of coastal benthos, the Voordelta area and the Frisian Front has been taken from the MILZON programme, the Voordelta Study and the Frisian Front Project, respectively.

Where water depth increases with northward movement, between the Southern Bight and the Oystergrounds, a transition area is encountered. This area, commonly known as the Frisian Front, is characterized by very silty sediment and continuous sedimentation of material as the result of hydrographic conditions. During summer months, this is often the site of a boundary between fully mixed water and stratified water masses. Nutrients are exchanged between these masses, leading to an increase in primary production. The Frisian Front area can be distinguished from surrounding areas by large numbers of *Amphiura filiformis* and an extremely high biomass of over 30 g ADW.m<sup>-2</sup>. The coastal zone and the Voordelta are also characterized by high biomass and densities; however, species diversity is low compared with the DCS offshore areas. A TWINSPAN cluster-analysis was carried out on the results of the MILZON programme. Macrozoobenthos densities and species composition produced four separate zones (Figure 5b). A number of species can be specified as characteristic for each of these zones.

	zone 1 coast	zone 2 transitional zone	zone 3 offshore West	zone 4 offshore North
Species	21	14	13	23
Density (N.m <sup>-2</sup> )	4232	1171	826	3300
Biomass (g ADW.m <sup>-2</sup> )	53	13	7	18

Table 2: Average number of species (number.m<sup>-2</sup>), density (N.m<sup>-2</sup>) and biomass (g ADW.m<sup>-2</sup>) for the principal taxa and the entire macrofauna in the four clusters distinguished by the MILZON study, based on cluster analysis of species density (after van Schepplingen and Groenewold, 1990).

Up to 5 km from the shore, the benthic community is dominated by polychaetes (*Nephtys*) and bivalves (*Spisula subtruncata*, *Macoma baltica*, *Tellina fabula*), with a mean biomass of 53 g ADW.m<sup>-2</sup>. Biomass and density gradually fall to 6.6 g ADW.m<sup>-2</sup> in a westward direction resulting in a western offshore zone dominated by echinoderms (*Echinocardium cordatum*) and polychaetes. Off the Wadden coast, biomass falls to 18 g ADW.m<sup>-2</sup> (*Spiophanes bombyx*, *Magelona papillicornis*, *Echinocardium cordatum*) (Table 2).

As far as division into functional groups (the way in which food is gathered) is concerned, most coastal zone animals are 'suspension-eaters' (they filter their food from the water). In the western zone offshore of North and South Holland 'sediment-eaters' predominate, those that take their food from the sediment or its surface.

The Voordelta is a high-energy, dynamic area with both deep channels and plateaus uncovered at low tide. This has a clear effect on sediment composition and thereby on benthic fauna. Spatial variation in biomass and benthos density is strongly correlated with sediment characteristics and bathymetry. Mean biomass is 20 g ADW.m<sup>-2</sup>, but this can rise in silty outer deltas to 60 g ADW.m<sup>-2</sup>. 60% of total biomass is made up of four species, namely *Spisula subtruncata* (mollusca), *Lanice conchilega* (polychaeta), *Echinocardium cordatum* (echinodermata) and sea anemones. Mollusc biomass falls from north to south, with the highest values being found in outer deltas of the Haringvliet. Here, 75% of biomass is made up of the cockle *Cerastoderma edule*. Sediment-eaters predominate in terms of density, while suspension-eaters represent the most important group in terms of biomass.

	stratum 1	stratum 2	stratum 3	stratum 4	stratum 5
Density (N.m <sup>-2</sup> )	400	2000	14000	5000	1100
Biomass (g AFDW.m <sup>-2</sup> )	2	13	40	40	20

Table 3: Average number of species (number.m<sup>-2</sup>), density (N.m<sup>-2</sup>) and biomass (g ADW.m<sup>-2</sup>) of macrofauna in the five clusters distinguished by the VOORDELTA study based on TWINSPAN cluster analysis of species density. Stratum 1 corresponds to sandbanks occasionally left dry at low tide, strata 2 - 4 correspond to transitional areas towards deeper channels, and stratum 5 corresponds with an area close to the Slufterdam and Haringvliet (after Craeymeersch et al., 1990).

Cluster analysis based on species composition and species density produces five clusters corresponding to the transition between intertidal areas and deeper channels (Table 3). The Klaver Bank is characterized by a shifting pattern of gravel- and sandbanks, whereby sand is transported over the 0.5 m to 1.3 m thick gravel layer during heavy storms. For this reason a community has evolved showing characteristics of both 'sand communities' (as found elsewhere on the DCS) and 'hard-substrate communities' found, for example, on wrecks. The gravel areas typically show large numbers of molluscs at least ten years old: the rayed artemis (*Dosinia exolata*), the island cyprena (*Arctica islandica*) and echinoderms. Polychaetes predominate in density terms. Biomass is comparable to that of the surrounding sandy areas, 6 g - 23 g ADW m<sup>-2</sup>. The presence of specific epifauna species (sea fingers and ascidians) raises species diversity: 30 to 60 species per station. The presence of bare stone is a condition for herring egg deposition.

(Source: Craeymeersch et al., 1990; data 1984-1986; Creutzberg et al., 1984; data to 1983; Groenewold & van Scheppingen 1990; data 1989; Künitzer et al., 1992, data 1986; van Moorsel & Waardenburg 1990; data 1988-1989; van Scheppingen & Groenewold, 1990; data 1988-1989; Sips & Waardenburg 1989).

### 3.3.2 Meiozoobenthos

The meiozoobenthos constitutes only 4% of total benthic fauna, but its turnover speed is such that it is responsible for about one-third of total benthic production. Epibenthic meiofauna forms an important food source for macrobenthos and young flatfish, especially in shallow sub-littoral and intertidal areas. Factors determining the structure of North Sea meiofauna communities include water depth, sediment type and latitude.

The large-grid ICES Synoptic Benthic Mapping project of 1986 also made an inventory of meiobenthos which included the southern North Sea (Table 4). Nematodes predominate, with densities between 60 to 4170 individuals per 10 cm<sup>2</sup>. Copepod densities equal this figure only in the Southern Bight (Broad Fourteens) area. There, the nematode/copepod ratio is lowest, 16 to 25, the ratio rising to 250 as one moves north. Five large and two small meiofauna communities may be distinguished on the basis of copepod species composition (Figure 5c).

TWIN A corresponds to the Southern Bight of the North Sea. Here, predominantly interstitial copepod species and a number of taxa typical of coarse-sandy sediments occur in large densities. TWIN B includes the Dutch coastal zone (Figure 5c). The TWIN groups are classified according to decreasing median grain size and increasing proportion of silt/clay.

	cluster 1 TWIN A	cluster 2 TWIN B	cluster 3 TWIN C	cluster 5 TWIN D	cluster 6 TWIN E
Species	29	11	8	9	10
Density	192	30	25	19	51
Individual ADW	0.5	0.8	3.0	1.6	3.2
Biomass	86	29	66	32	159

Table 4: Average number of species, density (N. 10 cm<sup>-2</sup>), individual weight ( $\mu$ g ADW/individual) and biomass ( $\mu$ g ADW. 10 cm<sup>-2</sup>) for the 5 discrete TWINSPAN groups of copepod fauna occurring on the DCS (Huys et al., 1992).

	cluster 1	cluster 2	cluster 3	cluster 4
Taxa	5.1	9.7	8.6	6.2
Density (N.m <sup>-2</sup> )				
Nematoda	2532	1402	604	966
Copepoda	14	191	126	22
Gastrotricha	11	54	143	60
Turbellaria	6	30	37	25
Total	2576	1762	944	1084
Nematode/copepod ratio	458	19	15	101

Tabel 5: Average number of taxa (number.m<sup>-2</sup>), density (N.m<sup>-2</sup>) of the four most important meiobenthos taxa and the nematode/copepod ratio in the four clusters distinguished by the MILZON study, based on analysis of the density of meiofauna taxa (van Scheppingen and Groenewold, 1990).

The aim of the intensive monitoring study carried out in 1988 and 1989 (MILZON) had been the description of the current status of benthic communities. With regard to meiobenthos, the results showed that the most important taxa (Nematoda, Copepoda, Gastrotricha and Turbellaria) all occurred in the highest densities in the coastal zone (0 - 12 km). Four clusters may be differentiated on the basis of the densities of these taxa (Table 5). The coastal zone above the Wadden islands is dominated by nematodes and diversity is lower. A weakly significant relationship between total density and sediment characteristics is found. Median grain size is negatively correlated with nematode density and positively correlated with copepod density. The Voordelta is a heterogenous area with regard to sediment type and water depth, with interstitial copepods predominating.

	stratum 1 deep	stratum 2 deep	stratum 3 shallow	stratum 4 shallow
Taxa	6	7	9	6
Density (N.m <sup>-2</sup> )				
Nematoda	2626	2564	286	237
Copepoda	19	25	325	126
Gastrotricha	7	2	70	31
Turbellaria	54	42	100	84
Total	2714	2998	801	493
Nematode/copepod ratio	137	103	0.9	1.9
Biomass (0 - 10 cm) g ADW.m <sup>-2</sup>				
Nematoda	747	482	80	90

Tabel 6: Average number of taxa (number.m<sup>-2</sup>), density (N.m<sup>-2</sup>) of the four most important meiobenthos taxa, the total meiobenthos density and the nematode/copepod ratio of the four clusters differentiated in the Voordelta study, based on TWINSPLAN analysis of density per taxon. Average nematode biomass per stratum ( $\mu$ g ADW.10 cm<sup>2</sup>) is also given (Craeymeersch et al. 1990).

The nematode community is made up of 242 species belonging to 90 genera and 29 families. TWINSpan analysis based on species composition distinguishes between deep and shallow stations (Table 6). Shallow stations typically display high diversity, low density and biomass (20 - 100  $\mu\text{g ADW } 10 \text{ cm}^{-2}$ ). Deeper stations, up to 15 m deep, are less diverse, with higher densities and biomasses (100 - 2050  $\mu\text{g ADW } 10 \text{ cm}^{-2}$ ). The nematode/copepod ratio varies between 0.9 and 137. In the  $\text{TiO}_2$  discharge area off the coast of the Hook of Holland, discharges of titanium dioxide appear to have influenced the meiobenthos community. Vertical distribution of meiobenthos within the dumping area differs from that outside it. Within the dumping area, the highest concentrations of meiofauna are found spread over the upper 5 cm and the densities of Nematoda, Copepoda, Gastrotricha and Turbellaria in the upper 10 cm is significantly lower than in the reference area where meiobenthos is generally found in the upper 2 cm.

Diversity in the dumping area is lower than outside it and nematodes of the type 'non-selective deposit-feeder' predominate.

(Source: Craeymeersch et al., 1990; data 1984-1986; Groenewold & van Scheppingen 1990; data 1989; Huys et al. 1992; data 1986; van Scheppingen & Groenewold, 1990; data 1988-1989; Smol et al. 1989a, 1989b; data 1986-1988).

### 3.3.3 DCS subareas by benthic fauna

The DCS may be divided into the following subareas on the basis of current understanding of its benthic life (Figure 10a):

**Voordelta:** The area lying off the coast of the Zeeland and South Holland delta, characterized by strong dynamics and steep gradients between the various communities. Species that might be seen as typical of the open sea and species typical of estuarine areas can both be found.

**Dutch coast:** Large biomass near to the coast, especially shellfish; decreasing biomass levels towards the west, with the heart urchin (*Echinocardium*) an important species.

**Wadden coast:** Just as in the Dutch coast, a large shellfish biomass; moving north, only a small decrease in biomass. Important species include small polychaetes such as *Magelona papillicornis* and *Spiophanes bombyx*.

**Frisian front:** Close to the 53°40' N line of latitude, characterized by silty sediment and an extremely rich benthic fauna dominated by the echinoderm *Amphiura filiformis*.

**Klaver Bank:** Characterized by many large molluscs, polychaetes and epifauna species such as sea finger and brittle-star.

**Oystergrounds:** Between the Frisian Front area and the Dogger Bank. The fauna comprises predominantly echinoderms (heart urchin and brittle-star) and the parchment worm (*Cheatopterus variopedatus*).

**Dogger Bank:** Fine sand whose fauna is made up chiefly of polychaetes (*Nephtys longosetosa* and *Ophelia borealis*).

The distinction between the Oystergrounds and the Dogger Bank accords with the divisions arising from the ICES Synoptic Mapping project. A more detailed picture can be drawn from the

results of small-scale spatial inventories carried out more recently ((MILZON-BENTHOS 1988/89, MILZON-Klaverbank 1988/89, Frisian Front project).

### 3.4 Fish

#### *Fish spawning and nursery areas*

A schematic representation of areas functioning as fish nurseries and areas used for spawning by smelt, plaice, herring and cod is given in Figure 6a. The majority of the DCS is important as a (potential) spawning area. The exact areas cannot be given, as during the development from egg into juvenile fish via a larval stage transport and movement occurs from southwest to northeast. The entire coastal zone functions as a nursery in which young fish can grow. The Wadden Sea is the most important area, especially for the commercially interesting species of sole, plaice and herring. The occurrence of huge numbers of fish, including young fish, in the Frisian Front indicates the importance of this area.

Between 1935 and 1985, catches of thornback ray fell dramatically. The numbers of their egg capsules washed up onto the beach has also fallen dramatically. It is difficult to establish the cause for this reduction in numbers with any certainty, but it is possible that intensive beam trawling has played a role. The ray, which reaches sexual maturity only in its seventh year and produces only a small number of offspring, is sensitive to overfishing. Its practice of anchoring the egg capsules to sea grass, seaweeds or stones in shallow coastal waters and estuaria makes their chances of survival strongly dependent on beam trawl fishing.

(Source: Bosschieter 1981; data ca. 1960-1976; Bergman, in: Ecologisch profiel Vissen DGW, 1989)

#### *Commercial fish*

The fish fauna of the entire North Sea can be divided, based on the distribution of the 50 most common fish species, into three general groups (Figure 6b). The DCS is characterized by the south-eastern fish fauna of these three. During summer there are typically large numbers of flatfish and herring, intermediate numbers of codfish and shark, and a low ray biomass. Limited deviation from this pattern may be observed in winter. With respect to physical conditions such as depth, temperature and salinity, younger year-classes (0-, 1- and 2-year-olds) may exhibit a distribution different from that of older year-classes. The plaice, *Pleuronectes platessa*, is one of the commercially interesting fish studied in the Young Fish Survey programme. The highest densities are found in late summer and in winter (Figure 6c). Plaice, like sole, is generally fished by means of a beam trawl. More than 80 fish per hour can be caught in the Frisian Front area. The highest catch rates for dab (*Limanda limanda*) are much larger still: more than 1000 fish per hour are caught. More data are being collected on fish diseases and contaminant levels within the framework of an international monitoring research project (the Joint Monitoring Group, North Sea Task Force).

(Source: Welleman 1989; data 1985-1987; Daan et al. 1990; Bergman et al. 1991; data 1960-1985; Bergman et al., 1991)

### 3.5 Seabirds

Four groups of seabirds may be distinguished on the basis of foraging behaviour and distribution. The fish-eaters are divided into three groups: birds of the open sea (e.g. razorbills, gullies, fulmars), birds with a seaward distribution (e.g. great black-backed gulls, kittiwakes and skuas) and birds limited to coastal areas (e.g. herring gulls, black-headed gulls). Large numbers of birds (except for razorbills and gullies) are attracted to fishing vessels, eating the bycatch

and fish entrails thrown overboard. There is also a coastal group of birds feeding principally on shellfish (e.g. seaducks and terns).

Seabird densities on the DCS are highest after the breeding season. Breeding birds, their young, and seabirds migrating northwards in order to breed may all be found, with large numbers of birds occurring in certain localities.

The most important overwintering areas for auks and seaducks are in the southern DCS, including coastal waters.

There are three times as many fish-eating seabirds in the Frisian Front area during and after the breeding season, compared with the Broad Fourteens and the Oystergrounds (Figure 7). In all likelihood the reason for this is increased fish numbers. Guillemot numbers are high in autumn and winter (ca. 10,000 individuals), followed by fulmar, great black-backed gull and kittiwakes.

North of the Frisian Front, fulmar, great black-backed gulls and kittiwakes are present all year round. Around the Dogger Bank, summer sees large numbers of guillemots (parents and young) and gannets, followed later in the year by herring gulls and auks. The Brown Bank is an important overwintering area for guillemot, razorbill and fulmar.

The coast is an internationally important bird area: some years more than 1% of the global populations of the red-throated diver and the great crested grebe, and over 1% of the European populations of common scoter and lesser black-backed gull can be found. Coast-breeding gulls (great and lesser black-backed gulls, herring gulls) and terns also forage here.

(Source: Leopold 1991; Baptist & Leopold 1990, 1991 (draft); data 1986-1989)

### 3.6 Marine mammals

#### *Seals*

The disastrous collapse of seal populations (the grey seal *Phoca vitulina* and the common seal *Halichoerus grypus*) in Dutch coastal waters between 1950 and the early 1970s was the consequence of a combination of unlimited hunting and the effects of pollution. PCB pollution, in particular, is still disrupting seal reproduction. Nevertheless, numbers have stabilized since 1973 and have clearly risen since 1980. The Wadden Sea is an important seal nursery, habitat and foraging area. In 1983 the international seal population of the North sea, the Baltic Sea and the Irish Sea was infected with the *Canine Distemper Virus* or a related variant. At least 17,000 seals died and it is expected that it will be 9 - 12 years before the population returns to 1988 levels.

(Source: Reijnders 1984, 1988, Osterhaus & Reijnders 1989; data 1977-1989)

#### *Cetaceans*

Four types of cetacean may be found on the DCS: the porpoise *Phocoena phocoena*, the white-beaked dolphin *Lagenorhynchus albirostris*, the white-sided dolphin *Lagenorhynchus acutus* and the bottlenose dolphin *Tursiops truncatus*.

Observations from ships and planes indicate that most marine mammals are dolphins (Figure 8). The relative turbidity of coastal waters hampers its aerial observation, so the reliable determination of distribution patterns requires combined sea and air observations. The greatest densities of white-beaked dolphin are found in the western DCS north of 53° N. They stay a considerable distance from the coast. After June they move westwards towards the English coast and reside west and north of the Dogger Bank (Figure 8a). The white-sided dolphin is often seen together with the white-beaked dolphin in the north-western DCS.

During the 1960s the porpoise population collapsed and was no longer seen from the Dutch coast. However, since sea-based observations started in 1985, porpoise have once again been

regularly seen on the DCS. In coastal areas especially, after a complete absence, numbers have been rising again over the last few years (Figure 8b). The greatest numbers of porpoise on the entire DCS are to be found at the Frisian Front.

As numbers vary from season to season it is supposed that migration to the English coast takes place. Other cetaceans (bottlenose dolphin, long-finned pilot whale, minke whale, common dolphin and Northern bottlenose whale) are far less common.

(Source: Baptist & Leopold 1990, Baptist 1990, Baptist et al. 1990; data 1984-1990; Ecologisch profiel, 1988. DGW: Zoogdieren; notitie DGW.GWAO 1991)

### 3.7 Overview of characteristic biological features

Table 7 gives an overview of the scores achieved by the various areas in the respective ecosystem parameters.

Primary production is highest in the coastal zone and around the Frisian Front. Macrofauna biomass is above 15 g ADW.m<sup>-2</sup> in the Voordelta, the coastal zone, the Frisian Front and the Klaver Bank. Only large-scale gradients can be observed in zooplankton distribution. The entire coastal zone serves as a fish nursery. Most of the offshore area functions as a spawning ground. The coastal zone, including the Wadden and Voordelta coasts, fulfils an important role as resting, foraging and migrating area for birds. Seals are currently encountered only in the Wadden Sea, but have prospects in the Delta area. Present observations of cetaceans are generally limited to the Frisian Front and the offshore area.

	Phyto-plankton		Macrofauna			Fish		Birds			Marine mammals	
	a	b	c	d	e	f	g	h	i	j	k	l
Voordelta	-	-	-	+	+	-	+	+	+	+	♂	-
South and North Holland coasts	+	-	-	+	+	-	+	+	+	+	-	♂
Wadden coast	+	-	-	+	+	-	+	+	+	+	+	+
Frisian Front	+	-	+	+	+	+	-	-	+	+	-	+
Klaver Bank	-	-	+	+	+	+	-	-	+	-	-	+
Oystergrounds	-	-	+	+	+	+	-	-	+	-	-	+
Dogger Bank	-	+	+	-	+	+	-	-	+	-	-	+
Broad Fourteens	-	+	-	-	-	+	-	-	-	+	-	+

Table 7: Overview of the ecological parameters for the various DCS areas.

#### Key to symbols

a	primary production in summer (0 - 20 m)	- < 400 mgC.m <sup>-2</sup> .h <sup>-1</sup> < +
b	primary production in winter (0 - 20 m)	- < 100 mgC.m <sup>-2</sup> .h <sup>-1</sup> < +
c	number of species	- < 40 species < +
d	biomass	- < 15 g AFDW.m <sup>-2</sup> < +
e	density	- < 2000 individuals.m <sup>-2</sup> < +
f	spawning area	- not present; + present
g	nursery	- not present; + present
h	seabirds: shellfish-eaters	- < 2 individuals.km <sup>-2</sup> < +
i	seabirds: fish-eaters (catching live fish)	- < 2 individuals.km <sup>-2</sup> < +
j	seabirds: fish-eaters (profiting from fishermen)	- < 2 individuals.km <sup>-2</sup> < +
k	presence of seals	- not present; + present; ♂ potentially present
l	presence of cetaceans	- not present; + present; ♂ potentially present

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#### **4 The effects of human activities on the ecosystem**

##### **4.1 Effect matrices: the relationships between human activities, the nature of the disturbance and the ecosystem**

The human uses to which the North Sea is put can be inconsistent with its sustainable development. To inventorize this issue, two matrices can be drawn up: a matrix relating human uses to the nature and intensity of the disturbance caused by the activity (Appendix 1) and a matrix relating human uses of a given kind of disturbance to the possible effects on various ecosystem features (Appendix 2).

The activities distinguished are: fishing, offshore mining, sand and gravel extraction, inputs of substances, military activities, shipping and recreation. The influence of each of these activities on the system has been tentatively assessed. In Appendix 1 the disturbances have been categorized according to their nature: pollution via inorganic and organic micropollutants, nutrient inputs, mechanical disturbance of the system, acoustic disturbance and the removal of organisms from the system. Independently of the nature of the disturbance, the potential degree to which the activity can influence the system may be estimated. A distinction has been made between direct and indirect influence, and also between weak (local and/or infrequent) influence and strong (widespread and/or frequent) influence. Appendix 1 shows that the fishing industry is the one human use having the potential to strongly and directly disturb - through mechanical disturbance - the ecosystem. Offshore mining and riverine inputs of pollutant materials also form potentially strong and direct disturbances.

In Appendix 2 the potential effect of different human uses is related to different ecosystem trophic levels. We may speak of a 'potential effect' when a link between a human activity and a biotic component can be posited, but the actual effect is seen only after actual exposure. As is the case in Appendix 1, Appendix 2 is hindered by a lack of systematic research into dose-effect relationships. For this reason the table makes some assumptions: large-scale and/or frequent activities result in strong effects, local and/or infrequent activities result in weaker effects. Possible indirect effects have also been considered.

Appendix 2 shows that the integrated potential effect on each of the biotic system components is the result of a (considered) summation of the potential effects of each of the activities distinguished. Riverine (nutrient) inputs have potential effects on all parts of the ecosystem, from phytoplankton to marine mammals. The mechanical disturbance and removal of biomass caused by the fishing industry have possible effects on benthos, fish and marine mammals. Recreation is considered as having a weak (indirect) effect on birds and mammals. Appendix 2 demonstrates that benthic communities suffer the greatest potential pressures. The conclusion is drawn that benthic communities may be employed as a key parameter in the indication of effects on the biotic system. The map of benthic organism communities (see 3.3.3) may therefore serve as basis for the assessment of the relative ecological value of the subareas under consideration.

##### **4.2 Known effects of human activities on benthos**

Disturbances of the environment are expressed as alterations in the conformation of the benthic community. These effects are partly the subject of tentative guesses and partly the subject of ongoing research. Up to now, research has concentrated on the effects of two activities: oil pollution and fishing.

The effects of oil on macrobenthos are twofold: physical (suffocation) and chemical. Oil-containing drilling cuttings (OBM) cause long-lasting measurable effects on benthic fauna. The No Observed Effect Concentration (NOEC) of oil attached to oil-containing drilling mud on macrobenthos lies in the order of 10 mg oil per kg dry sediment.

A number of effects may be observed under increasing concentrations, varying from reductions in the densities of more sensitive species, rising numbers of opportunistic species, increased mortality in more sensitive species, and eventually, at concentrations over 100 mg oil kg dry sediment<sup>-1</sup>, reduced density and biomass in the entire macrobenthos community. It appears that the Oystergrounds comprise considerably more OBM-sensitive species than do other areas of the North Sea (Figure 9). It must however be noted that reasons for the presence or absence of a species cannot be deduced from its distribution alone; the causes for this may be several.

Beam trawl fishing, too, may well affect benthic fauna. Starfish, heart urchins and crabs form a large part of the catch and are thrown, partly dead, overboard. If the island cyprena *Arctica islandica*, a large bivalve, is caught, it is extremely unlikely to survive. The same applies to the heart urchin *Echinocardium cordatum*.

The sensitivity of a community is also determined by the length of time it needs to recover after a disturbance. Physical disruption and instability lead to changes in abundance, species composition, size-class division and productivity. Communities made up of larger, slow-growing organisms are - thanks to their longer generation times - less able to withstand disturbance. Continuous disturbance leads to lowered species diversity and to communities composed of smaller, opportunistic species.

The recovery time needed by a given benthic community after disturbance and the (in)stability and sensitivity to disturbance of given species or communities has not been considered in this ecological evaluation. The potential vulnerability of a given benthic community, independently of its ecological value, is determined partly by the presence of species sensitive to OBM and/or to fishing activities. In considering measures to be taken, account should be taken of this vulnerability.

(Source: Bergman and Duineveld, 1990; Bergman et al., 1990; Bergman et al., 1991; Daan et al., 1990, 1991; data 1985-1990; Witbaard, 1989).

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## 5 Environmental Zoning of the DCS

### 5.1 Criteria for the evaluation of ecosystem features

On the basis of the spatial differentiations that have so far been established we can now define areas of greater or lesser ecological value according to specific criteria. Structural and functional features of the ecosystem have been made central to the development of ecological evaluation criteria. Each criterion has been made as unequivocally quantifiable as possible.

As far as possible criteria have been chosen which correspond to the objectives set out in the Third National Policy Document on Water. Following the stated aims of stability and diversity, great importance has been attached to the objective of an ecosystem functioning in equilibrium, expressed by the presence of stable and diverse benthic communities, marine mammals, stable and diverse bird populations and healthy, highly productive fish populations.

The presence of the following features in various factors leads to a high ecological value:

#### **Abiotic factors**

##### *Sediment*

Not all sediment types occur in similar amounts on the DCS. Certain types having a limited presence are accorded a higher value. For example, the area of sea-bed comprising gravel deposits is rather small. The fauna associated with this substrate, which represents a separate element of the North Sea ecosystem, therefore has a rather limited distribution.

##### *Morphology*

In a dynamic environment in which gulleys and plateaus alternate, steep gradients in exposure and sediment composition are encountered. This heterogenous environment, limited to the Voordelta, displays a specific variety of biota which contributes to the diversity of the ecosystem as a whole.

##### *Water masses*

The exchanges that take place between water masses on either side of a frontal system is characterized by increased biological activity. Favourable food conditions lead to a highly productive ecosystem, from the lowest to the highest trophic levels. High concentrations of animals can often be found at a frontal system, since it functions as a foraging area. For this reason its influence also extends to outlying areas. Aside from raised productivity, a frontal system can also display its own specific species composition, linked to the unusual physical circumstances and food conditions.

#### **Biotic factors**

##### *Macrozoobenthos*

In the North Sea distinctions have been made, based on the presence and density of benthic organisms, between various communities having characteristic compositions and often characteristic species. Each community contributes towards total diversity and thereby towards the structural and functional characteristics of the ecosystem as a whole.

##### *Fish*

Certain areas fulfil an essential function in fish life cycles. Spawning grounds and nurseries therefore fulfil functional roles in the ecosystem, and have an accordingly high ecological value.

**Birds**

Parts of the North Sea are of international importance for certain bird populations. During certain seasons and in certain areas more than 1% of the entire international population of a bird species is present. Such bird concentrations can occur after the breeding season, during migrations or while foraging. These areas fulfil a functional role in the life cycle of these animals and therefore have a high ecological value.

**Marine mammals**

A drastic fall in the numbers of marine mammals on the DCS has occurred. Areas in which these organisms reside or through which they migrate therefore have a high ecological value. Where certain species have suffered stress and have consequently disappeared, areas with abiotic characteristics suited to the inhabitation of these species have a high ecological value.

**5.2 Assessment of subareas with regard to ecological values**

The Dutch Continental Shelf, being relatively shallow and having nutrient-rich water inputs, is an ecologically rich area with high productivity.

Its (potential) ecological values will now be examined per subarea. Physical and morphological characteristics, the presence of macrobenthos, the function of the subarea to fish, the presence of birds and mammals, and where relevant the potential of each subarea will be respectively examined (Figure 10a). The various subareas each represent a characteristic biotope but are accorded distinct ecological values (see also Table 7, chapter 3.7).

**Voordelta**

This area is distinguished by considerable natural dynamics, expressed in particular by the morphology of the system (plateau and gulley formation). Macrozoobenthos exhibits high density and low diversity, the latter due to the heterogenous sediment composition and instability of the system. Interaction with the Zeeland Delta is important here; for instance, the Brouwershavense Gat functions as an area in which juvenile flatfish can mature before migrating to the outer delta. The significance of the area to bird life as a resting and foraging area and migrating station may also be noted. From the morphological viewpoint, the Voordelta is still in a developmental stage. Plateau and gulley formation make it a potential settlement area for seals; preconditions for this would be a reduction in PCB loads and a limitation on recreational activities.

**Coastal zone: the South and North Holland coasts**

The coastal zone displays relatively high silt levels and these are probably linked to both the high densities and high biomass of macrozoobenthos in this area. In spring and summer there are high densities of phytoplankton, followed by zooplankton in the water phase. The coastal zone has an important function as nursery for various species of flatfish. For seabirds too, the coastal zone is an important area, and actually of international importance for a number of species (red-throated diver, great crested grebe, scoter and lesser black-backed gull). In autumn, the migratory routes of tens of thousands of birds lie within this area, which then also fulfils an essential role as a foraging area. However, river-borne contaminants entering this area form a heavy burden on this environment, as can be seen in the extremely high nematode/copepod ratio. The large share of opportunistic species and the relatively low diversity within the macrozoobenthos community are also indicators. High pollutant levels give the coastal zone a lower ecological value. It may be assumed that if the contaminant and nutrient loads were reduced, current, relatively low levels of benthic diversity would increase. The area certainly has

a high potential value: it is capable of re-establishing itself as a valuable ecosystem. It also functions as a corridor between the Voordelta area and the Wadden coast and Frisian Front.

#### **Wadden coast**

In morphological terms the Wadden coast shows some similarity to the Voordelta. Like the Voordelta it is characterized by high dynamics, but unlike the Voordelta we may also speak of an equilibrium. The coastal area above the Wadden islands shows high primary production and high macrobenthos biomass but low species diversity. The area is of international importance to birds, in which interaction with the Wadden Sea plays an important role. The presence of seal populations makes it unique in the Netherlands. This area, like the rest of the coast, also functions as a fish nursery. High PCB levels in this area have a negative influence on seal reproductive success.

Shallow coastal waters in particular form an important area in which young fish can mature.

#### **Frisian Front**

The Frisian Front lies parallel to 53°40' N: the transition zone between (erosion) transport areas and sedimentation areas. Here, in spring and summer, primary production is high. The consequently favourable food conditions give rise to rich macrofauna communities, large numbers of fish and an accordingly large number of birds. Porpoises are frequently seen in this area.

#### **Klaver Bank**

This area is distinguished from the rest of the DCS by the presence of gravel- and sandbanks. It therefore displays a specific (and for the DCS, unique) epifauna. Benthic communities found on these gravel banks include particularly high numbers of large molluscs and epifauna species. These species are sensitive to physical disturbance; moreover, large shellfish have lengthy regeneration times.

The Klaver Bank is a potential substrate for the deposition of herring eggs.

#### **Oystergrounds**

The Oystergrounds are characterized by stratification during the summer, for which reason there is little seasonal variation in bottom water temperatures. This area supports a large number of macrozoobenthos species, albeit in relatively low densities, and a reasonably high biomass. Part of the area functions as a spawning ground for smelt, plaice, herring and cod. The white-beaked dolphin and white-sided dolphin are commonly seen here, and are resident between December and June.

#### **Dogger Bank**

This area is a fine-sandbank in relatively shallow water. Part of it functions as a fish spawning ground.

#### **Broad Fourteens**

The Broad Fourteens are characterized by fine to coarse sand, relatively few macrobenthos species and low biomass. Most of it functions as a fish spawning ground. Cetaceans have been observed here.

### 5.3 Environmental Zoning

With the results set out in the previous section it is now possible to come to some conclusions about which areas can be accorded a special ecological value. The ecosystems in these areas require special protection, and this can be provided within an 'environmental zone'.

By environmental zone is meant:

"an area within which a special level of protection can contribute towards the protection, recovery and development of the entire water system of the North Sea".

For this reason, it has been taken as a first principle that every selected special area should be represented. If protection, recovery and development of ecological values and potentials is to be guaranteed, it is necessary that the choice is made for one continuous and unbroken **environmental zone**. This means that ecologically valuable areas are connected by areas of potential ecological value. These areas, apart from their own specific development potential, make significant contributions towards the likelihood of the successful preservation of gradients, recovery and migration. In this way the **environmental zone** becomes a representative mirror of the multifaceted nature of the DCS ecosystem itself; provided, that is, that its surface area is at least the minimum necessary for such ecological recovery and development. The establishment and enforcement of regulatory measures is also best realizable in a single, unbroken area.

The **environmental zone**, as it has been adopted by the North Sea Water System Management Plan, therefore consists of the following areas:

- the Voordelta, the Wadden coast, the Frisian Front and the Klaver Bank as the most ecologically valuable areas (Figure 10b). The coastal zone, which is considered to have a potential for ecological development, part of the Southern Bight and the Oystergrounds have been included as 'corridors'. By this means, areas have been included in the **environmental zone** which fulfil important functions as fish nurseries, as (migrating) bird resting and foraging areas, and which support productive benthic communities in both sandy and silty areas. The Wadden coast is currently the only area in which seals occur; this function can be developed in the Voordelta.

In establishing the boundaries of the **environmental zone**, correspondence has also been sought with the protected areas envisioned by the Nature Policy Plan Project Report (NBP-22, Bergman et al., 1990), which also included proposals for the size and position of protected areas in the North Sea.

In the light of current knowledge, it is our considered opinion that regulation of human activities within the designated area regarding (1) the choice of selected ecological values, and (2) the structure, extent and position of the zone, provides an adequate ecological benefit to the entire DCS.

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## Appendices and Figures

Appendix 1 Matrix relating selected human uses to the type of influence.

Appendix 2 Matrix relating selected human uses to ecosystem features.

- Fig. 1a Depth contours, mining sectors and topographical areas on the DCS (North Sea Directorate, 1987).
- Fig. 1b North Sea water masses: conditions in winter (North Sea Atlas, 1992).
- Fig. 1c North Sea water masses: conditions in summer (North Sea Atlas, 1992).
- Fig. 1d Sediment map of the DCS (Montfrans et al., 1988).
- Fig. 1e Silt sediments on the DCS (Creuzberg et al., 1984).
- Fig. 1f Silt sediments in the north and west coastal part of the DCS (MILZON-BENTHOS) (van Scheppingen & Groenewold, 1990).
- Fig. 2a Cadmium levels in DCS sediments, 1986-1989 (DNZ/WL 1988; Klamer, 1989).
- Fig. 2b PCB-153 levels in DCS sediments, 1986-1989 (DNZ/WL 1988; Klamer, 1989).
- Fig. 2c Total number of oil slicks observed in 1990 (RWS/DNZ, 1990).
- Fig. 3a Primary production measured at midday in 1986-1987 during the summer (Sündermann & Degens, 1989).
- Fig. 3b Primary production measured at midday in 1986-1987 during the winter (Sündermann & Degens, 1989).
- Fig. 3c The distribution of *Phaeocystis pouchetii*, *Noctiluca scintillans*, *Dinophysis acuminata* en *Gyrodinium aureolum* on the DCS in 1989. (Zevenboom et al. 1990).
- Fig. 4a The spatial distribution of copepods (zooplankton) in the whole North Sea during May/June 1986 (Sündermann & Degens, 1989).
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- Fig. 5a TWINSPAN classification of North Sea macrobenthos, based on density (Künitzer et al., 1992).
- Fig. 5b Zones distinguished in the MILZON-BENTHOS area (1988-1989) on the basis of macrobenthos density (van Scheppingen and Groenewold, 1990).
- Fig. 5c Distribution of the five most important TWINSPAN station groups in the North Sea, with the most important ecotypes in each TWIN-group (Huys et al., 1992).
- Fig. 6a Fish spawning and nursery areas on the DCS, 1960-1976 (Bosschieter, 1981).
- Fig. 6b Distribution of fish fauna in the North Sea, in three main groups (Daan et al., 1990).
- Fig. 6c The number of plaice caught per hour during the third quarter, averaged over the years 1985-1987 (Welleman, 1989).
- Fig. 7 Distribution of the guillemot (number/km<sup>2</sup>) in August-September in the North Sea (Leopold, 1991).
- Fig. 8a Dolphin distribution in the North Sea in the period 1984-1990 (Baptist et al., unpublished material).
- Fig. 8b Porpoise distribution in the North Sea in the period 1984-1990 (Baptist et al., unpublished material).
- Fig. 9 Distribution of species sensitive to oil-containing drilling mud (max. 17) on the DCS (De Wilde and Duineveld, 1990; Daan et al., 1990).
- Fig. 10a Areas of the DCS based on ecosystem features (this document, 1991).
- Fig. 10b Environmental Zone on the DCS based on ecosystem features (WSMP, 1991).



HUMAN USE	NATURE OF DISTURBANCE				
	1	2	3	4	5
Fisheries	-	◆	■	-	■
Offshore mining	■	-	-	○	-
Sand/gravel extraction	-	◆	○	-	■
Input of substances	■	■	-	-	-
Military activities	-	-	-	■	-
Shipping	■	-	-	■	-
Coastal recreation	-	○	○	■	-

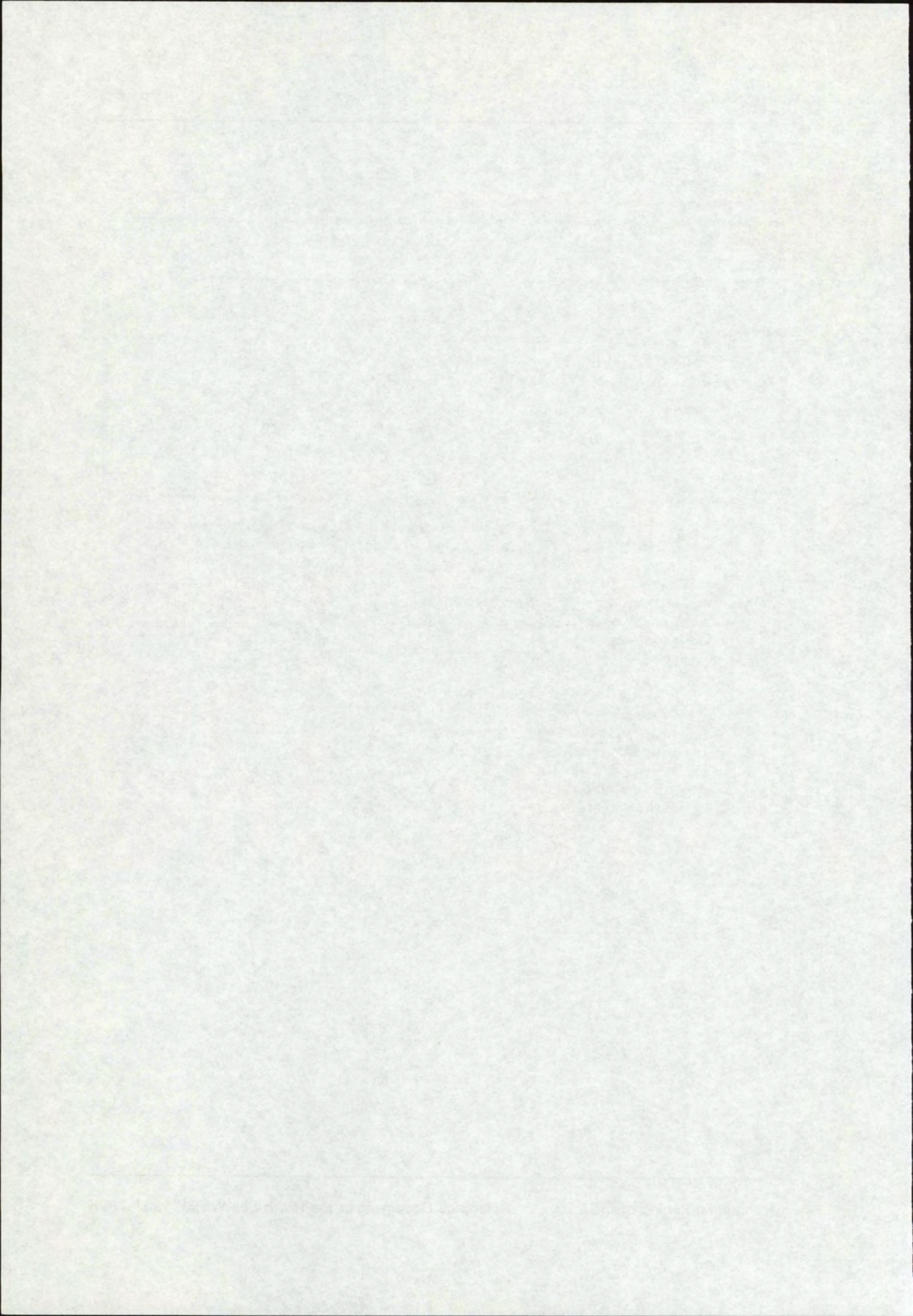
**Appendix 1:** Matrix relating selected human uses to the nature of disturbance caused to the North Sea ecosystem (based on a tentative assessment).

symbols:

- = direct, strong effects (large-scale and/or frequent)
- = direct, weak effects (local and/or infrequent)
- ◆ = indirect effects
- = no effects

Type of disturbance:

1. = pollution (inorganic and organic micropollutants)
2. = nutrients (increased eutrophication)
3. = mechanical disturbance
4. = acoustic disturbance
5. = removal of organisms



HUMAN USES (type of influence)	BIOTIC SYSTEM					
	phytoplankton	zooplankton	zoobenthos	fish	birds	mammals
Fishing (2, 3, 5) (according to method)		X	■2 X	■2 X	◆2	■2
Offshore Mining (1, 4)	○1	○1	■2	○1	‡1	■2
Sand/gravel extraction (2, 3, 5)	‡1		■2	○1		
Input of substances (1, 2)	■2	■2	■2	■2	■2	■/◆2
Military activities (4)				■2		■2
Shipping (1, 4)	○1	○1	■2	○1	○1	○1
Recreation (2, 3, 4)					○1	‡1
INTEGRAL EFFECT	5	4	10	9	7	10

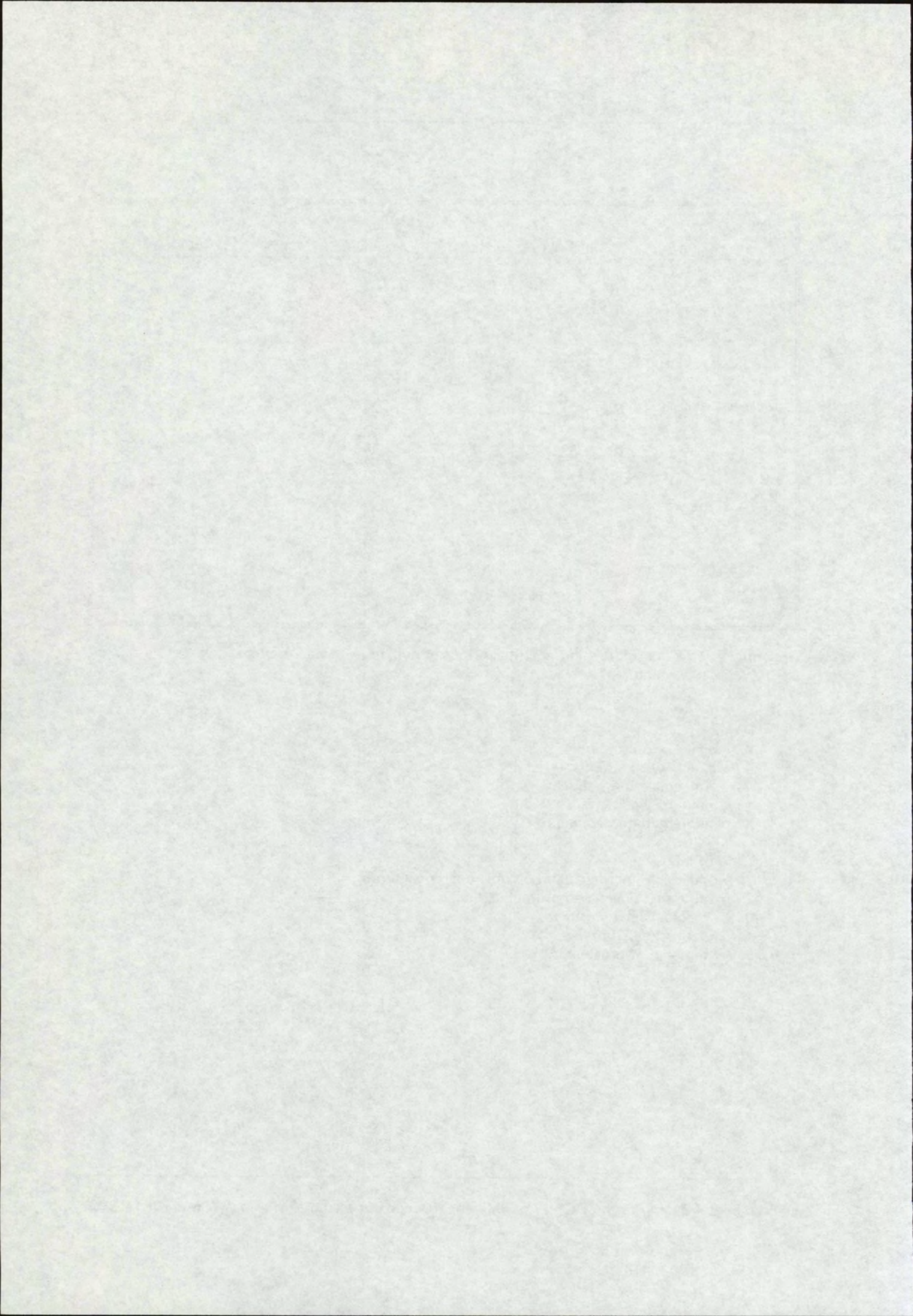
**Appendix 2:** Matrix relating potential effect of human use to ecosystem features.

symbols:

- = direct, strong effects 2
- = direct, weak effects 1
- ◆ = indirect, strong effects 2
- ‡ = indirect, weak effects 1
- X = indeterminate demands

Type of influence:

- 1. = pollution (inorganic and organic micropollutants)
- 2. = nutrients (increased eutrophication)
- 3. = mechanical disturbance
- 4. = acoustic disturbance
- 5. = removal of organisms



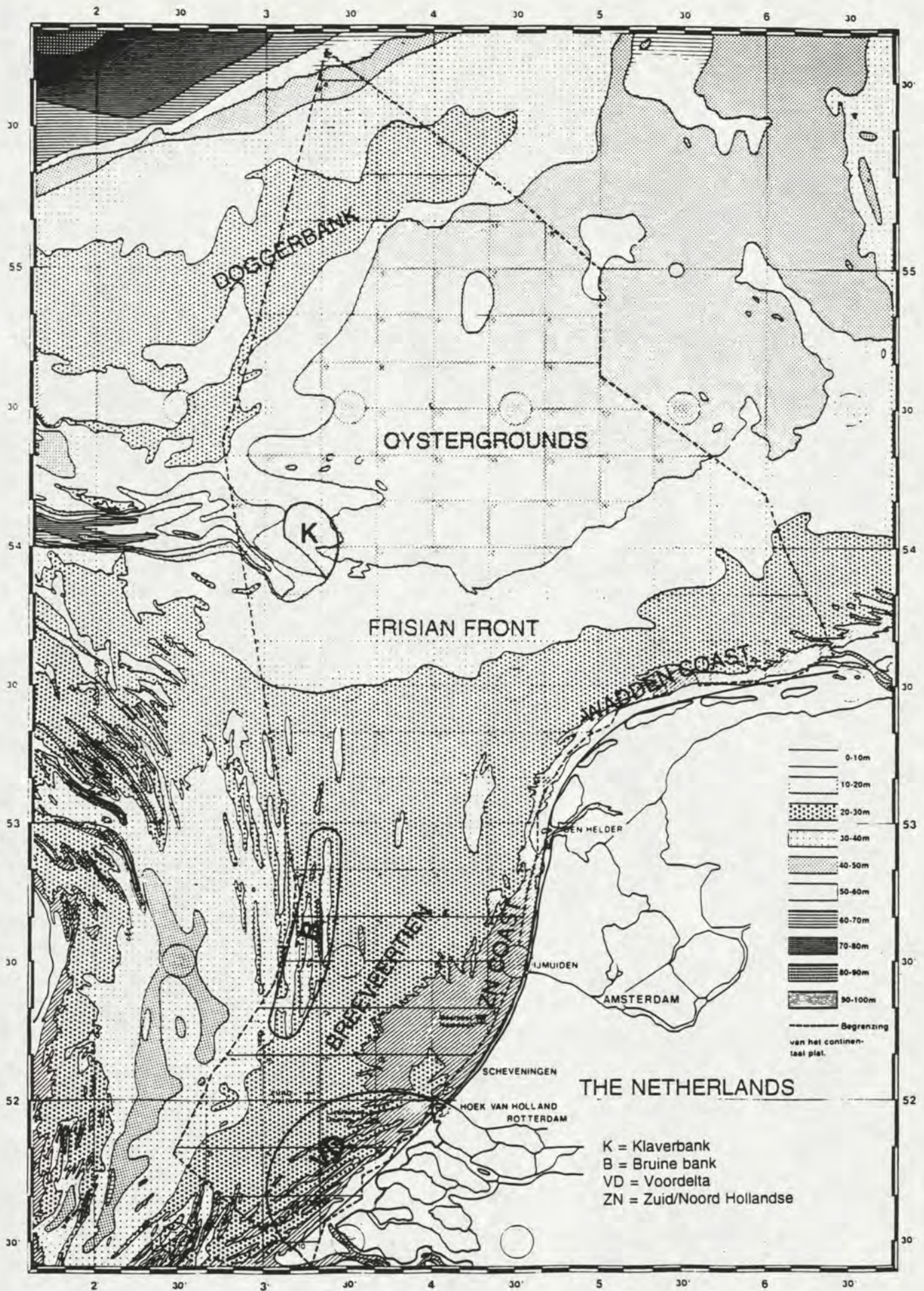
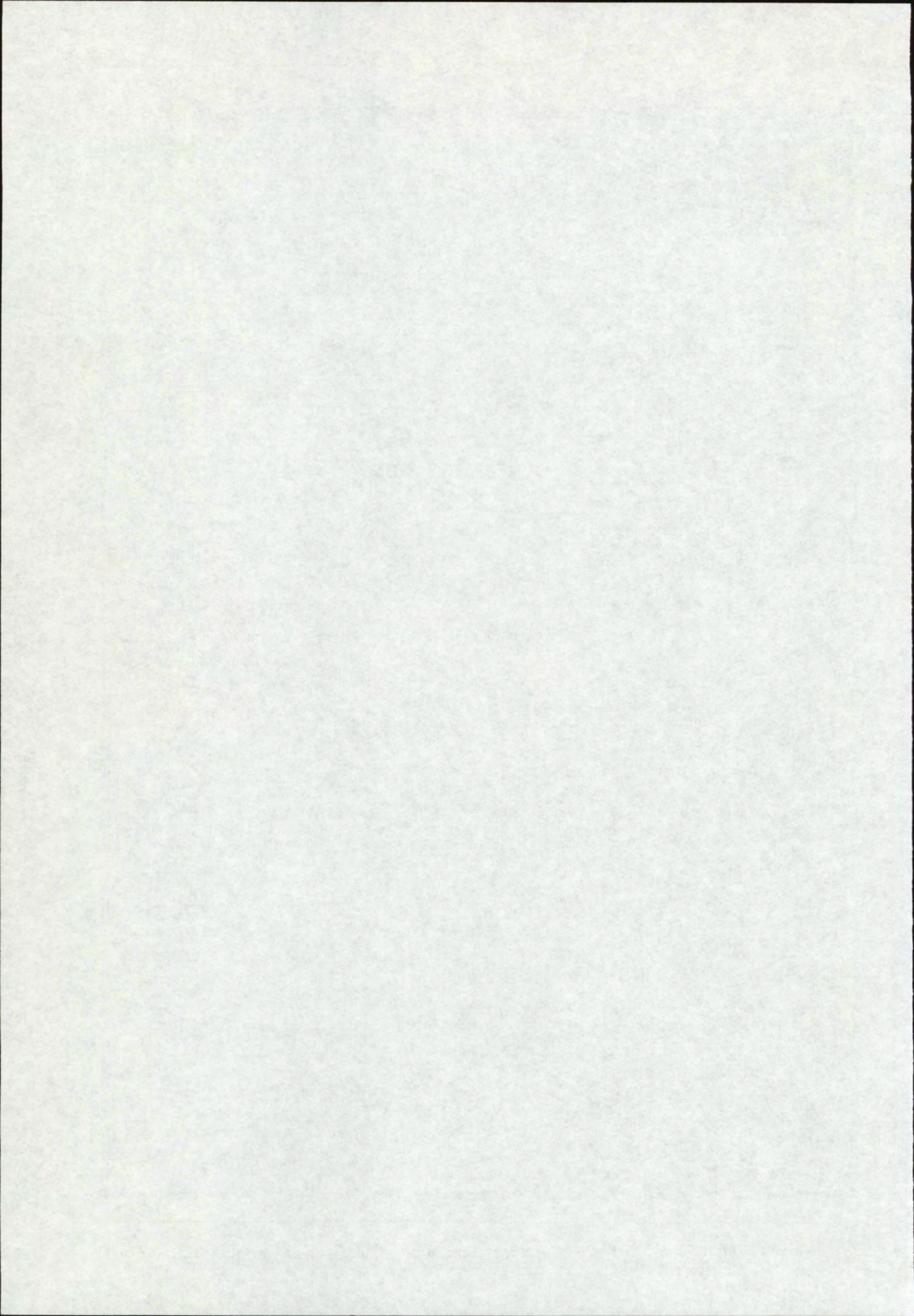


Fig. 1a Depth contours, mining sectors and topographical areas on the DCS (North Sea Directorate, 1987).



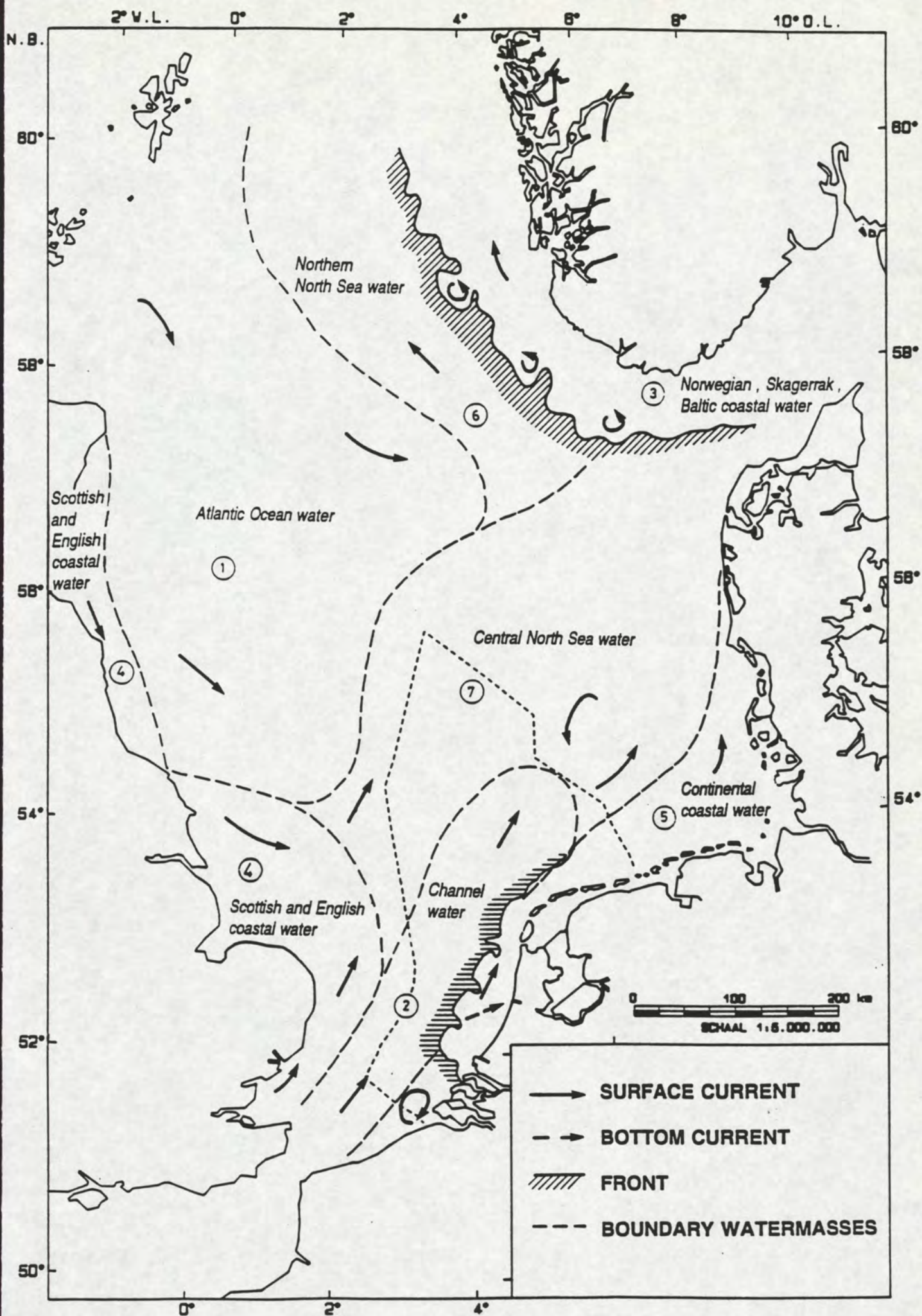
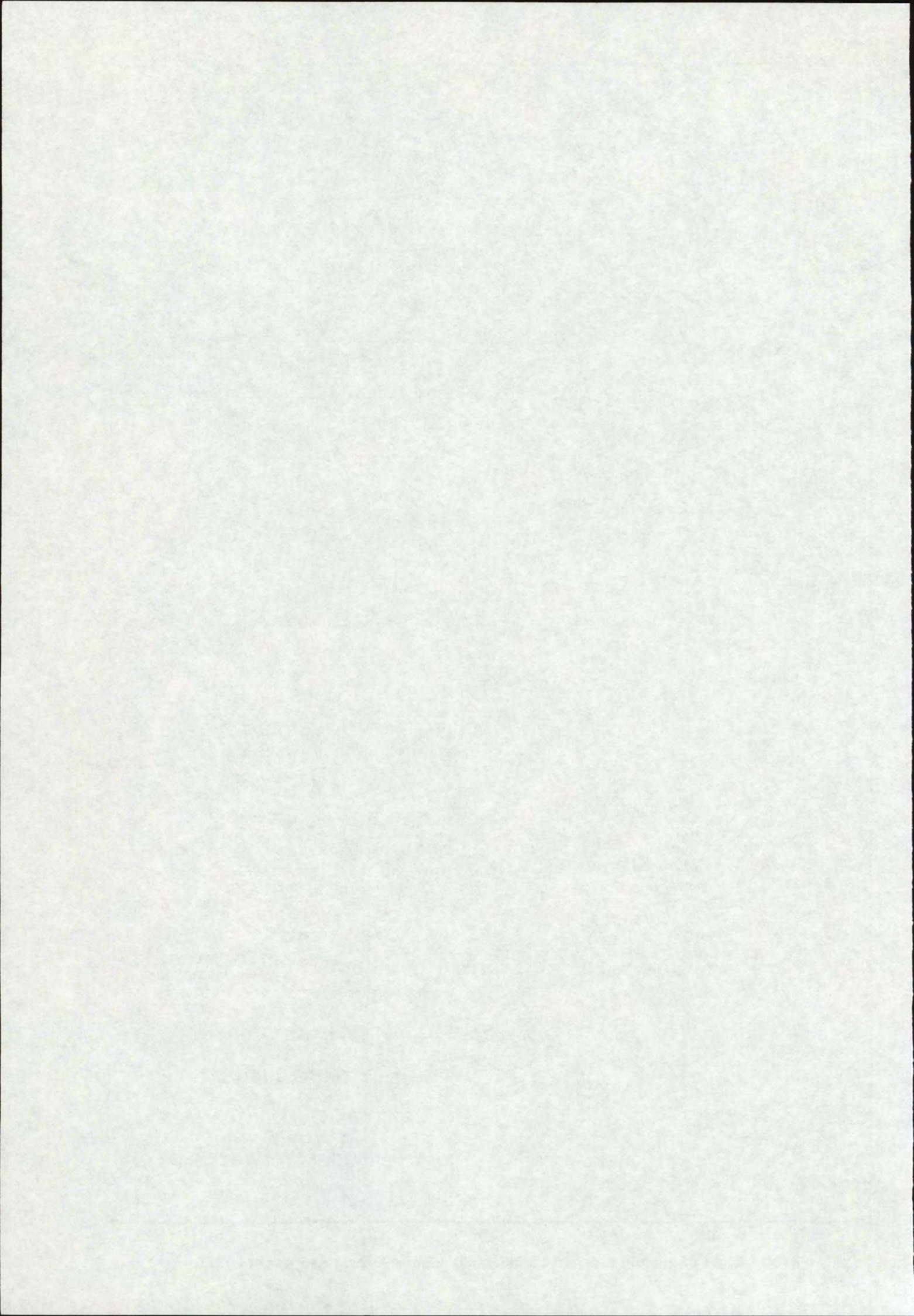


Fig. 1b North Sea water masses: conditions in winter (North Sea Atlas, 1992).



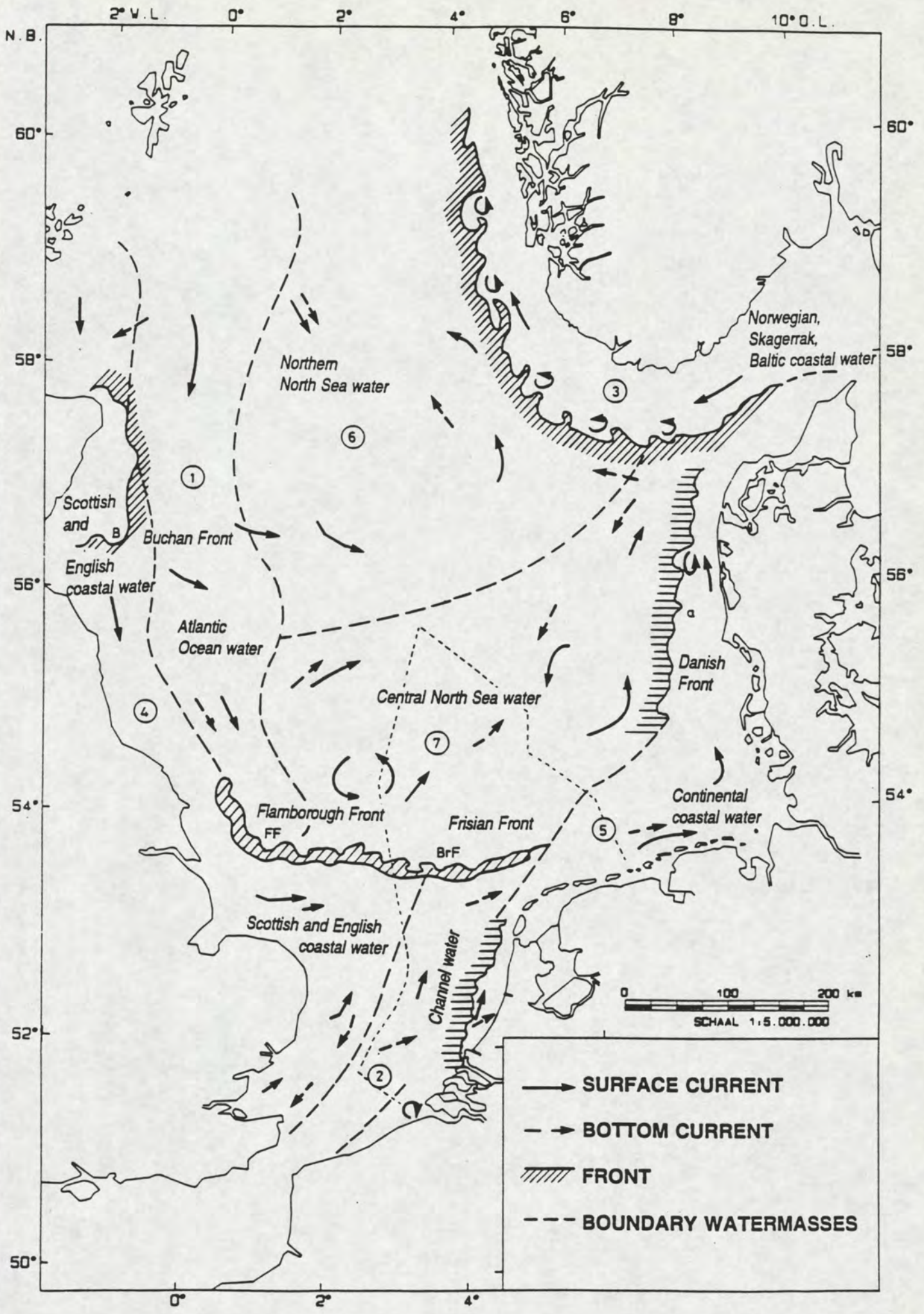
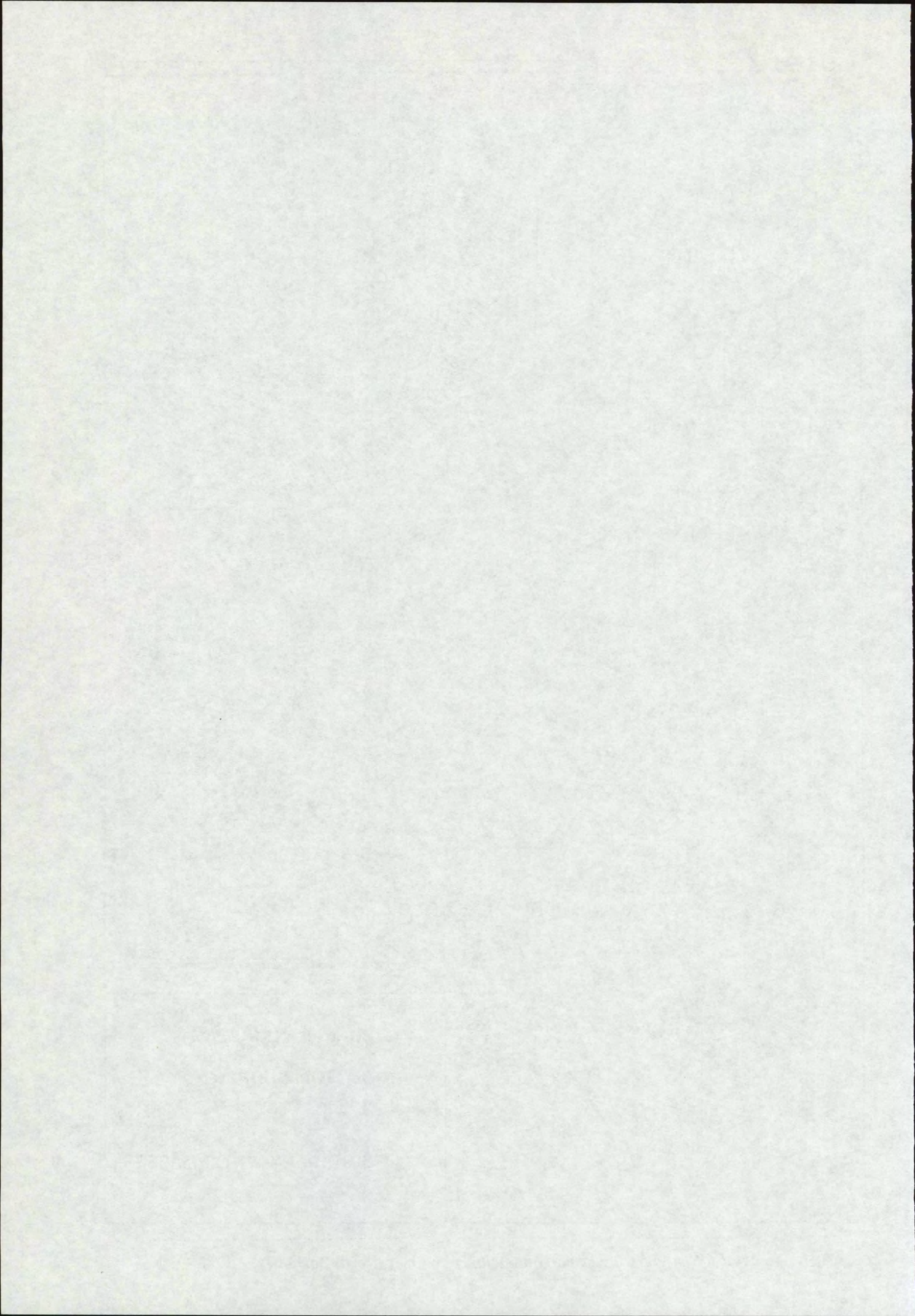


Fig. 1c North Sea water masses: conditions in summer (North Sea Atlas, 1992).



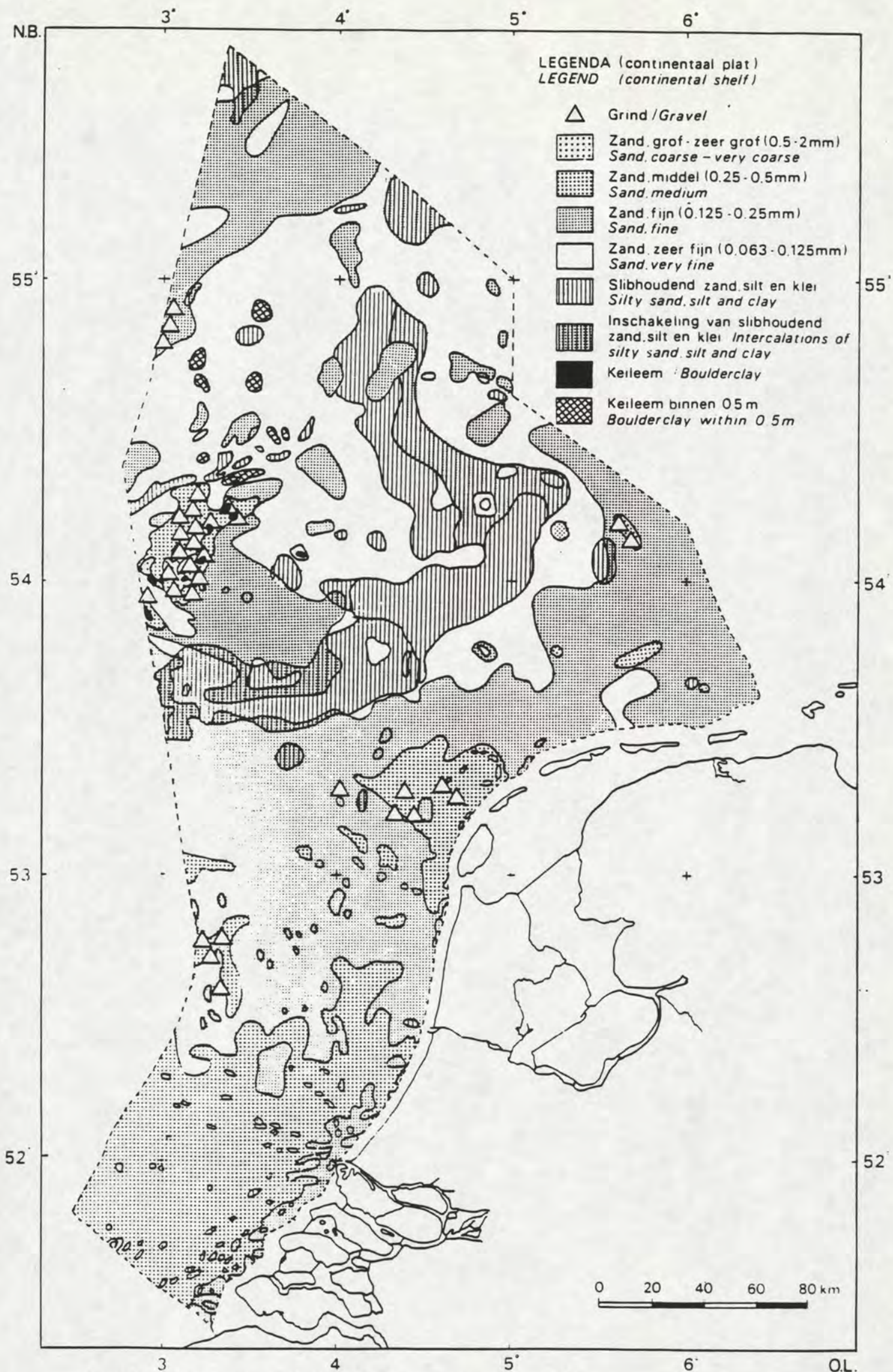
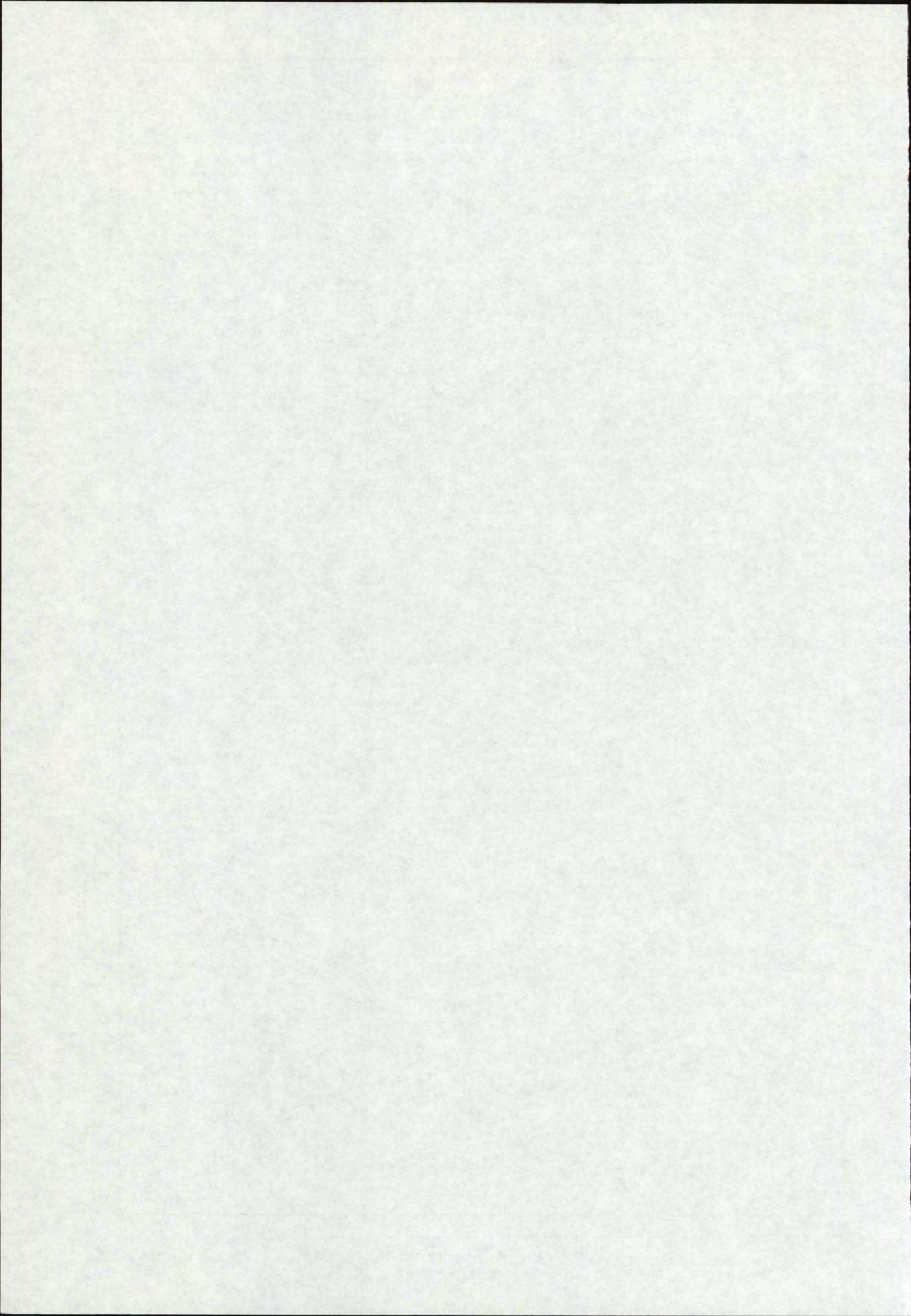


Fig. 1d Sediment map of the DCS (Montfrans et al., 1988).



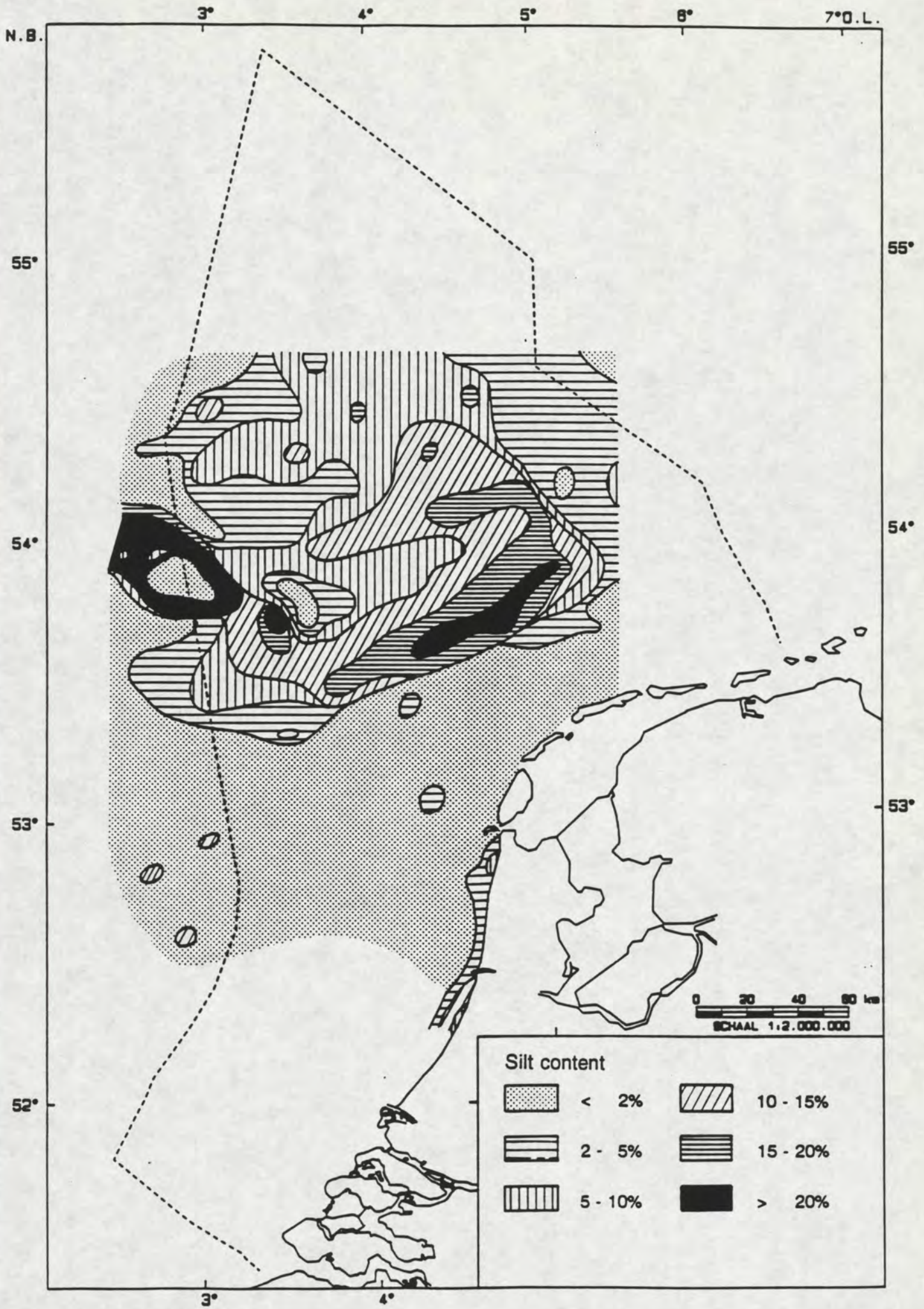
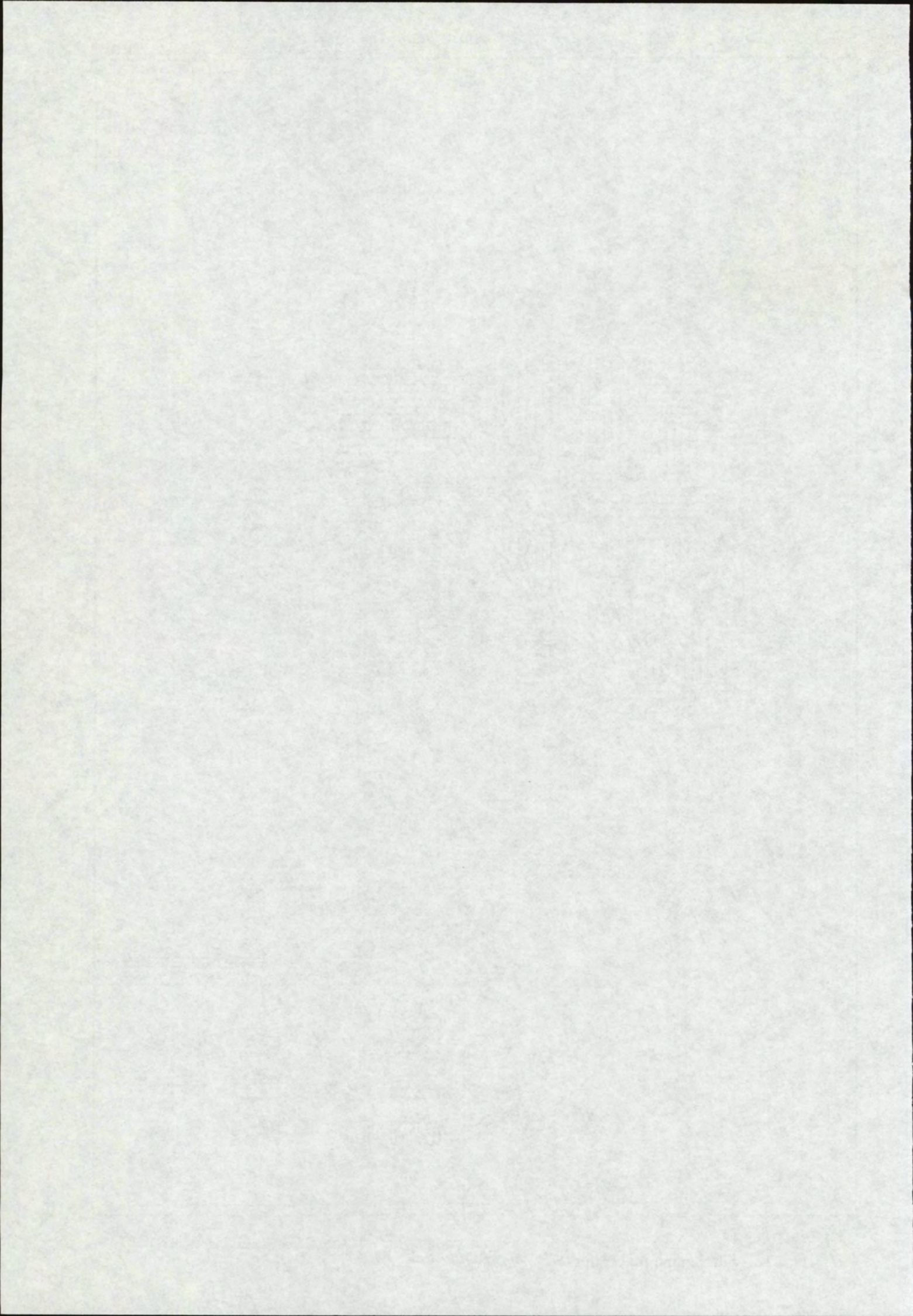


Fig. 1e Silt sediments on the DCS (Creuzberg et al., 1984).



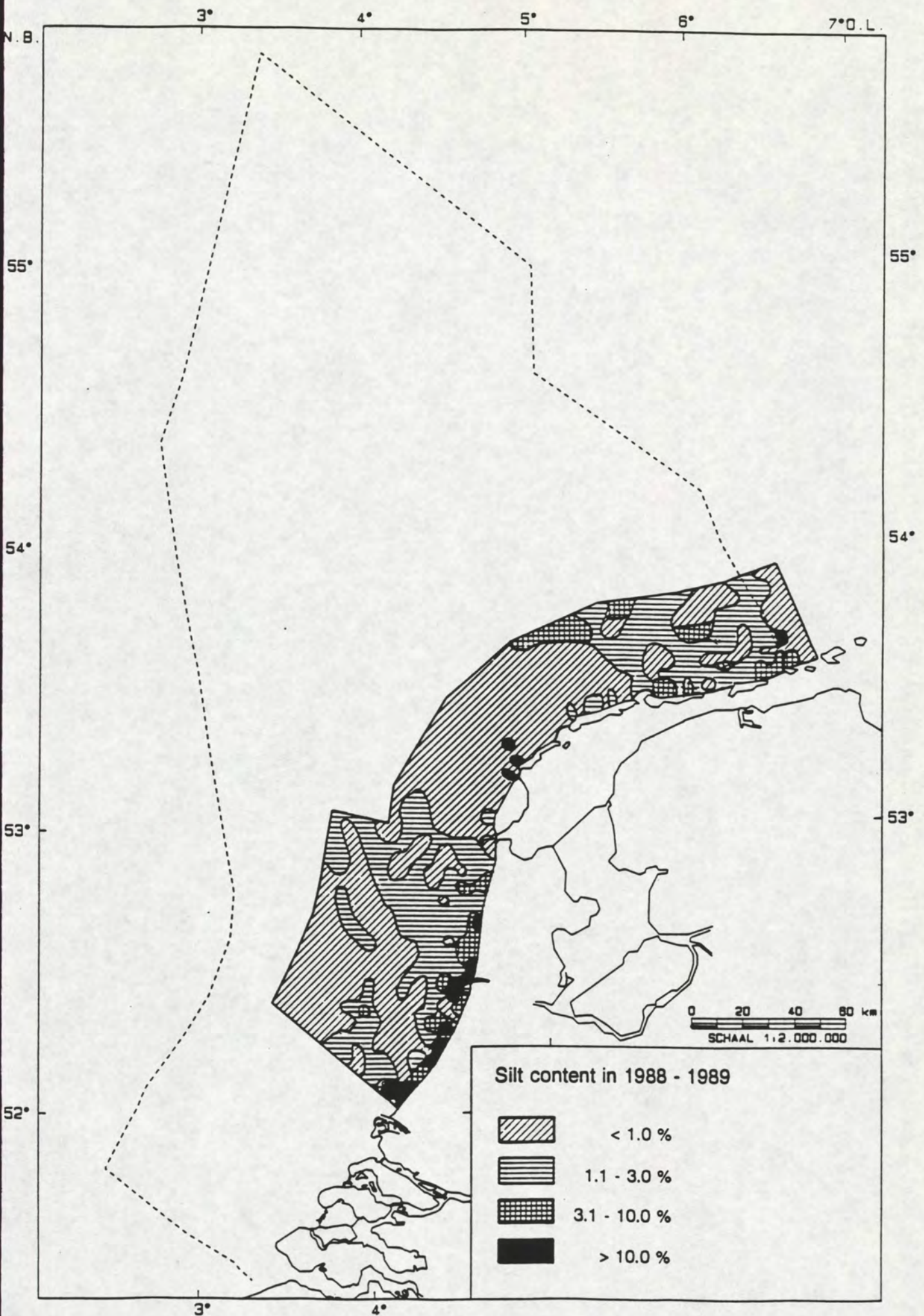
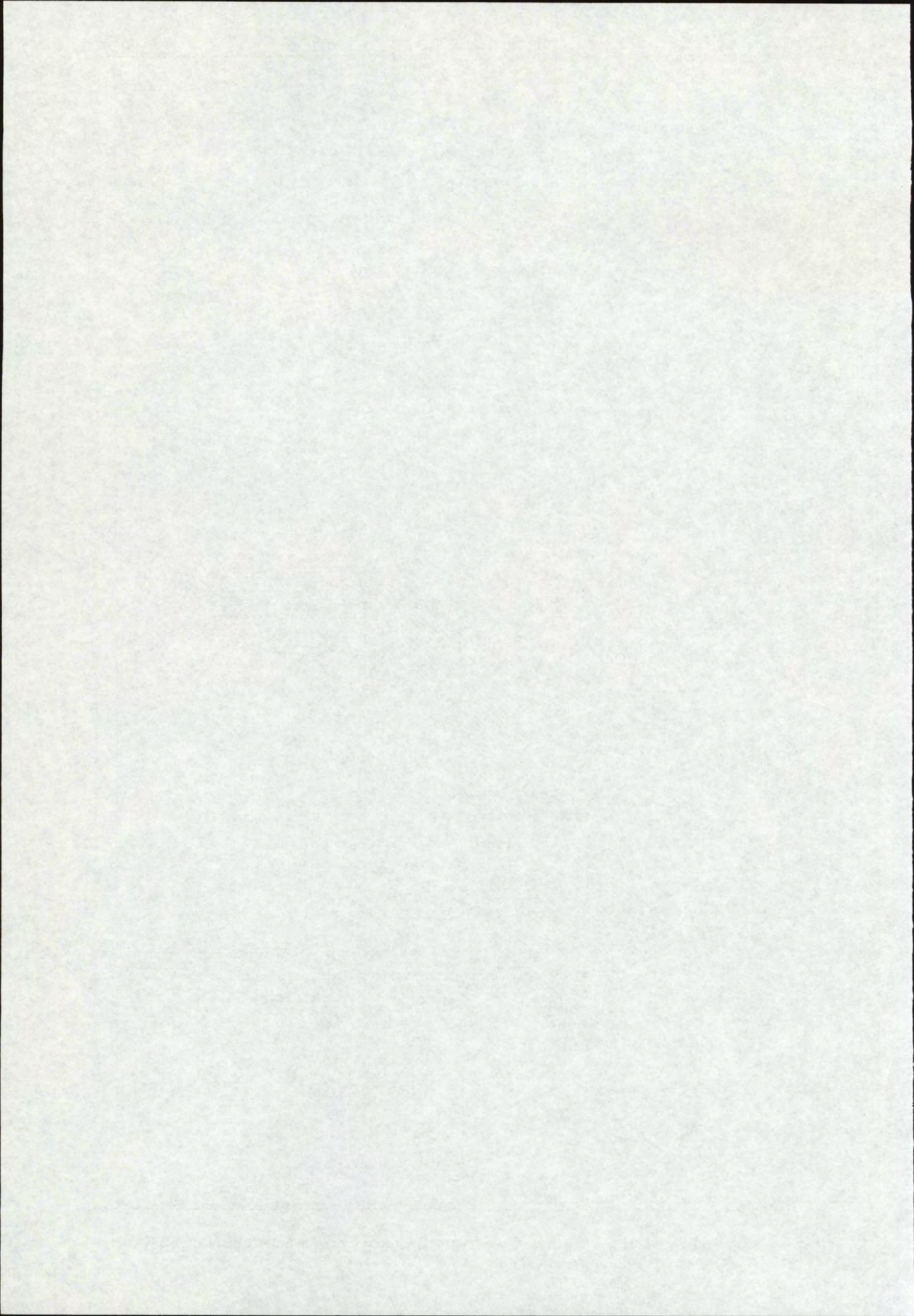


Fig. 1f Silt sediments in the north and west coastal part of the DCS (MILZON-BENTHOS) (van Scheppingen & Groenewold, 1990).



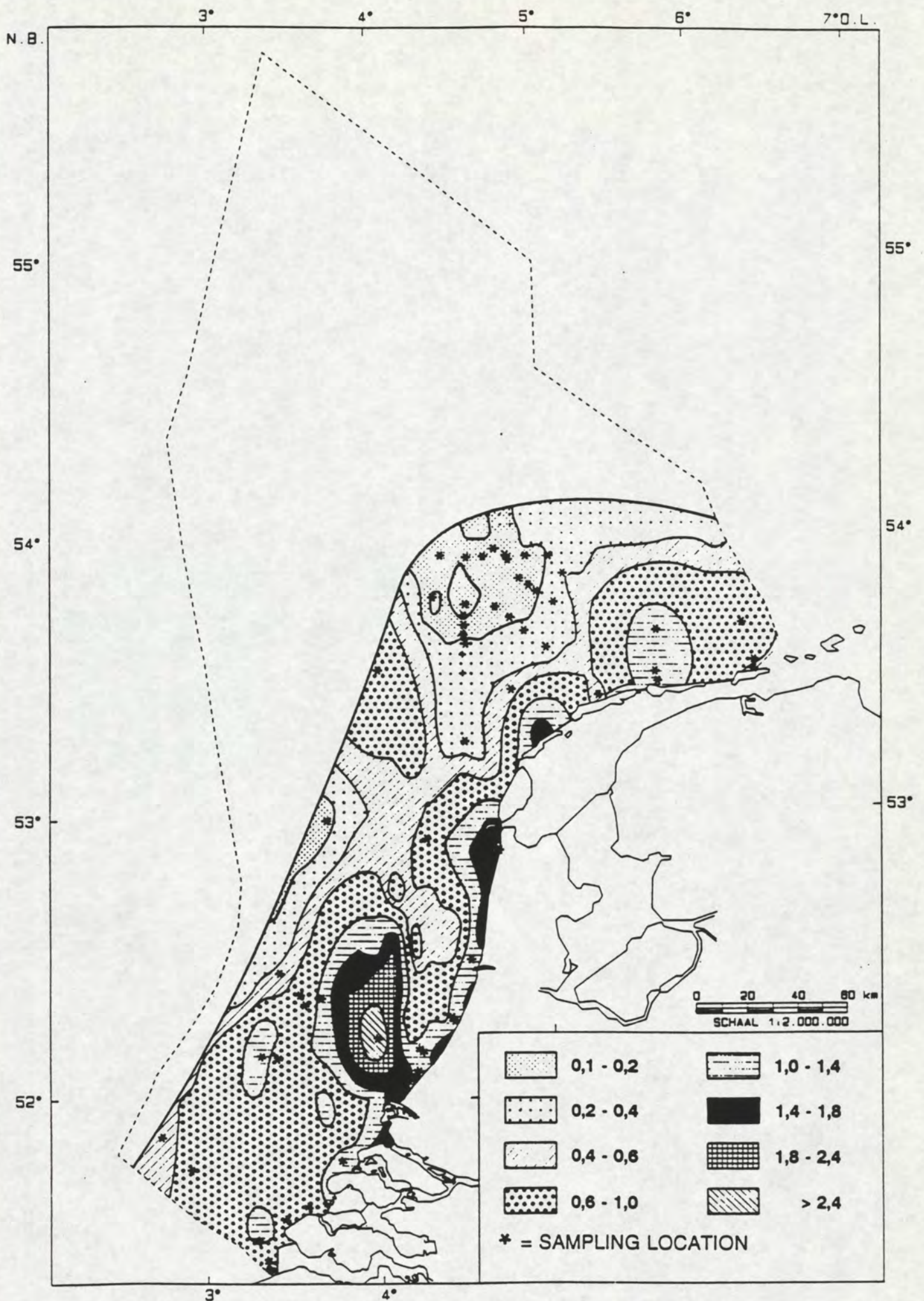
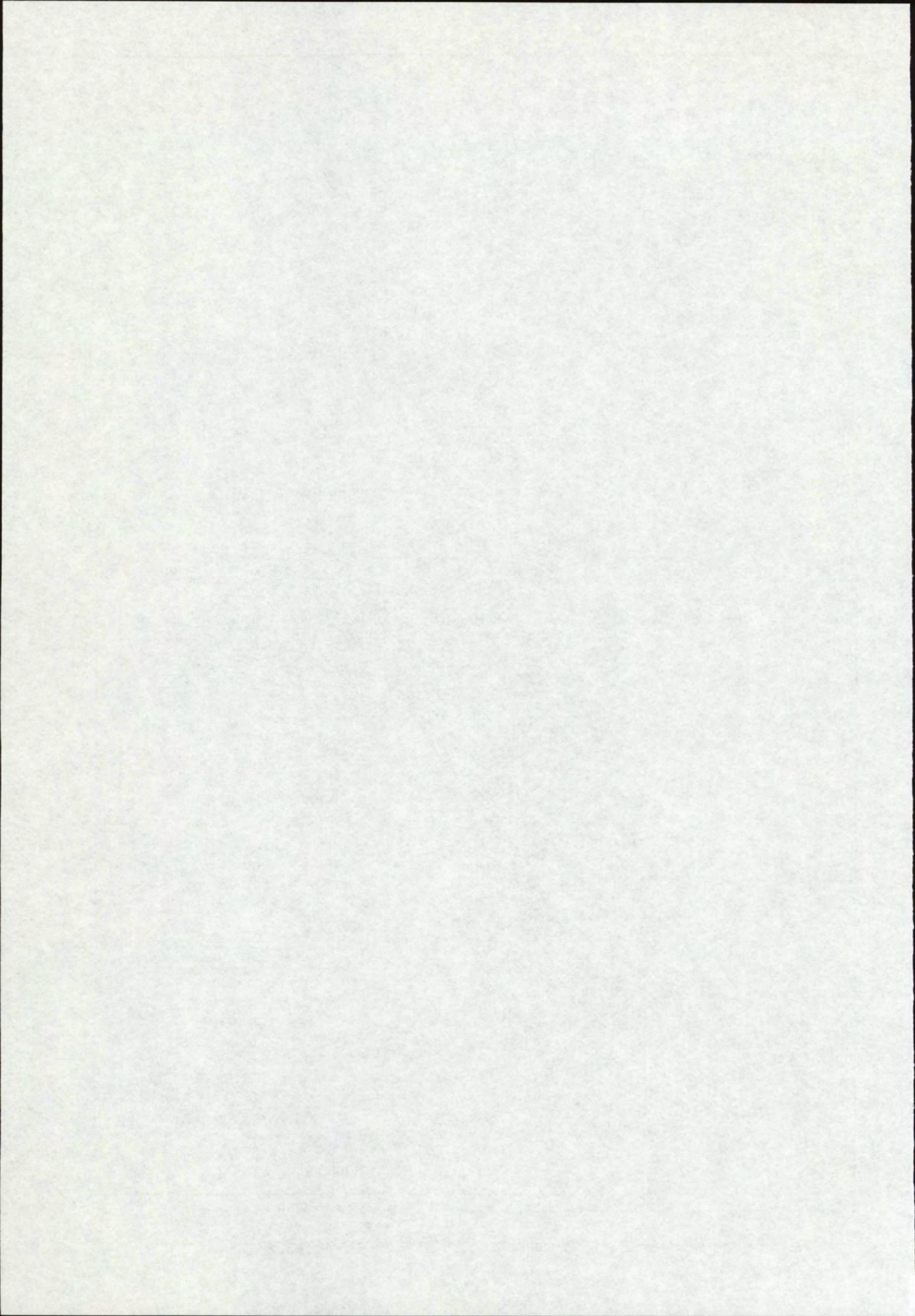


Fig. 2a Cadmium levels in DCS sediments, 1986-1989 (DNZ/WL 1988; Klamer, 1989).



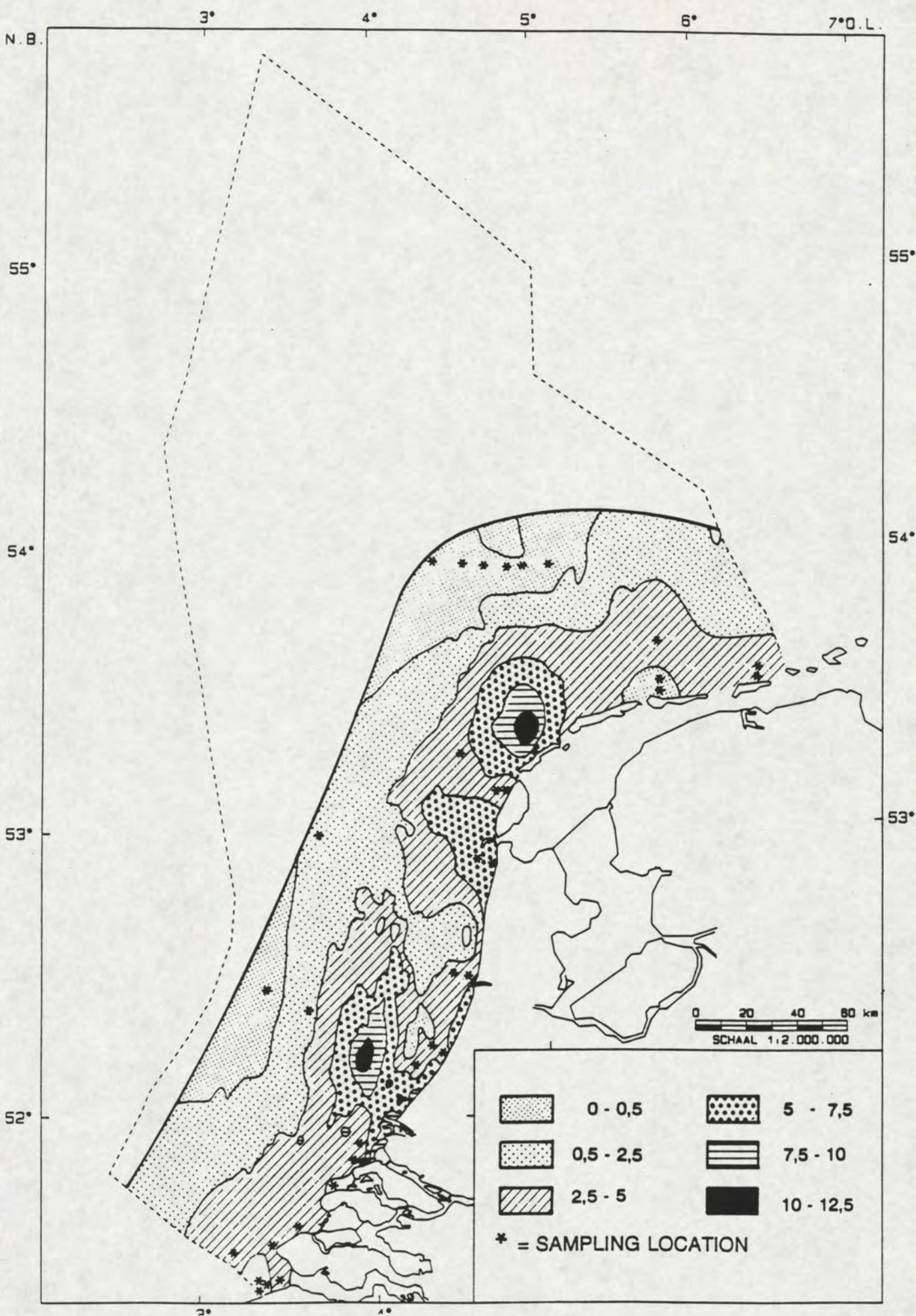
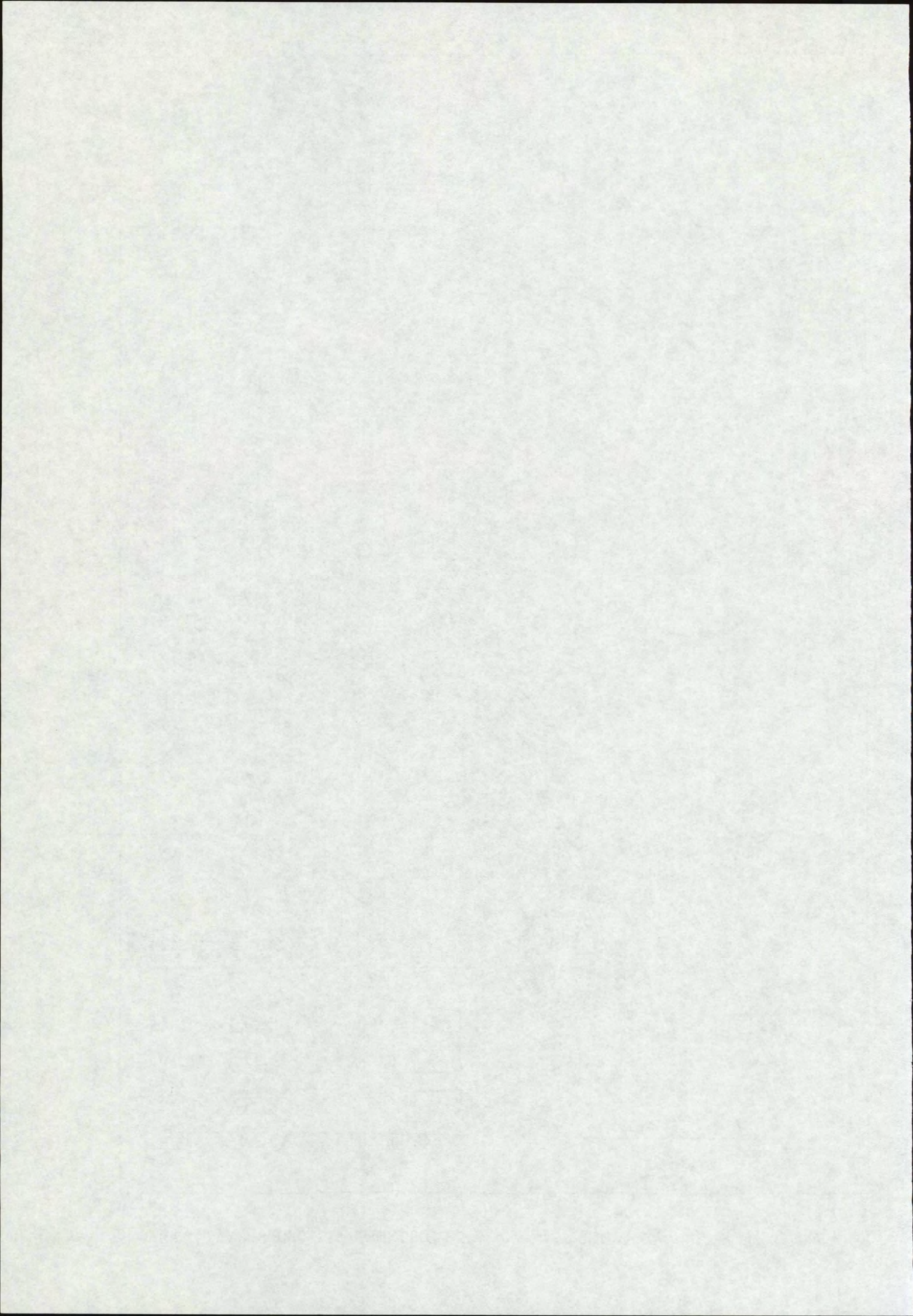


Fig. 2b PCB-153 levels in DCS sediments, 1986-1989 (DNZ/WL 1988; Klamer, 1989).



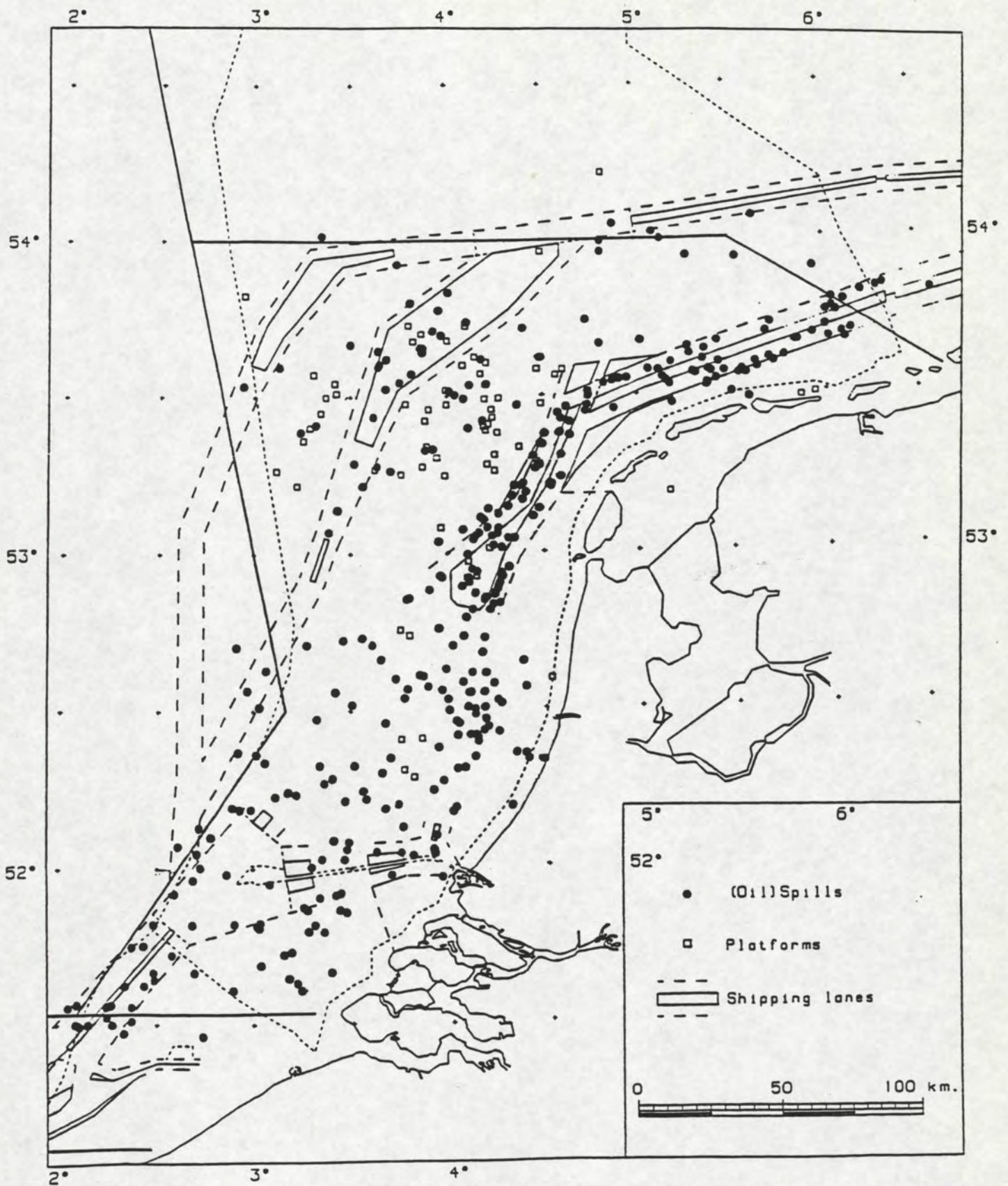
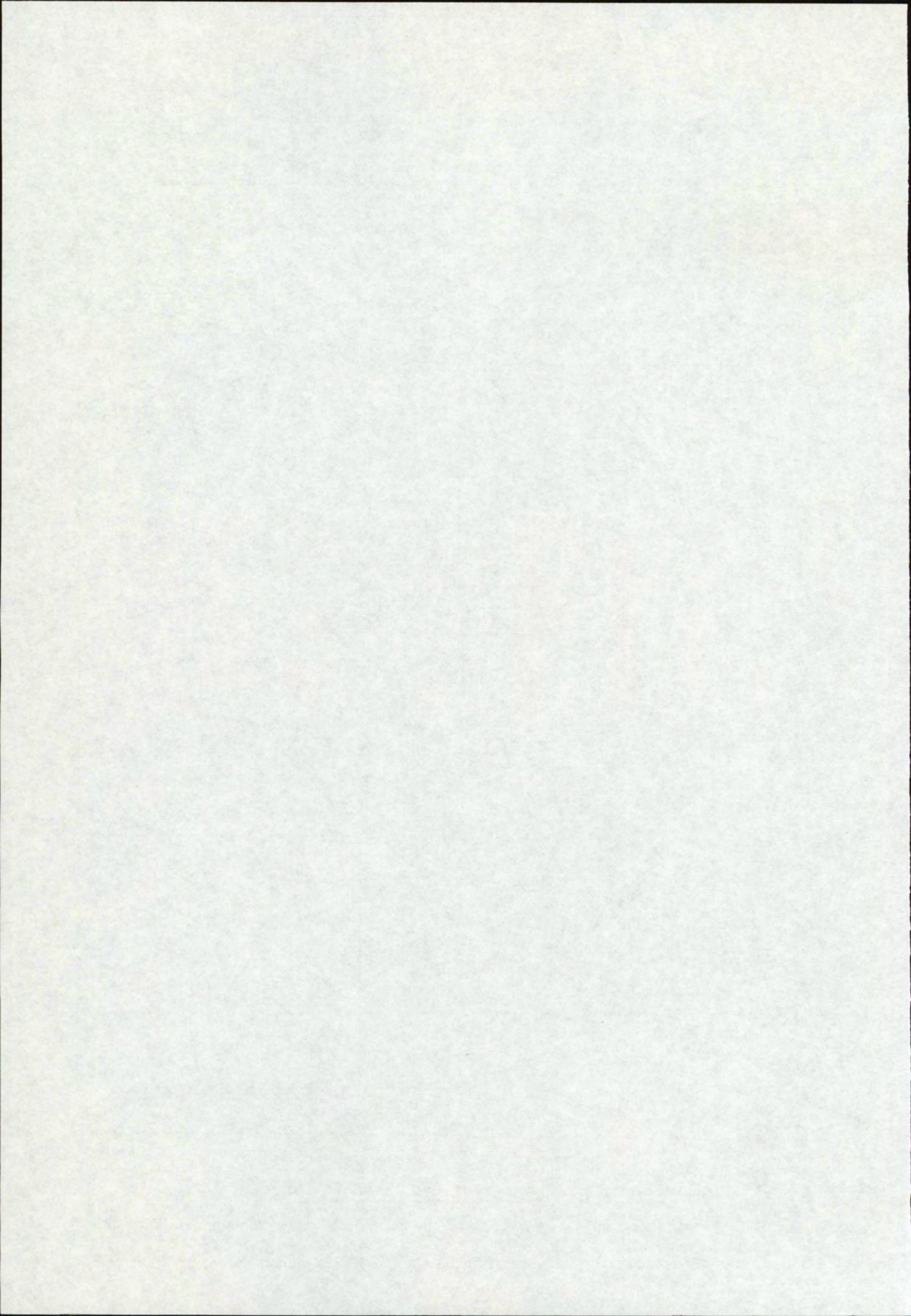


Fig. 2c Total number of oil slicks observed in 1990 (RWS/DNZ, 1990).



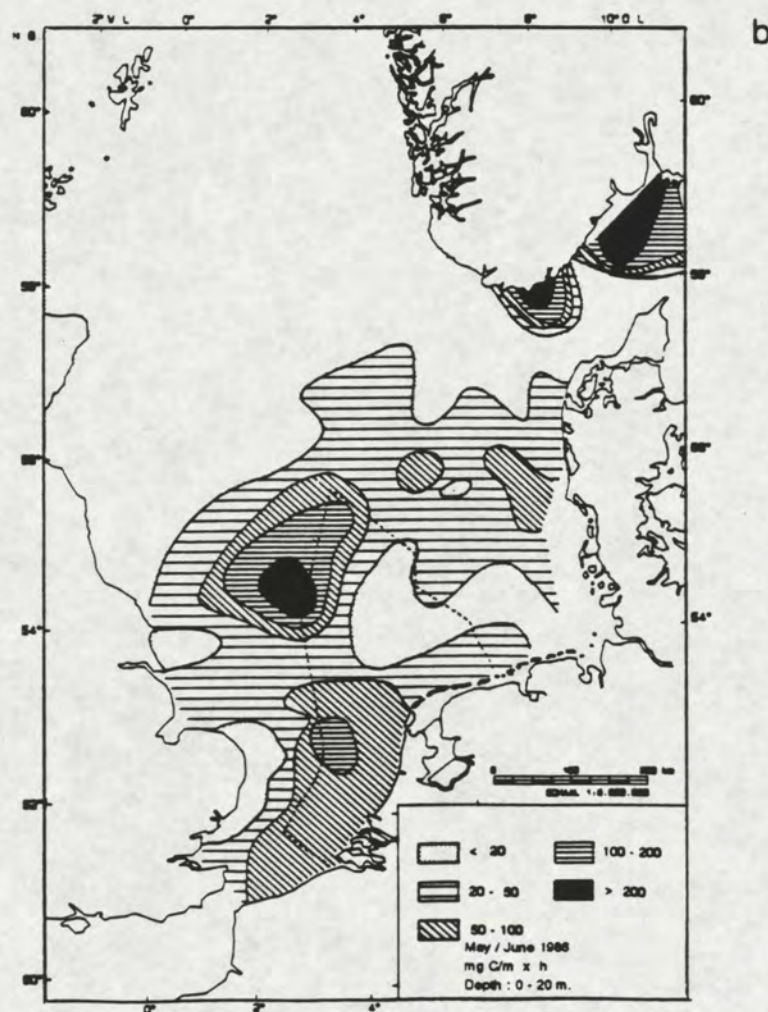
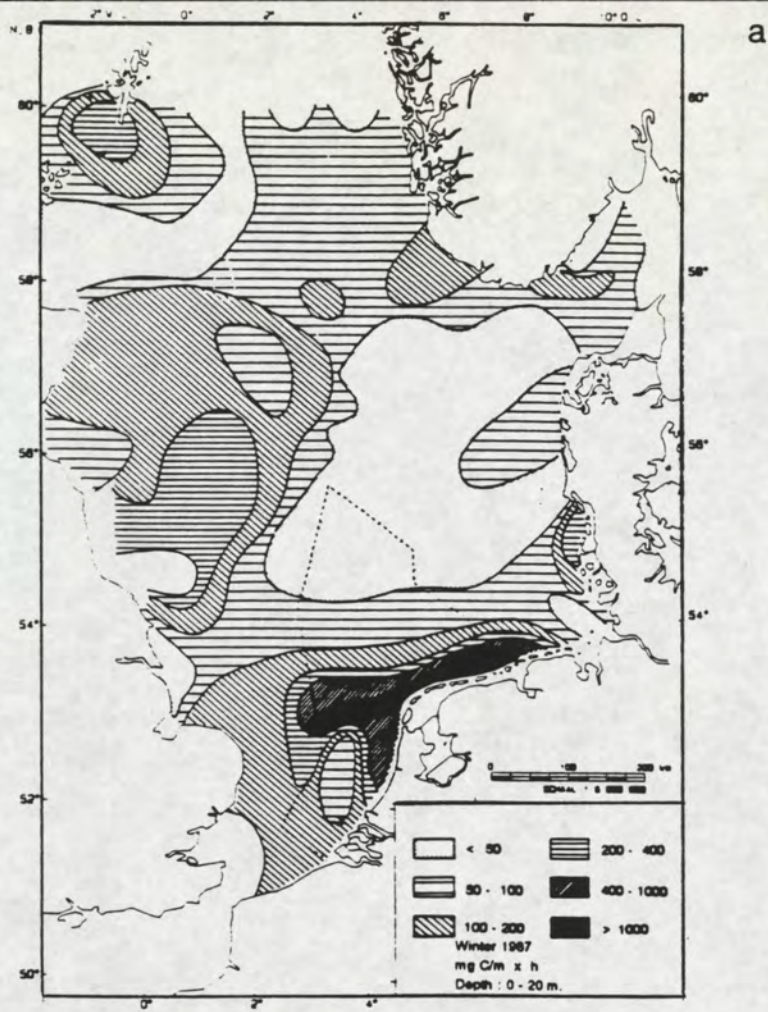
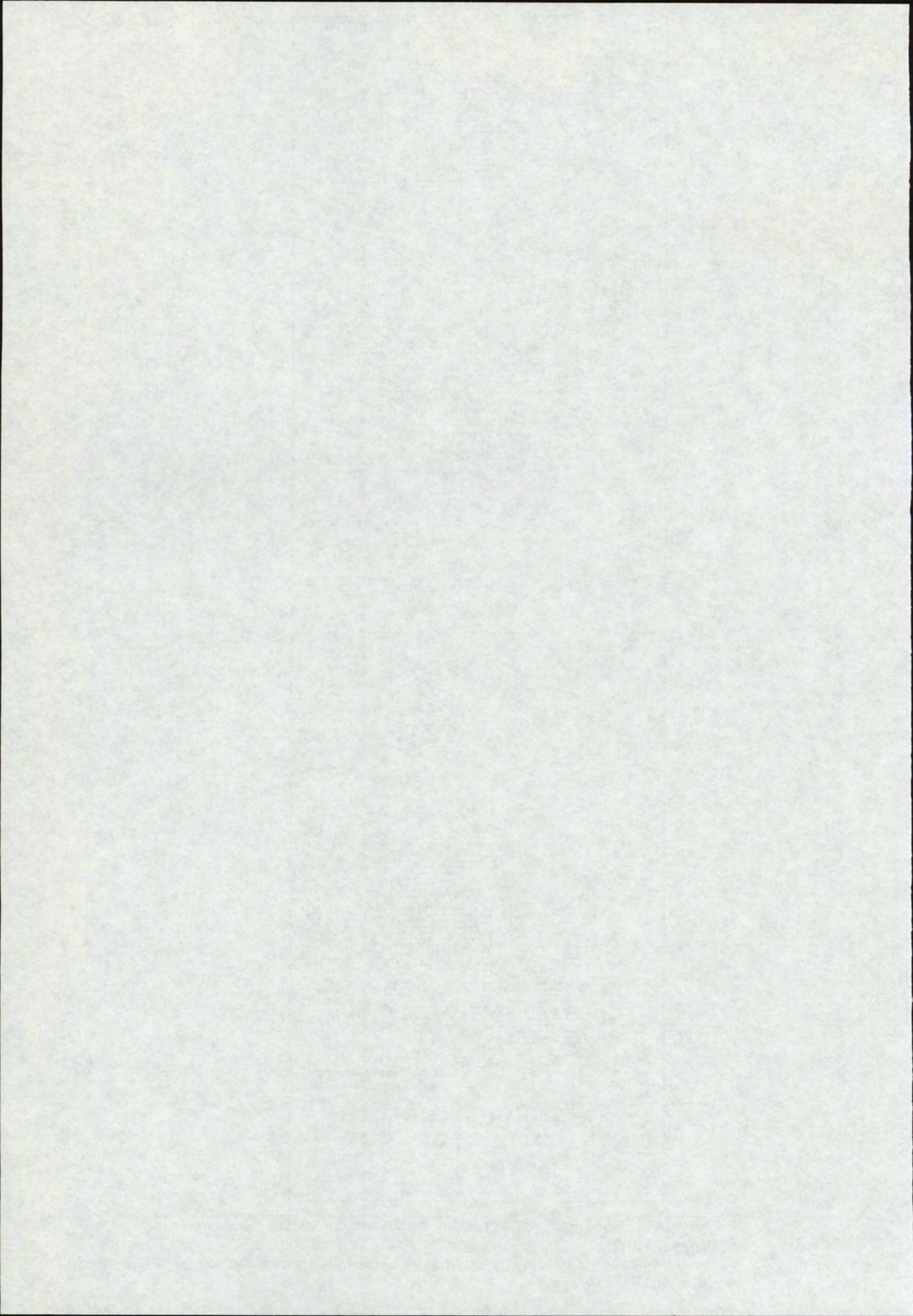


Fig. 3a Primary production measured at midday in 1986-1987 during the summer (Sündermann & Degens, 1989).

Fig. 3b Primary production measured at midday in 1986-1987 during the winter (Sündermann & Degens, 1989).



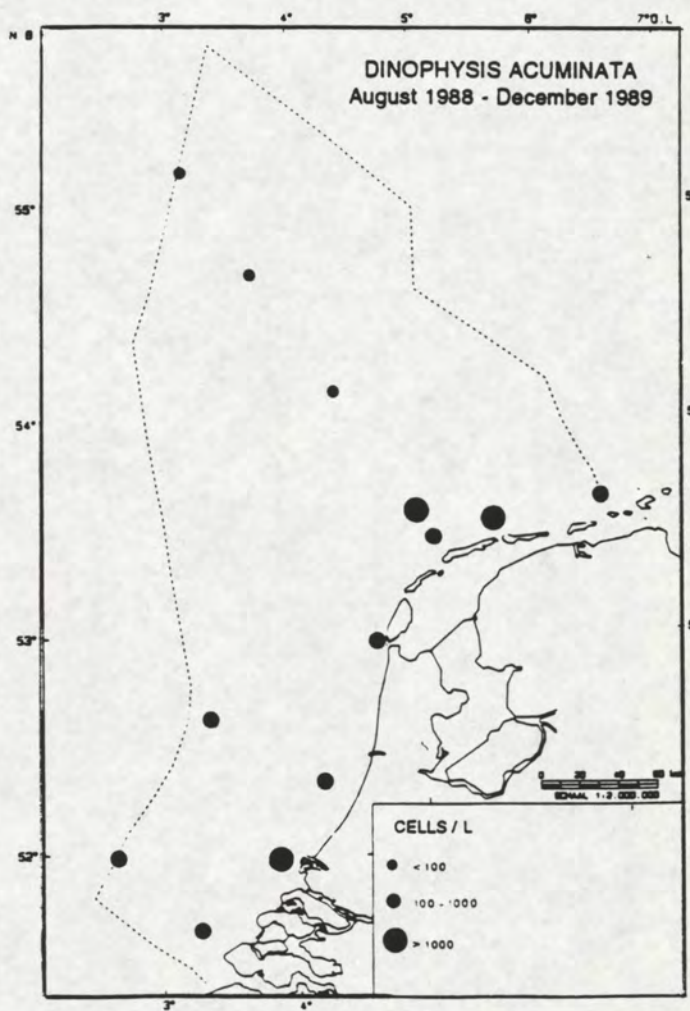
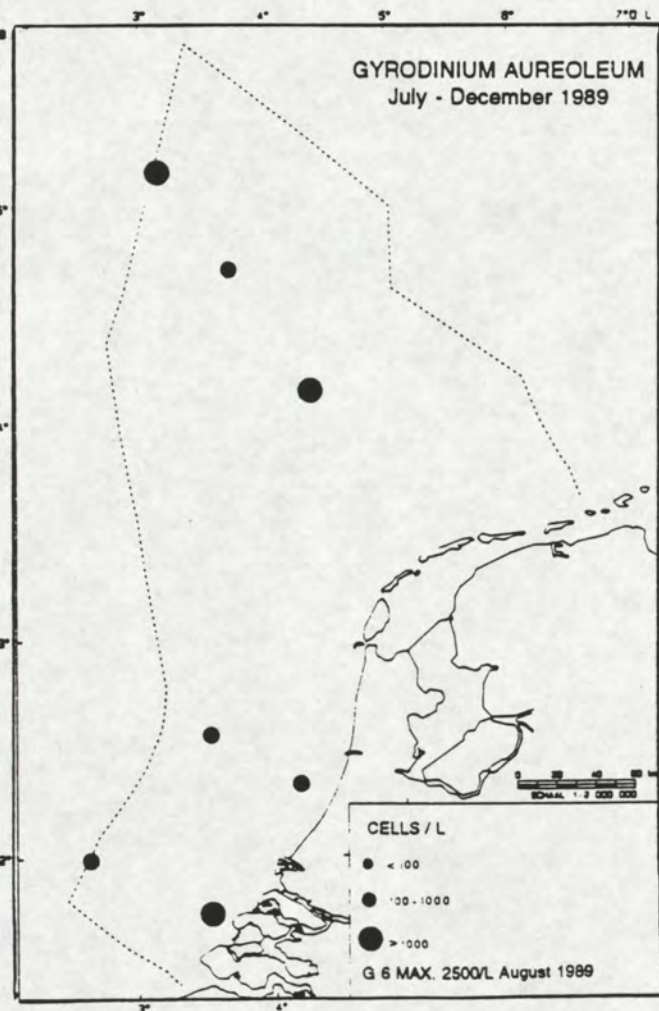
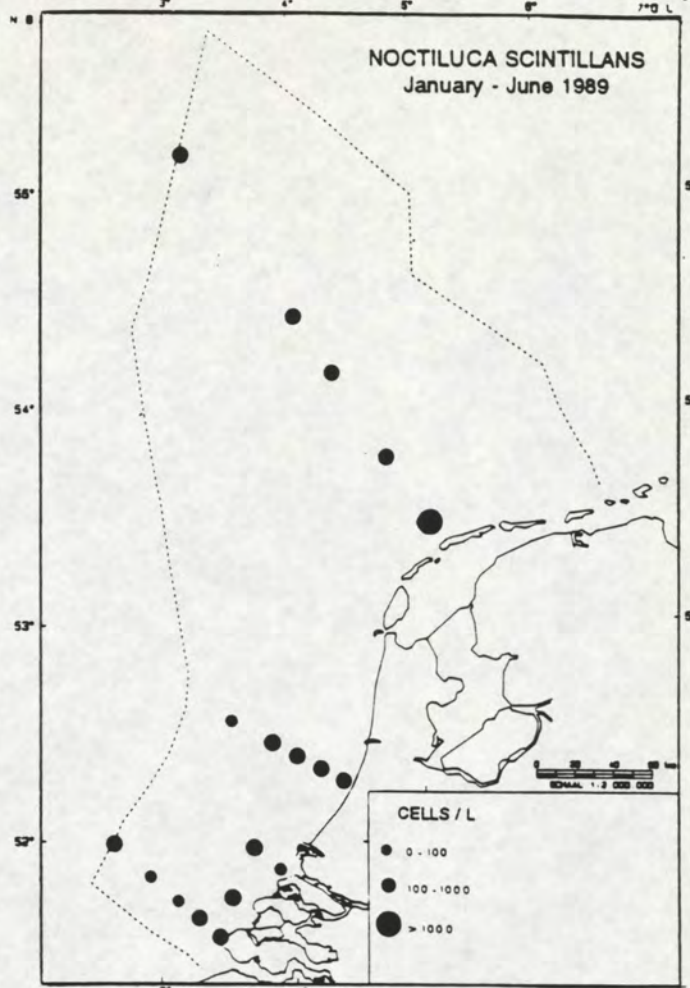
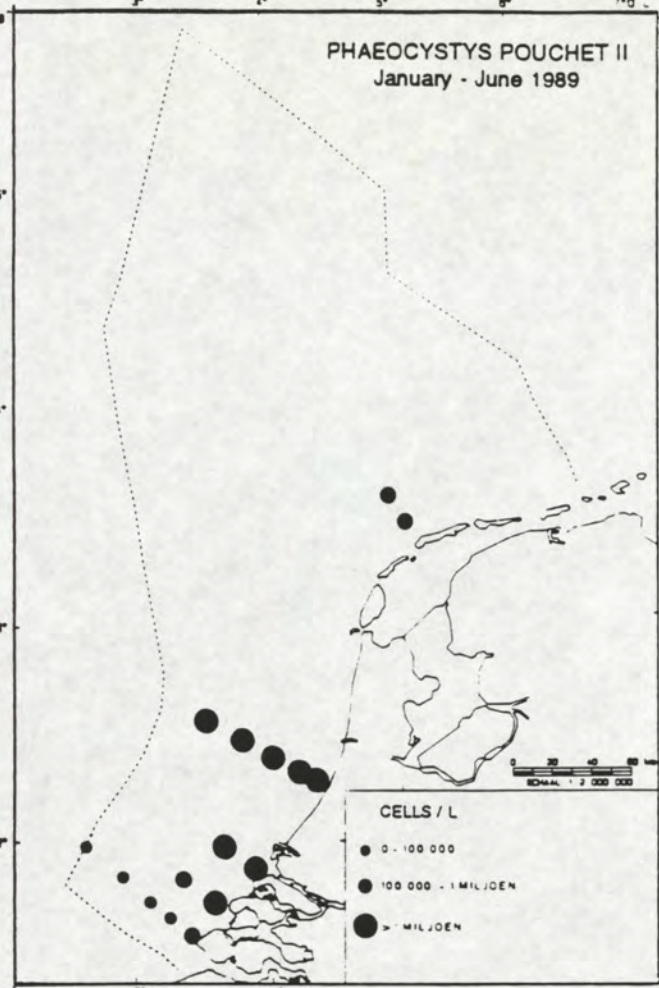
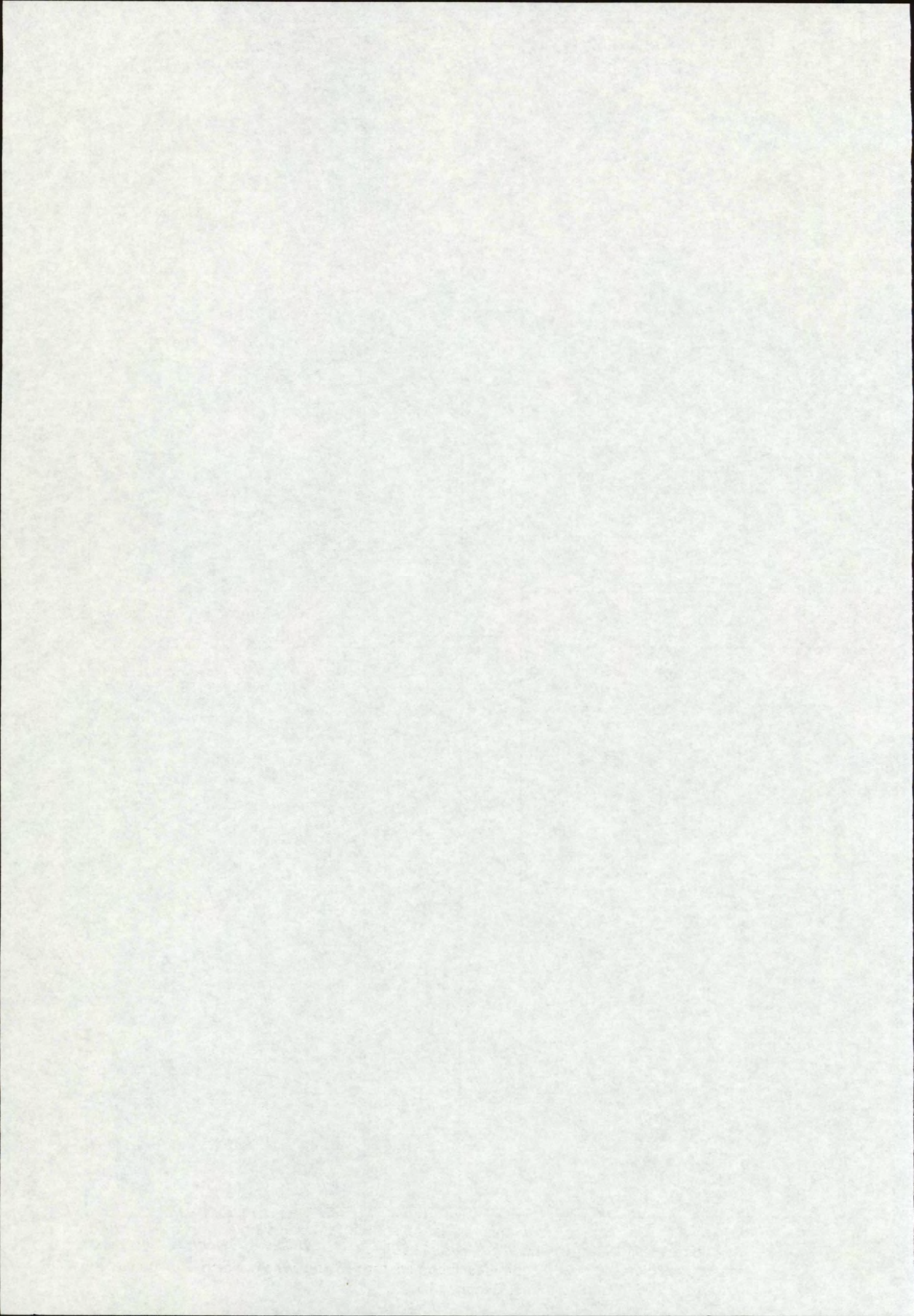
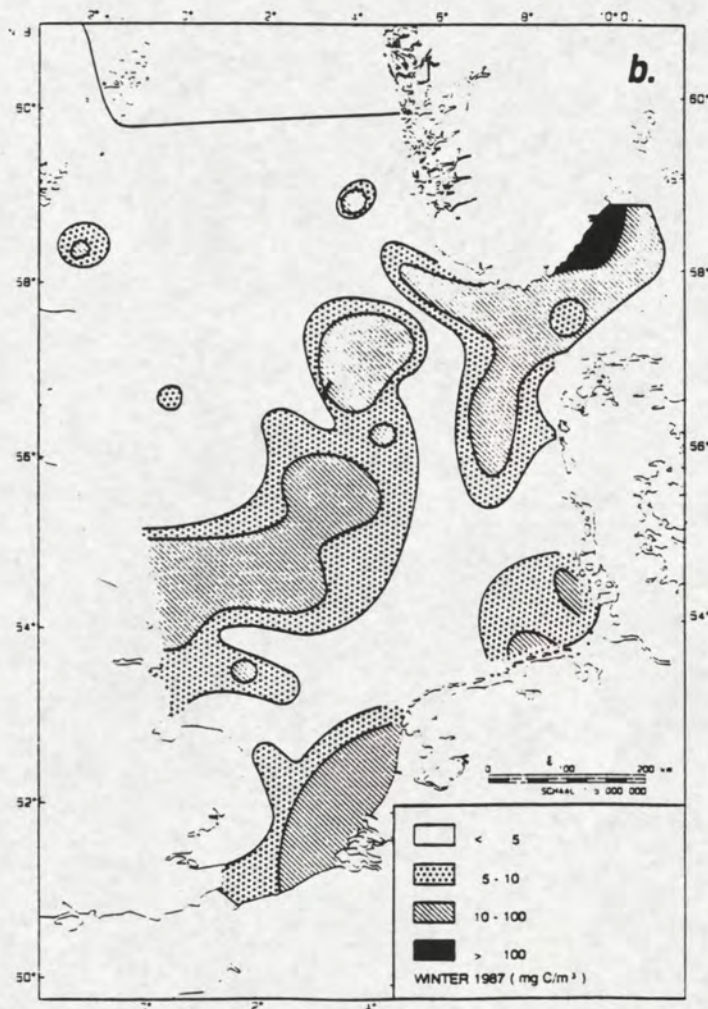
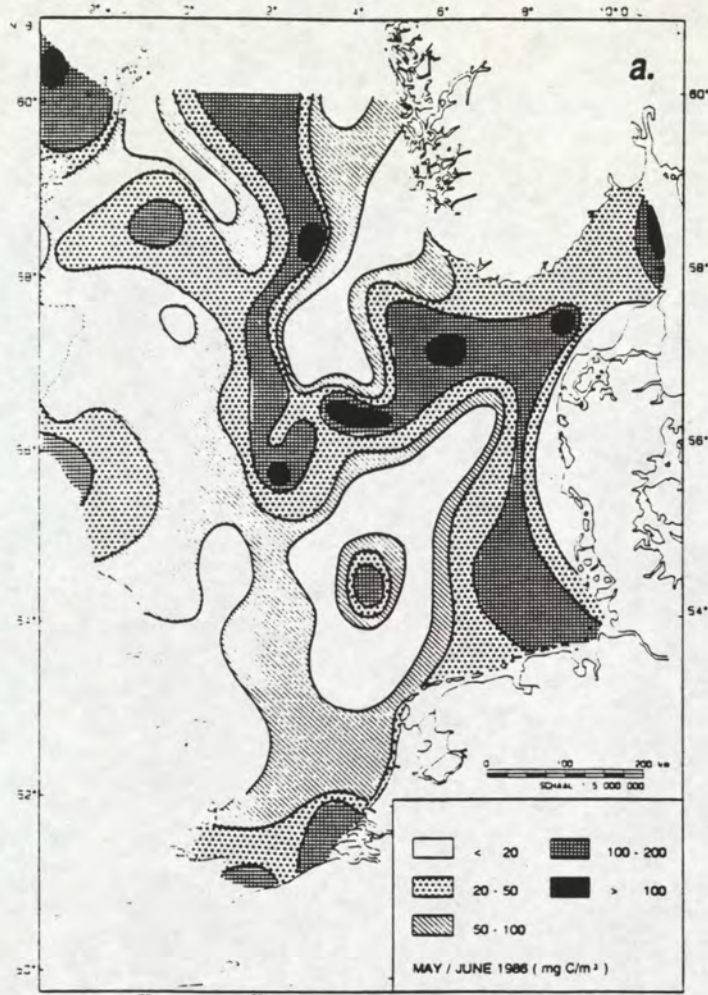


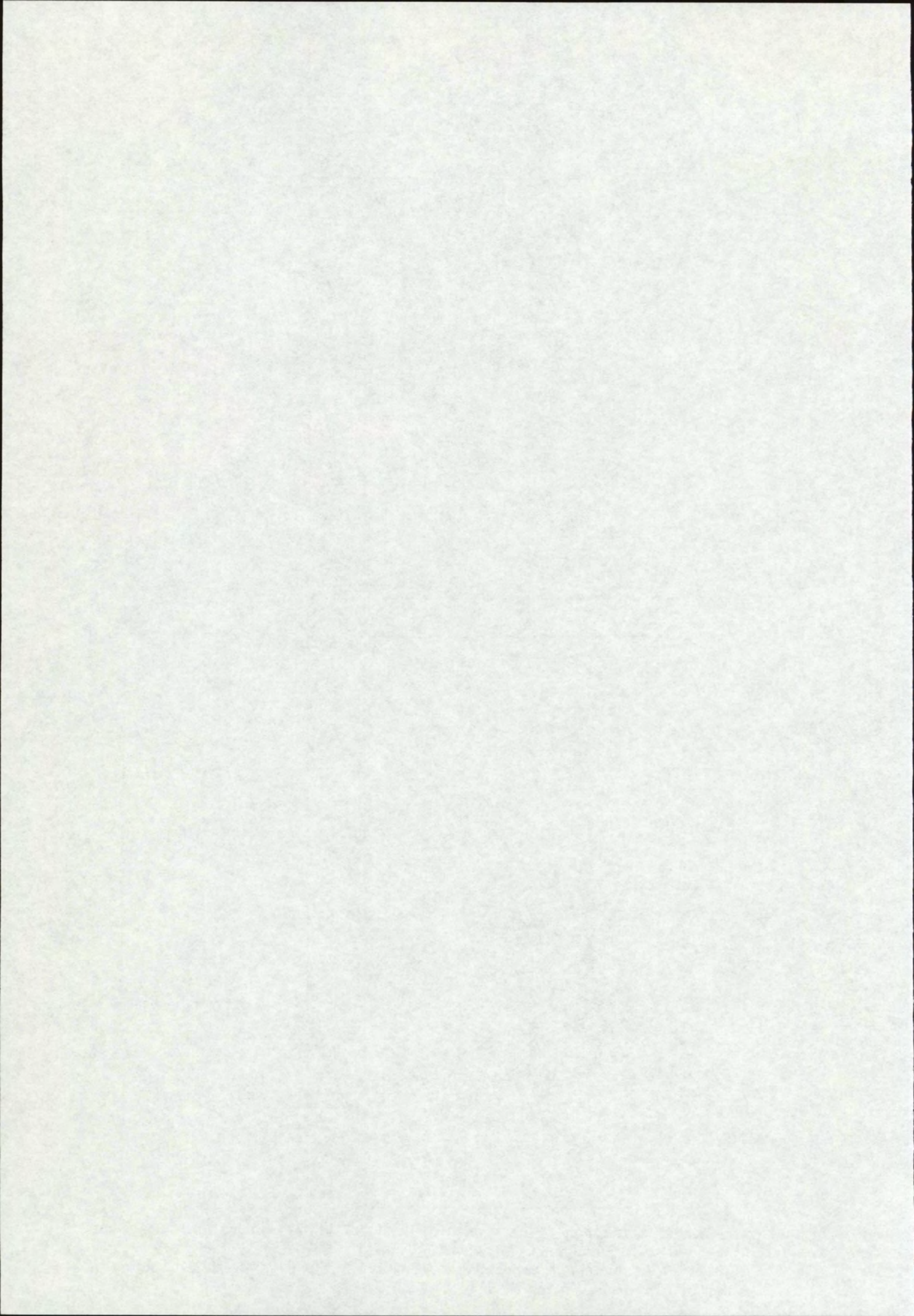
Fig. 3c The distribution of *Phaeocystis pouchetii*, *Noctiluca scintillans*, *Dinophysis acuminata* en *Gyrodinium aureolum* on the DCS in 1989. (Zevenboom et al. 1990).





**Fig. 4a** The spatial distribution of copepods (zooplankton) in the whole North Sea during May/June 1986 (Sündermann & Degens, 1989).

**Fig. 4b** The spatial distribution of copepods (zooplankton) in the whole North Sea during the winter of 1987 (Sündermann & Degens, 1989).



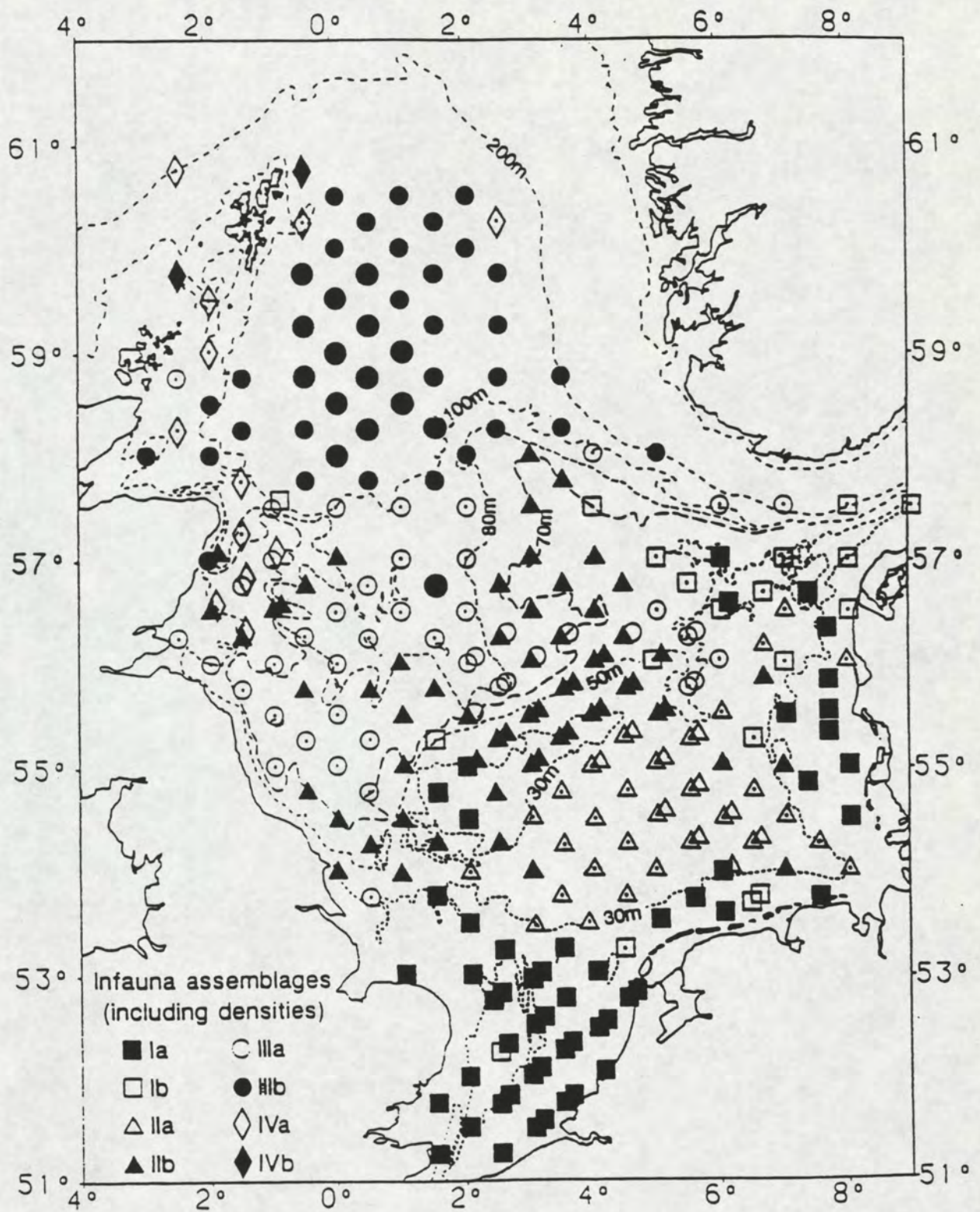


Fig. 5a TWINSpan classification of North Sea macrobenthos, based on density (Künitzer et al., 1992).

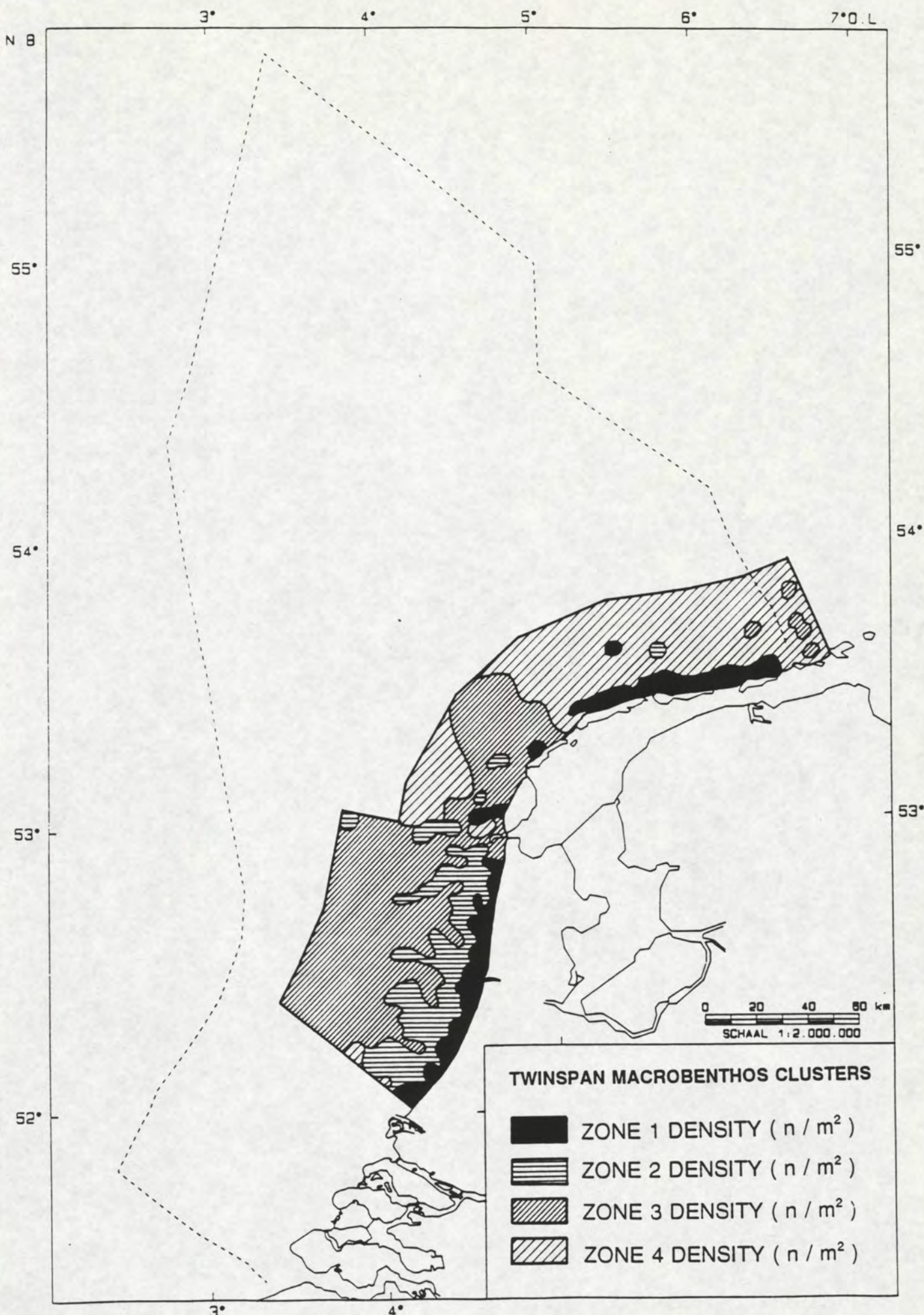
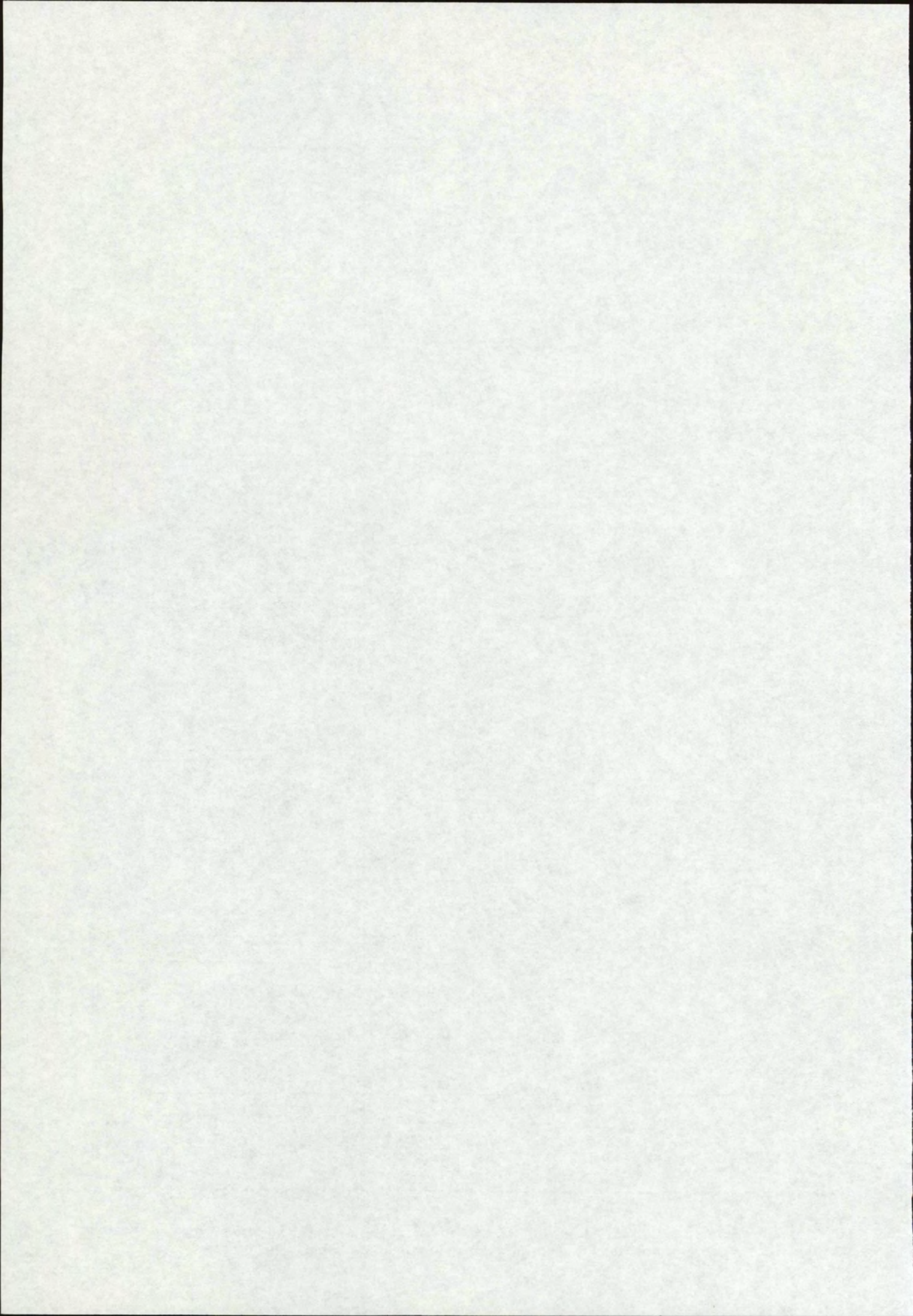


Fig. 5b Zones distinguished in the MILZON-BENTHOS area (1988-1989) on the basis of macrobenthos density (van Scheppingen and Groenewold, 1990).



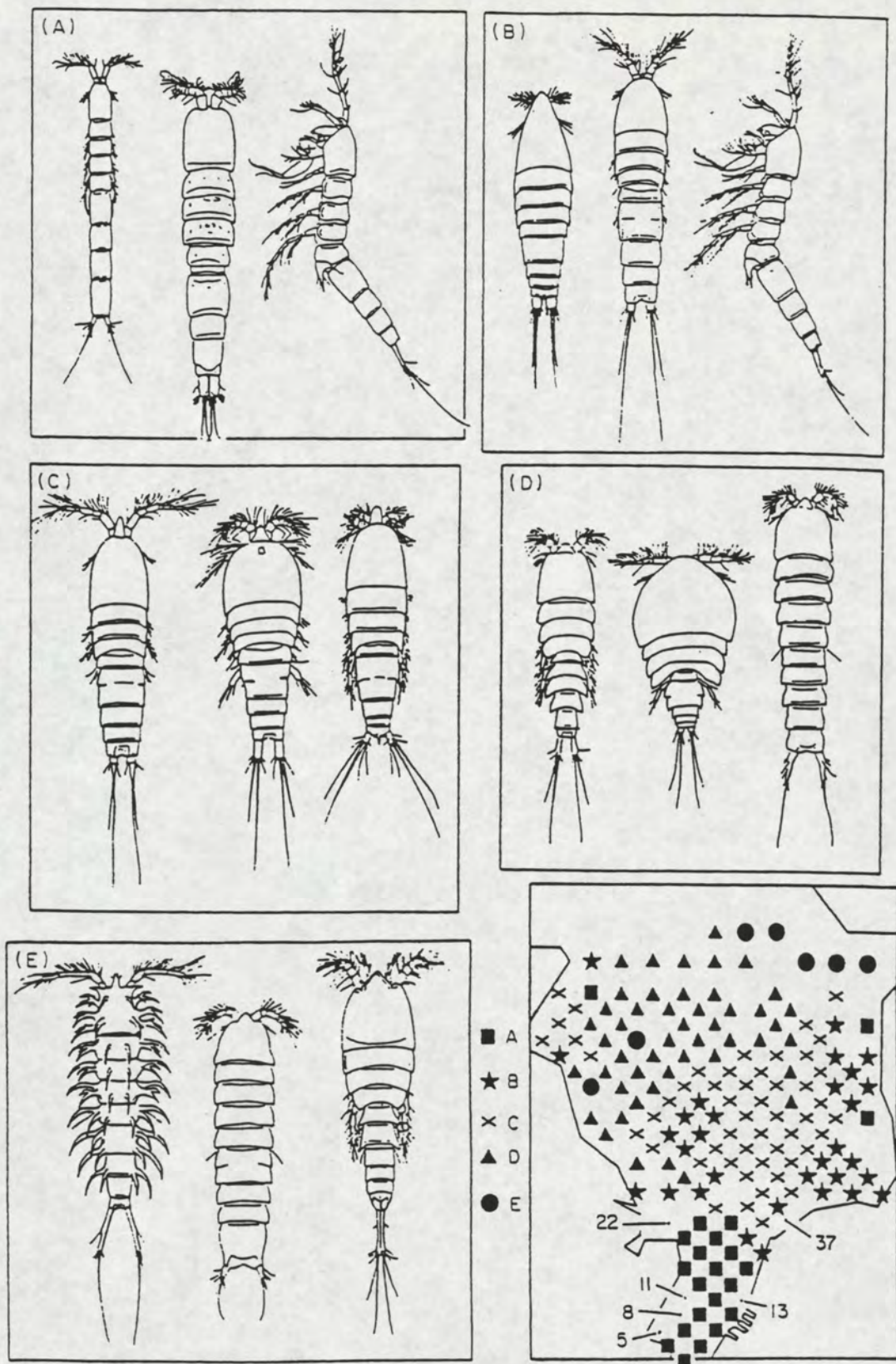
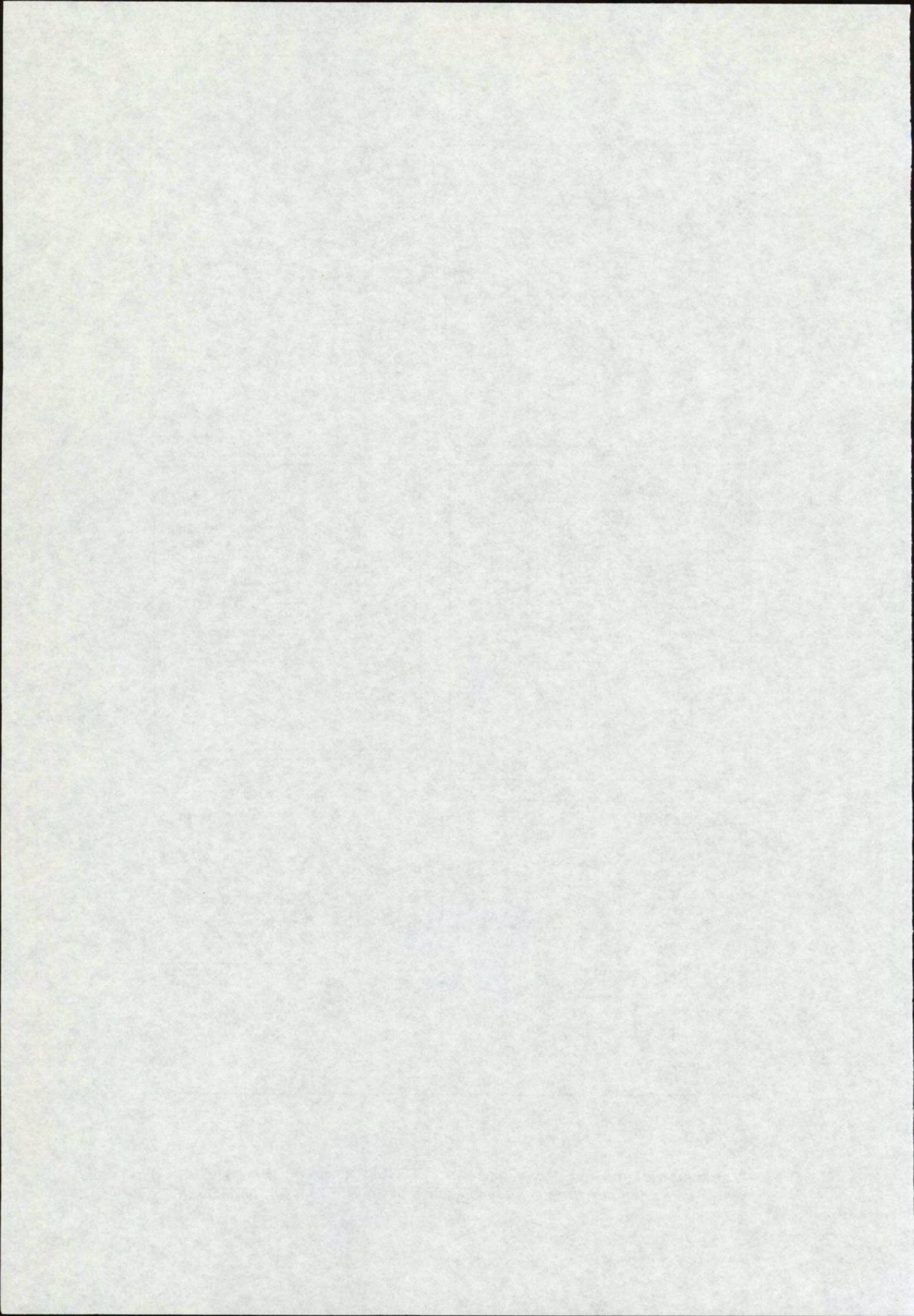


Fig. 5c Distribution of the five most important TWINSPAN station groups in the North Sea, with the most important ecotypes in each TWIN-group (Huys et al., 1992).



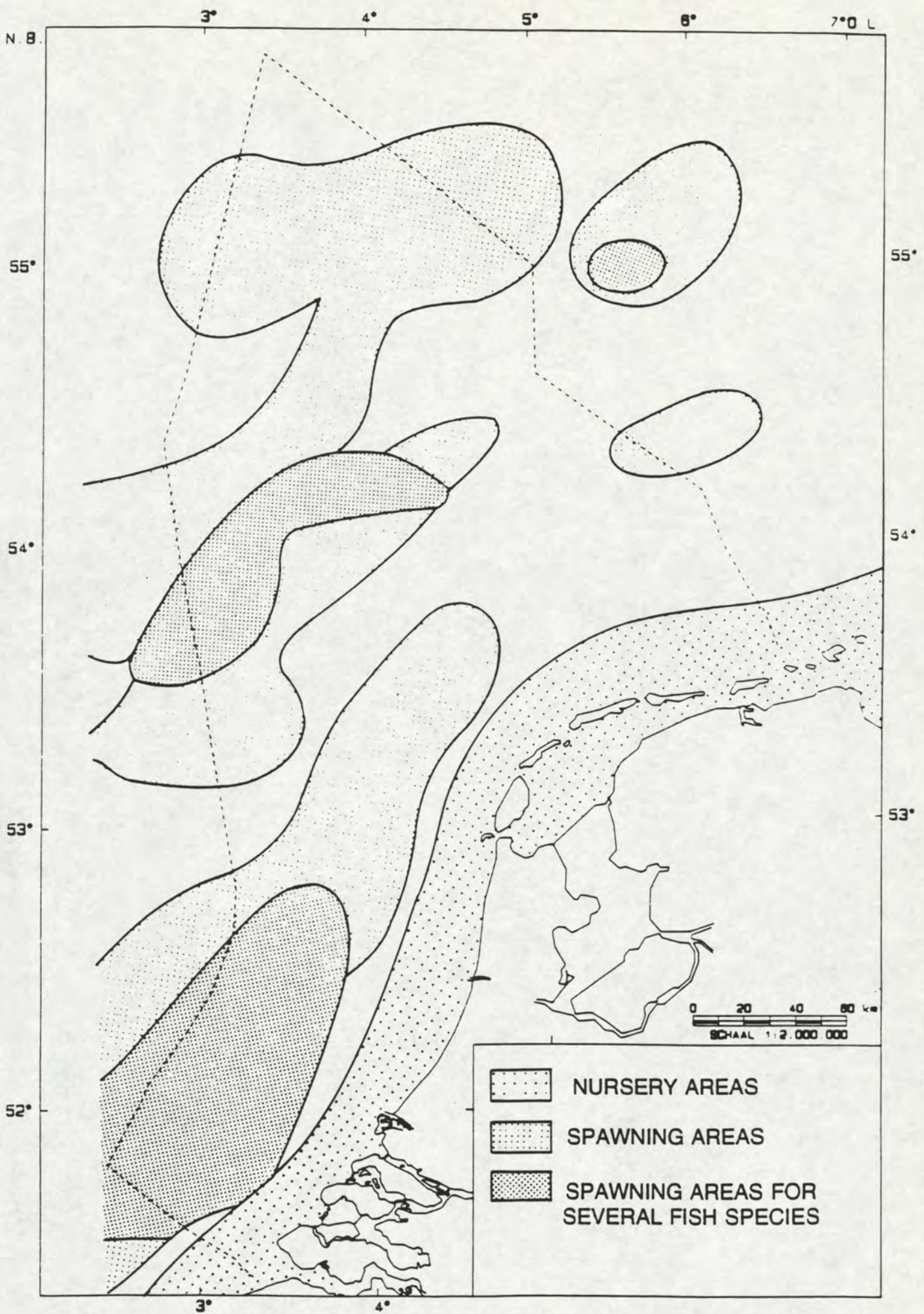
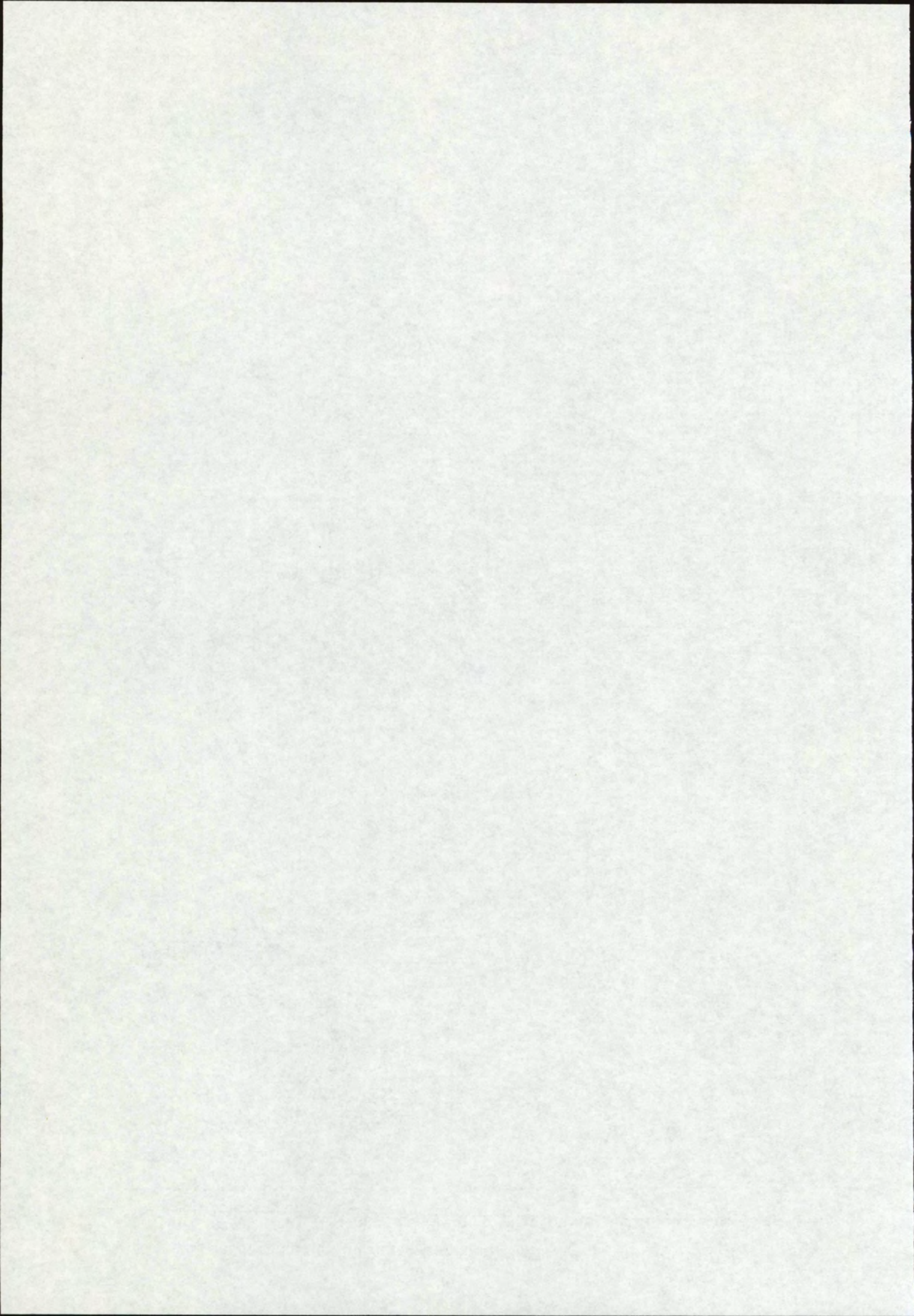


Fig. 6a Fish spawning and nursery areas on the DCS, 1960-1976 (Bosschieter, 1981).



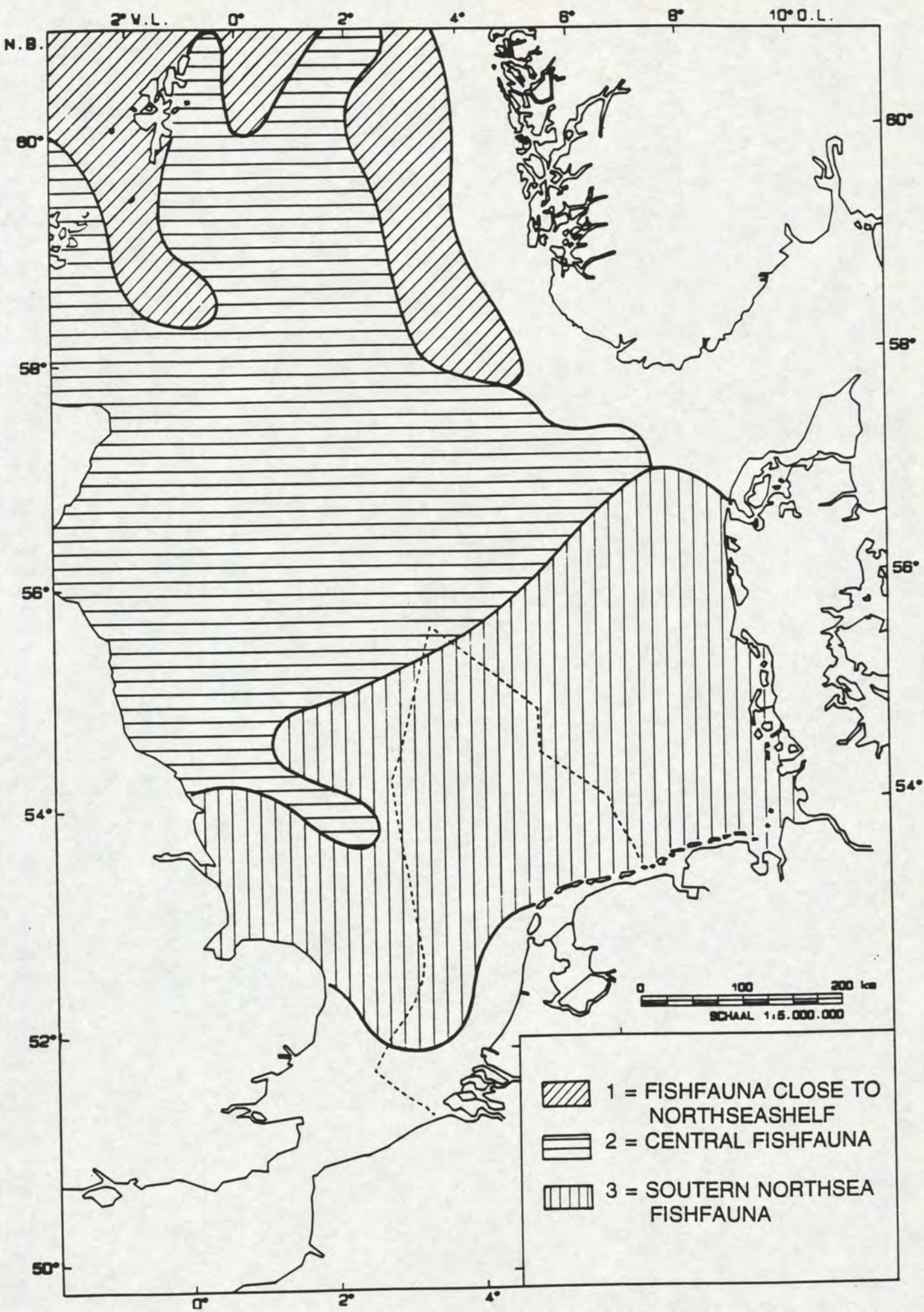
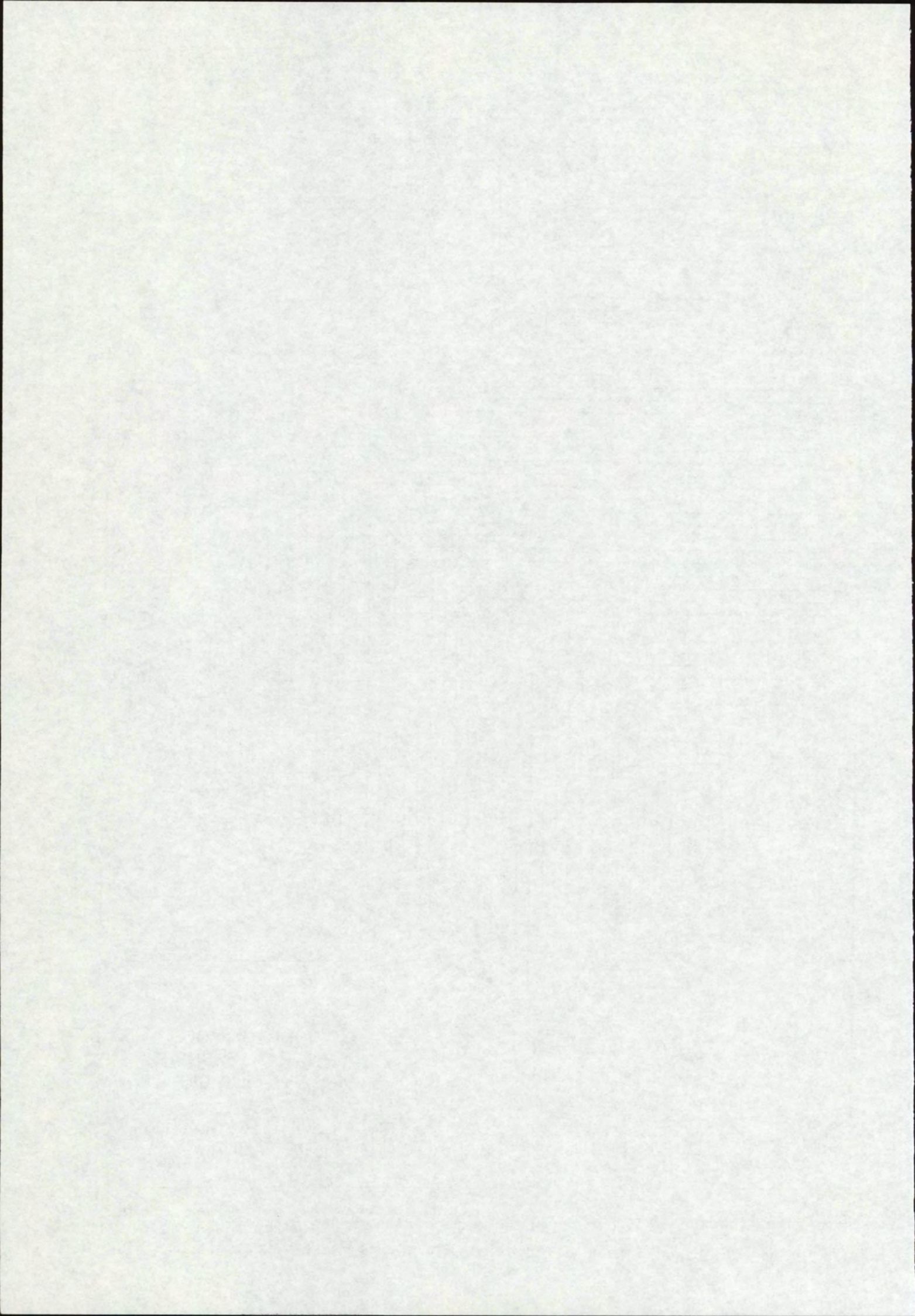
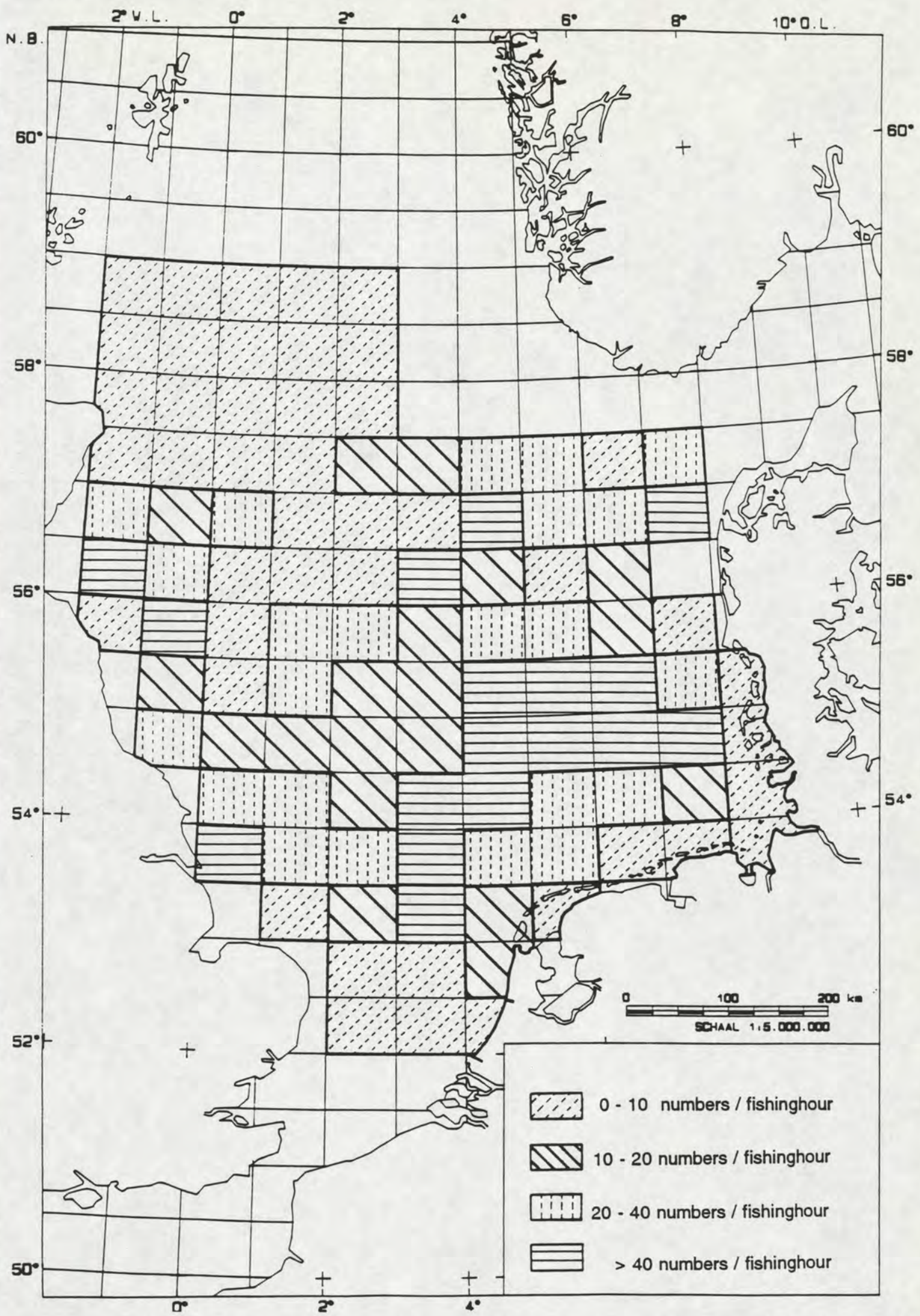
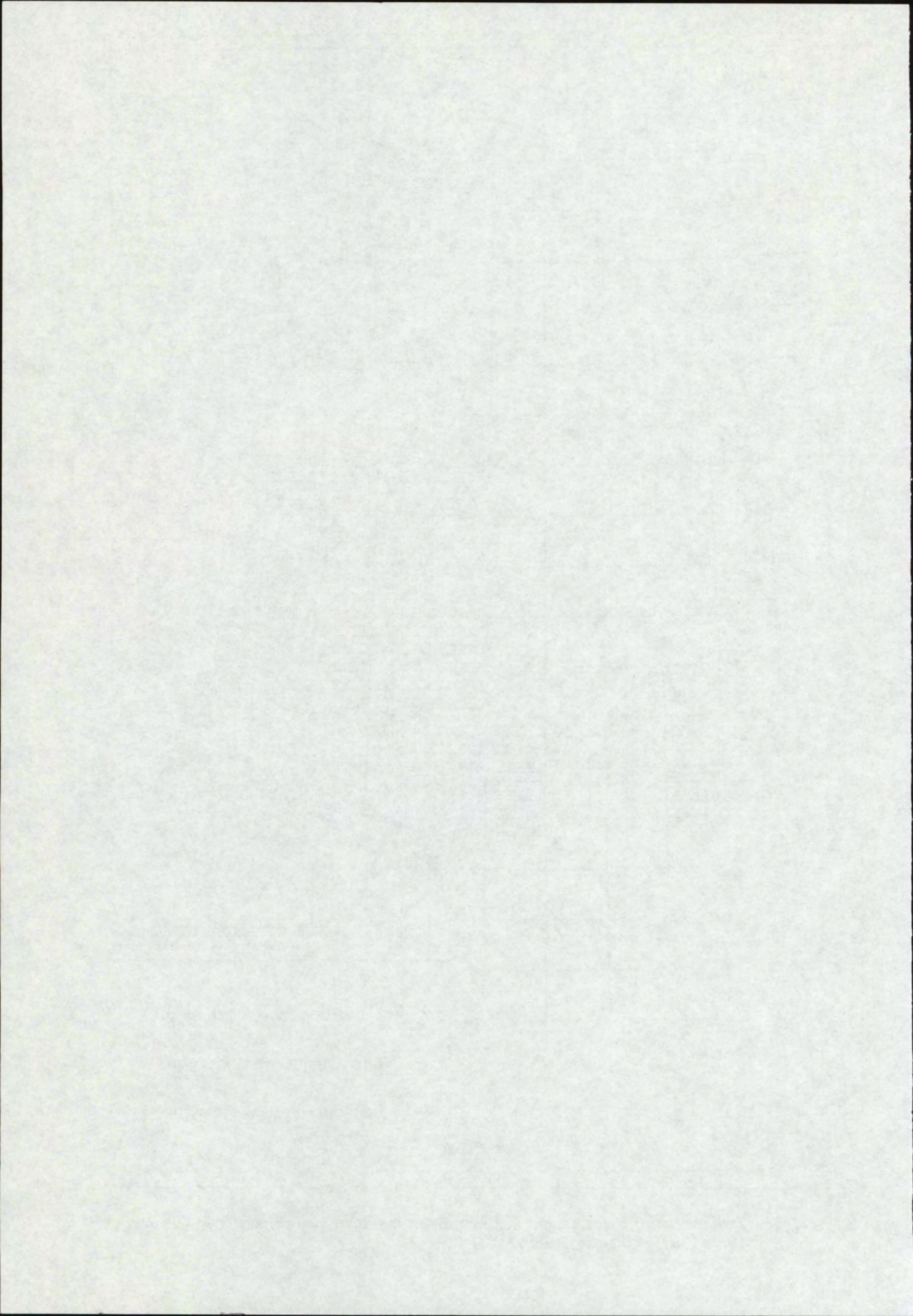


Fig. 6b Distribution of fish fauna in the North Sea, in three main groups (Daan et al., 1990).





**Fig. 6c** The number of plaice caught per hour during the third quarter, averaged over the years 1985-1987 (Welleman, 1989).



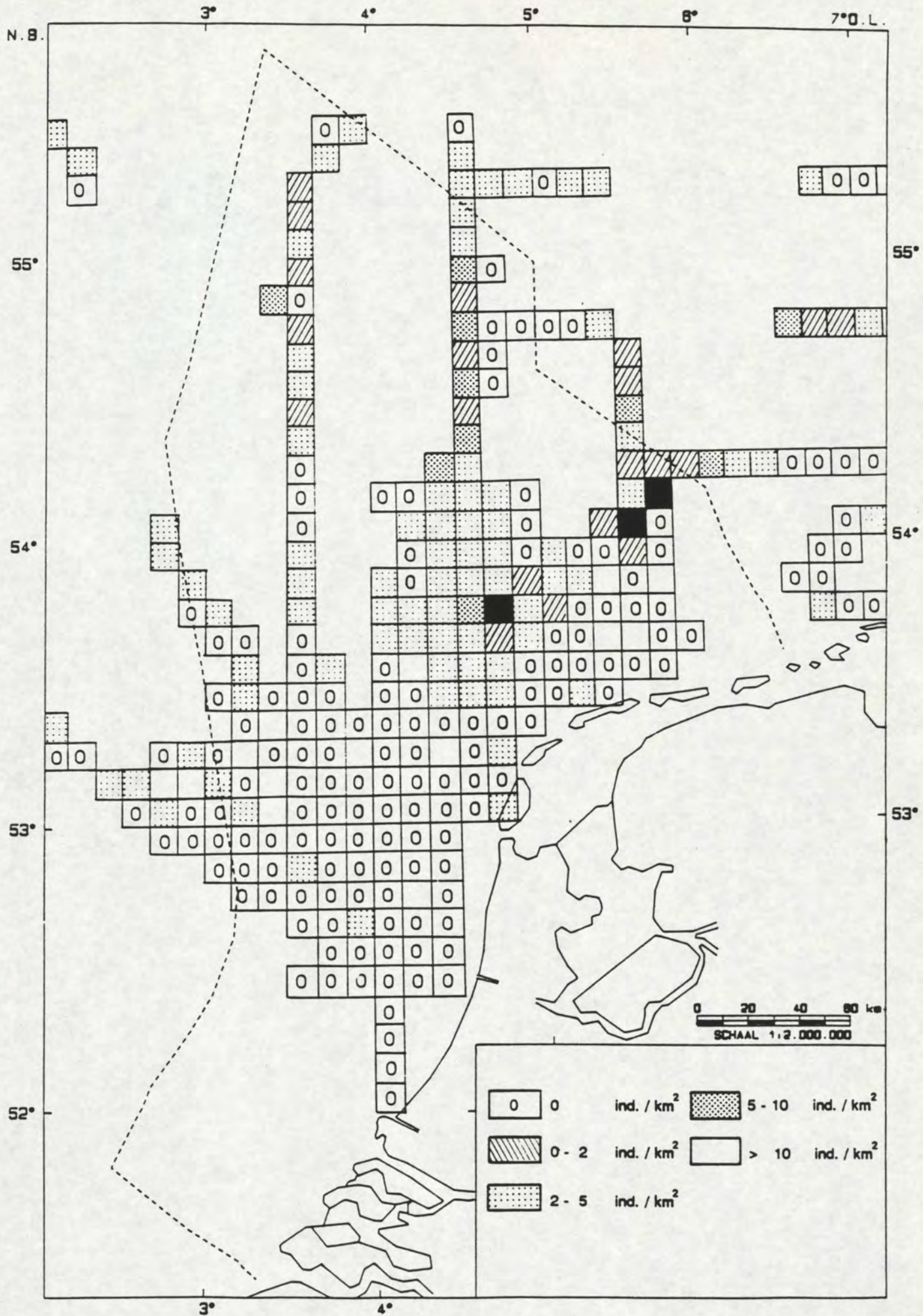
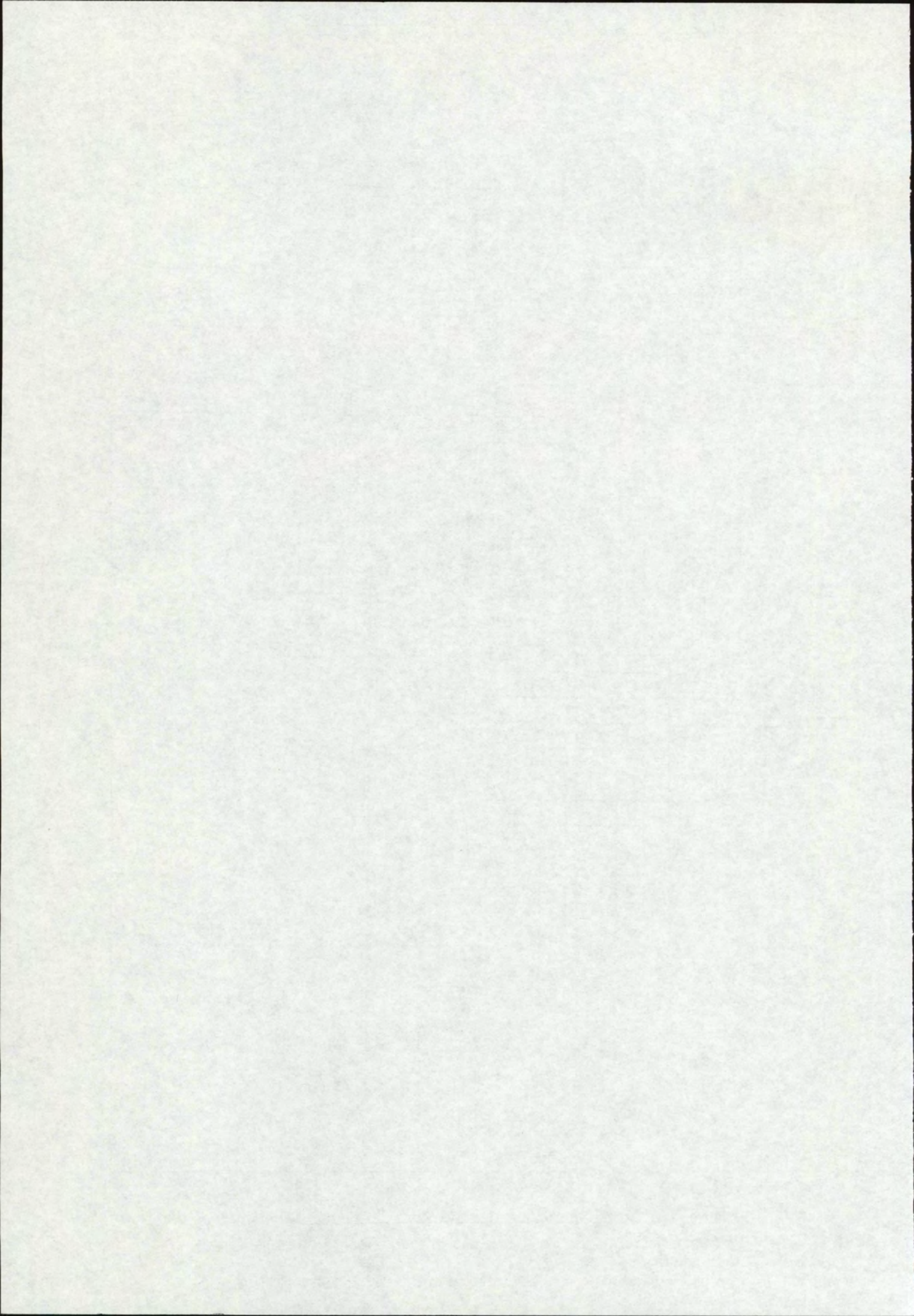


Fig. 7 Distribution of the guillemot (number/km<sup>2</sup>) in August-September in the North Sea (Leopold, 1991).



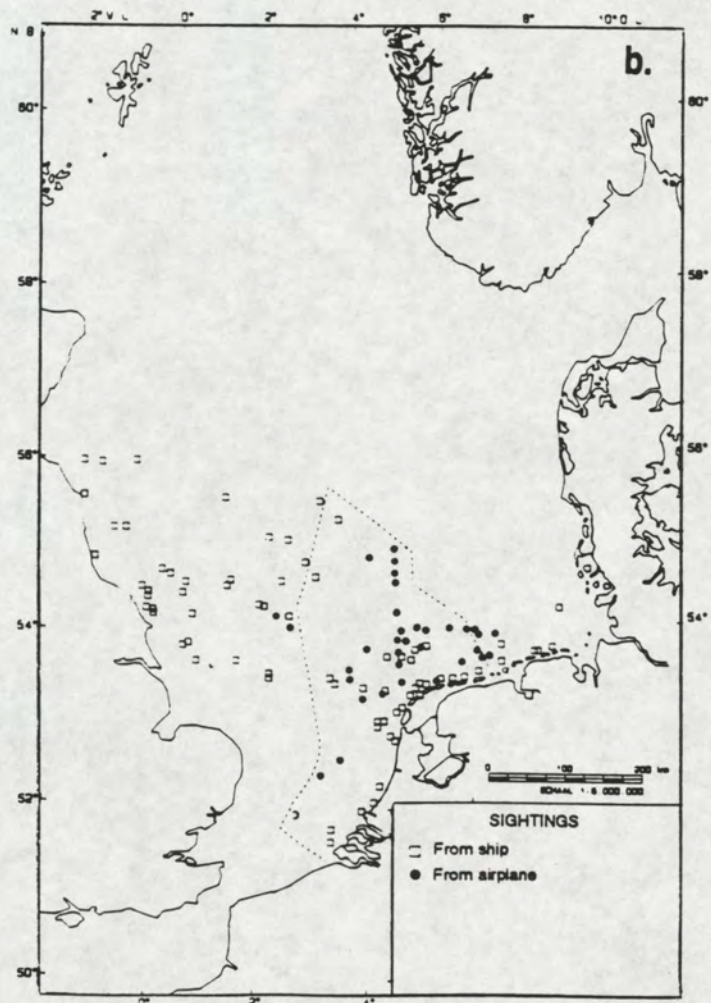
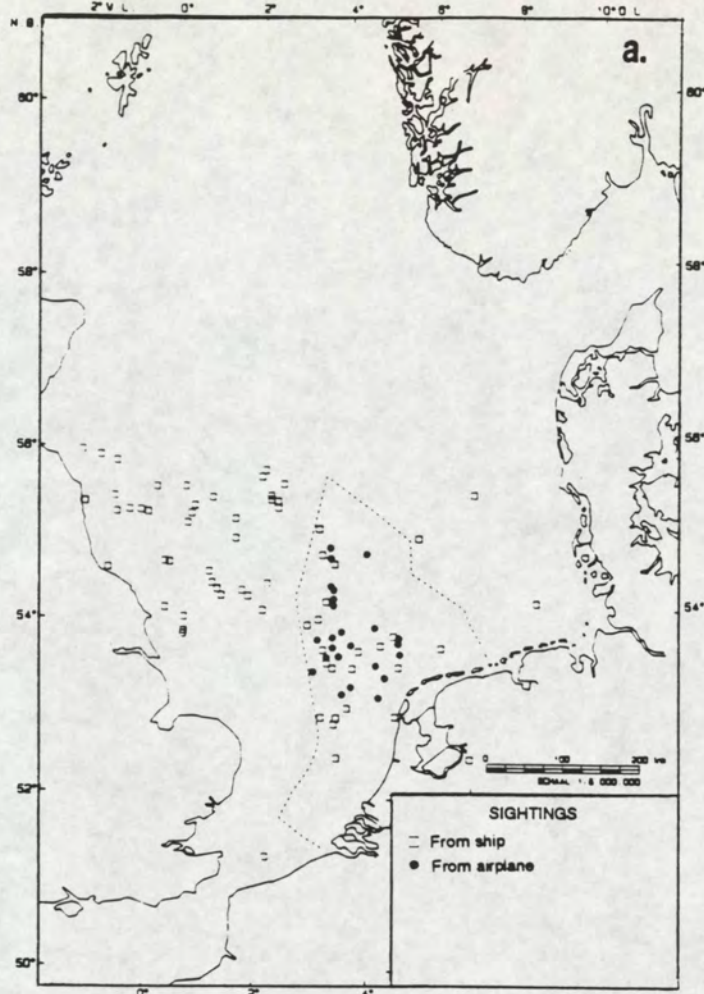
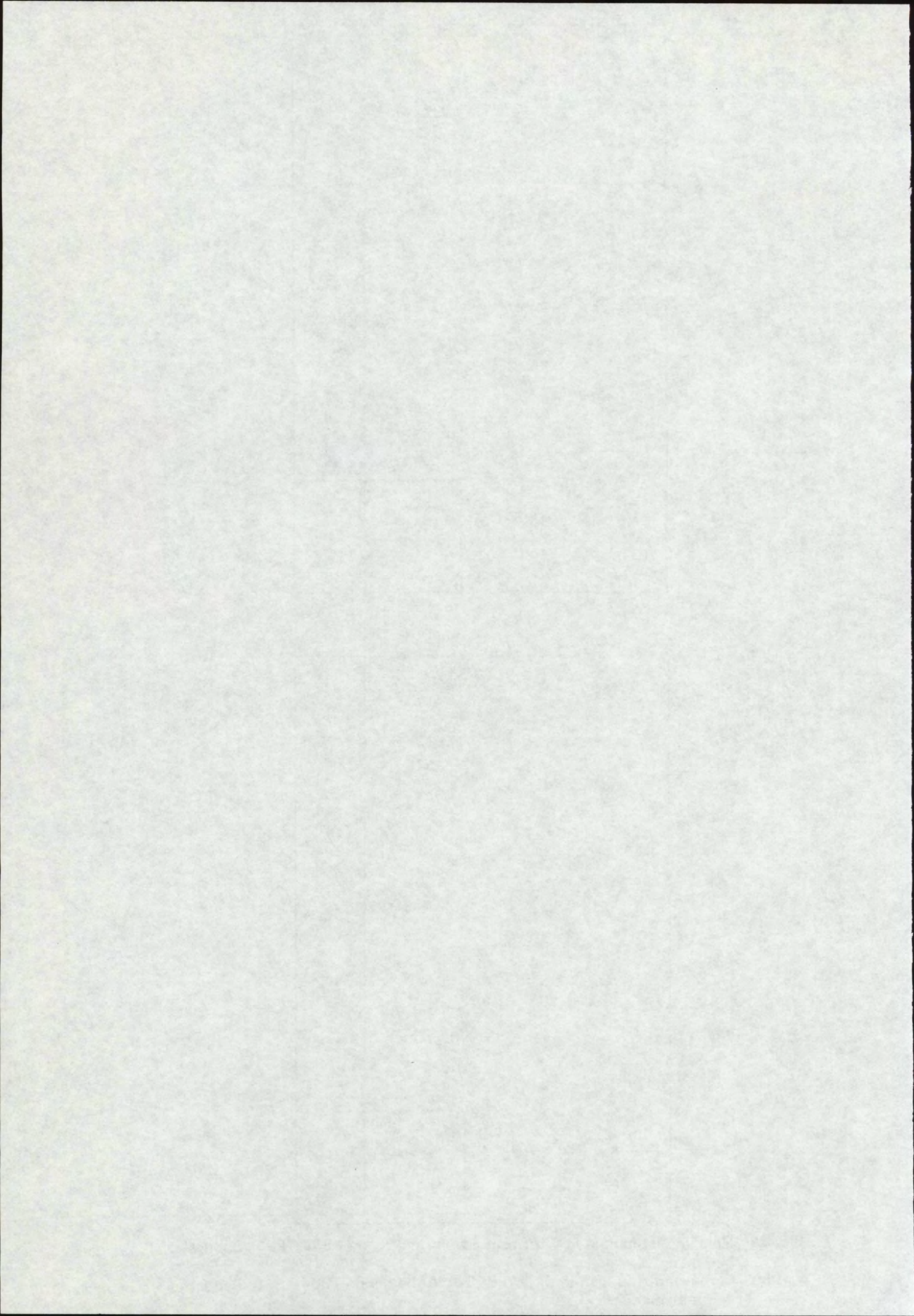


Fig. 8a Dolphin distribution in the North Sea in the period 1984-1990 (Baptist et al., unpublished material).

Fig. 8b Porpoise distribution in the North Sea in the period 1984-1990 (Baptist et al., unpublished material).



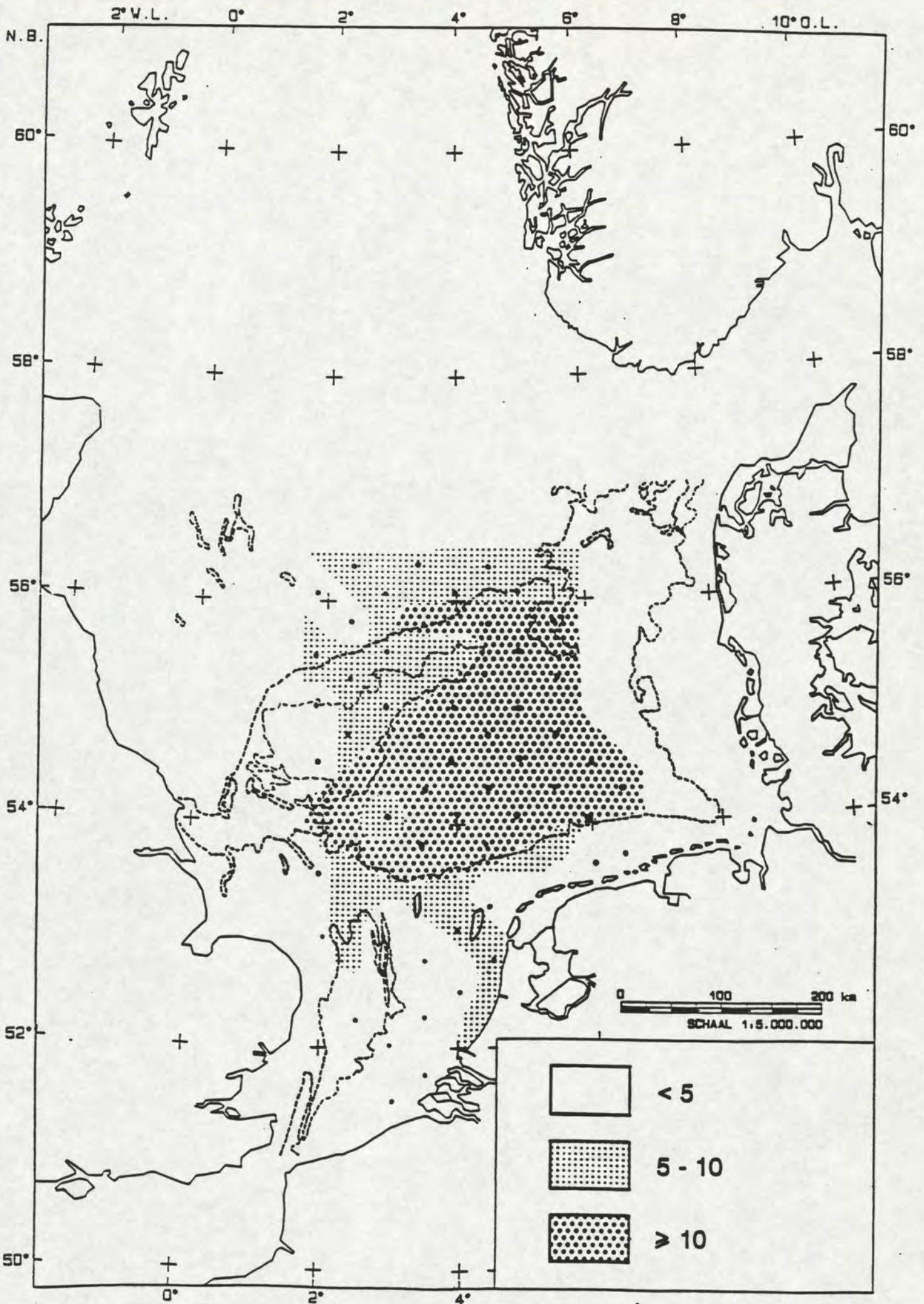
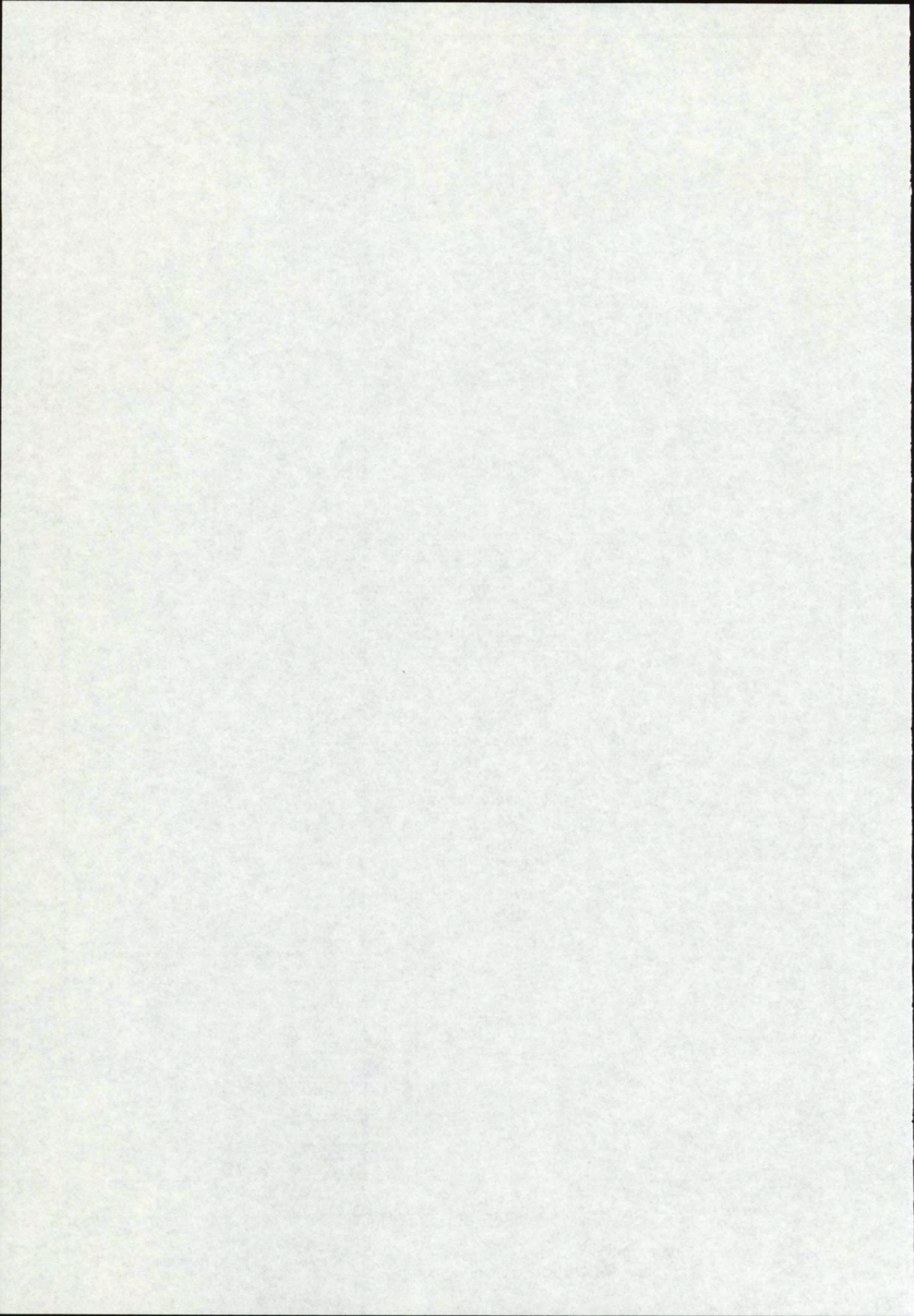


Fig. 9 Distribution of species sensitive to oil-containing drilling mud (max. 17) on the DCS (De Wilde and Duineveld, 1990; Daan et al., 1990).



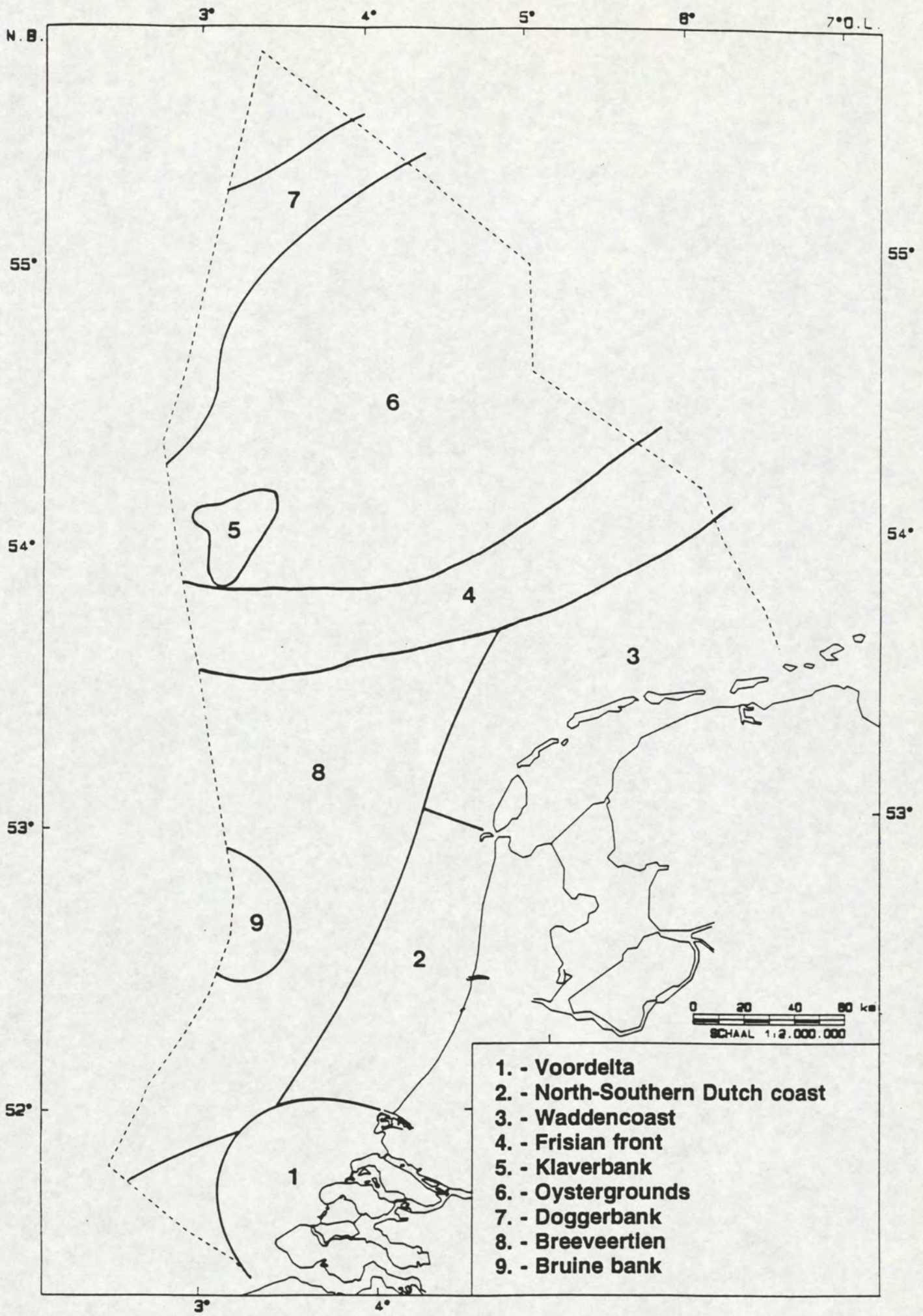
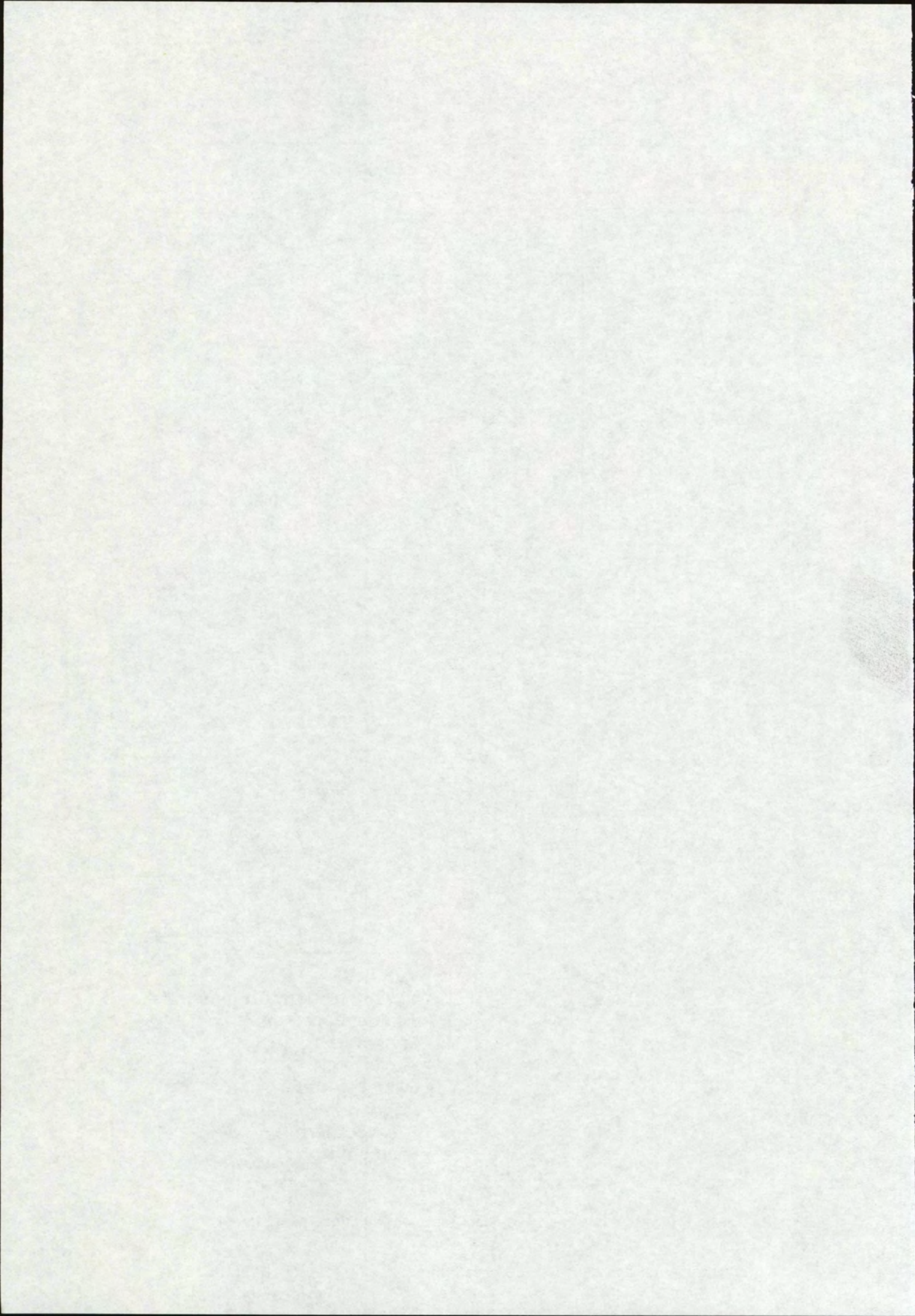


Fig. 10a Areas of the DCS based on ecosystem features (this document, 1991).



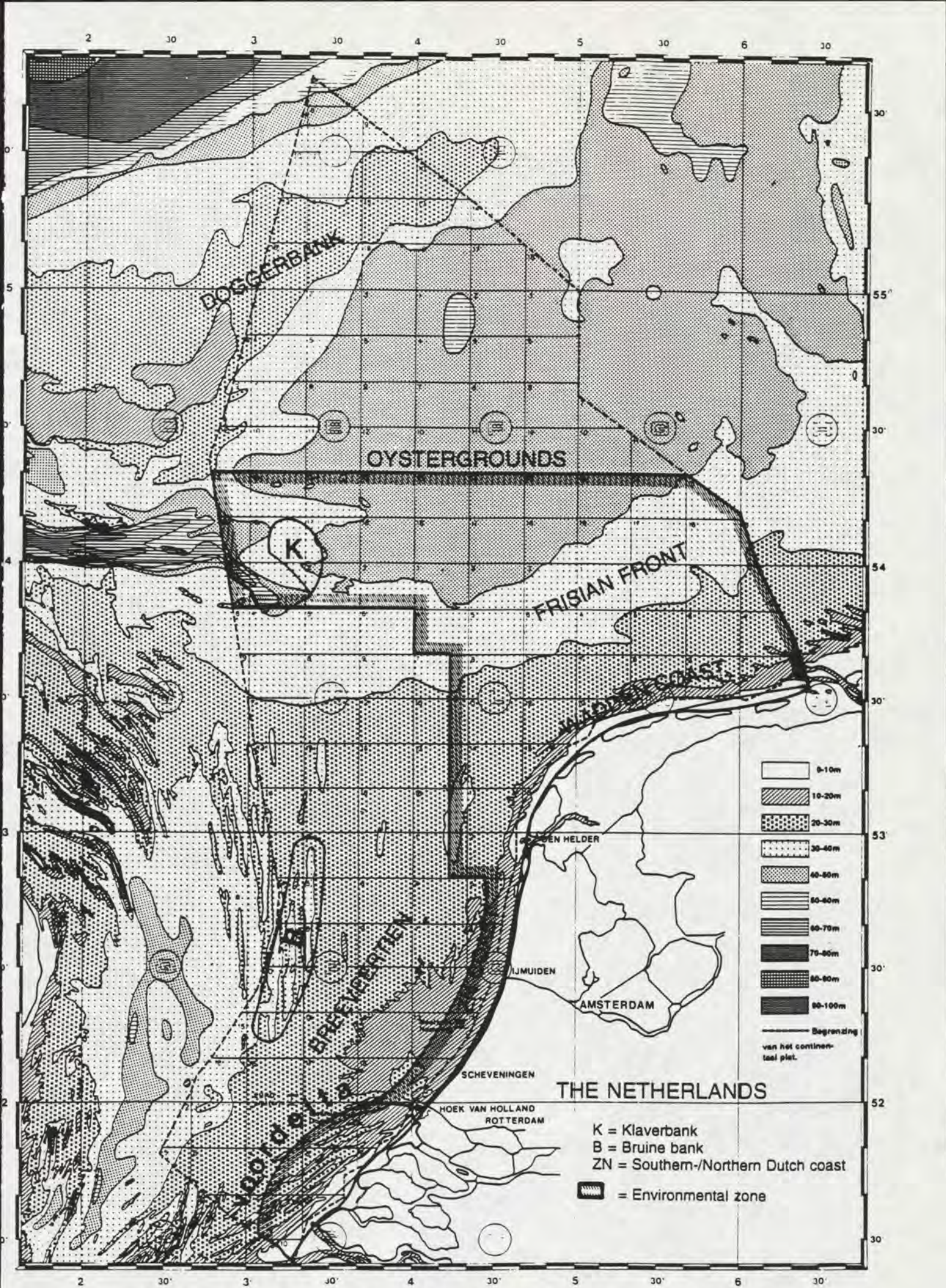


Fig. 10b Environmental Zone on the DCS based on ecosystem features (WSMP, 1991).

