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EUTROPHICATION ON THE NORTH SEA CONTINENTAL ZONE, A BLESSING IN DISGUISE

by

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SUMMARY

North Sea landings of demersal fish rose after 1963 to more than 1 million tonnes from a rather constant level of about 400,000 tonnes since 1909. Landings of bivalves from the Dutch coastal zone increased greatly after 1950. From the data presented, a structural change in productivity of the Southern and Central North Sea in the period 1950-1985 as the result of eutrophication of the continental coastal waters emerges as the most likely cause of the enhanced commercial production. Therefore, the continuing decrease of the discharge of phosphate to the southern North Sea since the beginning of the eighties, is likely to have negative effects on the production of fish and shellfish in the S-E North Sea.

INTRODUCTION

Landings of demersal fish species from the North Sea have been remarkably stable for a long period (fig.1). Holden (1978) described the trends in the total yield of North Sea fisheries in 1909-1973. He points at the marked stability in demersal landings till 1955 and shows the exponential rise after 1960. Large individual stocks show the same pattern. Daan (1978) demonstrated the remarkable constant nominal catch of North Sea cod from the beginning of the century up to 1965, varying between 60 and 100 thousand tonnes. The annual yield of the North Sea plaice stock deviated not very much from the 55,000 ton level between 1906 and 1938 and fell after a post-World War II peak of 100,000 tonnes in the early fifties towards the prewar average level (Bannister, 1978).

The stability in demersal landings, in spite of climatological fluctuations and varying yearclass strength of individual stocks, suggests that in the first half of the 20th century the demersal fish production was a derivation of a rather constant natural productivity of the North Sea. That the modest increases of landings after the world wars were not sustainable indicates that fishing effort indeed was rather high then in relation to recruitment and growth.

For North Sea plaice, Bannister (1978) calculated for the period 1929-1938 a weighted mean fishing mortality across all age groups of 0.32. In comparison, weighted fishing mortality of North Sea plaice of all age groups excluding age group 1, was 0.43 in 1980 and 0.41 in 1985. Bannister concludes also that it is likely that the plaice fishery approximated to a steady state in 1906-1938, perhaps on a flat-topped part of the yield per recruit curve (which is similar to the present day situation) and states that it is doubtful that any of the changes which have occurred in yield (after 1955) represent the effect of a major difference in the area of the plaice stocks being fished before and after World War II.

For North Sea cod, fishing mortality shifted towards the smaller sizes from the twenties till 1969-1973, although the general level of F over all size groups combined was very similar (Daan, 1978).

Baerends (1947) analyzed the North Sea fisheries in 1930-1939. He concluded that the landings of demersal fish in that period were negatively influenced by overfishing and an unfavourable exploitation pattern and calculated on basis of prewar data that the North Sea could produce not more than 392,000 tonnes of demersal fish including undersized specimens. The outcome of his analysis is in line with the long term trend in landings. No discard data were available from this period but discards were considered relatively small. Baerends stated further: "These calculations do not include the possibility that, due to changes in hydrographical conditions, the fertility of the North Sea and with that the production power can change. It is unlikely that in this century considerable changes in environmental conditions have occurred. In the future however, this possibility must be taken into account." Landings of demersal fish started to rise around 1955 and soared till a level of 1 million tonnes after 1963. The statements of Baerends get a prophetical value if we compare the maximum of 392,000 tonnes mentioned by him, with the average catch of demersal fish, in 1981-83 of 1,166,000 tonnes, including an estimate of unreported landings and (partially) discards. In the Dutch Wadden Sea, commercial landings of bivalves, mussel (Mytilus edulis) and cockle (Cerastoderma edulis) also rose strongly during the fifties and sixties.

Heessen (1988) points at the sequence of strong yearclasses of several demersal species since the sixties without giving an explanation for this phenomenon. An extensive overview of North Sea fish stocks has been presented by Daan et al, 1991. They mention the possibility that eutrophication in the waters along the continental coast has a local effect on the productivity in some important nursery areas, which may radiate over wider areas.

The total biomass of commercial demersal fish species in the North Sea was estimated to be 4.3 - 4.5 million tonnes in 1983-1984. (Sparholt, 1990). It is highly unlikely that a biomass of this size has been present in the North Sea in historic times. Against this plea the numerous indications that demersal stocks in the North Sea were overexploited before 1940 and that fishing mortality was considered too high as well in 1983. (Anon, 1985).

Improved catching possibilities in the central and southern North Sea after 1960 lead to the build up of specialized fleets in these areas. The international fishing effort on North Sea sole doubled from 1965 till 1967 when the very strong sole year class 1963 appeared in the catches. (de Veen, 1978). This mainly Dutch fleet turned to directed plaice fishing also in later years. After the appearance of very strong year classes in 1969 and 1970, fishing mortality of North Sea cod started to rise gradually from approximately 0.5 in 1970 to 0.8 around 1980 and stayed at that level ever since. (Anon. 1990). Thank to the specialization on flatfish and roundfish in southern and central North Sea, Dutch fisheries got an unproportional large share of the increase mentioned above (table 1). This increase took place in spite of a greatly reduced range of action. In historic times Dutch fishermen went to Iceland on sailing boats to catch modest amounts of cod, what is hard to imagine if this species could be caught in commercial quantities nearer by. Around 1920, Dutch hookliners fished occasionally in the central North Sea N-W of Heligoland, which area was known then among Dutch fishermen as "de Roggenzee" (the sea of rays). They fished there for rays and skates but only when catches of (more valuable) haddock in the northern North Sea were low (van Roon, 1975). The Dutch trawlers (689 in 1938) fishing mainly in the northern North Sea for haddock and cod, disappeared completely after 1960. In their place came cutters (610 in 1988) fishing mainly for plaice, sole, cod, whiting and brown shrimp in the south eastern North Sea.

Table 1. Demersal landings ('ooo tonnes) in the Netherlands in different time periods, percentage of total North Sea landings in brackets.

SPECIES	1935-38	1956-60	1971-74	1981-83
Cod	4.4 (6.3)	5.5 (4.6)	36.2 (12.0)	44.0 (16.7)
Haddock	6.7 (9.5)	9.7 (10.8)	4.8 (2.2)	1.6 (1.0)*
Whiting	2.2 (5.2)	6.7 (8.9)	9.6 (6.1)	12.4 (12.7)
Saithe	2.3 (7.2)	2.9 (7.7)	13.9 (6.3)	0.1 (>0)*
Plaice	8.4 (16.2)	12.4 (15.1)	52.3 (38.1)	92.7 (63.6)
Sole	1.9 (29.1)	5.8 (40.0)	17.3 (74.9)	17.0 (82.8)
Turbot	0.9 (16.2)	0.9 (15.1)	2.6 (60.5)	3.3 (57.0)

* Disappearance of distant water trawlers

HYDROGRAPHY

The North Sea is a shelf sea of the Atlantic Ocean, connected by the Straits of Dover with the English Channel and by Skagerak and Kattegat with the Baltic (Fig. 2). The northern part is mainly 70-90 m deep, with the exception of the Norwegian Trench with a depth up to 761 m. The southern part is an adjoining basin with depths up to 36 m, containing only 5% of the total North Sea water mass of 54,500 km^3. The North Sea is flushed by Atlantic water with a relative high salinity, entering from the north between Scotland and Norway (50,000 km^3/year) and from the south through the Straits of Dover (4800 km^3) (Otto, 1983). Water of lower salinity from the Baltic flows in via the Skagerak .

EUTROPHICATION

In the presence of sufficient light, nutrients, especially nitrogen, phosphorus and silicon (for diatoms) are essential for primary production. Nitrogen and phosphor occur on atom basis in a ratio of 16:1 in algal protoplasm, which means at a weight basis 7.2:1. Eutrophication, the introduction of more nutrients, will lead to an increase of the primary production when one of these elements is the limiting factor. In the North Sea nutrients are provided by natural processes, e.g. the inflow of nutrient rich water from the English Channel in the south and from the Atlantic in the north and the river run-off from land, as well as by human activities, the introduction of nitrogen (N) and phosphorus (P) compounds to sea from sewage, agriculture and industry.

Seawater may contain several inorganic and organic N and P compounds. The principal inorganic forms of N in seawater are under natural conditions: nitrate, NO_3 -N (0-500 mg/m^3), nitrite, NO_2-N (0-50 mg/m^3) and ammonium, NH_4-N (0-50 mg/m^3). The main inorganic form of P is orthophosphate, PO_4-P (0-70 mg/m^3) (Riley & Chester, 1971). The occurrence of organic N and P compounds, dissolved and particulate, is associated with the presence of marine organisms.

Nutrient concentrations of the main inflowing water masses from English Channel and Atlantic Ocean are approximately 200 mg/m^3 of total-N and 25 mg/m^3 of total-P. This implies that the annual inflow of nearly 55,000 km^3 brings 11 million tonnes of total-N and 1.4 million tonnes of total-P into the North Sea. In 1975-1985, annual average discharges of nutrients by fresh water to the North Sea in 1975-1985, were estimated at 1.2 million tonnes N and 0.2 million tonnes P (Postma et al, 1988). The average North Sea residence time is one year. Therefore, human activities increased in 1975-1985 the amount of N and P in the North Sea with about 10%, of which nearly half originated from Rhine and Meuse. In practice however, the increase of nutrient levels due to human activities is strong in coastal areas and virtually absent in open sea. (Hagel and van Rijn van Alkemade, 1973).

The coastal water zone along the Belgium and Dutch coast has a volume of about 200 km^3 (Laevastu, 1963). In this zone per year 1100 km^3 of Channel water (containing 200 mg total-N and 25 mg total-P/m^3) is mixed with 100 km^3 of fresh water. From this, an average level for 1978-1985 could be calculated of approximately 680 mg/m^3 total-N and 80 mg/m^3 total-P, a more than three fold increase above natural values. The water moves northward along the continental coast with the residual current. The residence time is about two months. Nutrient levels decrease with the distance from the coast (fig 3). This pattern suggests that decrease of the discharge of nutrients in general, or a one-sided reduction of P or N, will narrow the fertilized coastal zone.

Annual discharges of N and P compounds by the river Rhine showed a fivefold increase due to human activities from 1930 till 1970, with a sharp rise for P in the early sixties. (van Bennekom et al, 1975). While the load of N rose only a little further after 1970, the load of P doubled from 1970 till 1981 (fig. 12-13). In 1981, the N/P ratio in weight was 7.4 at Lobith. Since then the drastic decrease of the load of total phosphate of the Rhine at Lobith (German-Netherlands border), from the peak of 54,000 tonnes in 1981 till 18,000 tonnes in 1990 and the much smaller decrease in the discharge of N, resulted in a N/P weight ratio at Lobith of 12.2 in 1988 and of 16.0 in 1990. (van Gogh, 1989, Cappon, pers. comm.). The closing in 1970 of the Haringvliet (in earlier times a main estuary of the Rhine), will have lowered the phosphate discharge to the North Sea due to sedimention of silt and natural production in Haringvliet and upstream areas. The rather constant annual discharge of approximately 8400 tonnes of P (together with large amounts of phosphogypsum) to the Nieuwe Waterweg by the fertilizer industry west of Rotterdam therefore, represents a growing part of the amount of P finally discharged by the Rhine (van der Heijde et al, 1990).

The western Wadden Sea receives the major part of its nutrients from the lake IJsselmeer (de Jonge, 1990). The water of the IJsselmeer is supplied for 70% by the river Rhine. This shallow lake functions as a trap for P (Buijse et al, 1990). An additional inflow of 40 km^3 per year of nutrient rich water from German rivers (in particular from the Elbe and Weser) fertilizes the German Bight. The load of total P of the river Elbe with an average annual discharge of 23 km^3, dropped at Snackenburg from 16,000 tonnes in 1987, till 9000 tonnes in 1989 and 1990. The large difference in water discharge of the Elbe in these years, 36 km^3 in 1987 and 16 and 14 km^3 in 1989 en 1990 respectively, may have played a role in this decrease. At Glückstadt/ Grauerort (the upper brackish water limit in the Elbe) the ratio between discharged amounts of total N and P was 19 in 1980-1989. (Anon. 1990). Along the Danish westcoast, local sources such as rivers, sewage discharges and the Esbjerg fish industry, increase further the nutrient level in this area, but also here the weight ratio between discharged N and P (13.7) shows a relative shortage of P (Jensen, 1989).

STRATIFICATION

Under the influence of biological processes and physical effects as sinking of dead organisms and upwelling, total N and P concentrations in the upper layer of the sea can strongly fluctuate. In the North Sea free dissolved forms of N and P may show even stronger fluctuations. In winter, when remineralisation of organic material is the dominant process, nitrate and phosphate levels reach maximum levels, whereas in summer most of these nutrients are bound in marine organisms, e.g. phytoplankton. In areas where the water column is well mixed, e.g. the southern part of the North Sea, total-N and -P concentrations over the vertical may be more or less the same throughout the year. However, in stratified areas of the North Sea depletion of nutrients in the upper water layer may occur. During April-October, large parts of the central and northern North Sea become thermally stratified, resulting in depletion of nutrients and widely fluctuating seasonal concentrations of total N and P in the upper 40 m of the water column. In stratified areas increased production of organic matter can have negative effects on oxygen concentrations, because in these areas increased primary production in the upper water layer may lead to a strong decrease of oxygen concentrations in the bottom layer where most of the remineralisation takes place.

Most of the nutrients resulting from human activities enter the southern part of the North Sea, making this area in principle vulnerable for negative environmental consequences of eutrophication, also because mixing with the water from the open North Sea is very limited. Annual discharges were in 1980 about 200,000 tonnes of N and 30,000 tonnes of P from the UK, and 600,000 tonnes of N and 70,000 tonnes of P from the coasts of Belgium and the Netherlands. (Postma et al, 1988). However, the annual inflow of 4800 km^3 through the Straits of Dover induces a northward current resulting in a main residence time of about two months in this area. This counters the build up of high nutrient levels in the water column. Low water depth, strong tidal movement and prevailing western winds further contribute to the vertical mixing of the water mass in this part of the North Sea, limiting stratification practically to the convergence zone at the eastern edge of the periglacial Elbe valley. Haline stratification in this area is enhanced temporarily by calm weather, land winds and high discharges of the Elbe. Observed oxygen deficiencies therefore were limited in time. Only occasionally (in 1982 and 1983), mass mortalities of zoobenthos occurred. (Niermann, 1990).

Since 1970, discharge of Rhine and Meuse takes mainly place at Hook of Holland. Extension of the jetties in Hook of Holland, the dredging of an approach channel in the coastal area (21 m deep) and concentrating the run off of fresh water during ebb, have improved the (difficult) mixing of this fresh water in sea off the Dutch west coast and widened the zone of nutrient rich water (Boddeke, 1978).

PHYTOPLANKTON

Gerlach (1984) and Cadée (1986) reported a doubling of phytoplankton biomass and production since the mid-sixties in continental coastal waters. This is less than the average increase of nutrients, probably due to factors as turbidity in inshore areas and development of macro algae limiting production, and grazing reducing the biomass.

Human activities do not have a significant influence on dissolved silica levels of the North Sea. Therefore, the increased primary production of continental coastal waters consists mainly of phytoplankton other than diatoms, in particular flagellates.

In the period 1930-1980, the biomass of flagellates increased by 2-4 fold within 30 km off shore, causing a shift in dominance from diatoms to other phytoplankton. The ratio between other phytoplankton and diatoms, < 1 in 1930, was > 3 in 1980 (Fransz & Verhagen, 1985). Microflagellates are important as food for bivalves and copepods. (Vahl, 1972, Klein Breteler and Gonzalez, 1984). Dinoflagellates, important as food for fish larvae ≤ 5 mm, have created occasionally blooms along the Dutch coast in April-October. Bloom periods in spring of Gyrodinium spirale gradually extended after 1976 including the summer period (Kat,1988).

Fransz & Verhagen (1985) state that in the discharge of nutrients, not the increase of primary production itself but the increase of the area where it occurs may be most important. The mathematical model developed by these authors suggests that beyond 16 km from the coast diatoms are limited by Si and other phytoplankton by P depletion. Therefore, the discharge by the main rivers in the North Sea through deep gullies, natural in the case of Thames and Elbe and man-made for Rhine and Meuse, must be considered a relevant factor in the increased production of the coastal zone due to eutrophication.

MACROZOOBENTHOS

Reports of increased biomasses of zoobenthos in the North Sea as a response to eutrophication, have increased considerably in recent years. Beukema and Cadée (1986) found on basis of annual sampling that the biomasses of the macrozoobenthos living on the tidal flats in the western part of the Wadden Sea doubled in the period 1970 to 1984. Significant increases were observed in numbers of polychaetes like Nereis diversicolor, Heteromastus filiformis and Scoloplos armifer and bivalves like Macoma balthica , Abra tenuis, cockle (Cerastoderma edule) and mussel (Mytilus edulis). Eutrophication is mentioned as the most likely cause for this increase.

Rachor (1990) compared results of investigations of the macrozoobenthos of the German Bight as early as 1923-24 with data from 1966-1984. He found indications for a strong influence on the bottom macrofauna by increased eutrophication. Among the recognizable effects, the increased biomass and shifts in dominance in favour of adaptive, short-lived (and hence highly productive) species were the most obvious.

Kröncke (1990) revisited in 1985-87 some stations on the Dogger Bank sampled in 1951-52. She observed an increase in polychaetes like Spiophanes bombyx, Chaetozone setosa and Scoloplos armiger and small, short living bivalves like Abra prismatica and Tellina fabula. Numbers of long living bivalves were drastically reduced. The total benthic biomass (wet weight) was a factor 2.5 to 8 higher in 1987 compared to 1951-52. Beside eutrophication also increased levels of heavy metals and pesticides are mentioned as a possible cause for the observed changes. Differences in sampling gear however, can have influenced the results.

Changes found on the Dogger Bank were comparable to those in the eastern Skagerrak, considered to be the result of eutrophication (Rosenberg et al, 1987).

COCKLE (Cerastoderma edulis) Fishing for cockles has been for long a manual activity in the Dutch coastal area. Annual catches in 1949-1955 were on average 195 tonnes. Fishing with technical means started after 1955 in the Wadden Sea and expanded after 1975 to other areas. Annual catches increased sharply between 1955 and 1973 and reached a level of 64,900 tonnes in 1987-1989. This impressive rise is partially due to the increase in the stock as observed between 1970 and 1984 in the Wadden Sea (Beukema and Cadée, 1986). It also reflects the build up of (a too high) fishing effort.The percentage of the exploitable stock caught per year in the Wadden Sea rose from 4 in 1971-1982 till 28 in 1984-1986 (Anon.,1987a). Since 1980, the stock of cockles in the Wadden Sea has gradually decreased and could be considered depleted in 1990. No substantial spatfall occurred in 1989 and 1990.

MUSSEL (Mytilus edulis) During the fifties, exploitation of the mussel stock in the western Wadden Sea changed from fishing on wild banks to culture on plots.The area of wild mussel banks expanded considerably after 1960 as was observed during RIVO surveys in this area. The annual production from the western Wadden Sea rose from 6000 tonnes in 1949 till 67,000 tonnes in 1962 and fluctuated around 60,000 tonnes in the years after. Activities of mussel farmers, seeding their subtidal plots with juveniles from wild banks and protecting their mussels against predation by starfishes (Asterias rubens) enhance production. Basically however, this rise is the result of increased productivity of the area (Beukema aand Cadée, 1986). In the German Wadden Sea mussels reached a shell length of 6 cm after 3 years in 1986, while at the beginning of this century 3-4 years old mussels were mainly 3-4 cm long. This increase in growth is related to improved feeding conditions due to eutrophication (Meixner, 1987).

Commercial mussel landings from the Dutch Wadden Sea are negatively influenced by predation , in particularly by Eider ducks (Somateria mollissima). Since the sixties, 100,000-200,000 of these diving birds winter in the western Wadden Sea. Before 1960, numbers wintering here were estimated at several thousands (Anon. 1987b). The annual harvest of mussels from culture plots by Eider ducks during the eighties, has been estimated at approximately 30,000 tonnes. (Swennen et al, 1989). Failure of spatfall in 1989 and 1990, continuing commercial exploitation and predation by eider ducks has depleted the mussel stock in the western Wadden Sea in 1990.

CRUSTACEANS

COPEPODS Increase of copepod densities as a response to fertilization, is well known from marine shrimp and fish ponds where blooms of microflagellates are normally followed by a sharp increase in copepod densities. A similar development was observed in fertilized Scottish sea lochs. (weatherley, 1972). Reports of such an effect due to eutrophication of coastal areas however are lacking. Continuous reproduction and fast development, the influence of temperature on growth and the presence or absence of specific food items among the phytoplankton biomass, are major difficulties in assessing copepod populatations in nature (Fransz & Gieskes, 1984, Klein Breteler & Gonzalez, 1985).

BROWN SHRIMP (Crangon crangon) The brown shrimp is the dominating shrimp species on soft bottom along the European west coast. Commercial stocks are tied to areas characterized by the discharge of fresh water.

The distribution pattern of the brown shrimp along the Dutch coast since 1969 reflects the distribution of nutrients (Boddeke, 1978). In 1979-1982, brown shrimps occurred in substantial densities till 30 km off shore along the Dutch west coast, while in the less eutrophic water off the Wadden isles this zone was only 10-15 km wide. The sharp decrease of the P-discharge at Hook of Holland after 1987, corresponds well with the shrinking width of the zone in which brown shrimps occurred along the Dutch west coast in 1987-1990 in comparison with 1979-1982, while no change could be observed north of the Wadden Isles (fig. 4).

Large amounts of juvenile brown shrimps grow up in silty, tidal nursery areas where they settle in April-October after the pelagic larval stage. With increasing size, they move gradually to deeper water. Since 1930 large estuarine areas along the Dutch coast have been cut off the sea, resulting in a severe loss of nurseries and estuarine fishing grounds (Boddeke, 1978). At least since 1962, mass-wise settlement of juvenile brown shrimps occurred along the sandy Dutch west coast, but only in late May-July. A link is likely between this settlement and the annual bloom of calanoid copepods in May-July in the Southern Bight , because copepods are here the major food item for brown shrimps of 10-20 mm. (Fransz and Gieskes, 1984, Boddeke et al, 1986).

In comparison to estuarine areas, shrimps and in particular juveniles are more exposed to predators in this marine nursery. Very relevant in this respect are the swimming crab (Liocarcinus holsatus), whiting (Merlangius merlangus) and cod (Gadus morhua). Juvenile shrimps (6-25 mm) are the main food of swimming crabs in Dutch coastal waters (Bruné, 1988). Daily predation by swimming crabs on the brown shrimp stock along the Dutch coast, has been estimated at 0.42 % during July and 1.01

% in August. (Dulfer, 1988). 0-group whiting is a major predator on semi adult shrimps (25-50 mm) during autumn, while 1-2 group cod preys mainly on adult shrimps during the winter months. Cod ≥ 2 years however reduces the mortality on juvenile shrimps by preying on swimming crabs and small whiting. (Daan, 1988).

The loss of inshore fishing and nursery grounds since has resulted in a decrease of the average level of Dutch shrimp landings by approximately 35% from 1938 till 1985. Although improved survival of caught undersized shrimps has increased recruitment to the commercial stock since 1970, the increasing eutrophication of the Dutch west coast till 1981 seems to be the major reason for the comparatively small size of this decrease (Boddeke, 1989). In 1987-1990, densities of brown shrimp populations along the Dutch west and north coast decreased markedly, while the most southern population (Westerschelde estuary) did not show any trend. (Knijn and Boddeke, 1991).

SWIMMING CRAB (Liocarcinus holsatus) The swimming crab is abundant in Dutch coastal waters during summer. It does not occur in water with a salinity < 20-25 o/oo (Venema and Creutzberg 1973). Biomasses of swimming crab north of Hook of Holland were in 1987 approximately ten times higher than (in the less eutrophic waters) north of the Wadden Isles. (Dulfer, 1988).

FISH

GENERAL Landings of demersal fish species from the North Sea have been analyzed on basis of data from the Bulletin Statistique, issued by the International Council for the Exploration of the Sea (ICES) since 1903. Till 1958 the North Sea was handled in these tables as one unit (IV). Since 1958, southern (IVc), central (IVb) and northern (IVa) North Sea are distinguished (fig.2). Official landing figures till 1981 have been used. Landing figures from years after 1981 are corrected for unreported landings.

Because eutrophication of the marine environment is linked to the discharge of fresh water, the utilization (or not) of estuarine nursery areas has been the criterium for arranging species. We realize that this criterium is arbitrary. 0-group turbot and brill e.g. stay in shallow water along sandy coasts but outside estuaries and feed on mysids. Also the status of saithe is rather unclear.

SPECIES WITHOUT ESTUARINE NURSERIES Average annual landings of a large number of species without estuarine nursery areas did not show a trend in 1935-1981. (Fig.5,7). Landings of rays and skates decreased after 1970. Commercial fishing for these species N.W. of Heligoland as in 1915 seems no longer possible. Catches of haddock (Melanogrammus aeglefinus) jumped from 139,469 tonnes in 1968 to an average 655,500 tonnes in 1969-1970, thank to the extraordinary strong year class 1967. Catches dropped again in 1971 (257,915 tonnes). Fishing mortality, 0.61 in 1971, was on average 0.79 in 1972-1989. Annual landings in 1987-89 (93,000 tonnes) were at the same level as in 1956-1960 (90,000 tonnes) but somewhat higher than in 1935-38 (70,000 tonnes).

SPECIES WITH ESTUARINE NURSERY AREAS,

Gadoids. (ig. 8). Saithe (Pollachius virens). Adult and juvenile saithe is rare in the southern North Sea. It is included in this category because juveniles concentrate in estuaries, harbours and fjords at both sides of the central and northern North Sea. These scattered nurseries may have been eutrophicated during the last 30 years by outflowing fresh water, taking into account the general trend in western Europe.

Cod (Gadus morhua) North Sea landings of cod reached a high level in 1971-74 due to two successive strong year classes in 1969 and 1970 and were still high in 1981-83. (fig.8). The increased landings of cod after 1960, coming mainly from the central (IVb) and southern (IVc) North Sea, suggest a build up of the cod population in these areas. (Fig.9). The coastal area of the Netherlands, Germany and Denmark has been a very important nursery ground for 0- and 1-group of the entire North Sea cod stock, at least since the seventies (Fig.10). The spawning stock of cod in the southern and central North Sea is at present extremely low. In spite of a very high fishing mortality (0.79 in 1973-1989) and weak yearclasses after 1985, annual catches in 1987-1989 were still 141,000 tonnes, twice those in 1935-38 and well above the average landings in 1956-1960 (119,000 tonnes).

Whiting (Merlangius merlangus) Human consumption landings increased in the seventies in the southern en central North Sea (fig.8).These figures however do not reflect properly the stock due to mass discarding. Dutch flatfish cutters discard up to 85% of all whiting caught. Average numbers discarded per fishing hour in 1989-1990 were 47% higher than in 1976-1985 (van Beek, 1990). Also for whiting, the SE North Sea is an important nursery area. In 1971-1989 the fishing mortality of whiting was high (on average 0.64) but lower than for cod (0.79) (Anon, 1990a).

Whiting matures much earlier than cod. At age 2 more than 90% of whiting females is sexually mature, of North Sea cod only 50% at age 4 (Heessen, pers. comm). Numbers of 0-group whiting in the SE North Sea increased since 1985 and were extremely high in 1990. The scarcity in this area of large cod and whiting and consequently, the low predation in recent years, relatively low fishing pressure and early maturation are all favourable for the stock of (mainly small) whiting.

Flatfish. (fig. 6). Sole (Solea solea) Distribution in the North Sea is restricted to the area south of 56° North. O-group sole does not show a marked preference for estuarine areas. Wadden Sea and Schelde estuary together contribute on average 20% and shallow coastal areas 80% to the overall abundance of 0-group sole (van Beek et al., 1989). The 1-group of sole is even more concentrated in the coastal zone (fig. 11). With increasing age they disperse evenly over the southern North Sea. Growth of all age groups increased considerably in the sixties. Eight year old female soles, 34.5 cm long in 1963, were 40.2 cm in 1972 but no further increase occurred after that year (Rijnsdorp & van Beek, 1991). These authors also analyzed the increased growth in relation to the decreased stock size but could not find evidence for a density dependent effect on growth. They concluded that the availability of food for sole (mainly polychaetes) must have increased between 1960 and 1970 in the southern North Sea. The average length of 4-year old male sole decreased after 1982, but no distinct decrease could be observed in the length of 4 year old females. (fig. 12).

Recruitment data, available since 1957, show a slight increase in recent years, but irregularities, caused by mortality in severe winters and exceptional strong yearclasses, are considerable. (Rijnsdorp et al, 1991). Improved protection of juveniles caught in fishing for brown shrimps will have partially contributed to the rise in recruitment (Boddeke, 1989).

Dab (Limanda limanda). No information exists on historical trends in biomass and recruitment of this species. A modest rise in landings of this species can be observed since the thirties (fig.6). The extremely high discard rates of this species (Dutch flatfish cutters discard 97- 99 % of all dabs caught) however, will largely mask the developments in the stock (van Beek,1990). In the western Wadden Sea, adult dab increased in numbers in the late fifties but both adult and juvenile dab lost ground to 0-group plaice after 1965 (Boddeke, 1963, 1967).

Plaice (Pleuronectes platessa). Ecological changes in the Wadden Sea in the sixties have been in favour of 0-group plaice. After 1963, the western Wadden Sea till then dominated by adult and juvenile dab, turned in a few years in a specific nursery area for 0-group plaice. The increasing presence of mussels and its attendant changes in habitat seems the major reason (Boddeke, 1967). The effects on the benthic fauna of the severe winter 1963 (in favour of opportunists like polychaetes, which are suitable food for juvenile plaice but not for dab) and the enormous plaice year class 1963, can have accelerated this take over.

Plaice move gradually off shore with increasing age. In 1970-1988, at least 47% of all 0-group plaice occurred in the Wadden Sea and 66% of the 1-group in the coastal zone, in particularly in the German Bight (van Beek et al, 1989, Fig.11). The location of the plaice box, created in 1989 to protect 1-group plaice, coincides with a relatively strongly fertilized part of the coastal area (fig.2).

Length of 4 year old male and female plaice show a similar relation with the PO_4-P load of the Rhine. (fig. 13-14). Growth increased between 1950 and the early seventies (Bannister, 1978). A decrease has been observed in the eighties. Rijnsdorp & van Beek (1991) found the growth increase in sixties and seventies restricted to young plaice (< 4 years) largely occurring in the southern North Sea, while older plaice, mainly found in the central North Sea, did not show an increase in growth. They concluded that food availability in the southern North Sea had increased.

Data on plaice fishing illustrate the build up of the plaice stock in the southern and central North Sea after 1960 (fig.9). Fishing mortality more than doubled (from 0.25 till 0.55) in the period 1960-1989, but catches nearly doubled as well. The spawning stock, 382,000 tonnes in 1989, is well above the safe biological limit of 300,000 tonnes in spite of historic high levels of fishing mortality in recent years. Recruitment showed a clear upward trend since 1960, with exceptional strong year classes in 1963, 1981 and 1985 (Rijnsdorp et al., 1991). Improved sorting methods in brown shrimp fishing may have partially contributed to this trend (Boddeke, 1989).

DISCUSSION

A causal relationship between eutrophication and increased landings of fish is hard to prove. Other factors like incidental yearclass strength and fishing pressure also have a considerable influence on North Sea fish stocks and landings. However, a direct link between eutrophication, higher primary and secondary production and increased growth of demersal fish is suggested by the experiments in the Scottish sea lochs Loch Craighlin and Kyle Scotnish during 1942-43. Regular fertilization with balanced doses of superphosphate and sodium nitrate resulted after 2 to 3 days in increased numbers of microflagellates at all depths. Zooplankton abundance followed a seasonal course similar to an adjacent loch but at an appreciable higher level. Massive increase of zoobenthos (molluscs like Cardium and Hydrobia and chironimid larvae) was observed 1-1.5 year after fertilization, making benthic food for fish two or three times more abundant. In both lochs growth of plaice and flounder one year after the onset of the experiment exceeded greatly that in adjacent lochs and nearby fishing grounds (Weatherley, 1972). Phenomena observed in these experiments agree well with those in the SE North Sea after 1960 as described above.

The parallel trends in time of PO_4-P contents of the Rhine and the length of 4-year old plaice suggest strongly a causal relation in spite of changes in year class strength influencing growth as well. In 1970-1988 growth of 1-year old plaice was negatively correlated with year class strength (Rijnsdorp et al, 1991).

A positive influence of increased phyto- and zooplankton production on year class strength of fish species with concentrations of larvae in the SE North Sea is plausible. The general scarcity in sea of food particles of suitable size seems to be a main factor for the very high mortalty rates of fish larvae. Survival is often linked to incidental high concentrations of food particles (patches), the ability of fish larvae to reach such a patch and to stay in it (Rothschild, 1986, Paulsen, 1985). Dinoflagellates, tintinnids, larvae of polychaetes and lamellibranchs, Oikopleura dioica, copepod nauplii and copepodites are important food items for gadoid and flatfish larvae. (Last, 1978 a,b). Increased densities of all or several of these planktonic organisms in coastal areas of the SE North Sea due to eutrophication will enhance survival chances of fish larvae what may result in on average stronger year classes. The effect on species involved however, will not be similar due to specific differences in spawning grounds and food preference. Plaice larvae (born in deep water off shore) specialize on Oikopleura dioica, sole larvae (born in shallow coastal waters) eat mainly lamellibranch larvae and also relevant amounts of dinoflagellates. Larvae of dab, spawning everywhere in the North Sea at depths of 20-40 m, have a more generalised diet. (Last 1978a, Hersart de la Villemarque et al, 1986). For larvae of cod and whiting, nauplii and copepodites of calanoid copepods is the principal food (Last, 1978 b). Ecological changes in nursery areas will also have different effects on various species. From the widening of the eutrophicated coastal zone and therefore the extension of the nursery area, sole, dab, whiting and cod of which the large majority of the 0-group occurs outside estuaries, are likely to have profited in a similar way as the brown shrimp. For plaice, of which the 0 group occurs mainly within the estuaries, the ecological changes in the Wadden Sea in favour of this species, can have been a major reason for the observed increase in average yearclass strength.

In spite of the many questions that have to be answered yet, it seems justified to conclude on basis of available evidence that the productivity of the southern and central North Sea positively changed after 1950 due to the discharge of N and P compounds coming from human activities. In particular, the fast rise of P compounds in 1959-1965 making the N/P ratio more balanced, has been very relevant. Increased primary and secondary production in estuarine nurseries and a wide coastal zone, have resulted in structurally higher biomasses of stocks of fish, crustaceans and bivalves which use coastal estuarine areas as life long habitat or as nursery grounds. Stocks of fish species without estuarine nurseries does not have contributed structurally to the increase in commercial landings or, as in the case of rays and skates, decreased.

The estimate of the maximal sustainable yield of North Sea demersal fisheries of nearly 400,000 tonnes for the years before 1940, could be revised upwards to 1 million tonnes in the eighties, an increase in off-ship value of about $ 1.5 billion. The introduction of the plaice box in 1989 is a management measure aimed at maximizing the advantage of this favourable development.

Negative environmental effects of eutrophication have been limited, thank to the hydrographical situation in the North Sea. To mitigate these effects, a 50% reduction in inputs of nutrients into sensitive areas of the North Sea has been agreed on the Second International Conference on the Protection of the North Sea, London, November 1987).

The fast decrease of discharges of P since 1981, has brought levels of PO_4-P in the Rhine at Lobith in 1990 back at the level of 1960. The resulting strong reduction of the eutrophication of the continental coastal waters will lead to a decrease of food abundance for demersal fish species and their larvae, brown shrimp and bivalves.

Negative effects on the stocks of brown shrimp and bivalves in the Dutch coastal zone and demersal fish species in the southern and central North Sea, can already be indicated. At least for North Sea fisheries, eutrophication seems to have been a blessing in disguise during the last decades.

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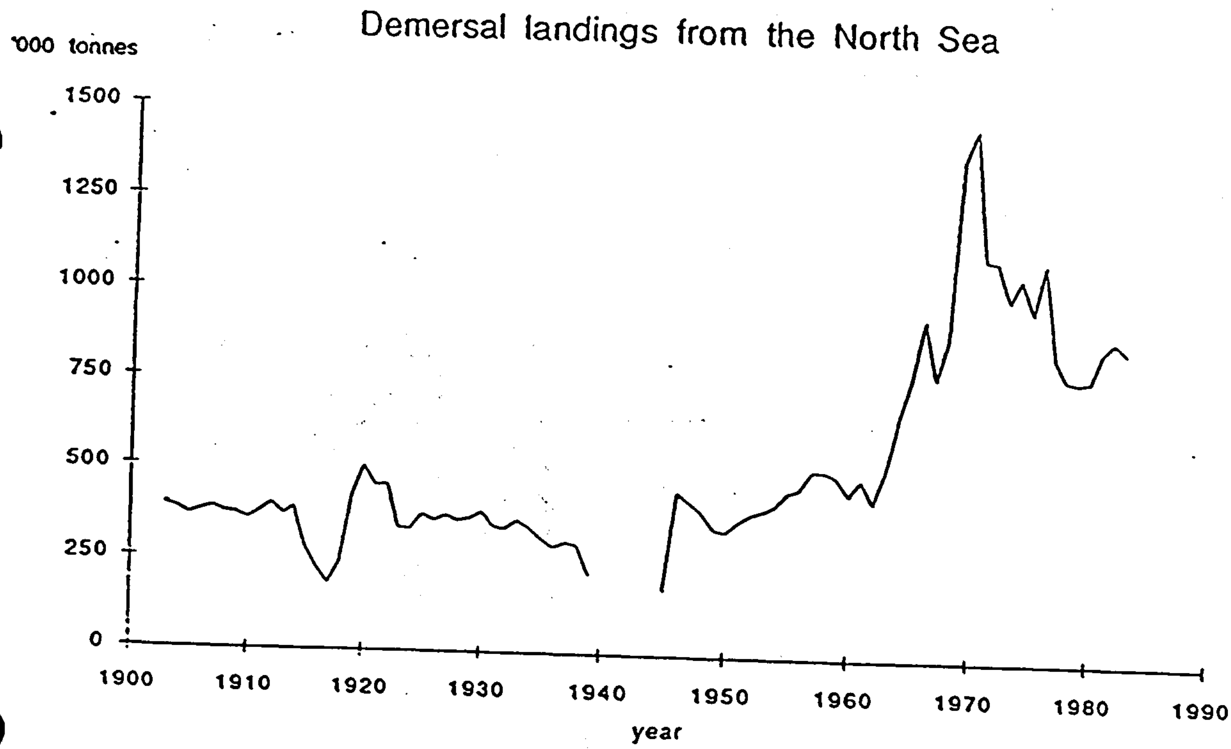

Figure 1. Demersal landings from the North Sea (After Heessen, 1988, supplemented).

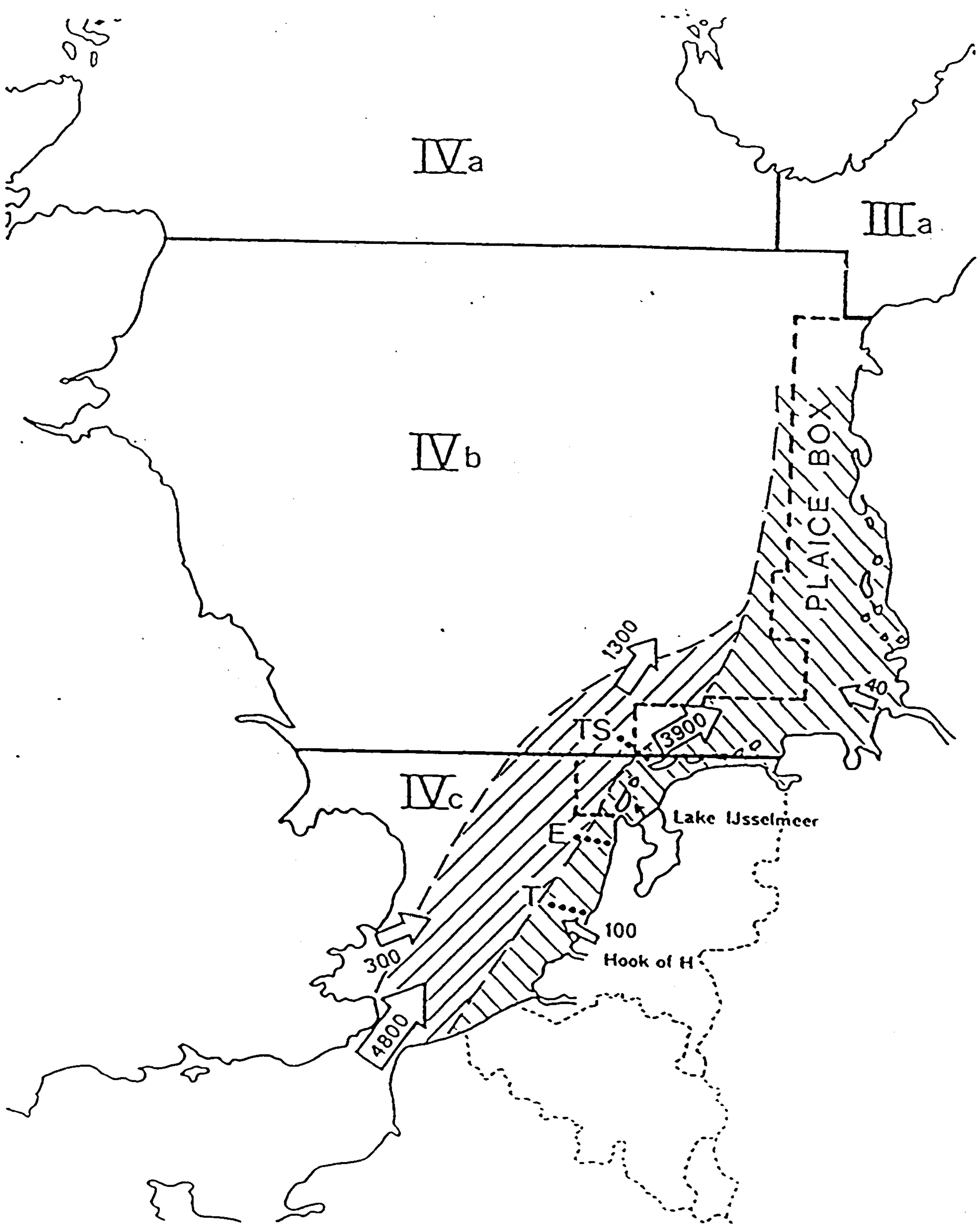

Figure 2. Hydrological situation in the south eastern North Sea. Arrows indicate water masses in km^3. Dotted lines correspond with figure 3, T= Terheijde, E= Egmond, TS= Terschelling. ICES fishing areas and plaice box indicated.

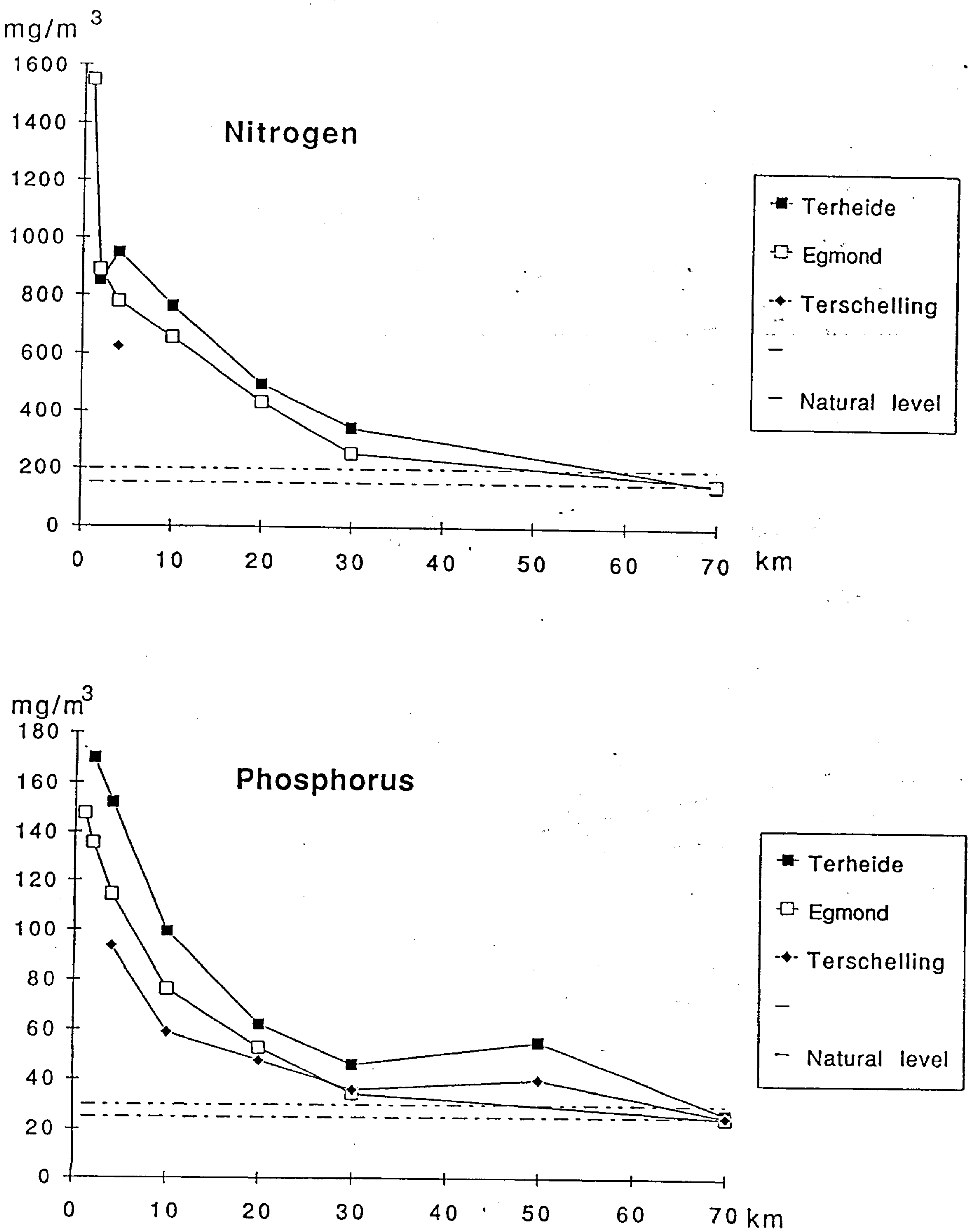

Figure 3. Total N and P distribution in 1973-1984 at locations along the coast of the Netherlands indicated at fig.1. Source: Rijkswaterstaat, Kwaliteitsonderzoek in de Rijkswateren. RIZA, Lelystad. Reports 1973-1984.

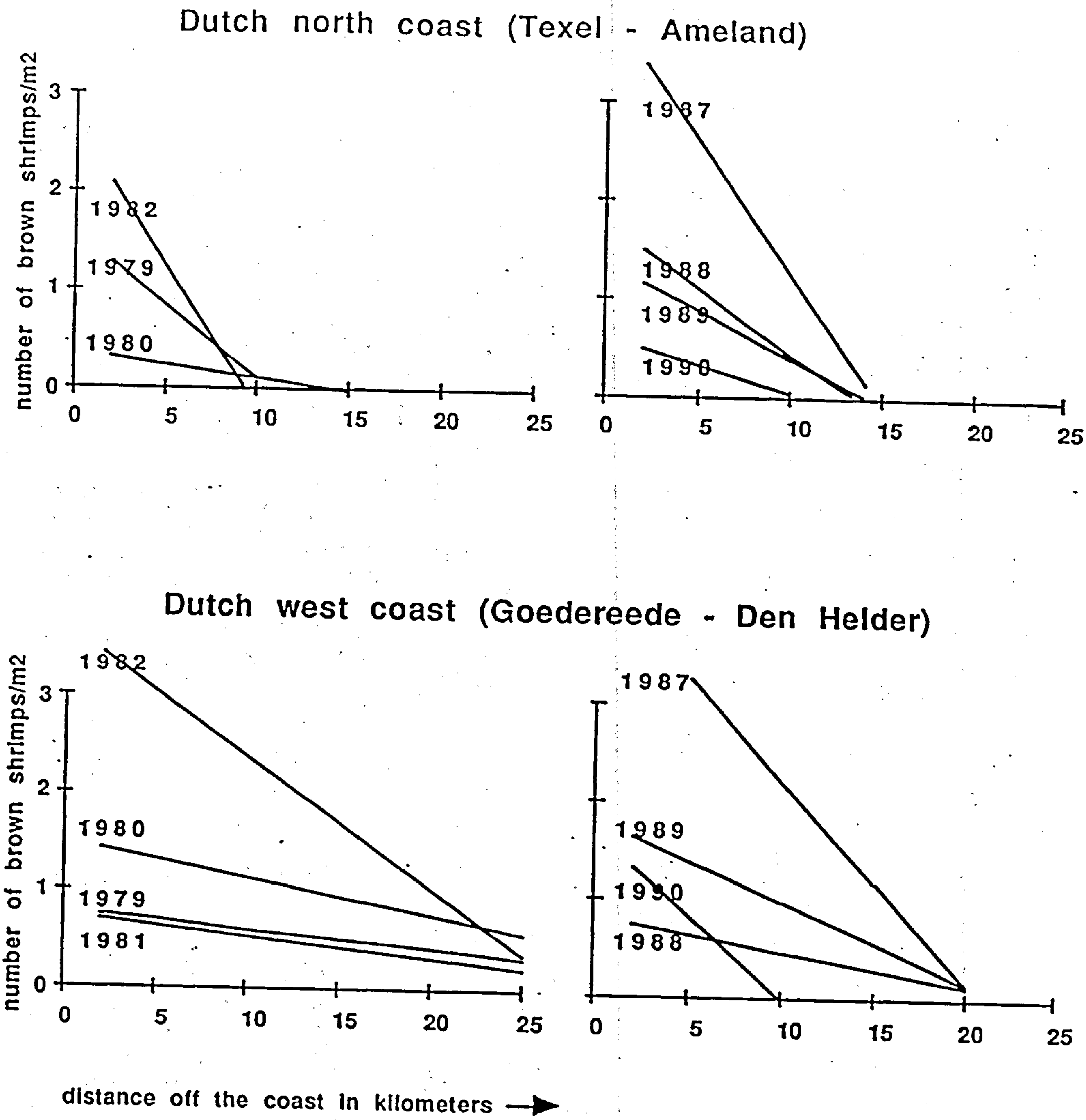

Figure 4. Relation between density of brown shrimps > 40 mm and distance off the Dutch north and west coast in the zone 2-30 km off shore (September-October). Data: International Young Flatfish and Brown Shrimp Survey. Numbers of stations sampled (N) and correlation coefficient (r), for 1979-1982:
North coast, 1979: N=10, r= -0.38, 1981: N=15, r= -0.48, 1982: N=14, r= -0.50. West coast, 1979: N= 23, r= -0.53, 1980: N= 28, r= -0.40, 1981: N= 22, r= - 0.48,1982: N= 25, r= -0.50.
For 1987-1990: North coast, 1987: N= 23, r= - 0.45, 1988: N= 26, r= -0.58, 1989: N= 23, r= -0.45, 1990: N= 26, r= -0.51. West coast 1987: N= 16, r= -0.53, 1988: N= 32, r= -0.41, 1989: N= 21, r= -0.33, 1990: N= 20, r= -0.40.

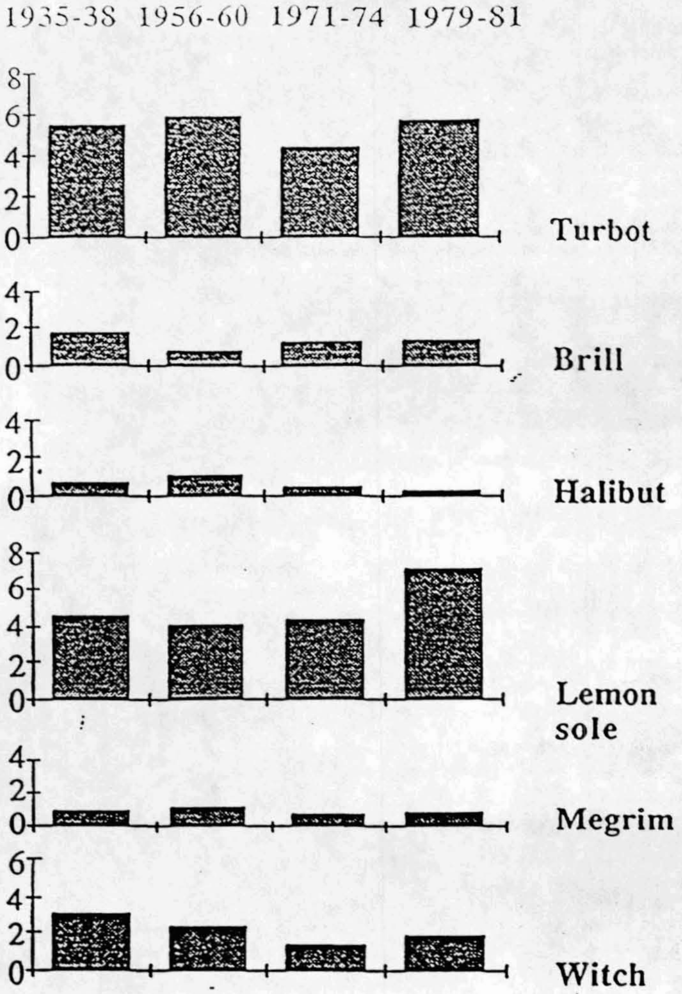

Figure 5. Average annual landings (in '000 tonnes) in different time periods from North Sea and Skagerrak of flatfish species without estuarine nursery areas.

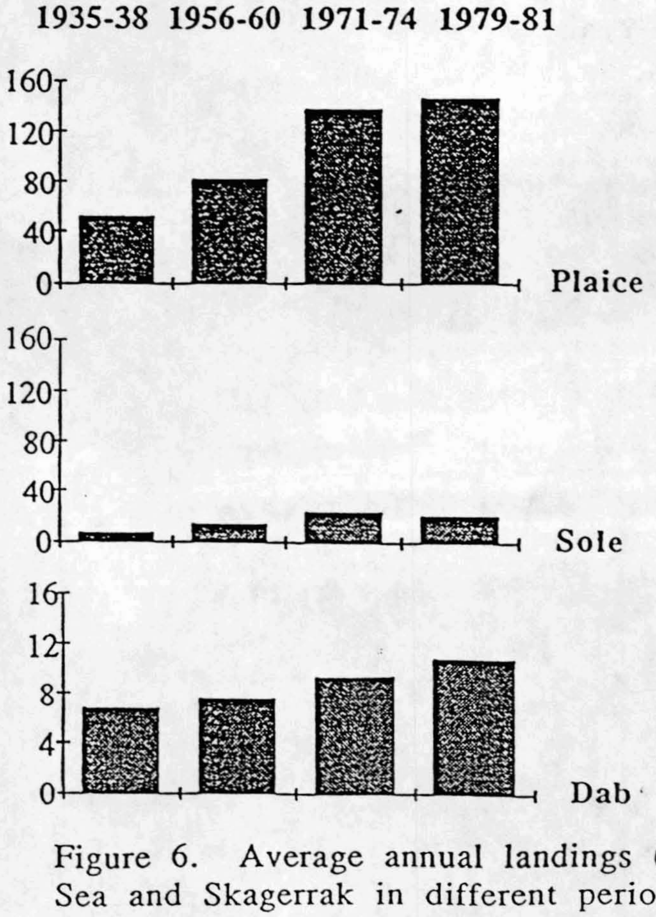

Figure 6. Average annual landings (in '000 tonnes) from North Sea and Skagerrak in different periods of flatfish species with estuarine nurseries.

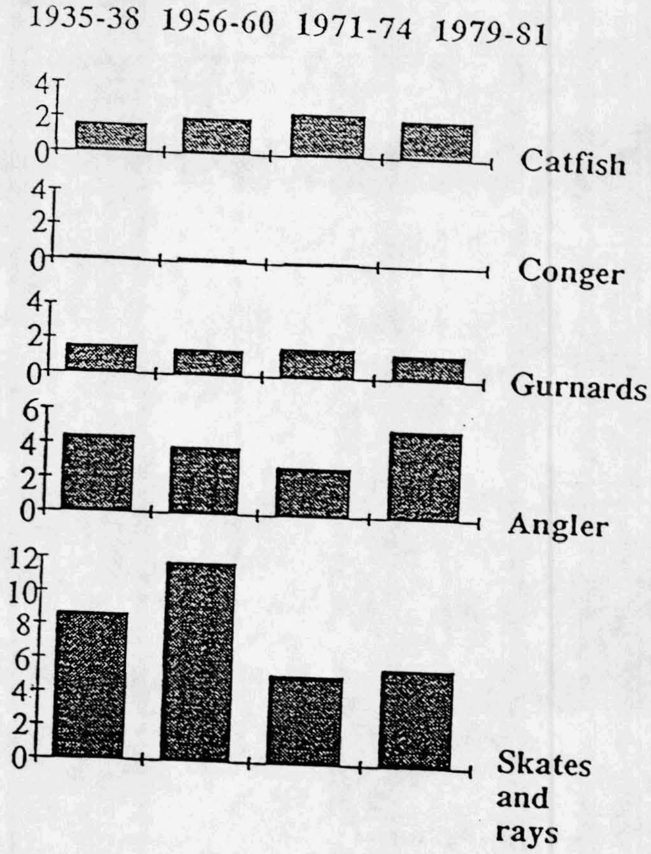

Figure 7. Average annual landings (in '000 tonnes) from North Sea and Skagerrak in different periods of various fish species without estuarine nurseries.

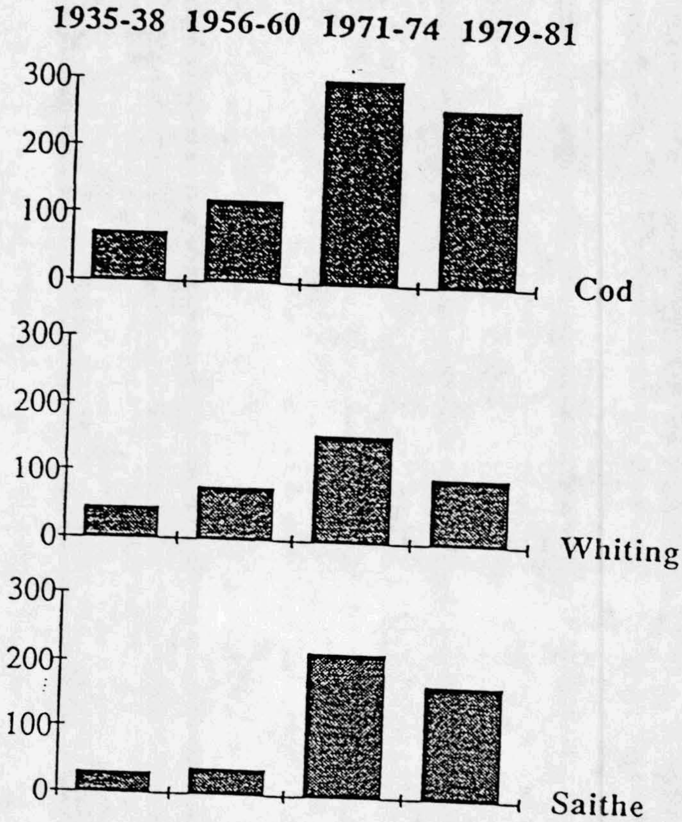

Figure 8. Average annual landings (in '000 tonnes) from North Sea and Skagerrak in different periods of gadoid species with estuarine nurseries.

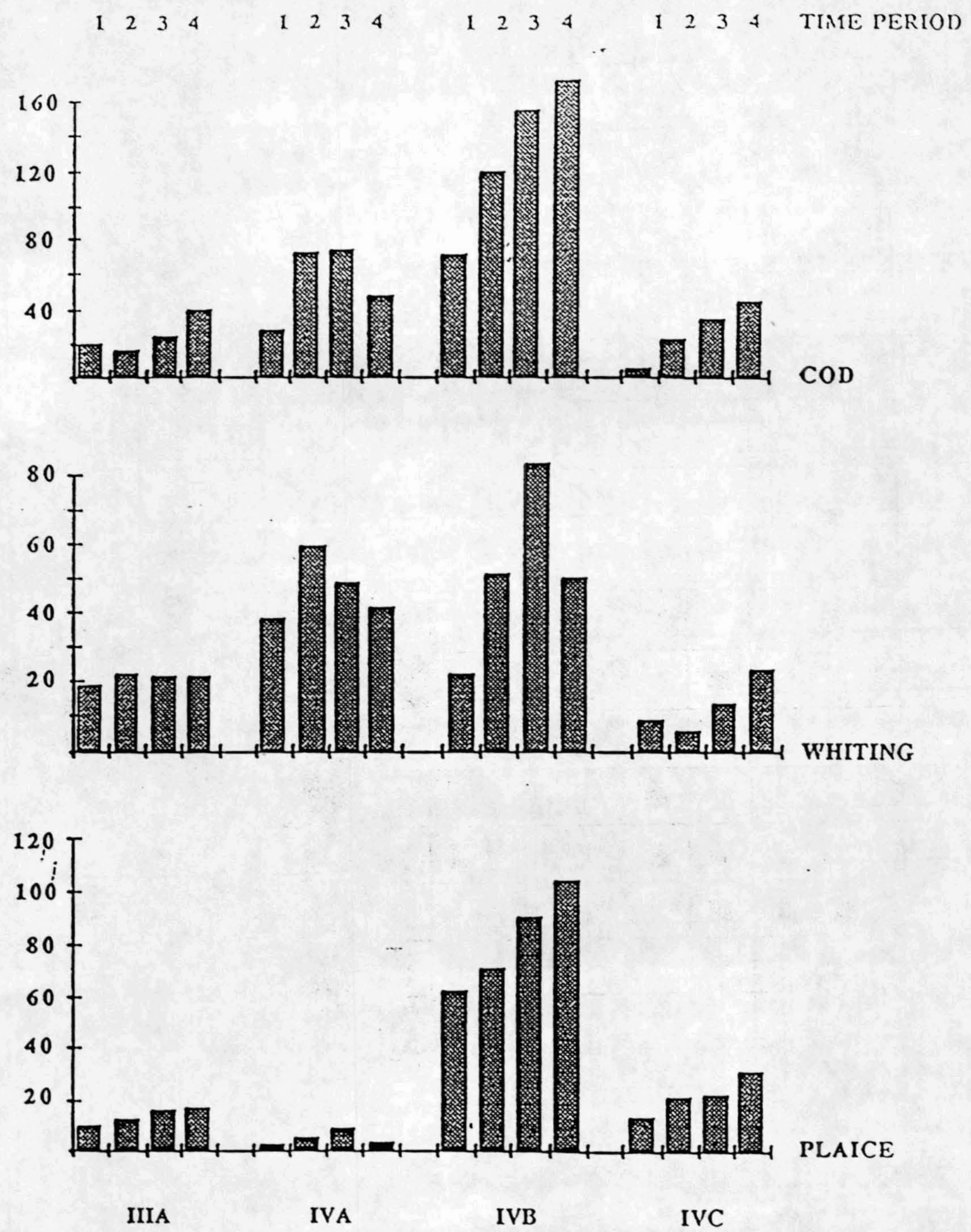

Figure 9. Average annual landings (in '000 tonnes) of cod whiting and plaice from sub areas of the North Sea, in different time periods. 1: 1958-60, 2: 1965-67, 3: 1972-74, 4: 1979-81.

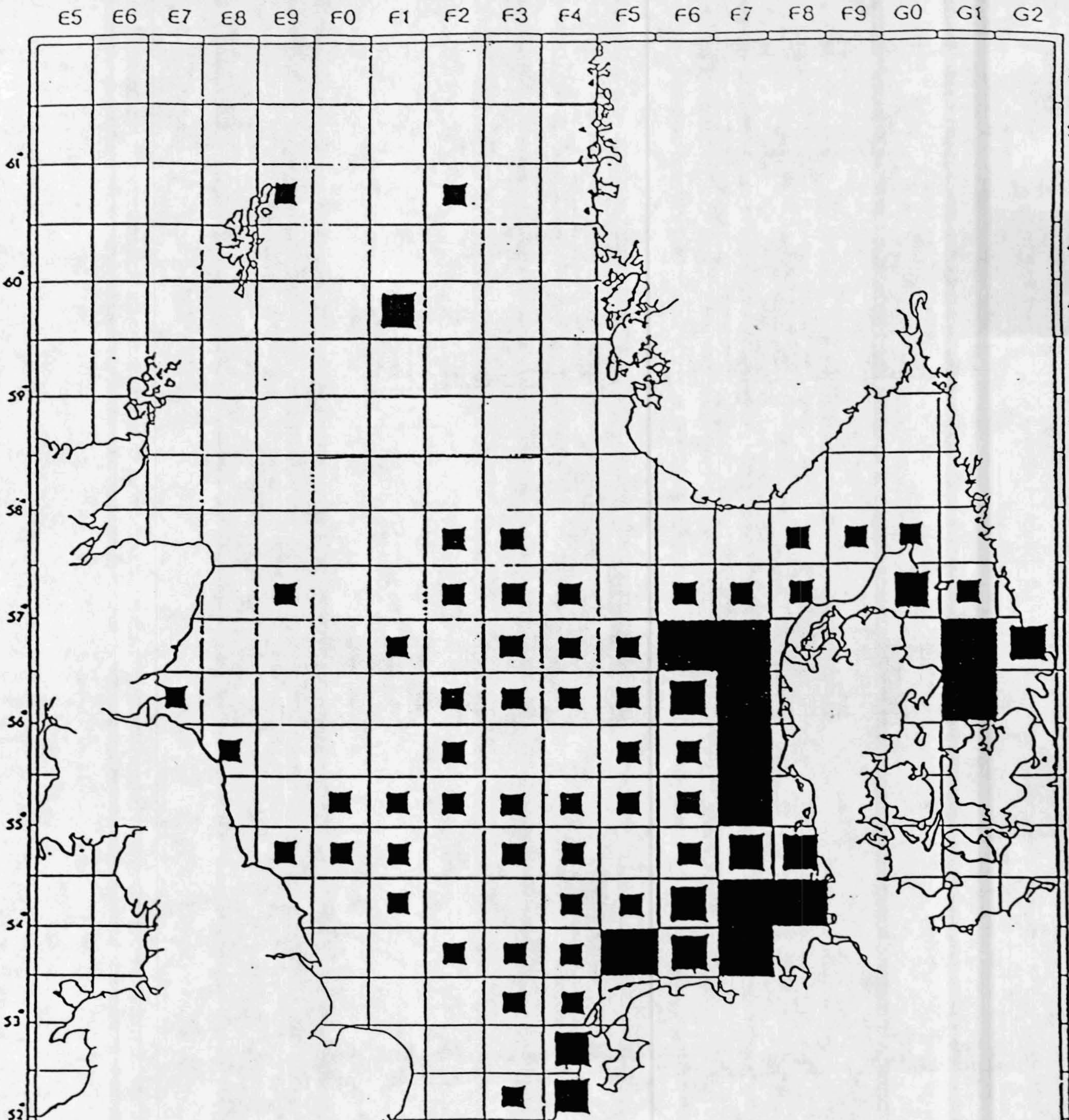

Figure 10. Density of cod age group 1. Long term average International Young Herring Survey (IYHS) 1974-1979. N per hour. Large squares > 100, medium squares 100-50, small squares 50-10. Source: Database IYHS Roundfish 1970-1979, edited N. Daan. Internal report RIVO, IJmuiden.

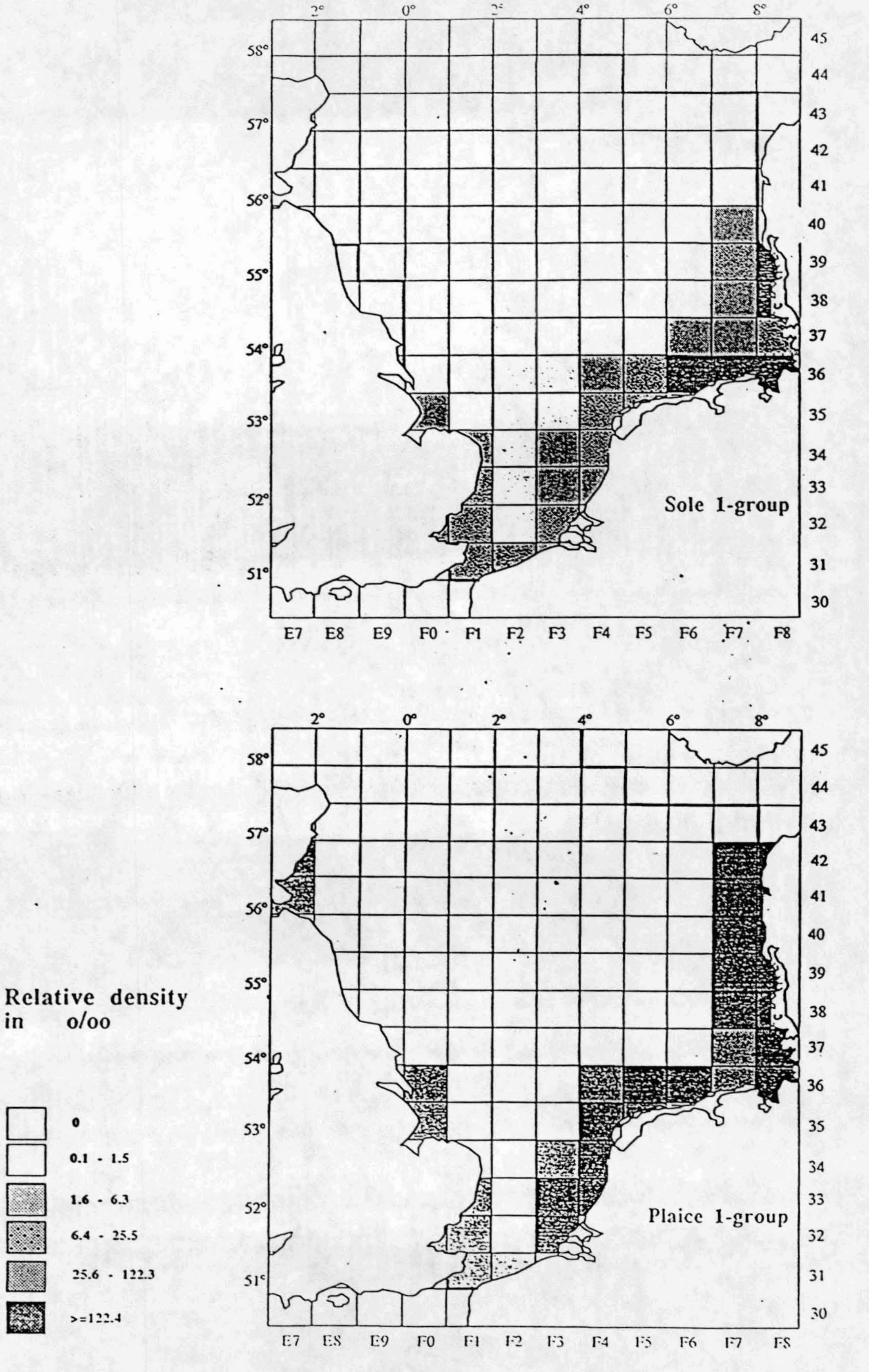

Figure 11. Average distribution pattern of 1-group plaice and sole in the third quarter, expressed as the proportion (0/00) of the total numbers present in each statistical rectangle (after Rijnsdorp & van Beek, 1991).

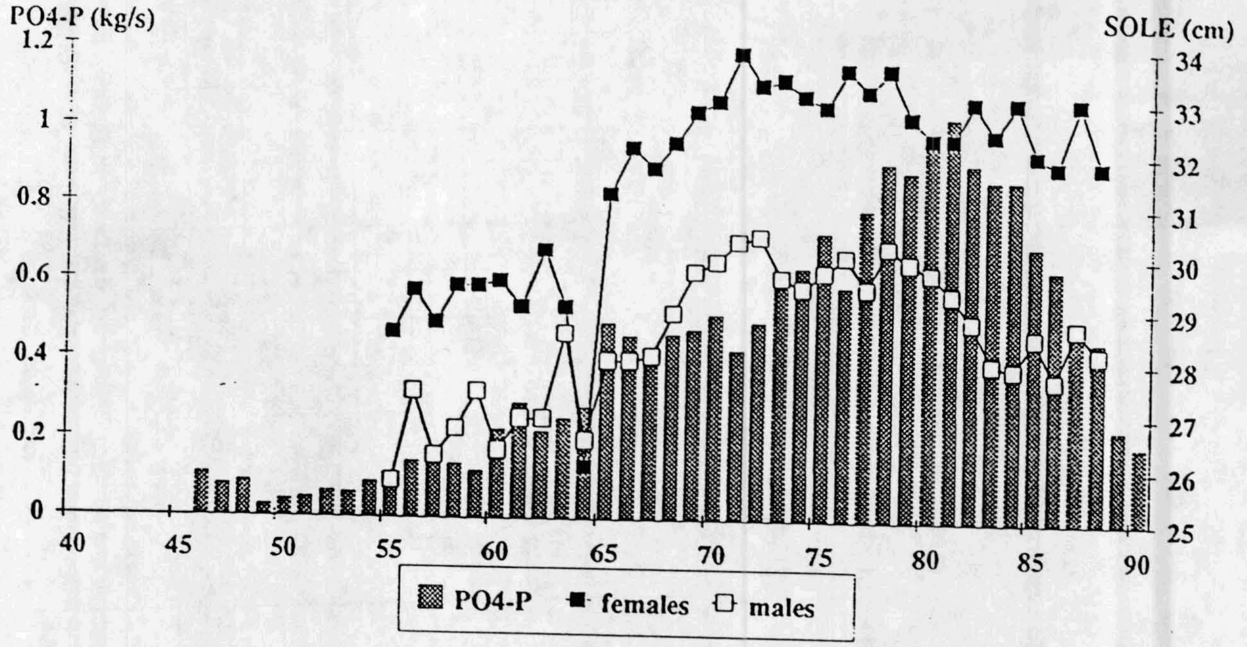

Figure 12. Average length of 4 year old sole (2nd quarter) per yearclass, two years after the birth of the sole, and the annual load of PO_4-P of the Rhine at the German-Dutch border (Lobith). Data of PO4-P: Rijkswaterstaat-RIZA. Sole: van Beek, 1988 (supplemented).

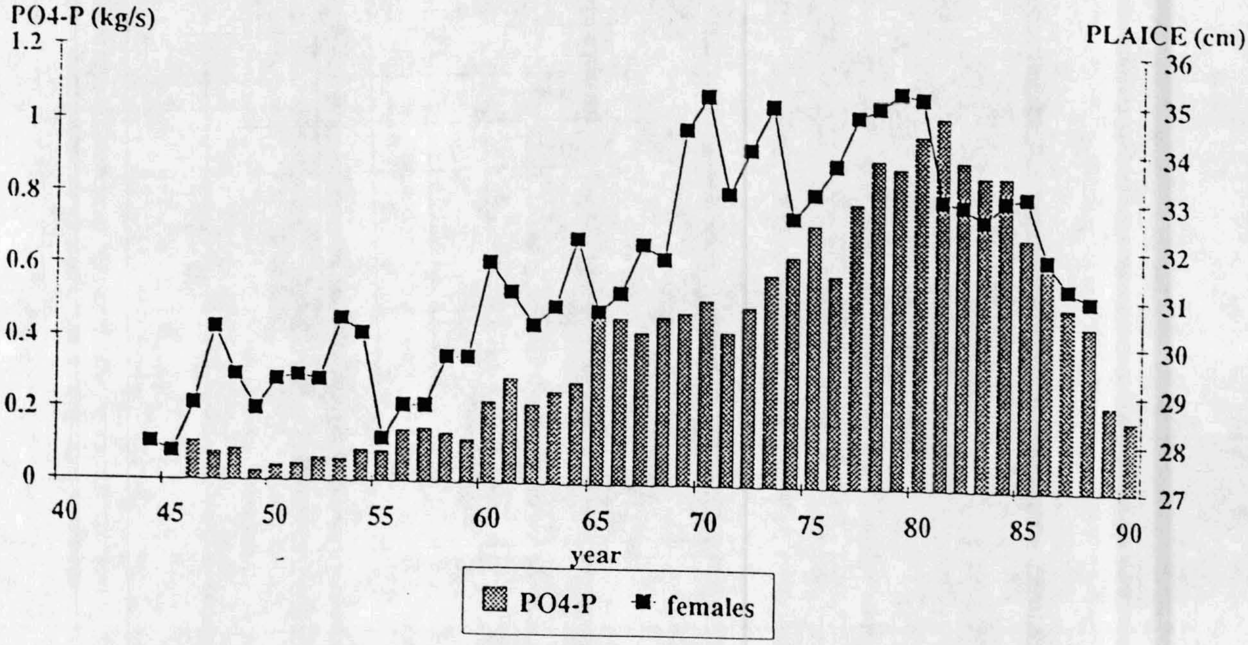

Figure 13. Average length of 4 year old female plaice (1st quarter) per yearclass, two years after the birth of the plaice, and the annual load of PO4-P of the Rhine at the German-Dutch border (Lobith). Data of PO4-P: RIZA. Plaice: Bannister, 1978 (adjusted for 1st quarter), Rijnsdorp et al, 1991, supplemented.

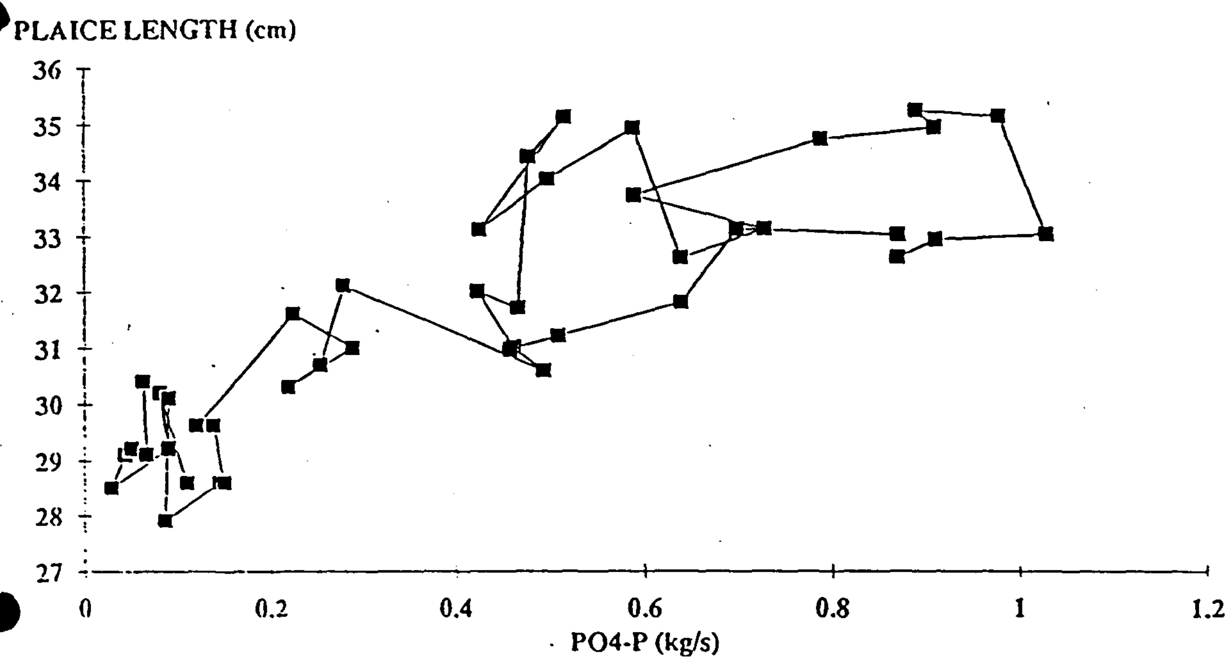

Figure 14. Length of 4 year old female plaice two years after the birth of the plaice as a function of the annual load of PO4-P of the river Rhine at the German-Dutch border (Lobith). Data of figure 13.