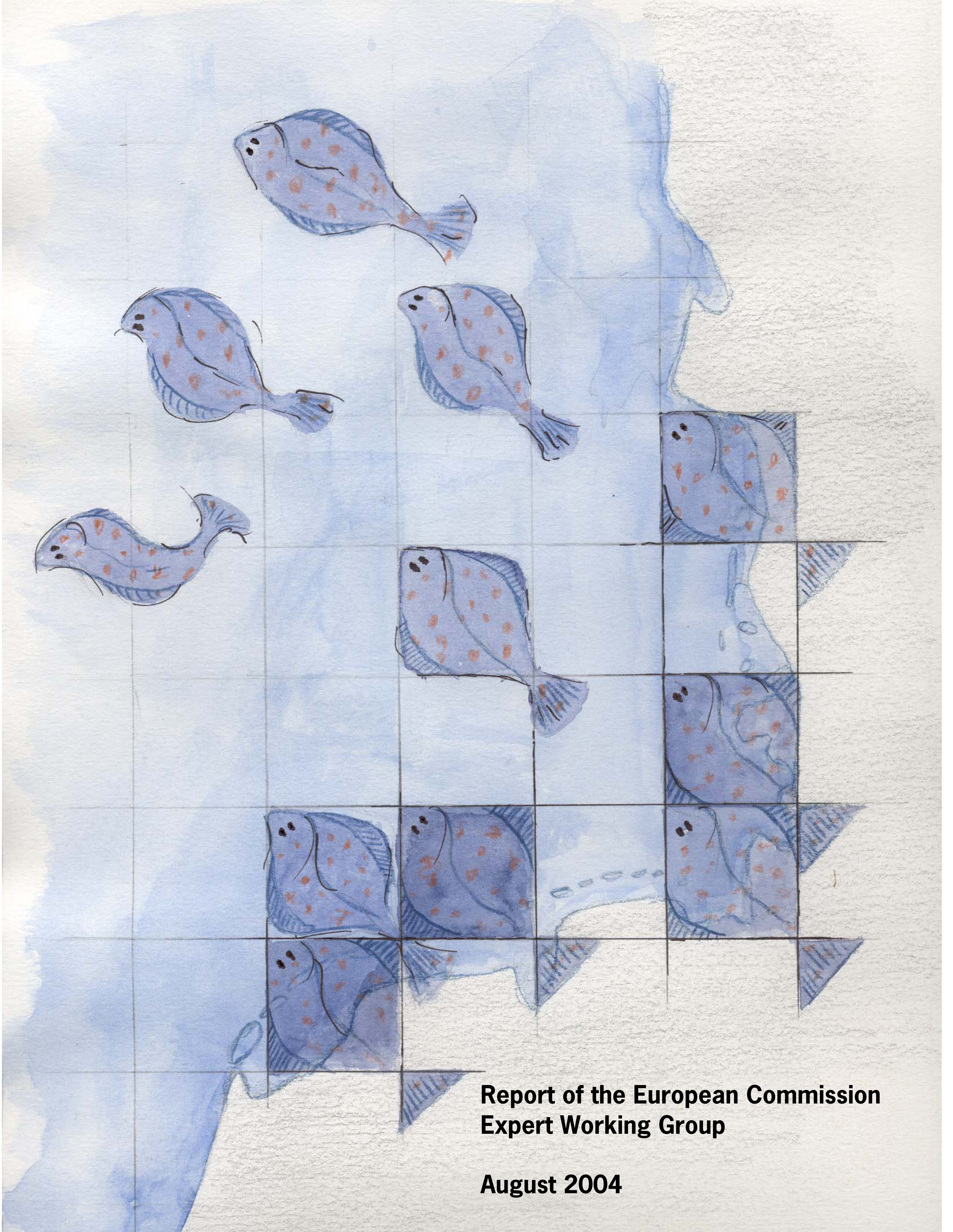
Assessment of the ecological effects of the Plaice Box



Report of the European Commission Expert Working Group

August 2004

Assessment of the ecological effects of the Plaice Box.

Report of the European Commission Expert Working Group

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Table of contents

Summary

The North Sea flatfish fisheries generate considerable numbers of discards, especially of Plaice *Pleuronectes platessa* in coastal waters. Their survival is very low. To reduce discard mortality, a partially closed area was established (Plaice Box) in 1989 in the coastal waters along the continental coast. The beam trawl fishery in this area was prohibited for vessels larger than 300 HP. From 1989 to 1995 beam trawlers larger than 300 HP were prohibited for part of the year and since 1995 all year round. Smaller beam trawlers (≤ 300 HP) were however still allowed to fish in the area. Because the Plaice Box encompasses the major nursery grounds of North Sea Plaice, it was expected that, at the same rate of exploitation, the introduction of the Plaice Box would enhance recruitment, yield and spawning stock biomass.

Evaluation of the Plaice Box

In 1999, the effectiveness of the Plaice Box was evaluated by an ICES working group (ICES, 1999) and in 2004 the European Commission established an expert working group to update this evaluation and in addition, to evaluate the effectiveness of the Shetland Box. According to Article 19 of Council Regulation (EC) No 2371/2002, the Commission must present a report to the Council and the Parliament on the justification, in terms of conservation and sustainable exploitation objectives, for any rules that restrict access to waters and resources outside the 12 mile coastal zone. On the basis of that report the Council may decide to adjust those rules of access. To help the Commission prepare its report, a working group was convened to evaluate the effectiveness of the Shetland Box and the Plaice Box. Because of the different characteristics of the Shetland and the Plaice Boxes, the evaluations are presented in separate reports. The group, however, worked together on the evaluation of both Boxes and had plenary meetings in Aberdeen and Brussels. In this report, only the Plaice Box will be addressed unless explicitly indicated.

Measuring direct effect not possible

To be able to evaluate the effectiveness of the Plaice Box it is important to define the criterion against which the effectiveness should be evaluated. In fact, the success of the Box should be determined from the increase in recruitment from the Box. This was, however, not measured from the introduction of the Box onwards and consequently, there is no single parameter from which the ecological effect of the Box can be measured. Therefore the approach of the current evaluation is to describe trends in important parameters and to infer the effectiveness of the Plaice Box from these trends. These parameters are landings and effort, discards rates, growth rates and spatial distribution of juveniles and environmental parameters such as water temperature and nutrient concentrations. This approach was necessary, as the management measure was not set up as an experimental design, with a control area, that would have allowed statistically sound comparisons and conclusions. Also, the hypothesis is investigated that food availability in the Box has decreased due to a reduction in bottom disturbance by the beam trawl fleet. This hypothesis is investigated by describing trends in spatial distribution and growth rates and using results from recently published studies.

Development of the Plaice stock

The spawning stock biomass of North Sea Plaice varied around the 300 thousand tonnes until 1989, the year in which the Plaice Box was established, after which it declined sharply to below B_{lim} (200 thousand tonnes) where it has since remained. Apart from the strong year-classes in 1963, 1981, 1985 and 1996 recruitment has shown rather little variability. There are some indications of a general reduction in recruitment since the early 1990s. Fishing mortality increased from 1970 up to a level of 0.65 in 1997 after which it sharply declined to 0.42 in 2001. So, despite the establishment of the Box, total recruitment and consecutively spawning stock biomass and yield decreased since it was installed.

Fishing effort decreased

Although fishing effort was significantly reduced in the Plaice Box following its complete closure to beam trawlers > 300 HP, the Plaice Box is not a closed area. There is still a high fishing activity by beam trawlers ≤ 300 HP

and other fleets (otter trawls, shrimp fleet). When the Plaice Box was partially closed in 1989, the total effort (in HP days at sea) from the international otter and beam trawl fleet decreased to 69 % of the pre-Box level. After the complete closure, effort decreased further to 23 % of the pre-Box level. The proportion of the total North Sea landings of Plaice taken from the Box also decreased. In 2003, however, still 7 % (6695 tonnes) of the total Plaice landings from the North Sea were landed from the Box.

Landings decreased and discards increased
Although the landings per unit effort for Plaice decreased by more than 50 % in the Box, the percentage of Plaice discards (as a percentage of the numbers caught) in the beam trawl fishery increased from 77 % between 1976 and 1990 to 87 % between 1999 and 2003. Percentages of Plaice discarded outside the Box have also increased, from 31 % in 1976-1990 to 77 % in 2003. At present, the difference in discard percentage inside and outside the Box is thus much smaller than in the period of 1976-1990. Both in terms of numbers and in biomass, Plaice discard percentages in the 80 mm beam trawl fishery are higher inside the Box. In the 100 mm fishery, however, discard percentages are lower here. This can be partly explained by the smaller sizes that are caught and discarded inside the Box.

Young Plaice moved towards deeper water
There is clear evidence that the spatial distribution of juvenile Plaice has changed such that the importance of the Plaice Box for juvenile Plaice has decreased. The change in spatial distribution was clearest in 1-group Plaice that moved to deeper areas further offshore. Distributional changes were observed not only in the Plaice Box, but also in the Wadden Sea. Temporal patterns in the abundance of juvenile Plaice inside the Box resembled those of the southern Dutch coastal zone that was not affected by the management regime of the Plaice Box. The abundance of both undersized and marketable Plaice decreased and showed the same pattern inside and outside the Box. Although the change in spatial distribution of this group had started around 1997, it was most pronounced from 2000-2003. Around 1990, about 90 % of the under-sized Plaice occurred in the Box and Wadden Sea whereas by 2003 this proportion had decreased and was lower than 70 %. This percentage decreased most dramatically for Plaice of 15-20 cm, the sizes that are most vulnerable to discarding. For this length class, the importance of the Box decreased rapidly since 1995.

Decreased growth rate
The growth rate of Plaice decreased around 1980 after which it stabilized until recent years. Inter-annual variation in growth rates has increased considerably in the last ten years. This time trend shows a striking correspondence with that of Sole *Solea solea*. Also, the time trends in growth rates of both species resemble trends in body condition. These patterns are thought to reflect changes in growth conditions in the coastal waters of the south-eastern North Sea, the main distribution area of the age groups analysed.

Change in environment: warming of seawater and lower nutrient concentrations
The environment in the Dutch and German coastal zone has changed significantly in recent decades. Since the 1950s, water temperature in and around the Box has increased by 0.5-1°C and the last four years (2000-2003) were extremely warm, especially in winter. The change in water temperature is also reflected by an increase in the number of southern species in the North Sea. In the Dutch coastal zone, both nitrogen and dissolved inorganic phosphorus increased from the 1950s until early 1980s, after which concentrations declined and stabilized in the early 1990s. Primary production in the Wadden Sea increased from 1970 into the 1980s and declined slowly thereafter. It is, however, unclear how these changes in primary production translate to higher levels in the food chain, such as benthos or fish.

The effect of the Box
This evaluation provided no direct evidence that the Plaice Box has enhanced recruitment, spawning stock biomass and yield, as was its purpose. Since the Box was established in 1989, recruitment has shown a negative overall trend, and spawning stock biomass and total yield have decreased by 60 %. However, because the Box was not established in an experimental set up with an equivalent control area, its functioning and effectiveness has to be inferred from trends in relevant parameters.

From trends observed it was inferred that the Plaice Box has likely had a positive effect on the recruitment of Plaice but that its overall effect has decreased since it was established. There are two reasons to assume that the Plaice Box has a positive effect on the recruitment of Plaice: 1) at present, the Plaice Box still protects the majority of undersized Plaice. Approximately 70 % of the undersized Plaice are found in the Plaice Box and Wadden Sea, and despite the changed distribution, densities of juvenile Plaice inside the Box are still higher than outside; 2) In the 80 mm fishery, discard percentages in the Box are higher than outside. Because more than 90 % of the Plaice caught in the 80 mm fishery in the Box are discarded, any reduction in this fishery would reduce discard mortality. There is, however, no proof of a direct relationship between total discard mortality and recruitment.

Although negative effect of the Box cannot be ruled out completely, the observed trends do not provide clear support for the hypothesis of decreased food abundance as a result of the Plaice Box: 1) contemporary literature shows that there is no positive effect of bottom trawling on ecosystem productivity; 2) the decrease in growth rates was initiated before the establishment of the Plaice Box; the temporal trends in growth rate are not correlated with the trends in beam trawling effort and 3) similar trends in the abundance and spatial patterns of Plaice were shown for areas outside the Box such as the Wadden Sea and the Dutch coastal zone southwards of the Box.

Future studies

The lack of pre-established criteria and of experiments to address specific research questions, make the evaluation of the effectiveness of the Plaice Box difficult. It is suggested that in future, monitoring the effectiveness of management measures like the Plaice Box should be carefully considered from the beginning. It is important to define the targets well, to develop appropriate and measurable evaluation criteria and to design a research programme to underpin conclusions with statistical evidence.

1. Introduction

1.1 Background[1]

The North Sea flatfish fisheries generate considerable numbers of discards, especially of Plaice *Pleuronectes platessa* in coastal waters (Van Beek, 1998). Survival of these discards is low ((Van Beek, Van Leeuwen & Rijnsdorp, 1989). In 1989, a partially closed area was established (Plaice Box) in the coastal waters along the continental coast between 53° and 57° N to improve the exploitation pattern by reducing discarding of undersized Plaice (Figure 1.1). The history of the management regime for the Plaice Box is described in Table 1.1.

Table 1.1. *Management regime in the Plaice Box.*

Period	Management regime
Before 1989	No restriction in fisheries in the Plaice Box
1989-1993	Beam trawl fishery of vessels >300 hp[2] prohibited in quarter[3] 2 and 3
1994	Beam trawl fishery of vessels >300 hp prohibited in quarter 2, 3 and 4
Since 1995	Beam trawl fishery of vessels >300 hp prohibited year-round

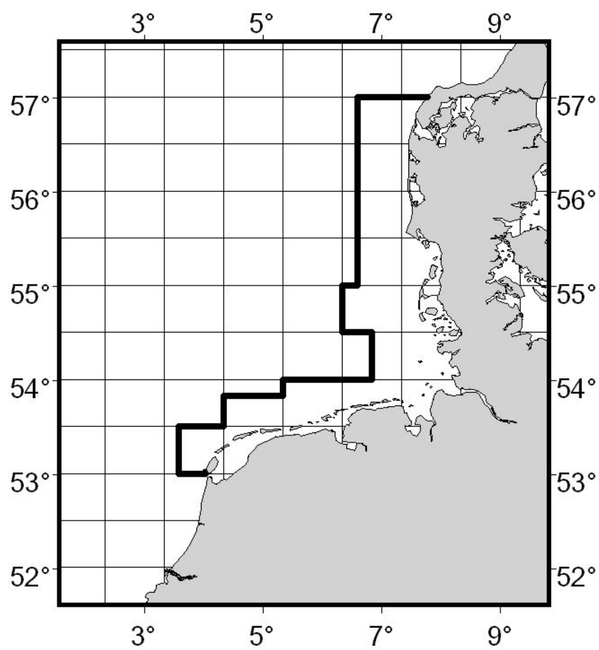

Figure 1.1. Map of the Plaice Box.

[1] The text for the background of the Plaice Box is extracted from the Plaice Box evaluation of 1999.

[2] Total beam trawl effort of the German, British and Dutch beam trawl fleet in the North Sea.

[3] Quarter 1 is January-March; 2: April-June; 3: July-September; 4: October-December.

As the Plaice Box encompassed the major nursery grounds of North Sea Plaice, it was expected that, at the same rate of exploitation, the introduction of the Plaice Box would enhance recruitment, yield and spawning stock biomass (ICES, 1987) compared to a no Plaice Box situation.

The scientific basis for the Box was developed in 1987 by the ICES North Sea Flatfish Working Group (ICES, 1987). To quantify the gains from a closed area this working group estimated the numbers of Plaice discarded by quarter and age group. The calculation assumed that the spatial distribution patterns were fixed, and that no feedback mechanisms did occur (density-dependent growth, density-dependent dispersion). The group predicted that, for a cohort, the proportion surviving could increase by about 25% if the Box was closed for all discarding fleets in the 2nd and 3rd quarter, and by almost 35% if the Box was closed all year round. The effects for Sole *Solea solea* have been estimated using the same methodology (Rijnsdorp & Van Beek, 1991). They concluded that the Plaice Box would generally enhance recruitment in Sole, but to a much lesser extend than in Plaice. This is due to the generally lower number of Sole discards in the flatfish fishery and the fact that dense concentrations of pre-recruit Sole also occur outside the Plaice Box along the Belgian coast. Because the Box, as established in 1989, was only closed for part of the fishery for part of the year, the expected positive effect would be reduced. A Working Group, evaluating the Plaice Box using the same methodology as used in 1987, concluded that the exemption fishery by small vessels and the increased fishing intensity during the 4th quarter reduced the positive effect of a 2nd and 3rd quarter closure from 25% to 11% (ICES, 1994). The group further noticed that the decrease in growth rate, observed by then, could further reduce the positive effect of the effort reduction because of the longer duration of the pre-recruit phase during which the animals are subjected to natural and discard mortality.

In 1994, the Plaice Box regulation was extended to the 4th quarter and since 1995 to the entire year. Despite this extension, no signs of an improvement of the yield and spawning stock biomass were apparent. This prompted the question as to whether the Plaice Box has contributed to an improved recruitment of Plaice.

1.2 Participation

The participants of the working group are listed below and contact details are given in Annex I.

Invited experts	Aberdeen (29 March-2 April)	Brussels (11-13 May)	Country
Clarke, Liz	+	+	Scotland
Damm, Ulrich	+		Germany
Grift, Rob (Chair)	+	+	Netherlands
McLay, Anne	+	+	Scotland
Reeves, Stuart	+		Denmark
Tulp, Ingrid	+	+	Netherlands
Vigneau, Joël	+	+	France
Weber, Wolfgang	+	+	Germany
Hopkins, Peter	+	+	EC Commission

1.3 Terms of reference

According to Article 19 of Council Regulation (EC) No 2371/2002, the Commission must present a report to the Council and the Parliament on the justification, in terms of conservation and sustainable exploitation objectives, for any rules that restrict access to waters and resources outside the 12 mile coastal zone. On the basis of that report the Council may decide to adjust those rules of access. To help the Commission prepare its report, the present working group was convened to evaluate the effectiveness of two areas of restricted access, namely the Shetland Box and the Plaice Box. The terms of reference of the working group were drawn up at a meeting of a number of the participants in Brussels on 21 October 2003 and are listed in Annex II.

Because of the different characteristics of the Shetland and Plaice Boxes, and the fisheries affected, the evaluations are presented as separate reports. The group worked, however, together on the evaluation of both Boxes and had plenary meetings in Aberdeen and Brussels. In this report, only the Plaice Box will be addressed unless explicitly indicated.

In relation to the Plaice Box, the following questions were derived from the terms of reference and were to be addressed:

1. Has the Plaice Box had a beneficial effect on the recruitment of Plaice?
2. Has the distribution of Plaice changed since the start of the Plaice Box?
3. Are there any changes in the growth of Plaice since the start of the Plaice Box?
4. Can any of these changes be related to changes in temperature, fisheries or productivity?

1.4 Methods and working strategy of the subgroup

The scope of the evaluation is explicitly limited to the conservation and sustainable exploitation objectives of the Plaice Box (Article 19 of Council Regulation (EC) No 2371/2002). This excludes any consideration of their socio-economic impact. For this, its first full meeting, the group was therefore asked to concentrate on the ecological impact of the boxes. It is nevertheless important that the Council is aware of the socio-economic impact when it considers the Commission's evaluation report. The terms of reference for the working group therefore include an evaluation of the socio-economic impact. At the first meeting, the working group was asked to provide biological data in a form that could be used in subsequent economic analyses.

To be able to evaluate the effectiveness of the Plaice Box it is important to define the criterion against which the effectiveness should be evaluated. The trend in recruitment, defined as the number of fish from a cohort reaching the minimum landing size, is not an appropriate measure. The number of settling demersal Plaice is highly variable due to variable mortality during the pelagic phase and the pre-recruit demersal phase (discard mortality, predation, diseases). Therefore the critical test for the evaluation would be if the cumulative discard mortality until the time when the cohort reaches the minimum landing size has decreased. Because direct observations of pre-recruit mortality are hampered by variable causes of mortality (other than discarding) and changes in distribution, an analytical approach in which the various underlying processes are evaluated is needed.

The approach of the current evaluation is to describe trends in important parameters and to infer the effectiveness of the Box from these trends. This evaluation addresses the same topics as the 1999 evaluation. A summary of that evaluation is given in Chapter 2. Important parameters are landings and effort, discards rates, spatial distribution of juveniles and growth rates. Trends in these parameters are presented and discussed in Chapters 4, 5, 6 and 7 respectively. In addition, an update of relevant scientific literature on the effect of bottom trawling on the productivity of benthic fauna is given in Chapter 9. All results are synthesized and discussed in Chapter 9.

To keep the report concise, many details are presented in the Annexes and only the major methods, results and discussion are presented in the main text. Therefore, the methods and analyses to describe trends are summarized in Chapters 3 to 7 and more details of these analyses are given in the Annexes. The main text also presents the most informative tables and figures whereas all relevant tables and figures are presented in the Annex.

The trends in important parameters in Plaice were compared with those in Sole because the majority of Plaice are caught in a mixed fishery that also targets Sole. Because Sole is more slender than Plaice it is fished with 80 mm mesh size which results in catching under-sized Plaice. Moreover, the comparison with Sole, a species with comparable feeding habits and ecology but differing in their sensitivity to temperature, could provide insights into factors responsible for the trends observed.

Every chapter will start with a brief summary of the previous evaluation. These summaries, that do not present results from the current evaluation, are marked with grey text blocks.

2. Summary of the previous evaluation

The previous evaluation of the Plaice Box was carried out by an ICES workshop in 1999 (ICES, 1999).

Two periods, corresponding to changes in management regime were distinguished: 1989-1994 when the Box was closed during the 2nd and 3rd quarter only and 1995 - 1998 when the Box was closed year round.

It was found that the establishment of the Plaice Box had reduced fishing effort in the Box area since 1989. The total beam trawl effort (HP-days at sea) in the Plaice Box in the period that the Box was closed during the 2nd and 3rd quarters was estimated to be less than 50% of the pre-Box levels. After the Plaice Box was closed year-round there was a further decrease in total beam trawl effort (HP-days at sea) to a level of 13% of the pre-Box level.

During the period 1989-1994, fishing effort of the exemption fleet of beam trawlers (≤ 300 HP) increased by 90%, but decreased by 45% between 1994 and 1998. A temporary increase in Danish gillnet effort was observed between 1989 and 1994. The later decrease in fishing effort in the Plaice Box coincided with a stricter enforcement of engine power limitations in the German area, and a reduction in the catch rate of commercial flatfish species.

It was found that the growth rate of Plaice showed a temporary decrease in the late 1980s, which was probably related to the high population abundance of undersized Plaice of the strong 1981 and 1985 year classes. Growth rate in the mid-1990s was as high as in the late 1970s and early 1980s.

Plaice smaller than the legal minimum landing size (27 cm) were mainly found within the Plaice Box, although a substantial part of undersized Plaice also occurred just outside the Box in later years. The largest concentrations of undersized Plaice typically occurred in the German part of the Box. Survey data indicated that the distribution pattern had changed from 1995 onwards. In the summers of 1995-1998, the largest concentrations of 2 and 3 year old Plaice were observed towards the western limit of the Box.

Discard estimation using a selectivity model suggested that discard rates of Plaice had declined since 1989, coincident with the introduction of the Plaice Box. The reduction was particularly evident for 3- and 4-year-old fish. However, there seemed to be no further decrease in the discard rates following the year-round closure from 1995 onwards. This may have been because of the smaller proportion of Plaice inside the Box during this period. The available discard observations show that discard rates in the Plaice Box remained high with values above 90% and that discard rates outside the Plaice Box may also have been very high.

The group's analysis of the Plaice Box was severely hampered by its inability to disentangle environmental effects from fishery-induced changes. The influence of water temperature, eutrophication and other natural variations in the biotic and abiotic environment and the response of Plaice to the reduction in beam trawl disturbance of the sea bed in the closed area remain unclear.

3. Trends in the Plaice stock

3.1 Current state of Plaice stock

The North Sea Plaice stock is assessed annually by the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). The most recent assessment of the stock is available in the report of the 2003 WGNSSK meeting (ICES, 2004). Stock trends from this assessment are presented in Figure 3.1.

The assessment indicates that apart from the strong year-classes spawned in 1963, 1981, 1985 and 1996 (which, with the exception of 1981, coincided with cold winters) recruitment has shown rather little variability. There are some indications of a general reduction in recruitment since the early 1990s, although such a trend might also be apparent if, for instance, there was an increase in numbers discarded, or misreporting of landings. Spawning stock biomass varied around 300 thousand tonnes until 1989, after which it declined sharply to below B_{lim}[4] (200 thousand tonnes) where it has since remained. This decrease reflects increasing fishing pressure and an absence of strong year-classes. Even the relatively strong 1996 year-class did not return the stock to above B_{lim}. Landings gradually increased over 1957 to 1989, going along with an increase in fishing mortality, but have subsequently decreased, reflecting the decrease in the stock size over the same period. Fishing mortality reached a maximum in 1997, since when some decrease is indicated[5].

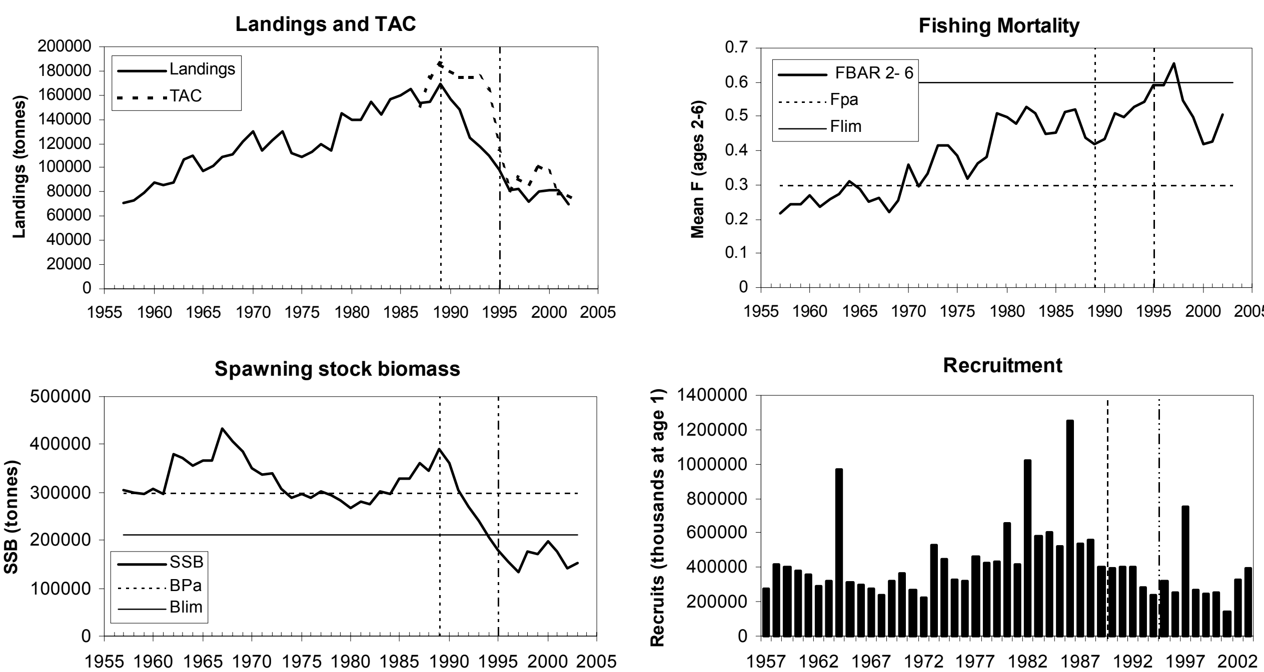

Figure 3.1. *Long-term trends in landings, fishing mortality, spawning stock biomass and recruitment for North Sea Plaice. The Figures also indicate the precautionary reference points where relevant, as well as the years 1989 (when the Plaice Box was introduced for two quarters of the year) and 1995 (when the Box was extended to cover all four quarters). Stock trends adapted from (ICES, 2004). Bpa=biomass precautionary approach.*

[4] B_{lim}= biological safe limit of the spawning stock biomass. If spawning stock biomass falls below this level, reproduction will be at risk.

[5] The assessment presented here does not include discards. As discards make up a large part of the catch, total fishing mortality is higher.

3.2 Trends in pre-recruit mortality

Data from three surveys were used to provide indications of trends in pre-recruit mortality (see for a description of surveys Annex V). This was estimated by taking logs of the ratio between the survey index in one year and the index of the same year class the following year. This approach results in nominal values of standard total mortality (Z) that are best interpreted as 'apparent total mortality' as abundance is confounded with catchability at age. However, if treated with caution, these values can be used to give an indication of trends in total mortality. Data were available from three surveys, the DFS, the SNS and the BTS[6]. Nominal total mortalities were calculated between ages 0 and 1 and between ages 1 and 2. To facilitate comparison between surveys, the values were standardised by first subtracting the mean of the series over the years 1982 to 1997, then dividing by the standard deviation over the same period. This year range was used for consistency with the corresponding analysis in the previous evaluation (ICES, 1999), though a slightly shorter year range was used for the BTS data as the survey only started in 1985. The resulting values are shown in Figure 3.2.

There is some correspondence between the trends apparent in all three series, suggesting that it would be reasonable to interpret the values as reflecting the abundance of the age groups concerned, rather than variations in catchability. It is striking that all three series indicate exceptionally high values for mortality between ages 0 and 1 since around 1998.

Data from the DFS were analysed per area to allow investigation of trends in apparent mortality on a more local scale. Again it is necessary to interpret the resulting values with caution, not least because of the possibility of movement of fish between areas. With that caveat, it can be seen that the sharp increase in apparent mortality remains clear on a local scale (Figure 3.3). The increase appears to be more pronounced along the Dutch Coast, in the Wadden Sea[7] and German Bight areas than in the Scheldt Estuary. Problems with area coverage and zero catches of 2-group fish in some years make it difficult to draw any conclusions about mortality between ages 1 and 2.

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[6] BTS: Beam Trawl Survey; SNS: Sole Net Survey; DFS: Demersal Fish Survey. A more detailed description of the surveys is presented in Annex 5.2.

[7] In the survey data, the Wadden Sea is defined as the coastal zone enclosed by the Dutch Wadden islands.

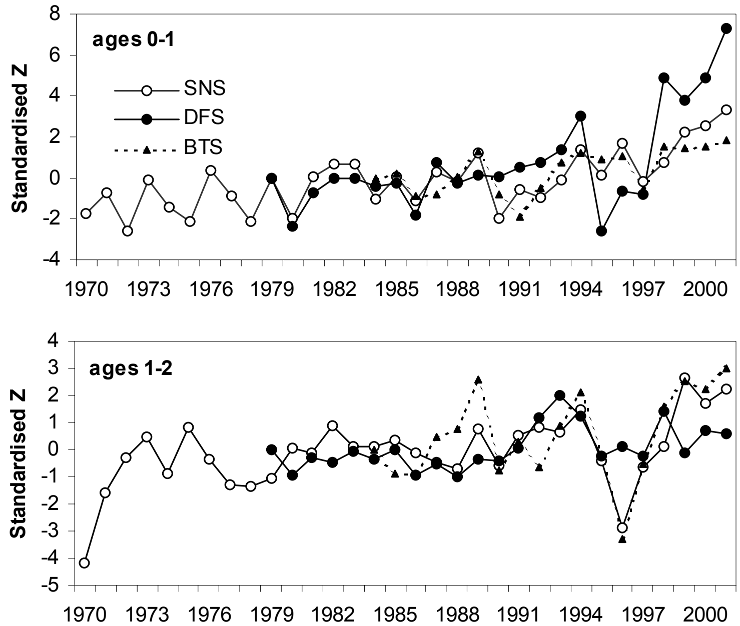

Figure 3.2. *Standardised estimates of Z (apparent total mortality) for Plaice from three survey series. For the BTS, analysis was restricted to data from hauls conducted by the RV Isis that fished in the South-Eastern North Sea.*

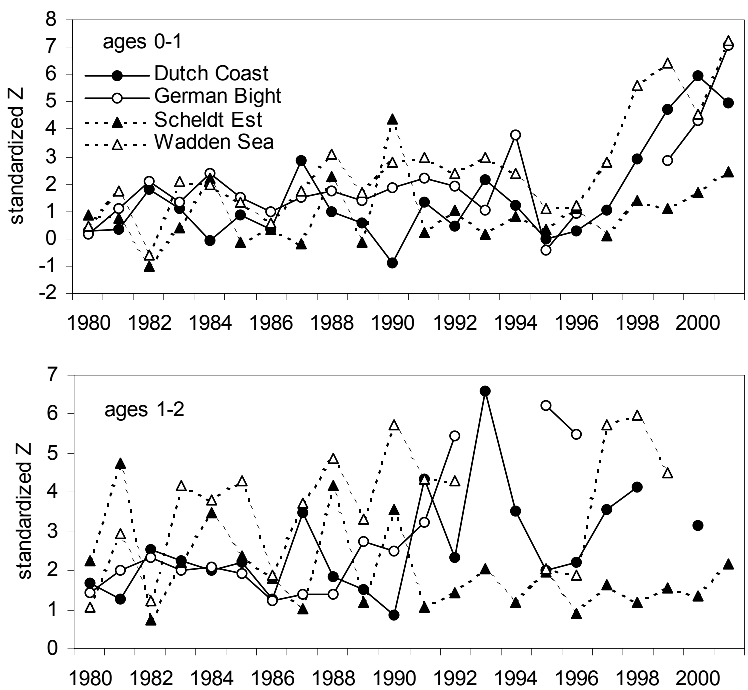

Figure 3.3. *Standardised estimates of Z (apparent total mortality) for Plaice from the DFS survey in four different sub areas.*

3.3 Abundance indices of Plaice and Sole in different areas

For age groups 0, 1 and 2, the abundance of Plaice inside the Plaice Box shows the same pattern over time as in a reference area south of the Box (see for the reference area Figure 3.6). In both areas, peaks and dips occur in the same years and trends are comparable. Patterns in the Wadden Sea, however, differ from those in both other areas. Densities of 1-group Plaice show a sharp decrease from 1997 to 2003 in the Wadden Sea whereas they show a moderate decline in the Box and are rather constant in the reference area. In the Wadden Sea, densities of 2-group Plaice show a strong decrease from 1980 onwards whereas they decrease less in both other areas.

For Sole, patterns inside the Plaice Box resemble those of the reference area and the Wadden Sea (Figure 3.5). No such clear differences for the Wadden Sea as for Plaice are evident. Only for Age 1 and Age 2 Sole densities are lower in the Wadden Sea and show some decrease.

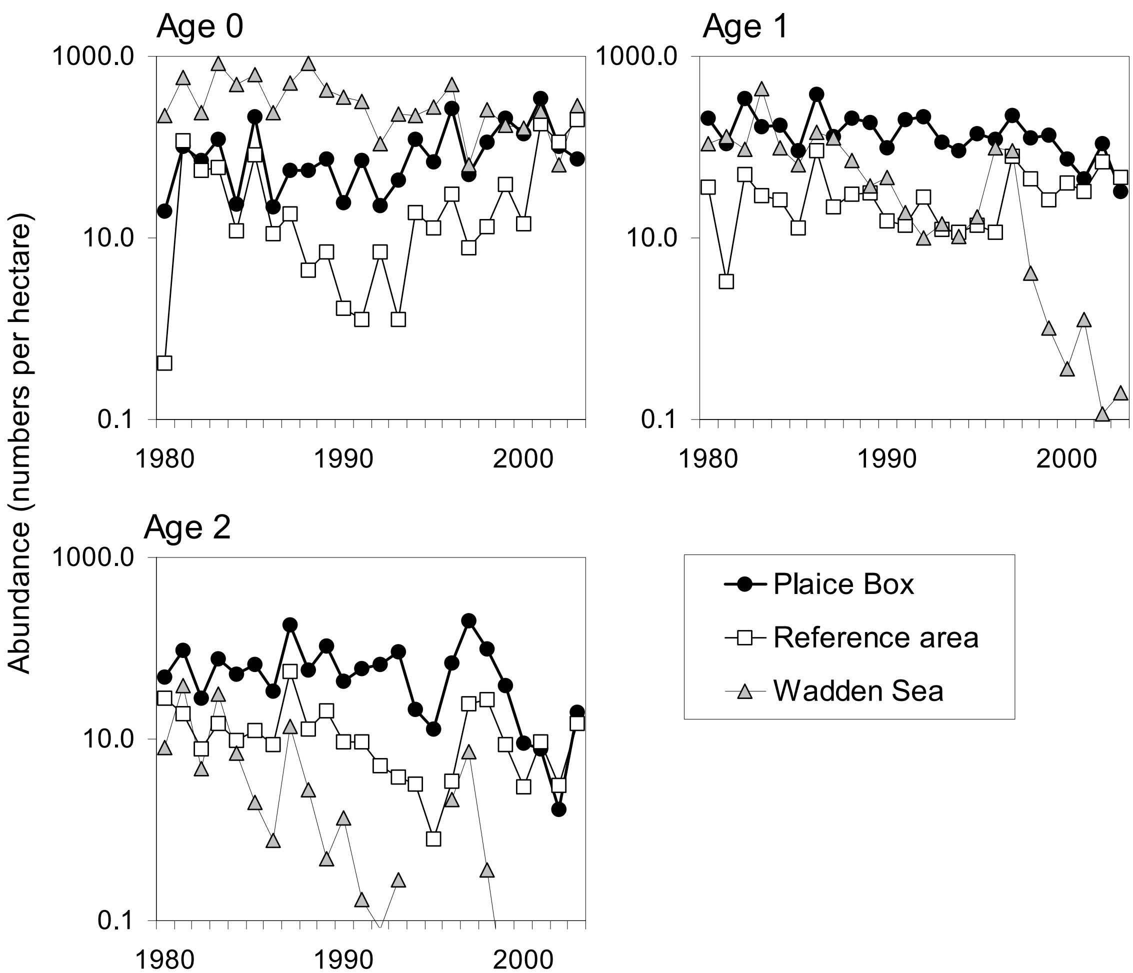

Figure 3.4. *Abundance of Plaice in the Plaice Box, a reference area (Ref S in Figure 3.6) and the Wadden Sea. Data for the Plaice Box and reference area from the BTS (from 1985 onwards) and SNS, data for the Wadden Sea from the DFS.*

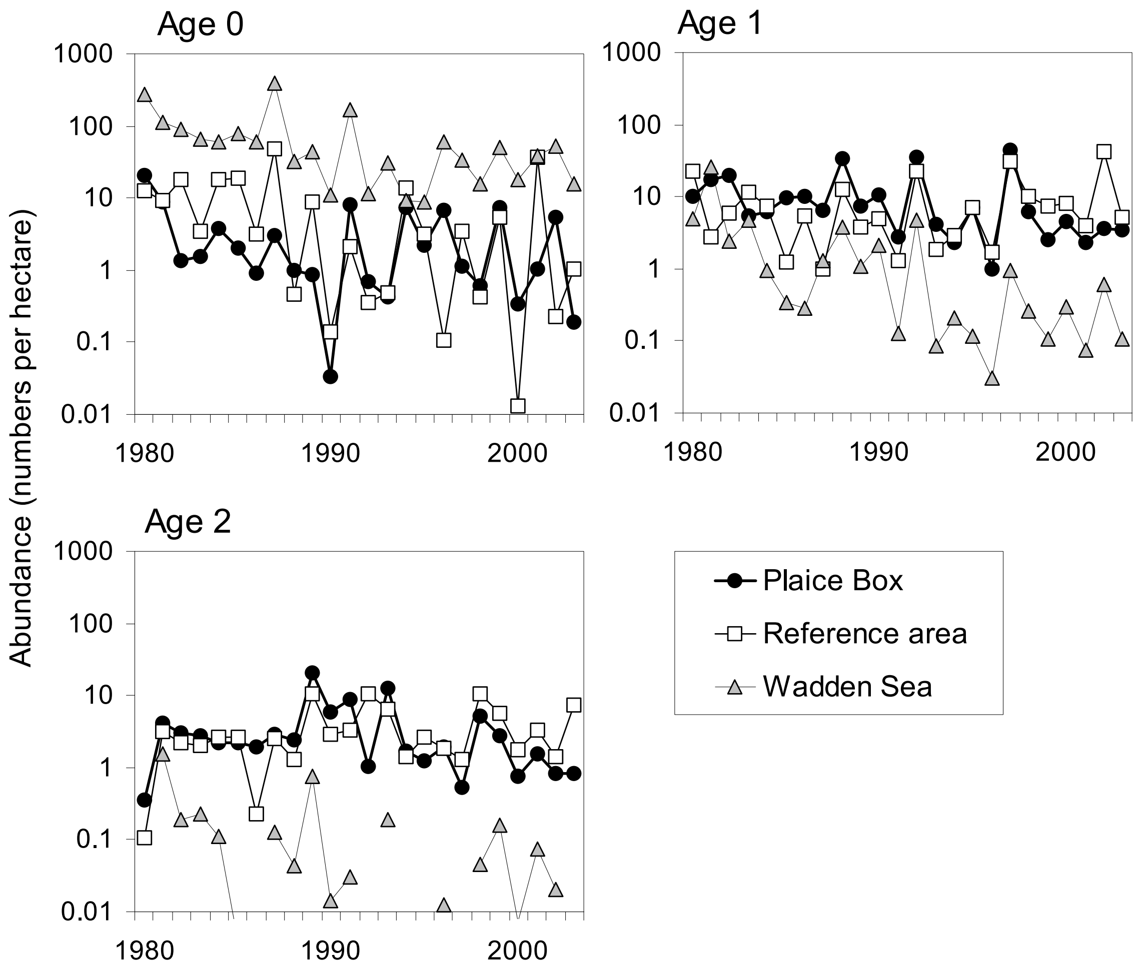

Figure 3.5. *Abundance of Sole in the Plaice Box, a reference area (Ref S in Figure 3.6) and the Wadden Sea. Data for the Plaice Box and reference area from the BTS (from 1985 onwards) and SNS, data for the Wadden Sea from the DFS.*

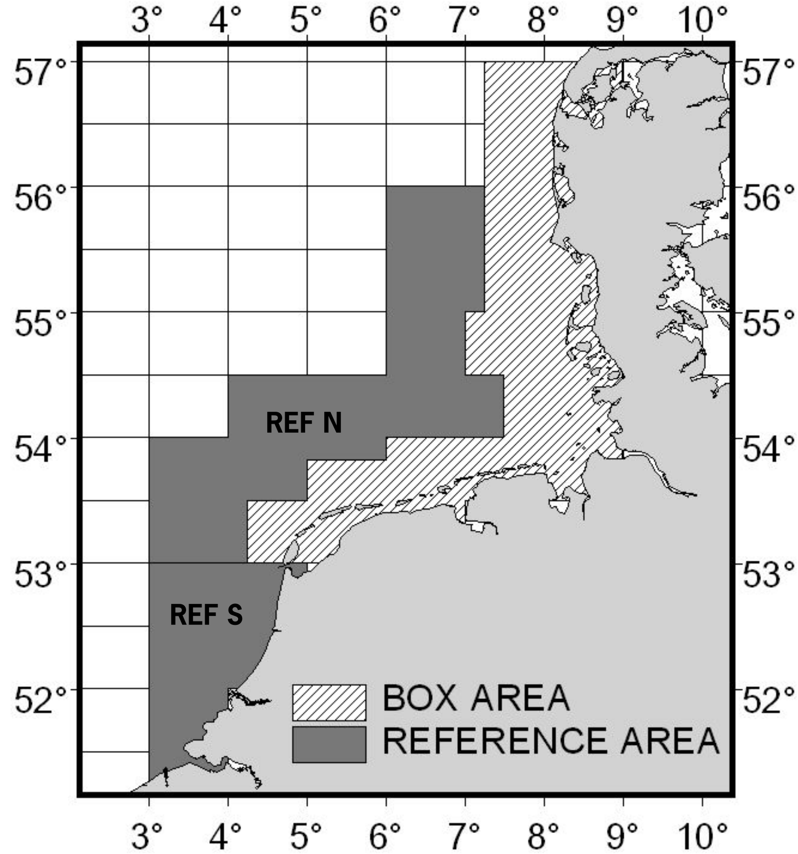

Figure 3.6. *The situation of the reference area (Ref S) that was used in figures 3.3 and 3.4 (Piet & Rijnsdorp, 1998).*

In addition to a decrease in the abundance of under-sized Plaice, the abundance of marketable Plaice has also decreased significantly in all areas (regression analysis on log-transformed numbers per haul, $P<0.0001$, Figure 3.7). The abundance decreased less rapidly in the northern reference area than in the Plaice Box (but differences were not significant (interaction term year*area, $P>0.05$). Given the change in distribution of Plaice towards deeper areas (Chapter 6) this is not surprising. The abundance of marketable Sole decreased at the same rate inside the Plaice Box and in both reference areas but the decrease was not significant ($P>0.05$, Figure 3.7).

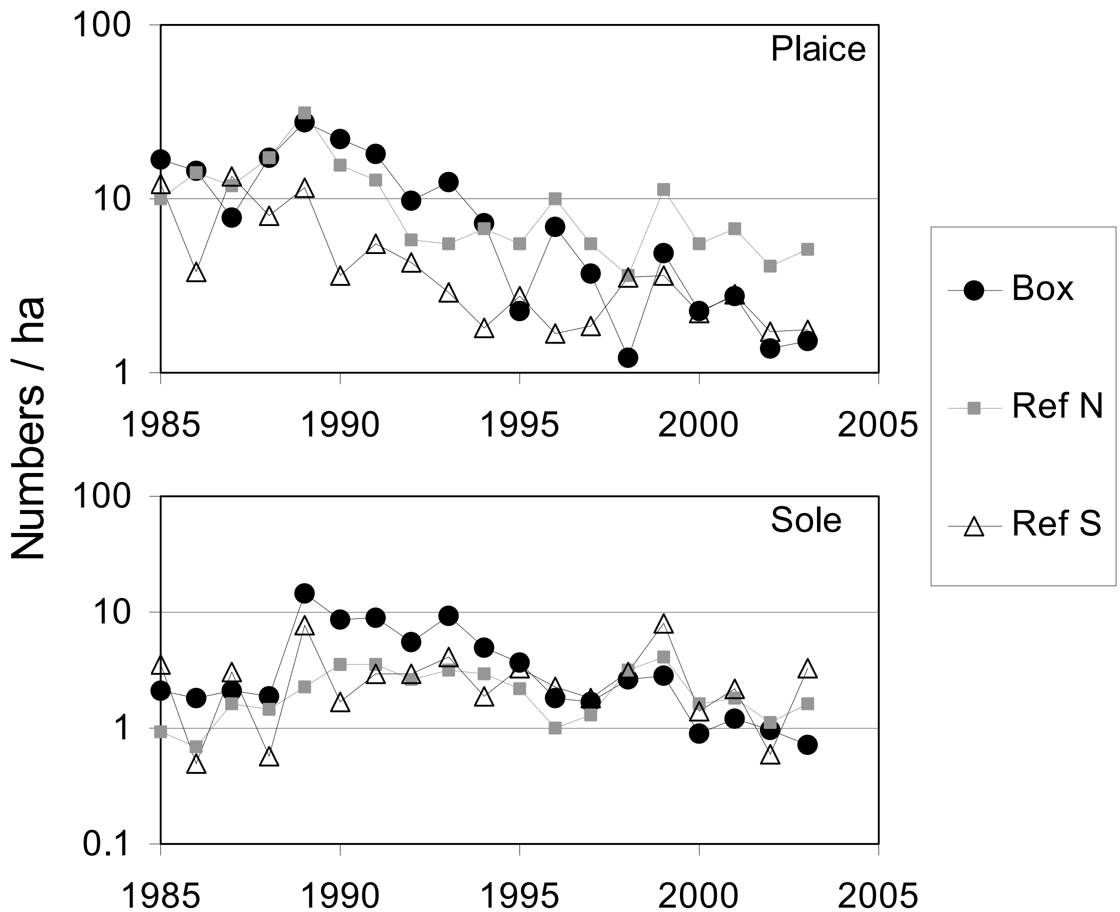

Figure 3.7. *Abundance of marketable Plaice (≥27 cm, upper panel) and Sole ≥24 cm, lower panel) in the Plaice Box and two reference areas (Ref S and Ref N from Figure 3.6). Data from the BTS survey.*

4. Trends in fishing effort and landings

4.1 Introduction

Because the main objective of the Plaice Box was to reduce discard rates by reducing fishing effort in the nursery area of Plaice by restricting access of the beam trawl fleet to trawlers ≤ 300 HP, it is important to assess how fishing effort has changed over time.

From the previous evaluation it became clear that in the period from 1995-1998 (within four years after the complete closure of the Plaice Box) effort of the beam trawl fleet, in terms of HP days at sea, had decreased to 13 % of the pre-Box level.

Here trends in effort over a period of almost 20 years, from 1985 to 2003 are described. In addition, trends in landings in and around the Plaice Box and trends in landings per unit of effort are described. Details of the available data, the assumptions made and of trends in landings and effort are presented in Annex III.

4.2 Analyses and assumptions

Landings and effort data by statistical rectangle, year, month (quarter for Denmark), country and gear were made available by working group members' institutes and were compiled as a single dataset (Annex III, Table III.1). Fleets were separated into two groups based on total engine power: ≤ 300 HP[8] (Exemption fleet or "Euro-cutters"); >300 HP. The total landings per species for Plaice, Sole, Dab *Limanda limanda*, Whiting *Merlangius merlangus*, Cod *Gadus morhua*, Haddock *Melanogrammus aeglefinus*, Nephrops and shrimps were available. Because Belgian landings data were available for three years only, and the proportion of Plaice landed by this fleet was less than 5 % of the total, Belgian data were not used in the evaluation. Of all data, it was determined whether it came from inside or outside the Plaice Box depending on ICES statistical rectangles, the type of gear and the HP of the vessel. Trends in effort and landings in the Plaice Box were compared with those in the rest of the North Sea (Annex III, Figure III.1). All gears were classified into six gear types: beam trawl, otter trawl, seine, shrimp trawl, gill net and other gears.

4.3 Trends in effort and landings

The initial introduction by a partial closure of the Plaice Box had almost no effect on the effort of the vessels ≤ 300 HP whereas the effort of larger vessels, especially beam trawlers, decreased rapidly (Annex III, Figure III.2). Since the closure of the Box in all quarters in 1995, total effort in the Plaice Box seems to have stabilized. Obviously, for beam trawlers >300 HP the contribution to the total effort has decreased and, in contrast to the pre-Box period, otter trawls now are the most important gear type for this type of vessel.

[8] Power is expressed here as horsepower, HP, 1 HP=0.7355 KW.

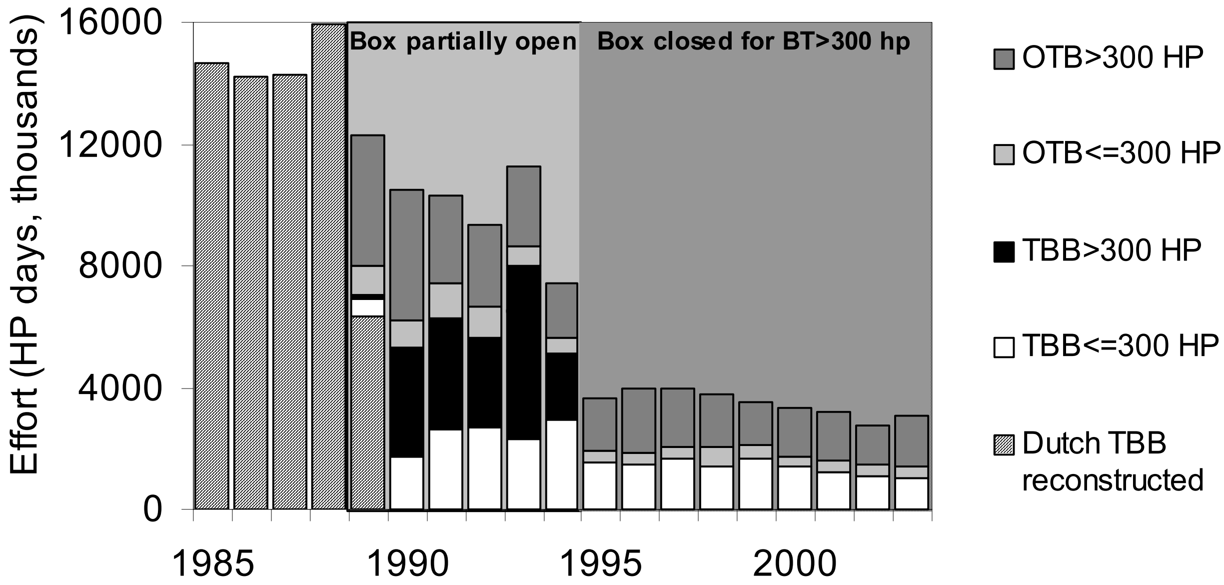

Figure 4.1. *Total effort (HP days, thousands) of beam trawlers (TBB) and otter trawlers (OTB) in the Plaice Box. Data from Germany, Denmark, England and the Netherlands combined. The effort in the years 1985-1989 represent data of the Dutch beam trawl fleet only, that was reconstructed (data from the 1999 evaluation (ICES, 1999). Total effort before 1989 was thus higher then presented here because data from beam trawlers of other countries and otter trawlers of all countries are lacking from that period.*

The total effort of otter and beam trawls, the types of gear that land most Plaice, was halved after the closure of the Plaice Box in 1995 (Figure 4.1). By 2003, the total effort of the Dutch beam trawl fleet had decreased to 3 % of the pre-Box level of 1985 (Annex, Figure III.3). Concurrently with the change in management regime, the decrease in effort of the Dutch beam trawl fleet occurred in three steps: to a level of 43 % of the pre-Box level in 1989, 23 % in 1994 and 6 % in 1996. Despite a stable effort of otter trawls, landings of Plaice in this fleet increased (Annex III, Figure III.12, Figure 4.2). This increase might be partially explained by the increase in twin trawling which was introduced in the Netherlands in 1997. In 2002, 47 vessels that were owned or operated by Dutch companies employed a twin trawl. In the Dutch fisheries statistics, the twin trawl is registered as an otter trawl and not as a separate gear type. The twin trawl is very efficient for catching Plaice although twin trawlers land less Plaice than beam trawlers per day at sea (Grift et al., 2004).

Since 1991, total landings of Plaice from the Plaice Box have been decreasing but the sharpest decline occurred in 1994 in the fleet of vessels>300 HP when total landings decreased by more than 90 %. Denmark, the Netherlands and Germany land more than 90 % of the Plaice from the Plaice Box (Annex III, Table III.2). In 2002, total landings of Plaice from the Plaice Box were 22 % (3459 ton) of those in 1990 (13137 ton). Plaice landings decreased more in the Plaice Box than in the total North Sea (Annex III, Table III.2). Over the same period, in the North Sea, total landings of Plaice decreased to 53 % (from 120307 tons in 1990 to 56455 tons in 2002).

Since 1990, the landings per unit effort (LpUE) of beam trawlers ≤ 300 HP have halved inside the Plaice Box whereas they have slightly increased outside the Plaice Box (Figure 4.3). Over the whole North Sea, LpUE of the beam trawlers >300 HP have also halved. When the strong 1996 year class recruited to the fisheries in 1999, the landings of Dutch beam trawlers ≤ 300 HP showed a peak. Outside the Box, this peak occurred one year later. This was probably caused by the offshore migration of the 1999 year class. In the case of Sole, the LpUE in the Dutch beam trawl fleet dipped in 1997 after which they increased rapidly in beam trawlers ≤ 300 HP (Figure 4.3). In larger beam trawlers, LpUE for Sole were rather constant with a small dip in 1997 also.

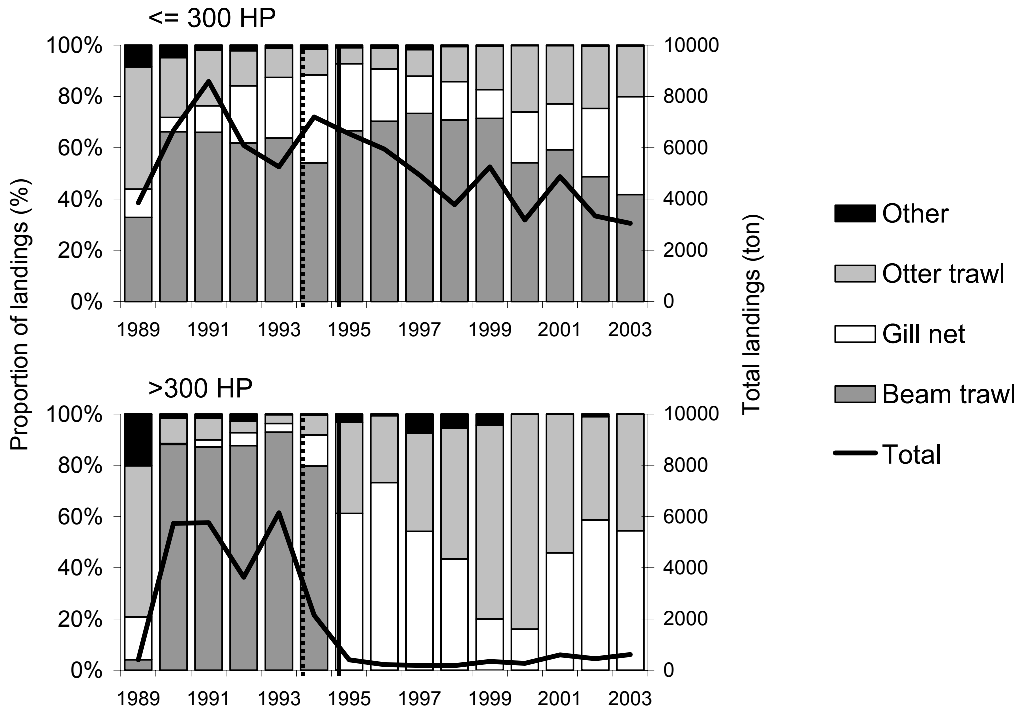

Figure 4.2. *Trends in the total landings of Plaice and the contribution of each of the fleets to the landings. The vertical lines indicate the different management regimes in the Box: 1994: Box closed for three quarters; 1995: Box closed year-round.*

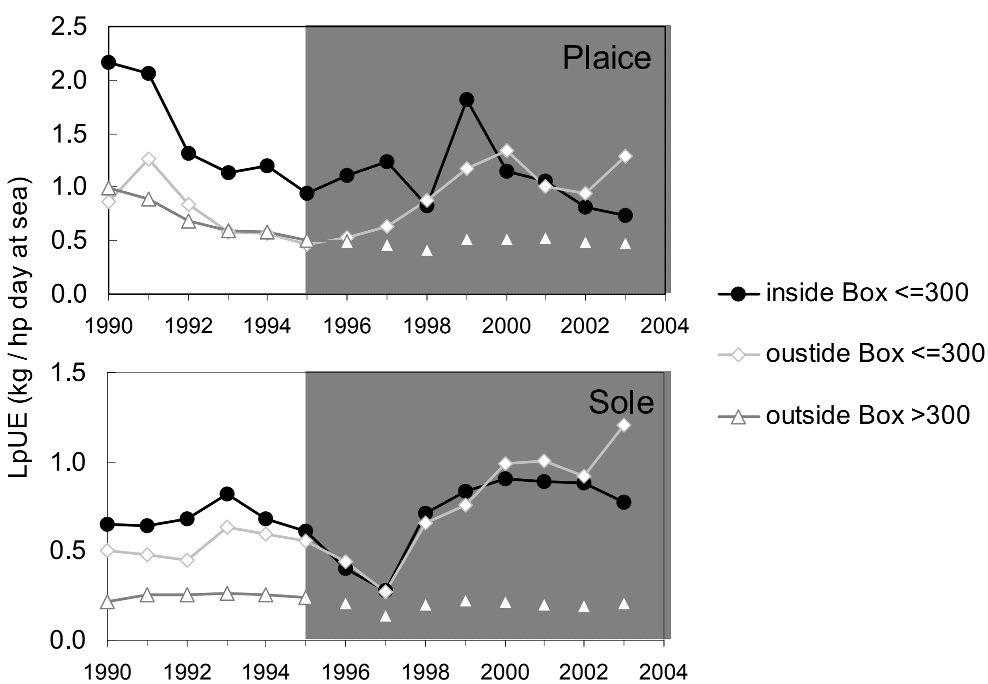

Figure 4.3. *Trends in Landings per Unit Effort (LpUE) for Plaice and Sole in the Dutch beam trawl fleet, inside and outside the Plaice Box.*

5. Discards

5.1. Introduction

In and around the Plaice Box, young Plaice are caught and the majority is discarded in the beam-trawl fisheries for brown shrimps and for flatfish. The shrimp fishery is not considered here because relevant data are absent. The main cause of discarding in the flatfish fishery is the 80 mm mesh that is used in this mixed fishery to catch Sole. The mesh size is too small to accommodate the 50% retention length for Plaice. All Plaice caught below the minimum landing size of 27 cm (mainly 1 and 2-year-olds) are discarded. Most discards (ca. 90 %) do not survive, either because they are damaged in the net during fishing or during the sorting process onboard (Van Beek *et al.*, 1989; Van Beek, Van Leeuwen & Rijnsdorp, 1990). The Plaice Box was established in the major distribution areas of 1 and 2 year old Plaice in order to reduce the amount of discarding.

The quantities of young Plaice discarded in the commercial fishery depend on several factors: Year-class strengths, spatial distribution in the area, growth rate (and indirectly through temperature regime and food availability) and last but not least the employed vessel, gear type and mesh size. As the youngest age groups are found mainly in the Wadden Sea, older juveniles stay near shore causing higher discard rates in these areas.

In the previous evaluation, discard information was available for only a few fleets directed to flatfish that are, or have been, operating in the Plaice Box area. Of these fleets, discarding of Plaice in the beam trawl fleet was most significant. Discard levels and percentages in the Box were higher than in other areas sampled. Most discards in the Box ranged between 18 and 27 cm in length and mainly consisted of age 2 fish. The numbers of Plaice discarded in the shrimp fisheries appeared to be high but the impact of discarding of the shrimp fisheries on the recruitment of Plaice was difficult to estimate (ICES, 1999).

5.2. Available data on Plaice discards

There are few data available on discards rates in the Netherlands fleets prior to 1975. The available data describe the percentage of the total catch discarded and the numbers of Plaice discarded per hour. Aggregated data are available from inside and outside the Plaice Box for the years 1976 – 1990 and 1999 – 2002. German data are available from 1993-2003 from both inside and outside the Box. These data allow the comparison of the length distribution of Plaice inside and outside the Box.

The Dutch data from 1999-2002 are based on 39 trips and the German data from 1993-2003 are based on 53 trips (Annex IV, Table IV.4 and IV.5).

5.3. Results from discard investigations

According to Dutch data, the amount of discarded Plaice per hour inside the Box decreased considerably after the Plaice Box was created (Annex IV, Table IV.1; Figure 5.1). As the number of *landed* Plaice inside the Box decreased even more, the percentage of discards increased from 77 % in 1976-1990 to 87 % in 1999-2003. The numbers inside and outside the Box, however, are not fully comparable, as the vessel speed and gear dimensions are different. In the German part of the Box an increase in discard percentages from 1993-1998 (Annex IV, Table IV.2.) was observed. It shows large inter annual variations due to year-class influences. In addition it shows that the use of a 100 mm mesh size obviously reduces discarding rates.

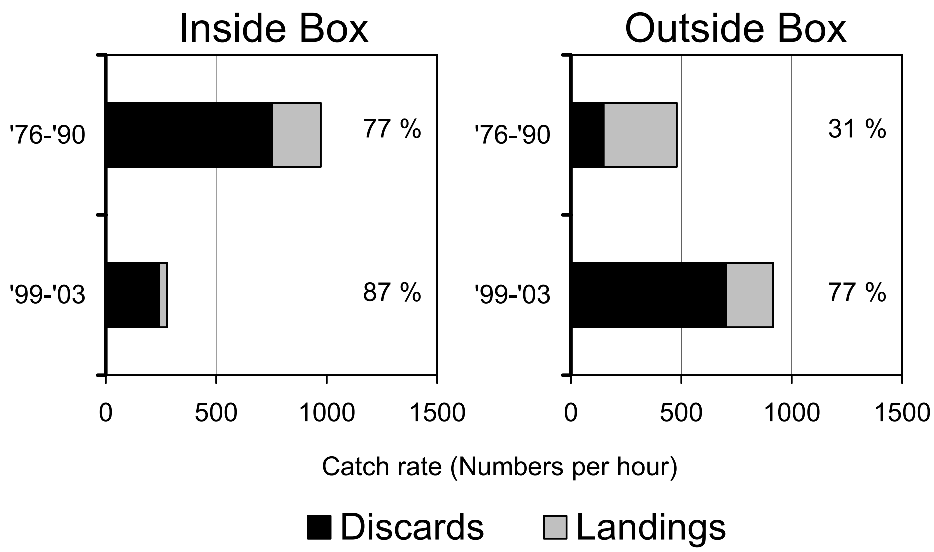

Figure 5.1. *Catch rates of discards and landings in the Dutch beam trawl fleet in numbers per hour fished. The percentages are the percentages of the total catch that was discarded (Keeken* et al.*, 2004)*

Table 5.1. *Percentage of discards in the total catch in terms of numbers and weight, in- and outside the Plaice Box averaged over 1998-2003 for Germany (GER) and the Netherlands (NLD). Disaggregated data per year and quarter are presented in Annex IV (Table IV.3).*

Mesh Size		Numbers			Weight		
		Inside	Outside		Inside	Outside	
		GER	GER	NLD	GER	GER	NLD
80 mm	Average	96	77	71	82	55	48
	Stdev	6	20	15	17	21	17
100 mm	Average	57	67		38	55	
	Stdev	22	34		29	37	

Inside the Plaice Box, the use of larger mesh sizes reduces the discard percentages whereas outside the Box this hardly has any effect (Table 5.1). Recent data show that using a mesh size of 80 mm on average 82% of Plaice is discarded inside and 55% outside the Box (in terms of weight; Table 5.1). It indicates that small Plaice are more abundant inside the Box and are caught by small-meshed nets. Applying 100 mm meshes the respective discards figures in- and outside the Box are 38 and 55%, respectively. Independent data from Germany and the Netherlands show similar discard percentages. Those young Plaice, that can escape through the bigger meshes are mainly living inside the Box, outside the Box the increased mesh size seems not to save additional undersized Plaice. Over the past four years, the percentage of Plaice discarded outside the Box has been increasing (Annex IV, Table IV.1).

Both before and after closure of the Plaice Box, discarded Plaice inside the Box are clearly smaller than those from outside the Box (Figure 5.2; Annex Figure IV.1).

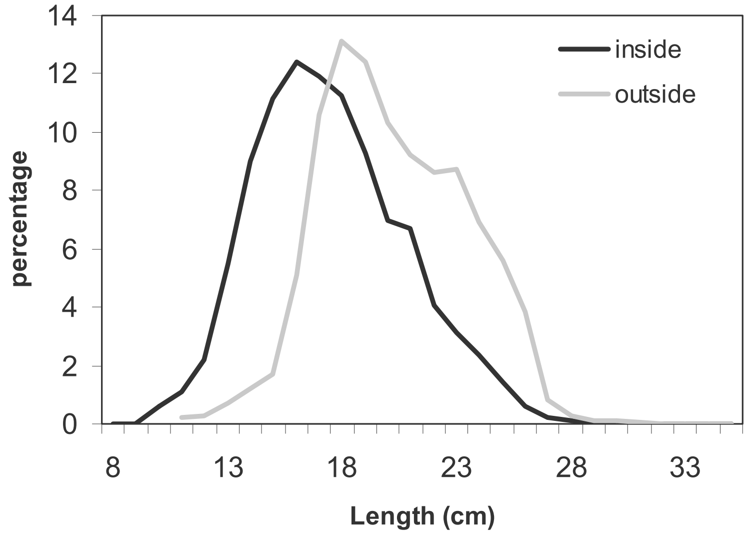

Figure 5.2. *Length-frequency distribution of Plaice discards inside (black line) and outside (grey line) the Plaice Box (mesh size 80 mm, German data averaged over 2000-2003).*

5.4. Conclusions

The discard data indicate that the proportion of under-sized Plaice is higher inside the Plaice Box than outside but over time, the difference has become smaller. Any fishery inside the Box, especially that with 80 mm, produces relatively higher numbers of discards than outside. Discard data are scarce but consistent conclusions can be drawn on the basis of German and Dutch observations.

6. Spatial distribution of juvenile Plaice

6. 1 Introduction

The Plaice Box was established to protect juvenile Plaice from being discarded. Among the factors that determine the discard mortality, the spatial distribution of the discard size classes relative to that of the fishery is important. The borders of the Plaice Box were determined such that it would cover 90% of the nursery area of Plaice. Whether the Plaice Box is still protecting a large proportion of juvenile Plaice or not depends on their current spatial distribution. In the previous evaluation a change in distribution was detected and in this evaluation it was analysed if this change has proceeded.

In the previous evaluation BTS survey data showed a reduction in the relative abundance of age groups 1 to 4+ Plaice in the shallow waters off Sylt. No change in spatial distribution was apparent neither in the Dutch part of the Plaice Box nor along the Dutch coast. The change in distribution was also reflected in the mean depth or mean distance from the coast estimated from the SNS survey data for 1 group Plaice but not for the older age groups. The change in distribution was also supported by the May surveys carried out by the German RV Solea. The change in distribution coincided with the exceptionally high water temperatures observed in that part of the Plaice Box from 1995-1999. A direct response of Plaice to temperature was considered unlikely but temperature may also have an indirect effect by affecting food availability. Changes in the spatial distribution may also be related to other environmental factors and to changes in the spatial distribution of the heavily trawled areas. Plaice of all size classes appeared to be concentrated along the borders of the Plaice Box in recent years, and the change in Plaice distribution was most pronounced in the German part of the Plaice Box (area 2), where the strongest decline in beam trawl effort occurred (ICES, 1999).

To evaluate the change in spatial distribution of Plaice, trends in the occurrence of Plaice at different depths using Dutch survey data from 1970-2003 were analysed. The comparison with Sole, a species with comparable feeding habits and ecology but differing in its sensitivity to changes in temperature could provide information as to the causes of the changing distribution.

Possible trends in the spatial distribution of juvenile Plaice are described in the following ways:

1. Maps with densities per year, age class and haul for Plaice and Sole that illustrate general patterns (Annex V and VI);
2. Maps with the presence/ absence per year, age class and haul for Plaice (Annex VII);
3. The change in the probability to catch at least one Plaice in relation to year, depth and closure in and outside the Box. A high probability of catching Plaice indicates that the species is evenly distributed whereas low probabilities imply a more patchy distribution (Annex VIII);
4. The change in the abundance of Plaice (numbers per haul) in relation to year, depth and closure, in and outside the Box (Annex VIII);
5. Changes in the abundance of Plaice relative to the distance from the coast to illustrate how distribution has changed irrespective of the Plaice Box (Annex IX);
6. Describing trends in the percentage of undersized Plaice and Sole that lives inside the Box. This percentage is indicative of the importance of the Plaice Box for juveniles.

6.2 Methods

Survey data (SNS, BTS, DFS) from 1970 to 2003 were analysed to describe the patterns in the spatial distribution in 0, 1, 2 and 3-plus group Plaice and to test if changes in the spatial distribution have occurred since the establishment of the Plaice Box. Also, it is tried to detect any possible influences of the Box on changes in the spatial distribution. A description of the different surveys is presented in Annex XIII.

The relationship between the abundance of Plaice of different age groups and the distance from the coast was assessed using data from two SNS transects that run perpendicular to the coast (Annex IX, area 601 and 666 in Figure IX.1).

General Linear Models (GLM) were used to estimate abundance (number of Plaice per haul and number per hour fishing) and the probability of catching at least one Plaice P(1). The probability of catching at least one Plaice was analysed using a logistic model (binomial distribution), while abundance was modelled with a log-linear regression (Poisson distribution). Variables tested in these regressions were depth, year, $year^2$, area (inside Box, outside Box and Wadden Sea), closure and the interactions: year*depth. The interaction term was entered to test for a change in distribution over time. Unfortunately environmental variables such as temperature, salinity or ecological variables such as food availability of food were not available for each haul and could not be included in the analysis.

The proportion of undersized Plaice that occurred inside the Plaice Box was estimated from the proportion of Plaice<27 cm in the survey data (Figure 6.1). This proportion was estimated as follows: The number of Plaice of this length category per haul (numbers per hectare swept) was averaged per ICES statistical rectangle. Next, this was averaged per area (inside/outside the Box) over all rectangles. The average number of Plaice per hectare in each area, was multiplied with the surface of the area to estimate the absolute number of Plaice for the whole area. From these, the proportion of Plaice in- and outside the Box was estimated. The border of the outside area was set at 52º00'N, 03º00'E and 55º30'N, 03º00'E.

All statistical analyses are described in detail in Annexes VIII and IX.

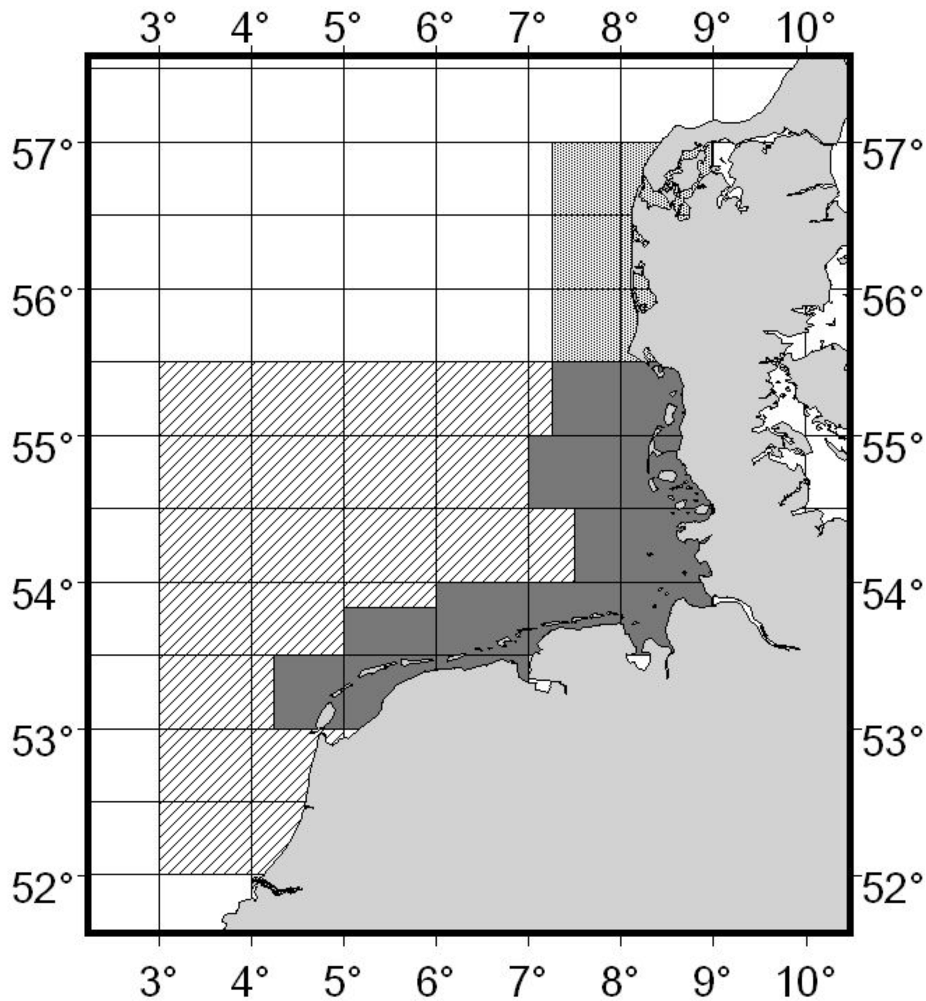

Figure 6.1. *Map showing the areas from which the proportion of undersized Plaice in the Box was estimated. The dark shaded area represents the Plaice Box area. The northern part of the Plaice Box (vertically striped) was excluded form this analysis. The proportion of undersized Plaice inside the Box was calculated as the number present in the dark shaded area relative to the total number of Plaice in both the hatched and the shaded area.*

6.3 Results

6.3.1 Patterns in the spatial distribution

The spatial distribution of age class 0 did not show major changes from 1970-2003 whereas age class 1 and to a lesser extent age class 2 were absent from the Wadden Sea at the time of sampling from 1998 onwards (Annex V, Figure 6.2). Initially, Plaice were absent from the eastern part of the Dutch Wadden Sea (the Eems-Dollard) but gradually, they were absent from other areas in the years after. The distribution of juveniles appears to have shifted from the Wadden Sea to the Plaice Box. At present the densities (numbers per hectare) are still higher inside than outside the Box. It must be noted that the spatial distribution is described from survey data that are collected only once a year in the autumn. These data thus do not reflect changes that occurred within a year. Sole showed quite a different pattern. No age groups show major changes in spatial distribution (Annex VI, Figure 6.3). The disappearance from of the Wadden Sea as observed of 1-group Plaice did not occur in Sole.

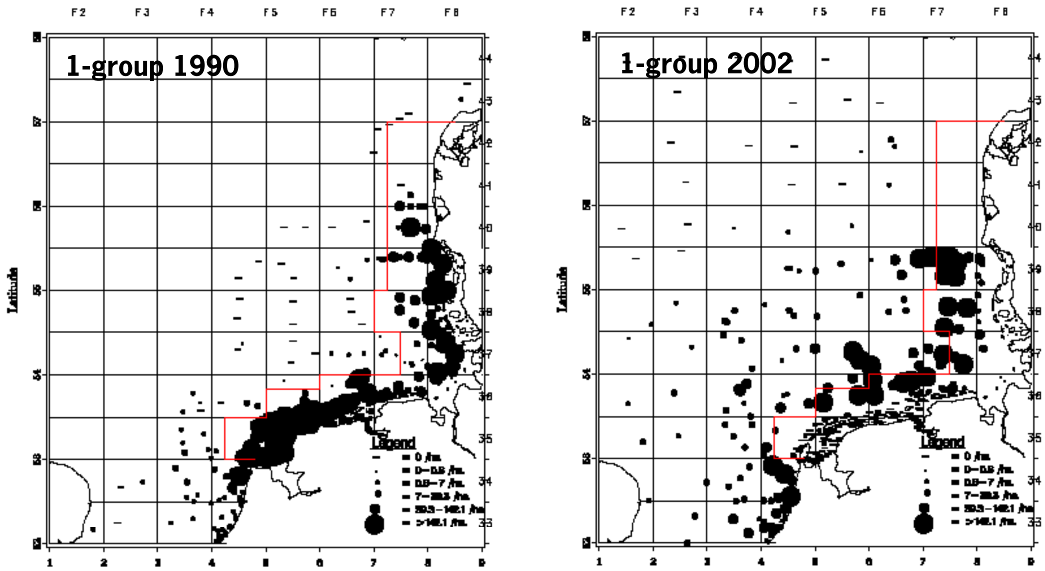

Figure 6.2. *Catches of 1 group Plaice (n/ha) in two years of the survey series (1990 and 2002). Similar maps from 1970-2003 are shown in Annex V.*

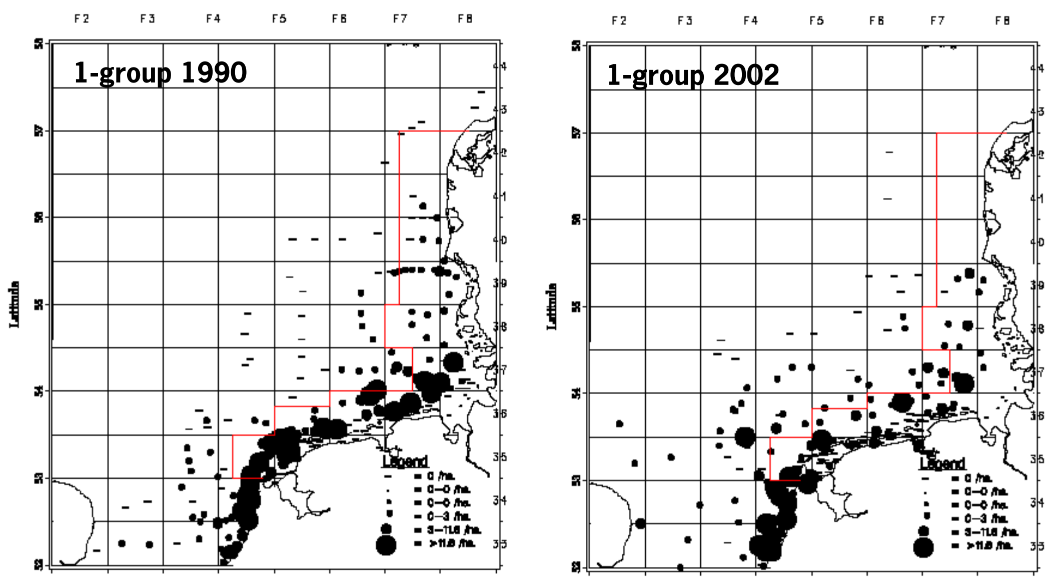

Figure 6.3. *Catches of 1 group Sole (n/ha) in two years of the survey series (1990 and 2002).*

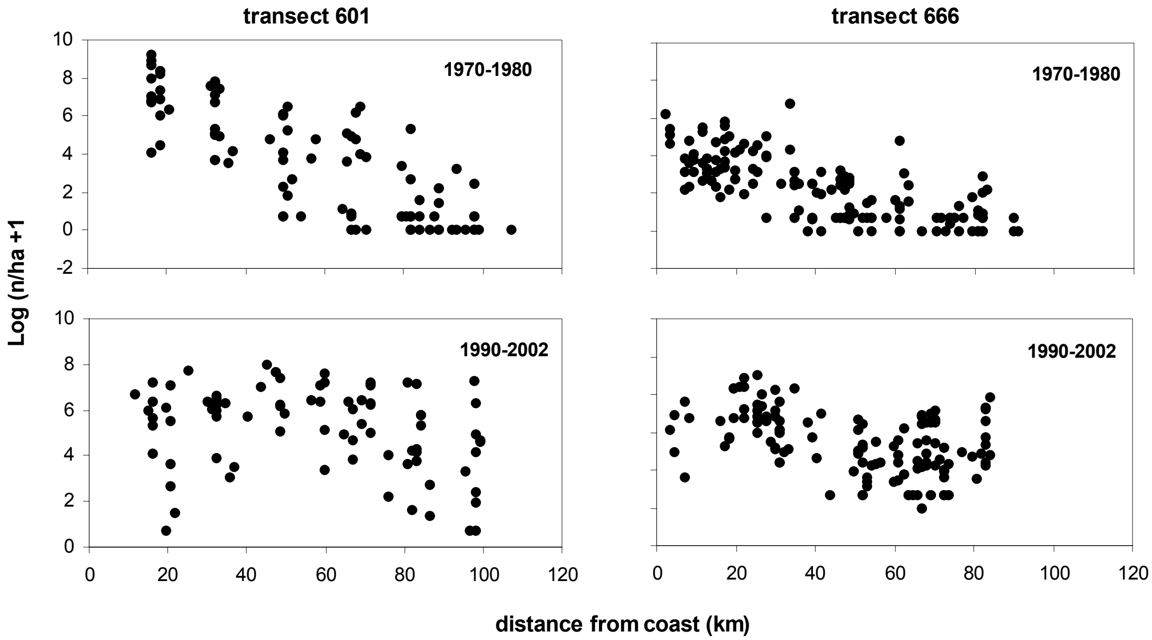

Figure 6.4. *Log catch rates of 1-group Plaice over distance from coast for the period 1970-1980 and 1990-2002 in transect 601 and 666 (see for location of transects Figure X.1).*

6.3.2 Trends in the distance offshore

For age groups 0, 1 and 2 the catch rate decreases with the distance from the coast in both transects (Figure 6.4). Highest numbers are generally caught close to the coast. In the statistical analyses (generalised linear model) the slopes of the relationship between the catch rate and the distance to the coast was analysed for each age group (see for complete analyses Annex X). The model explained >60% of the variance in catch rates. The slope differs among age groups and changed significantly over time (year effect, interaction term year*age group, interaction term distance*age group, all $P<0.001$, Figure 6.4). Especially for age groups 0 and 1 and to a lesser extent for age group 2 the slopes have become less steep (Figure 6.5). This means that young Plaice are no longer confined to the coastal areas, but have moved further offshore. In both transects a significant change in distribution pattern of juvenile Plaice was observed. The change in the spatial distribution of young Plaice seems to have started around 1994. The trend is more pronounced in transect 601, which is situated in the Box, than in 666, that is situated just south of the Box.

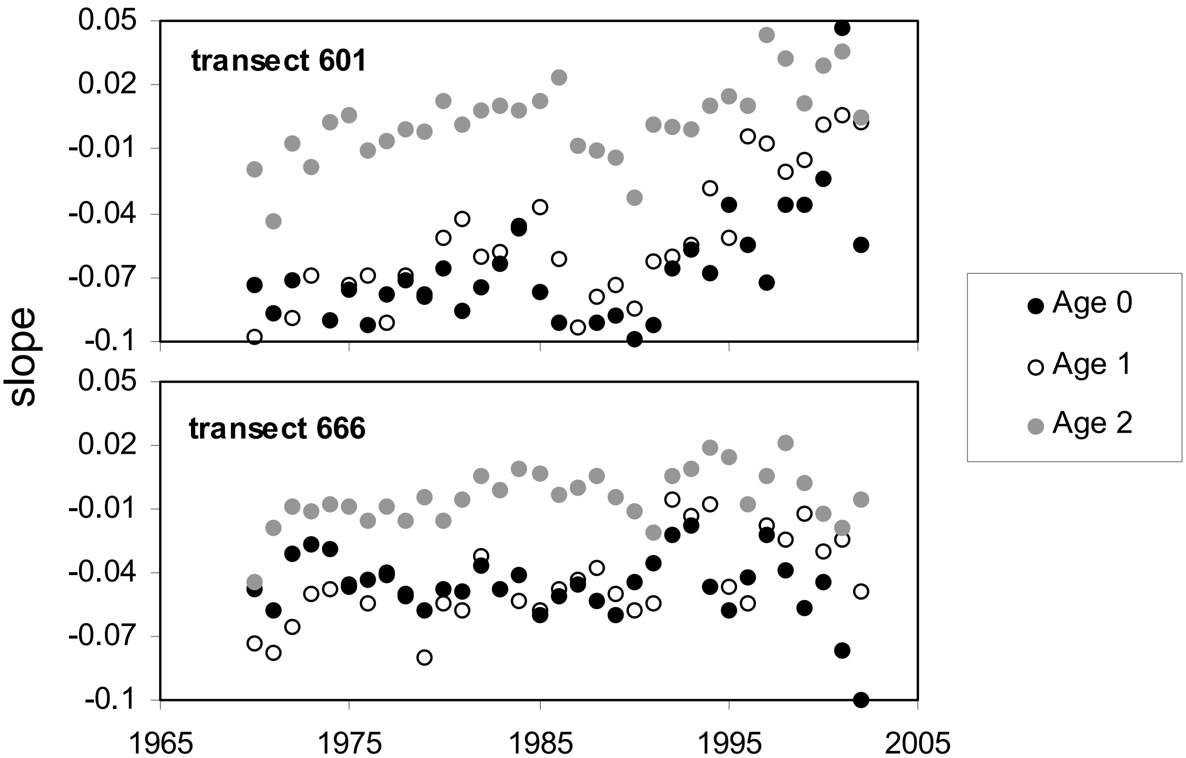

Figure 6.5. *Estimated slopes of the relationship between catch rate and distance from coast for age groups 0, 1 and 2 in the period 1970-2002 for transects 601 and 666. A negative slope indicates that abundance decreases with distance; a slope of 0 indicates that there is no relationship between distance and abundance; a positive slope indicates that abundance increases with distance.*

6.3.3 Distribution in relation to depth in and outside the Plaice Box

Two parameters were chosen to quantify the effects of predictor variables: 1) the probability to catch at least 1 Plaice in a haul (P1) and 2) the median of the numbers per 30 min haul (in classes). Predictor variables used in this study include year (+ quadratic term), depth class, the interaction year*depth class and year round closure (before or after 1995).

The probability of catching at least one Plaice in a haul (P1) of age group 0 is higher inside the Plaice Box and in the Wadden Sea than outside the Plaice Box (Figure 6.6). P1 for age class 0 has increased inside, but decreased outside the Plaice Box, whereas it showed no change in the Wadden Sea (Figure 6.6). The change in the probability of catching at least one Plaice of age 0 shows a long-term trend which does not appear to be related to the closure. For age one Plaice P(1) was stable until 1998 when it dropped in the Wadden Sea and the Plaice Box and showed a moderate decrease outside the Box. This phenomenon is unlikely to be attributable to the closure of the Plaice Box as similar patterns are evident in the three areas, although the effect is strongest in the Wadden Sea.

There seems to be a negative trend in P1 for age class 2 but the pattern is highly variable. In 1997 and 1998 P1 increased markedly in all areas. There is no clear-cut effect of the effect of the closure of the Plaice Box. Patterns in and outside the Plaice Box are similar.

For the age group 3+ no clear trend in P1 is visible. The probability is lower overall in the Wadden Sea and similar in and outside the Box. The same steep increase in P1 in 1997-1998 as seen in age 2 is also apparent in this age group, and is likely to be the result of the 1996 strong year class. The patterns are similar in and outside the Box.

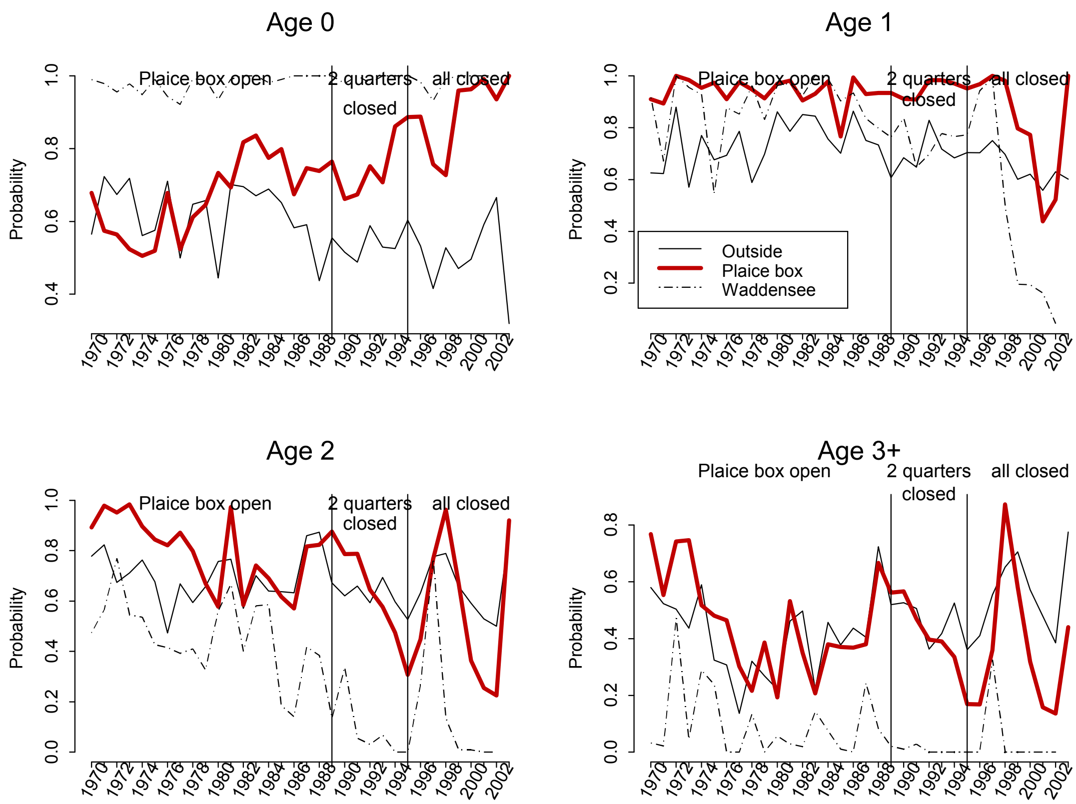

Figure 6.6. *Trends in the probability to catch at least one Plaice of age 0 (top left), age 1 (top right), age 2 (bottom left) and age 3+ (bottom right).*

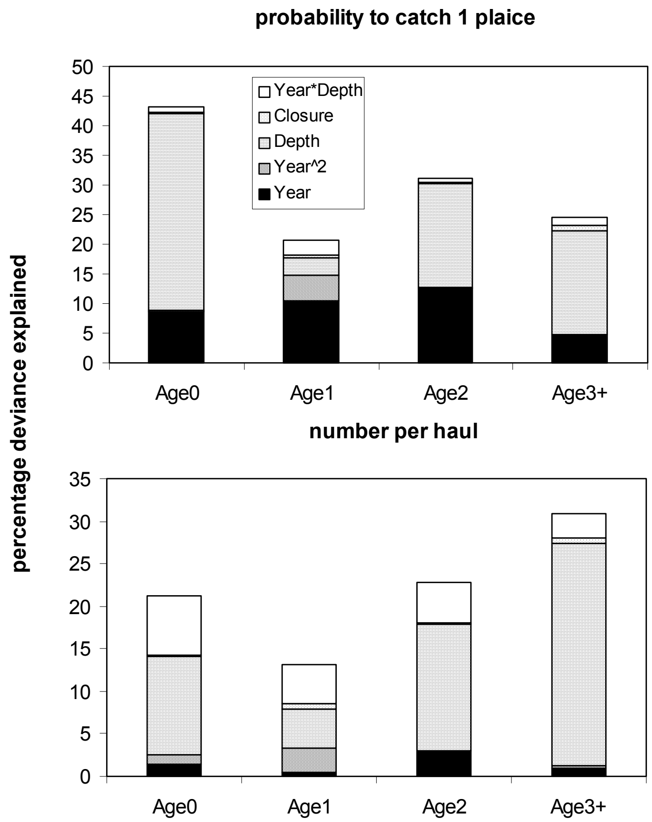

Figure 6.7. *Fraction of the total deviance explained by the different variables for the analyses of patterns inside the Plaice Box. Top: response variable represents the probability to catch at least one Plaice in a haul. Bottom: response variable represents the catch rate (mean number per haul).*

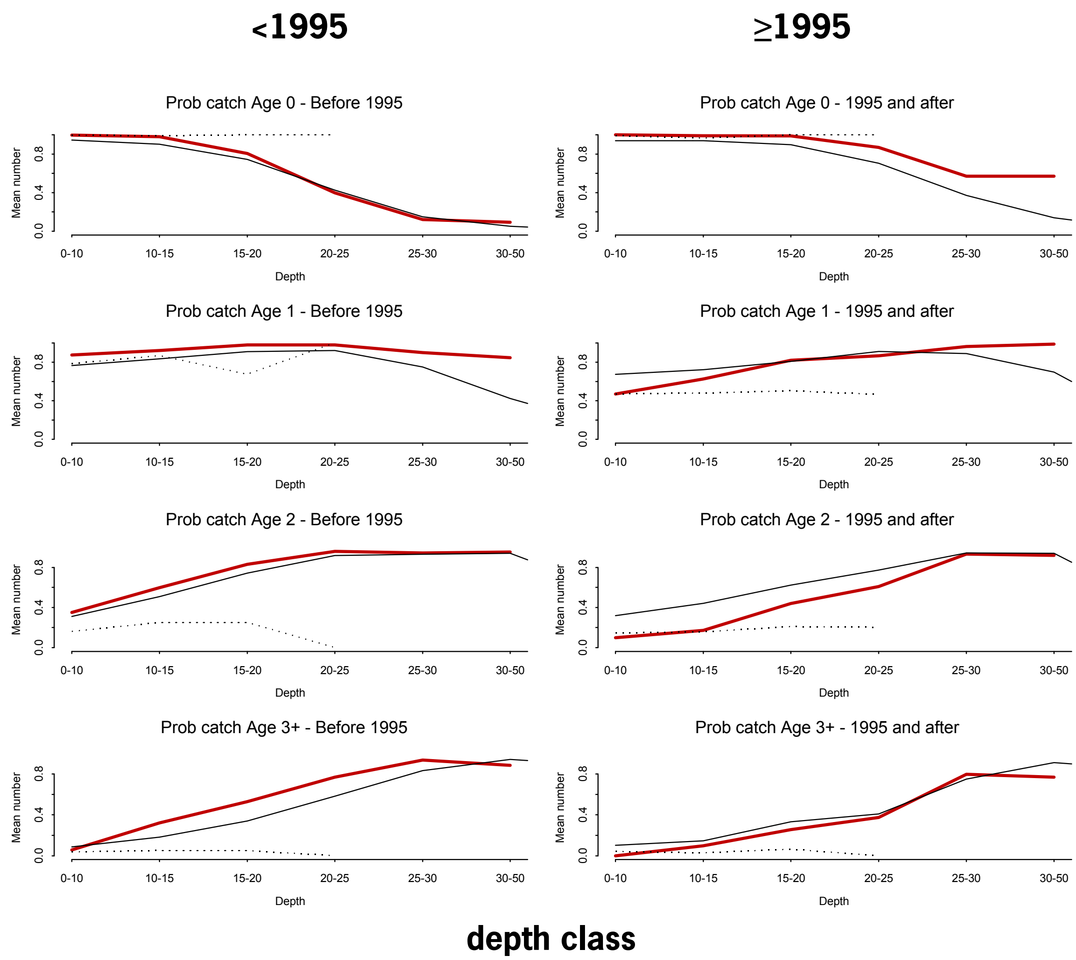

Figure 6.8. *Probability to catch at least one Plaice per age group in relation to depth before 1995 (left) and from 1995 onwards (right). Bold line=Plaice Box, thin line=outside Plaice Box, dotted line=Wadden Sea.*

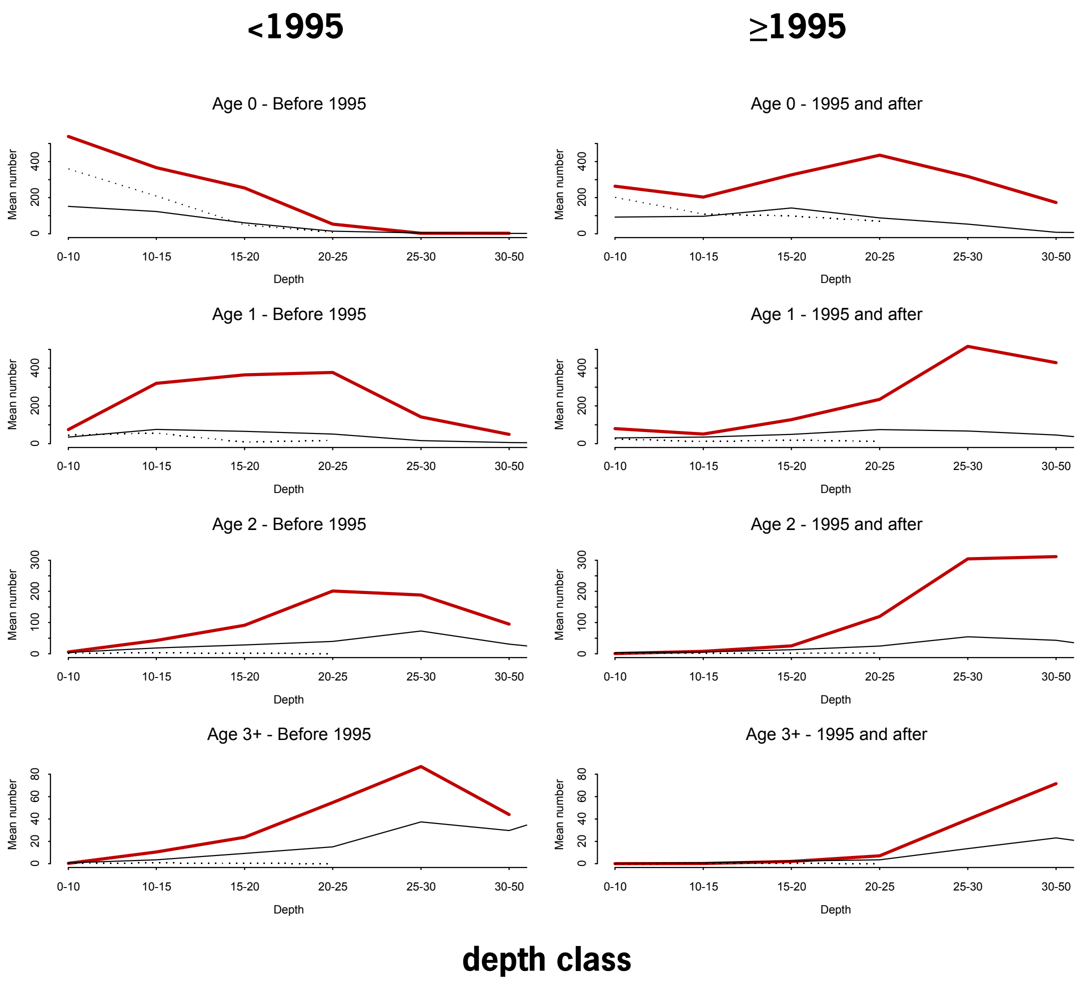

Figure 6.9. *Mean catch rate per age group in relation with depth. Before 1995 (left) and from 1995 onwards (right). Bold line=Plaice Box, thin line=outside Plaice Box, dotted line=Wadden Sea.*

Patterns in P1 and catch rate were analysed for the three different areas separately. Year + year^2 were entered as variables to test for a linear or polynomial time trend. Thereafter depth (as a class variable), the interaction between depth class and depth was entered, and the effect of closure (before and after the year-round closure in 1995). In all year classes most variables explained a significant part of the deviation. Details of all analyses (3 areas x 4 age classes for P1 and n/haul=24 analyses) are presented in Annex VIII (Tables VIII.1 and VIII.2).

In most analyses year and depth were the most important variables (Annex VIII, tables VIII.1 and VIII.2). In the Wadden Sea depth was not an important predictor variable, probably because depth variation is not very large. The significant interaction effect between year and depth indicates that the depth effect changed over the years, which again demonstrates the change in distribution already shown before. For the Plaice Box the distribution of the explained variation over the different variables is given in Figure 6.7. Although the effect of closure was significant in many of the analyses, it only explained a very small proportion (<2%) of the variation.

Model predictions show how P1 and mean catch rate vary in relation to water depth (Figs. 6.8 and 6.9). For **age group 0**, P1 remains almost at 100% outside and inside the Plaice Box in waters shallower than 15 meters. After 1995 also in deeper waters (>25 m) the probability is high. P1 has exactly the same pattern inside and outside the Plaice Box before 1995 but is higher in the Plaice Box after 1995. The catch rate shows a strong shift toward the deeper waters in the period after 1995, but is always higher inside the Plaice Box then anywhere else.

For age group 1 P1 is always high regardless of depth and period. Only in recent years does P1 drops from 90 to 50% in shallow waters. This pattern is also visible in a marked increase in the number of Plaice caught in the deeper waters. The main distribution depth for this age class shifted from 10 – 25 meters before 1995 to 25 - 30 meters recently. **Age group 2 and 3+** show the same patterns. P1 follow the same trends inside and outside the Plaice Box in relation to depth. P1 decreases in the shallow waters everywhere after 1995. As in age group 1, the maximum distribution depth shifted to deeper water.

6.3.5 Proportion of undersized Plaice and Sole

The overall proportion of undersized Plaice (<27 cm) caught in surveys inside the Box amounted to 90% when the Plaice Box was established. Since then the proportion has fallen rapidly to less than 70% in recent years. Split up by length group it is evident that changes occurred mainly in the 15-20 cm group (age 1) and to a lesser extent to the 25 cm group (age 2, Figure 6.10). The reduction in proportion of undersized Plaice seemed to have shown up first in the largest length group from 1992 onwards. The decrease in length group of 20 cm started in 1995 followed by the 15 cm group one year later. Up to now no changes have been recorded for the 5 and 10 cm groups.

In contrast, the proportion of undersized Sole (<24 cm) inside the Box did not change following closure and remained stable at 60-70%. The different length groups show, however, different patterns (Figure 6.11). The smallest length group shows a decrease from 2000 onwards, while the groups of 10 and 15 cm seem rather stable. The largest groups show a declining trend which had already set in years before the closure.

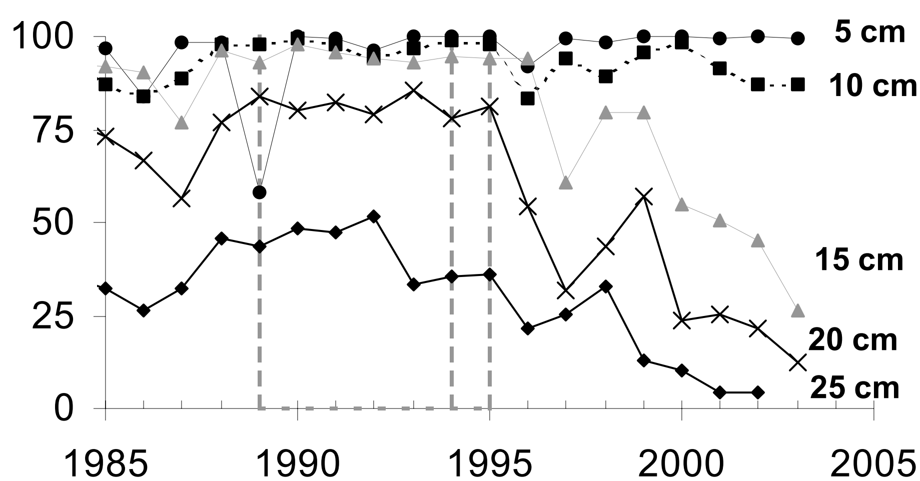

Figure 6.10. *Percentage of Plaice that occur within the Plaice Box for different size classes (mean class size: e.g. 20 cm represents 17.5-22.5 cm).*

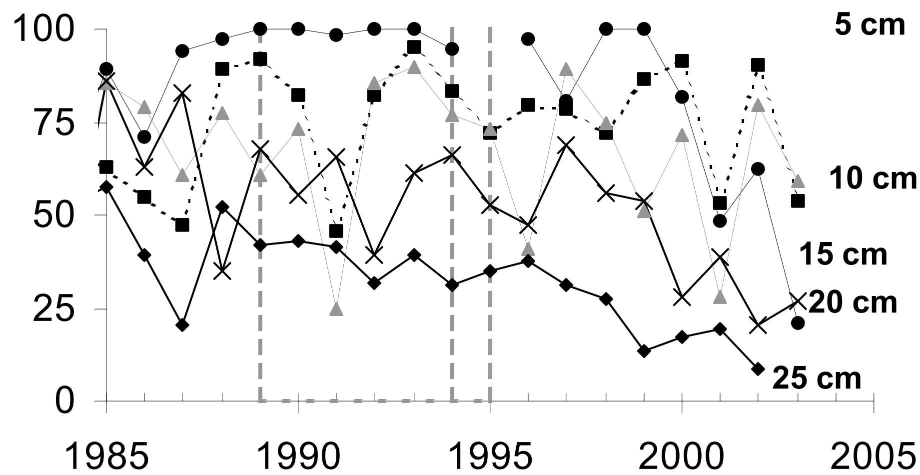

Figure 6.11. *Percentage of Sole that occur within the Plaice Box for different size classes (mean class size: e.g. 20 cm represents 17.5-22.5 cm).*

6.4. Conclusions

To evaluate possible effects of the Plaice Box it is important to distinguish between long-term ongoing trends and changes brought about by the closure. One way to do this is to compare areas and investigate whether observed changes in patterns of distribution differ in the Plaice Box as compared with other areas. As this analysis is not carried out on a set derived from an experimental set up with an experimental and control area, it is impossible to test if there is a causal relationship between the closure and any of the observed developments. At best patterns can be described and relationships to the closure be inferred.

From all analyses it has become clear that the spatial distribution of juvenile Plaice has changed considerably. This is especially true for the 1-group and to a lesser extent for the 0-group and 2-group, that have moved from shallow to deeper waters. The 1-group has shown a strong shift in the distribution becoming suddenly scarce in the Wadden Sea from 1998 onwards. These changes were less apparent in Sole. For all age classes of Plaice the patterns in presence-absence and densities are very similar in and outside the Plaice Box (Figure 6.7 and 6.8).

The statistical analyses showed that both depth and year (and sometimes $year^2$) were the most important variables explaining the variation in both P1, the probability of catching one Plaice) and densities. The significance of the interaction term year*depth illustrated that the pattern in relation to depth changed over the years.

7 Growth rate

7.1 Introduction.

The study of changes in the growth of Plaice is relevant in two ways in the evaluation of the Plaice Box. First, a reduction in growth affects the cumulative mortality of a cohort by extending the time period during which the cohort is subject to fisheries and natural mortality. Second, the study may reveal which factors may be implicated or causing the changes observed (ICES, 1999).

Discard mortality is determined by the level of fishing effort, the distribution of the discard size classes relative to that of the fishery and to the duration of the pre-recruit phase. The latter is directly determined by the growth rate. Changes in the pre-recruit phase alter the period that an individual is exposed to discarding during its life. Because growth rate is one of the factors determining discard rates, and reduction of discard rates was the purpose of the Plaice Box, trends in growth rate of Plaice are described.

In the previous evaluation, it was concluded that there has been an increase in the growth of the smaller size classes of Plaice (<35 cm) in the 1960s and early 1970s. In the mid 1960s and the mid 1980s a period of reduced growth was observed which could be related to the presence of the outstanding year classes of 1963, 1981 and 1985. Although, growth rate seems to be depressed at high population densities, there is no indication that the establishment of the Plaice Box in 1989 was followed by a decrease in growth rate. The increase in growth in the 1960s and 1970s coincided with increased levels of eutrophication and beam trawling, but the available data are insufficient to disentangle the contribution of these factors to the increase in growth (ICES, 1999).

7.2 Analyses

Length at age of Plaice and Sole were estimated from available Dutch research vessel surveys (DFS, SNS, BTS) and Dutch market sampling data. In order to extract a signal of the variation in growth of the age groups up to age 4, the length (L) at age (A) data were analysed in a generalized linear model. Details of the analysis are presented in Annex X.

7.3 Results and conclusions

Length at age varied significantly among year classes and this variation was consistent in all methods (surveys, market sampling and back-calculation; Annex X; Table X.1). The year class effects are plotted in Figure 7.1. The full lines, showing the 10-years moving averages, illustrate the overall pattern in growth rates with an increase of the year classes 1960-1970, a stable growth for the year classes 1970-1977, a decrease for the year classes 1978- mid 1980s, and a rather stable growth for the year classes from the 1990s. Growth indices for Plaice and Sole generally show similar trends. In Plaice however, the abrupt decrease around 1980 contrasts with the rather gradual decline in Sole. In Plaice, the individual growth indices based on the length at age showed a larger inter-annual variation than in Sole. Particularly low growth indices were observed for the year classes 1972, 1985, 1986, 1987, 1996 and 1997. Of these, the 1972, 1985 and 1996 year classes were particularly strong.
Overall the interannual variation in growth indexes is much larger recently than in the period before 1990.

The temporal trends in length at age of age groups <4 for Plaice and Sole show a striking correspondence, as well as with the changes in condition factor of both species (Figure 7.2). Both growth indices are likely to reflect changes in growth conditions in the coastal waters of the south-eastern North Sea, the main distribution area of the age groups analysed (Rijnsdorp *et al.*, 1991).

The length at age data of Plaice and Sole were analysed in relation to environmental parameters and population abundance. The results in Table X.2 indicate a significant negative relationship between growth and population abundance and a positive relation between growth rate and dissolved inorganic phosphate (eutrophication). The temporal trends in growth do not match the trends in beam trawling effort.

The literature on the relationship between nutrients, primary production and secondary production clearly shows that there is no simple straightforward relationship because of the existence of separate food webs that differ in the efficiency at which production is transferred to higher trophic levels. Furthermore there is ample evidence that large-scale changes in ocean climate occur on a time scale of decades that affect changes in productivity. The observation that the declining trends in length at age in Plaice occurred in several populations in the northeastern Atlantic (North Sea, English Channel, Irish Sea, (Millner et al., 1996) suggests that the growth signal may be related to large-scale changes in ocean climate in conjunction with the local effect of eutrophication and beam trawling.

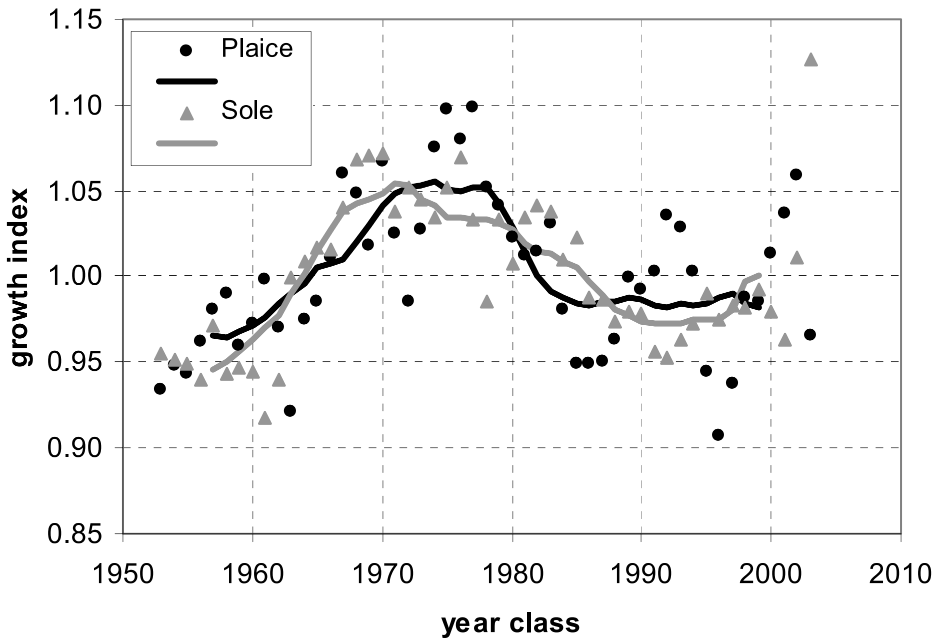

Figure 7.1. *Growth index of year classes according to the analysis of the length at age 0-4 from surveys and market sampling. The continuous lines show the 10-year moving averages.*

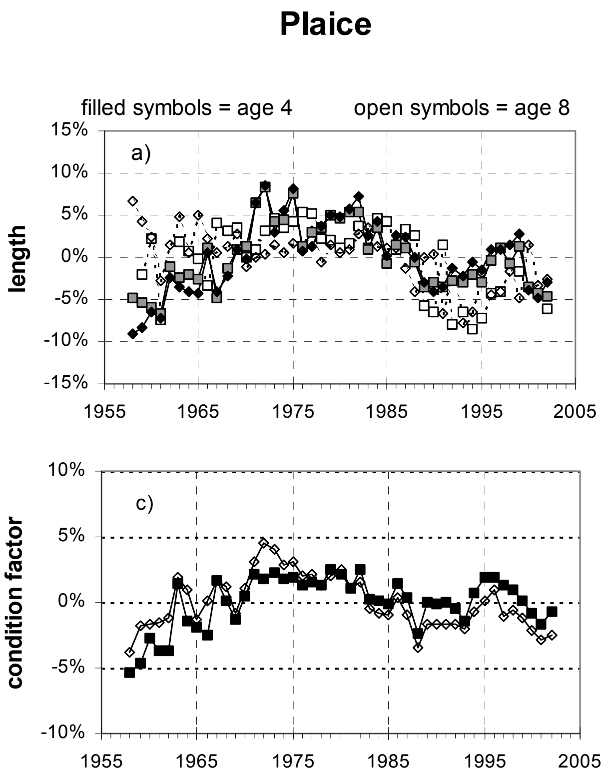

Figure 7.2. *Time trends in mean length at age and condition factor of male (diamonds) and female (squares) Plaice and Sole in the Dutch market sampling data. The data are expressed as the difference (%) of the overall mean. a) deviance in length of 4 (full lines) and 8 (hatched lines) year old Plaice during the 1st quarter spawning period (mean length of female age 4 = 31.8, female age 8 = 38.5, male age 4 = 30.9, male age 8= 35.5); b) deviance in length of 4 and 8 year old Sole in the 2nd quarter spawning period (mean length of female age 4 = 31.0, female age 8 = 37.7, male age 4 = 27.8, male age 8 = 32.0); c) deviance in annual condition factor Plaice (mean condition of female = 1.034, male = 0.945) ; d) deviance in mean annual condition factor of Sole (mean condition of female = 0.959, male = 0.863).*

8. Trends in environmental variables

8.1 Introduction

The spatial distribution of fish may be affected by changes in physical parameters such as water temperature and turbidity. Effects of water temperature are apparent on all life stages of Plaice (Wegner, Damm & Purps, 2003). Different parameters may influence the distribution and abundance of Plaice at different developmental stages; food, predators and temperature have all been identified as important factors contributing to growth and survival of juvenile stages of flatfish (Gibson 1994).

Flatfish may show a direct response to extremely high or low water temperatures by moving towards deeper and colder water. Different species and sizes groups have different optimum temperatures for growth (Fonds et al., 1992). If food is not limited, growth rate will increase with temperature up to a maximum beyond which growth rate will decrease. Small juvenile fish eat more and grow faster at higher temperatures than larger older fish. Large fish grow better in colder conditions. Plaice is a cold-water species, which means that the optimum temperature is relatively low (Fonds et al., 1992) In contrast Sole is a warm-water species that is not as sensitive to changes in water temperature (Fonds & Saksena, 1977).

In addition to water temperature there is increasing evidence that nutrient levels in the south-eastern North Sea, such as phosphate and nitrogen, have been changing since the 1980s. A variety of changes have been related to these developments in environmental parameters (Berghahn, Bullock & Karakirir, 1993; Beukema, Cadee & Dekker, 2002; Cadee & Hegeman, 2002; Hawkins, Southward & Genner, 2003; Wegner *et al.*, 2003). Recent studies have investigated whether in addition to gradual changes in environmental parameters there is evidence for coinciding region-wide environmental shifts (regime shifts (Weijerman & Lindeboom MS).

Within the scope of this study only changes in environmental conditions can be described and it can only be speculated on how these might have affected time trends in parameters in Plaice such as spatial distribution and growth rate.

The previous evaluation concluded that water temperatures from 1990-1998 were exceptionally high with peak summer temperatures reaching values above 20°C. Benthos studies conducted since the establishment of the Plaice Box showed that benthic biomass in the German Bight has remained high. Benthos studies further suggested that changes in the epi-benthos composition occurred that coincided with the shifts in the management regime of the Plaice Box. However, there is no information to confirm whether there have been changes in food availability for Plaice and Sole.

8.2 Available environmental data

To investigate the possible effect of changes in seawater temperature on the spatial distribution of Plaice, two datasets were available. Both sets represent sea surface temperature and are monthly averages. Comparable data sets on sea bottom temperatures were not available at the time of this evaluation. However, it is likely that in the period October - April the water in the German Bight is mixed anyway, and that partial mixing through tidal streams takes place in the shallower parts also during summer, such that the pattern in the bottom water temperature is highly correlated with developments in surface water temperature (Tomczak and Goedecke, 1964).

Long-term datasets on other environmental parameters are available from the ICES website for the North Sea area. The lack of information from the location of sampling stations makes it difficult to choose appropriate stations. Therefore the concentration of dissolved inorganic phosphorus ($\mu mol.s^{-1}$) and nitrogen ($kmol.s^{-1}$) in the river Rhine at Lobith (Van Raaphorst & De Jonge, 2004a) was used as an index of the nutrient input in the coastal waters. In addition published data were used (Cadee *et al.*, 2002; Colijn & Cadee, 2003; Fock, 2003; Reid *et al.*, 1998).

Environmental data were thus only available from the Wadden Sea and not from the Plaice Box area.

8.3 Patterns in temperature and nutrients

The two near shore data sets (Texel and Buesum) show a similar pattern of a slowly increasing temperature of 0.5-1 °C over the last 50 years (Figure 8.1), both in winter (Jan-March) and in summer (July-September). These two sets are strongly correlated although mean temperatures at Texel are on average 1°C higher than in Buesum (Figure 8.1). The strongest increase seems to have taken place in the last few years. Especially in summer of 2003 water temperature was very high.

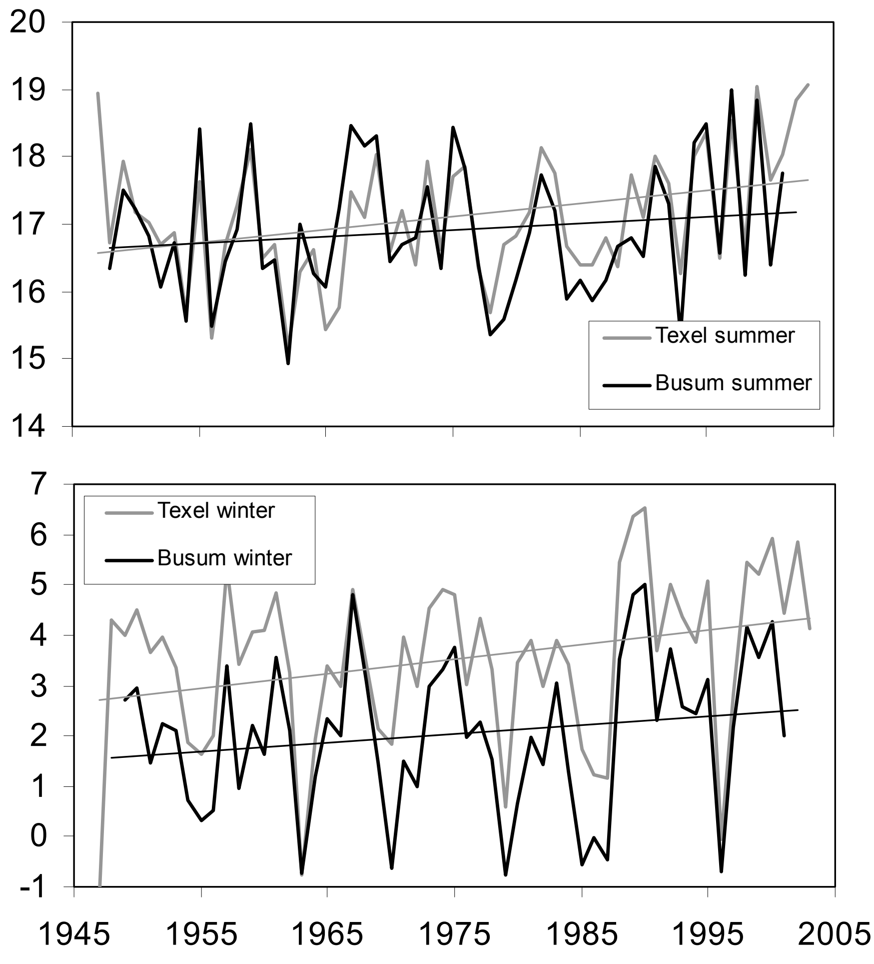

Figure 8.1. *Time trends of temperature in the southeastern North Sea in summer (July-September) and winter (January-March) from two independent data sets. The Busum set was collected at a near shore site by the German Meteorological Office. The Texel set was collected at the south point of Texel by the Royal Netherlands Institute for Sea Research (NIOZ).*

Both nitrogen and dissolved inorganic phosphorus inputs into the Wadden Sea (from its major freshwater source Lake IJsselmeer) showed an increase from the 1950s until early 1980s, where after concentrations declined and seemed to stabilize in the early 1990s (Van Raaphorst & De Jonge, 2004b), Figure 8.2).

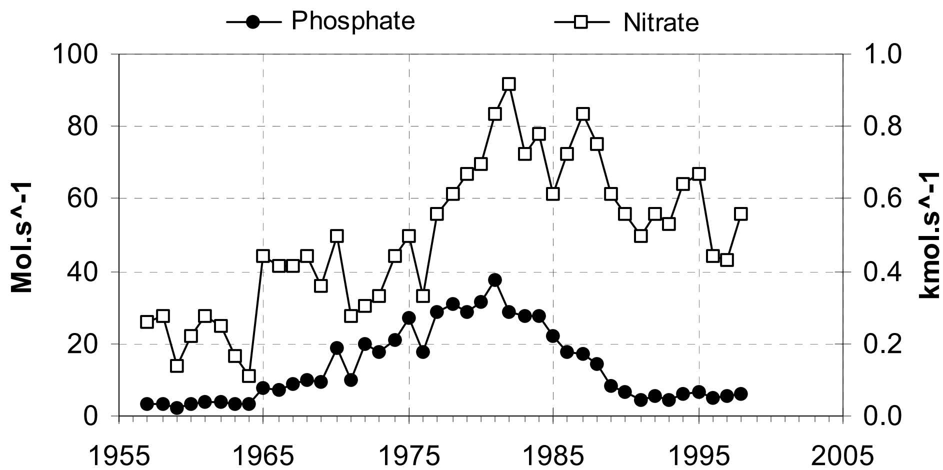

Figure 8.2. *Development of Phosphate (DIP) and Nitrate (NO_3) in the outflow of the River Rhine into the North Sea since 1955 (data from (Van Raaphorst et al., 2004a).*

The apparent changes in nutrient loads in the Wadden Sea are also reflected in chlorophyll-a concentrations (Fig 8.3, (Cadee *et al.*, 2002). These concentrations increased from 1970 to the 1980s after which they slowly declined. There was, however, a considerable delay in the response to the reduced nutrient input (Cadée & Hegeman 2002). Although the lowering of phosphate already started in the 1980s, the effect on primary production became only apparent from 1994 onwards (Figure 8.3). In recent years primary production has stayed on the level comparable to that of 2000 (K. Philippart pers. comm.). Information on trends in higher trophic levels (e.g. zoobenthos) is very scarce and time series available do not show clear trends ((Daan & Mulder, 2003)

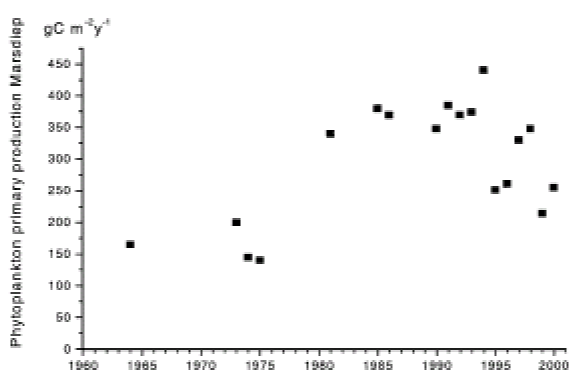

Figure 8.3. *Development of Chlorophyll-a in the Marsdiep (annual mean values 1973-2000). Figure from (Cadee et al., 2002).*

Patterns in changes in temperature and nutrients as observed in the Wadden Sea may not necessarily reflect those in the deeper water in the North Sea. A model study has shown that nutrient input by rivers has a significant contribution to the annual primary production in the Southern North Sea (Skogen, Soiland & Svendsen, 2004). A 50% reduction in the loads of N and P reduces the primary production with 10-30% in the southern North Sea.

However indications for a change in temperature have also been found in phytoplankton in the North Sea (Reid et al., 1998). In the period between 1950 and 1995 an increasing trend is evident, with an indication of a stepwise increase after the mid-eighties. The authors explain this pattern as a response to the warming of the water rather than a change in nutrient loads. Since the early nineties phytoplankton biomass shows a decrease (Figure 8.4). This paper suggests that meteoclimatic factors also affect nutrient cycles.

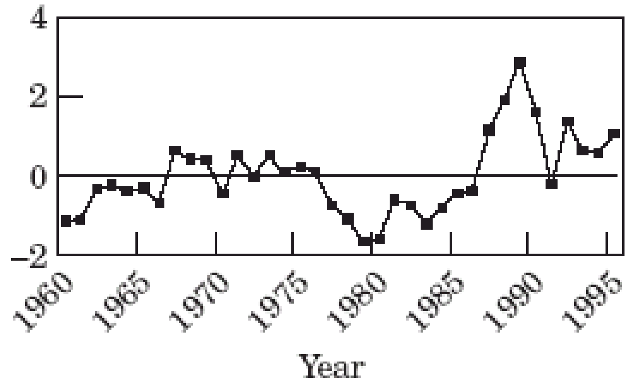

Figure 8.4. *Long-term trends of phytoplankton biomass represented by annual means (standardized to zero mean) for the southern continental North Sea (after (Edwards, Reid & Planque, 2001).*

8.3 Biodiversity

Since 1970, the mean number of fish species caught per haul has increased, especially in the SNS and BTS survey (Figure 8.5). This pattern occurred both inside and outside the Plaice Box. In the DFS survey no such increase is clear. If the species are divided in those with a northern and a southern distribution (Daan, 2000) it becomes clear that most of this increase is due to an increase in southern species (Figure 8.6). This cannot be an effect of increasing number of hauls per year and survey in SNS and DFS (generally the probability to catch a species increases with number of hauls), as number of hauls in these surveys have remained constant. The increase in number of species seems to have started in the late 1980s and was already reported by Piet and van Rijnsdorp (1998). Especially the increase in number of southern species indicates that this might be a climate driven development.

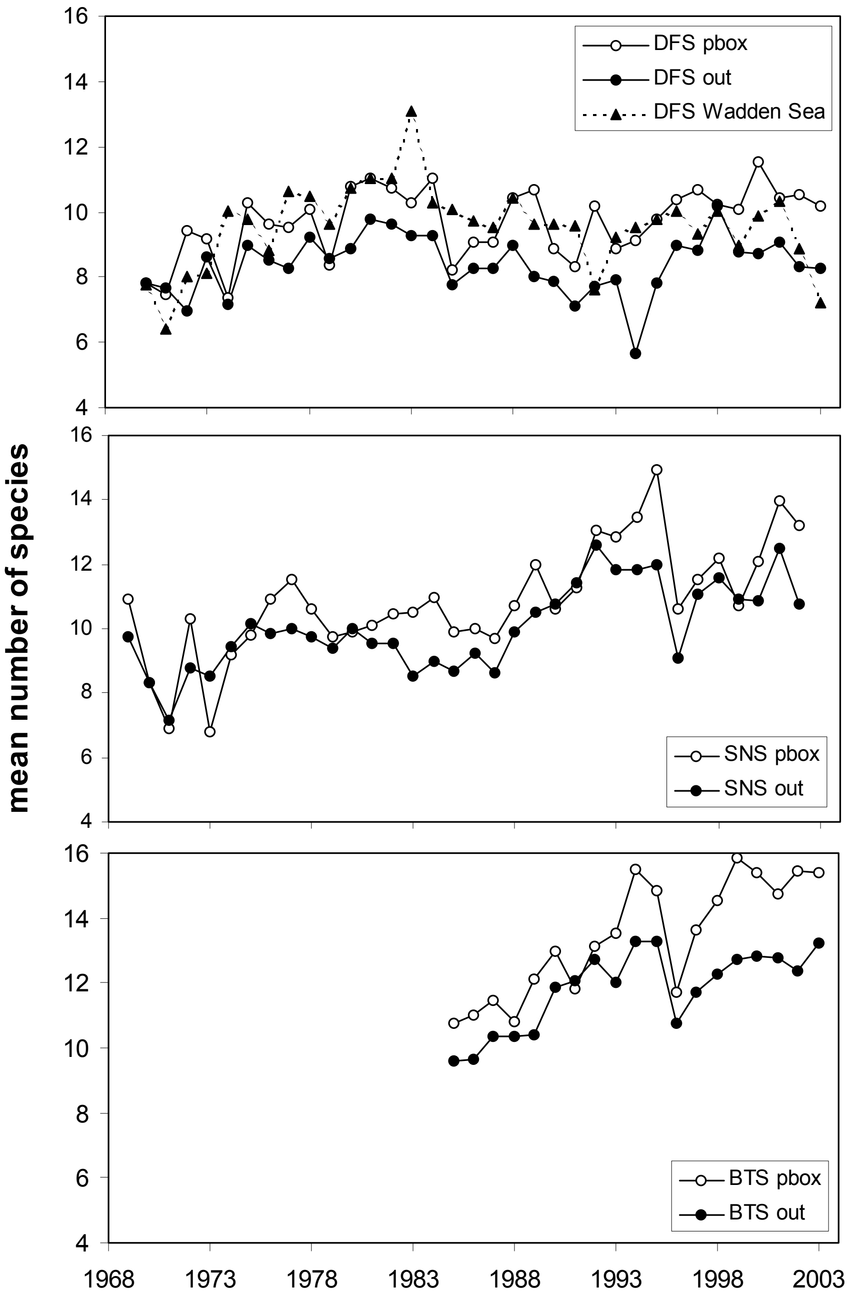

Figure 8.5. *Mean number of fish species per haul inside and outside the Plaice Box and the Wadden Sea for the three different surveys.*

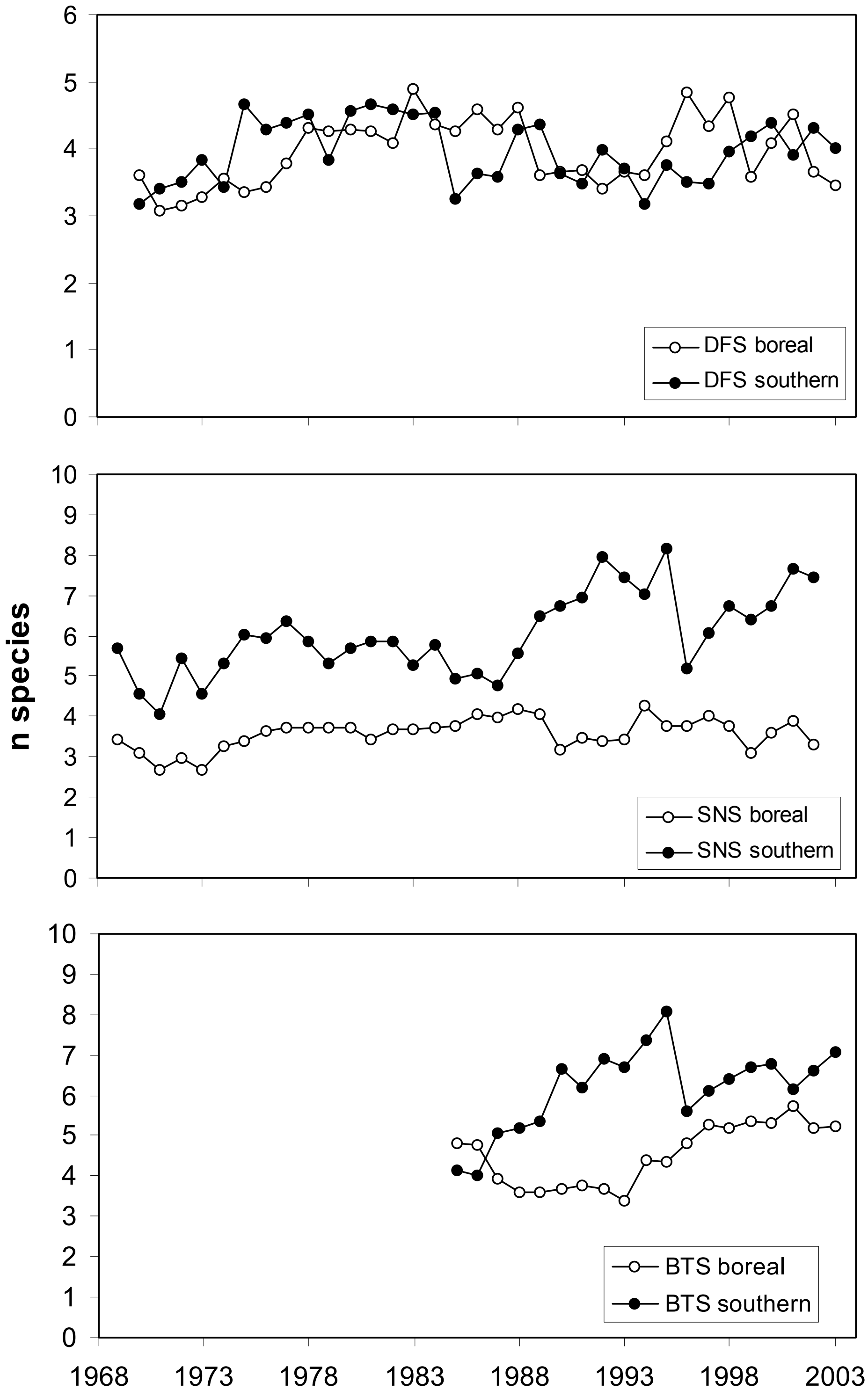

Figure 8.6. *Trends in the number of boreal (northern) and southern fish species in three beam trawl surveys. Data from the entire area in which the survey was executed are included. The classification of species was done according to Daan 2000.*

9. Discussion

9.1 Synthesis

As the Plaice Box encompassed the major nursery grounds of North Sea Plaice, it was expected that, at the same rate of exploitation, the introduction of the Plaice Box would enhance recruitment, yield and spawning stock biomass (ICES, 1987) compared to a no Plaice Box situation. In fact, the success of the Box should be determined from the increase in recruitment from the Box. This was, however, not measured and consequently, there is no single parameter from which the ecological effect of the Box can be measured. Therefore, the approach of the current evaluation was to describe trends in important parameters and to infer the effectiveness of the Box from these trends. Trends were described for landings and effort, discards, spatial distribution, growth rate and environmental variables. The potential effect of these parameters on recruitment and consequently on spawning stock biomass and yield, are schematised in Figure 9.1.

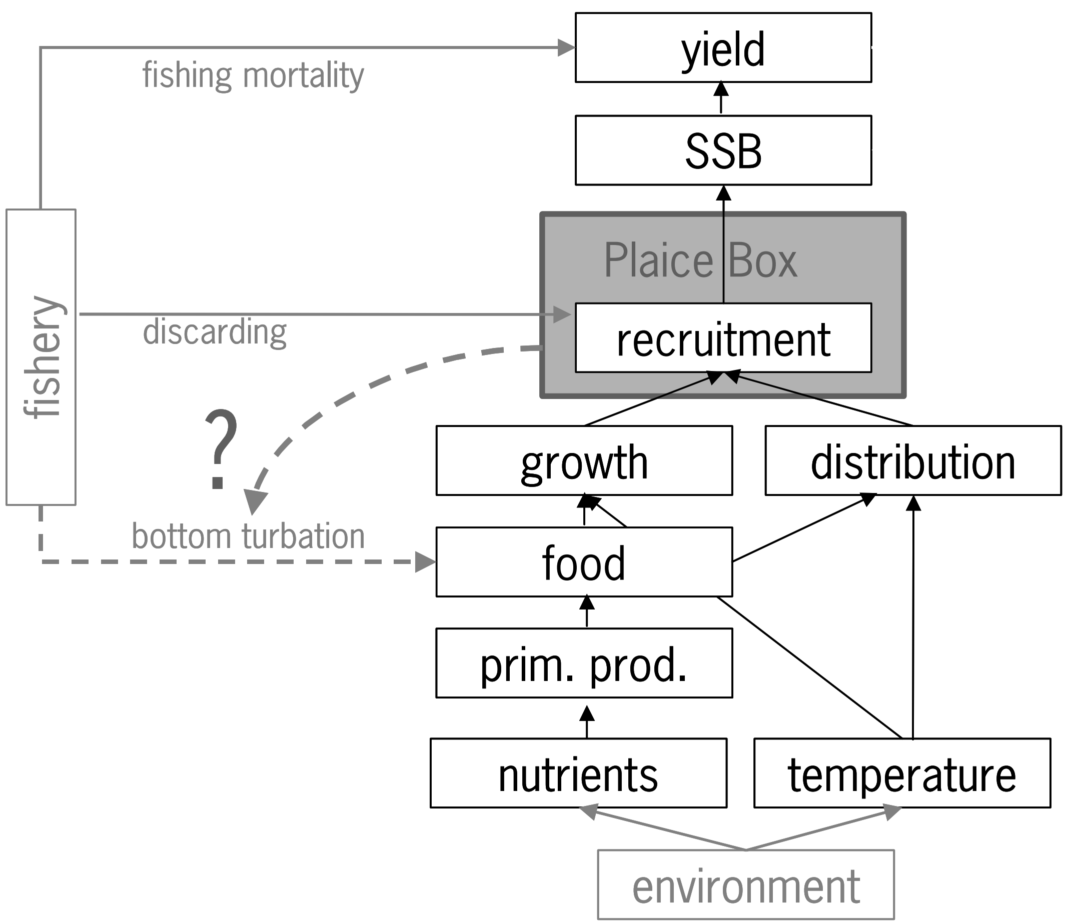

Figure 9.1. *Scheme representing the chain of effects determining recruitment, spawning stock biomass (SSB) and yield. External factors influence this chain. Fishery has impact on yield and on recruitment (via discarding). It is also hypothesized (hatched line) that the fishery enhances food availability through bottom turbation. Nutrient levels and water temperature are determined by the climate or by nutrient inputs from rivers. The Plaice Box was aimed to enhance recruitment by decreasing discard rates in the nursery areas of Plaice. If there would be a positive effect of bottom trawling on food availability, the Plaice Box would thus decrease food availability through a reduction in bottom trawling.*

There is thus no direct evidence that the Plaice Box has had a positive effect on the recruitment of Plaice. In addition, since the Plaice Box was established in 1989, recruitment in the Southern North Sea has shown an overall negative trend and spawning stock biomass and total yield have decreased by 60 %. Although any positive effect of the Box cannot be disentangled from such trends, trends in discard rates, growth rates and the spatial distribution indicate that the Plaice Box can still have had a *positive* effect on the recruitment of Plaice. Its effectiveness has, however, decreased over the period since it was established, because the spatial distribution and growth rate of juvenile Plaice have changed. Also, the hypothesis exists that the Box has had a *negative* effect. It is based on the idea that the decreased bottom turbation by beam trawls has led to decreased food availability (and changes in growth). This hypothesis is, however, not supported by contemporary studies and the occurrence of similar patterns in the Plaice stock in the Box and in other areas, but with the information currently available, this hypothesis cannot be unambiguously accepted or rejected. Below, the ecological effects of the Plaice Box will be discussed.

9.1.1 Positive effects of the Plaice Box

The Plaice Box is still an important nursery area for juvenile Plaice and there are two observations that support the conclusion that the Plaice Box has had a positive effect on the recruitment of Plaice, but that this effect has decreased since the Box was installed:

1. *At present, circa 70 % of the undersized Plaice lives in the Plaice Box and Wadden Sea.*
   At the start of the Plaice Box, circa 90% of all undersized Plaice lived inside the Box but due to the changed spatial distribution this has recently decreased to less than 70 % (Chapter 6). As before the closure of the Box, densities of undersized Plaice are still higher inside the Box than in other areas (Figure 9.2). The differences in densities between the Box and other areas have, however, become smaller (Figure 3.4). So even though the absolute number of young Plaice protected by the Box has decreased, still a considerable proportion lives inside the Box, and is protected by the restriction on fishing effort. This decrease was most pronounced for 1-group Plaice of 15-27 cm that is most vulnerable to discarding and which showed the most dramatic change in spatial distribution. For this group the proportion of all Plaice that was present in the Box even dropped from 80% to 25% (Figure 9.3).

2. *In the 80 mm fishery, discard percentages in the Box are higher than outside;*
   In terms of numbers and biomass, discard percentages in the 80 mm beam trawl fishery are currently higher in the Box: more than 90 % inside the Box and 71-77 % outside the Box (in terms of numbers) of the Plaice caught is discarded. In terms of weight these percentages are 82 % and 48-55 % (Annex IV, Table IV.3). In the 100 mm fishery, obviously, discard percentages are lower (57 and 67 % in and outside the Box respectively). The higher percentage of discards in the 80 mm fishery in the Box can be partly explained by the smaller sizes that are caught and discarded (average length 17.5 cm in the Box, 20.2 cm outside). Because more than 90 % of the Plaice caught in the 80 mm fishery in the Box is discarded, any reduction in this fishery would reduce discard mortality. Although a relationship between total discard mortality and recruitment can be expected, there is no demonstration of such a relationship in the data. The difference in discard percentages in- and outside the Box has, however, decreased over time (Figure 5.1). From 1976-1990, inside the Box, 77 % of the Plaice caught was discarded and outside the Box 31 % was discarded (in terms of numbers). At present (1999-2003) these percentages are 87 and 77 %.

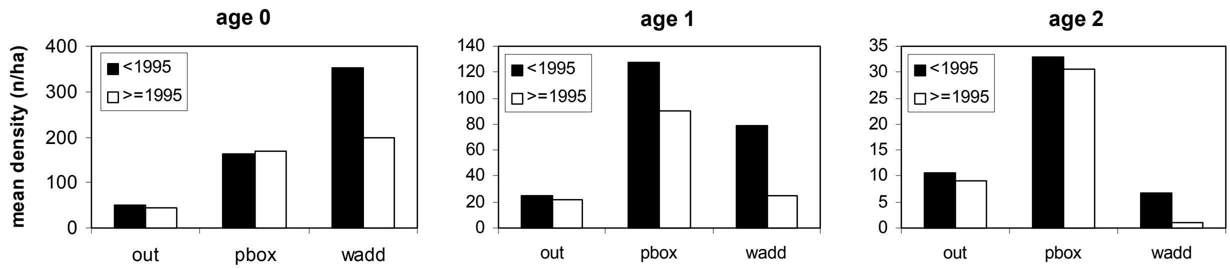

Figure 9.2. *Mean densities (n/ha) of 0-group, 1-group and 2-group Plaice outside, inside the Box and in the Wadden Sea in the period before 1995 and since the closure in 1995. Densities are the average number per hectare per haul from survey data, for the periods of 1970-1994 and 1995-2003.*

Over time, discarding rates have increased considerably both inside and outside the Box, which is probably caused by a higher exposure of undersized Plaice to discarding. This higher exposure was caused by the combination of the retarded growth rate (Chapter 7) and the change in spatial distribution (Chapter 6). Both effects work multiplicatively: the period that Plaice stay undersized is longer, and more of the undersized Plaice are exposed to discarding (Figure 9.3). This process can, however, not be quantified.

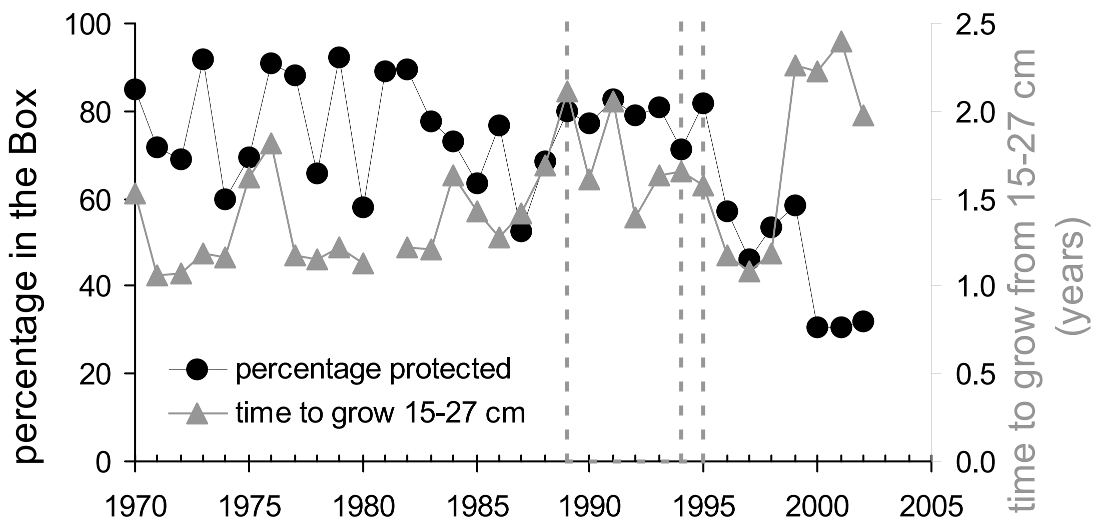

Figure 9.3. *Illustration of the increased exposure of Plaice to discarding showing the percentage of Plaice (15-27 cm) that was observed in the Plaice Box and the duration of the period they need to grow from 15-27 cm. The percentage of Plaice in the Box has decreased because of an offshore movement to deeper areas. The increase in the duration of the period from 15-27 cm was caused by retarded growth rates.*

9.1.2 Negative effects of the Plaice Box

The idea that the Plaice Box might have had a negative effect is based on the hypothesis that bottom trawling changes the benthic fauna community and increases food availability for Plaice. The reduction of trawling activities in the Box would thus have decreased food availability. Bottom trawling is thought to have a direct effect on the benthic community, by destroying benthic organisms that become available to scavenging flatfish, and an indirect effect by favouring fast growing pioneer species with a high productivity at the expense of long-lived slow growing species (Rijnsdorp et al., 1996). Some of the trends described seem to support a causal relationship with the closure of the Box:

- The co-occurrence of the closure with a sharp drop in spawning stock biomass and a negative trend in recruitment (Chapter 3);
- Retarded growth rates of Plaice and Sole;
- An offshore movement of (young) Plaice outside the Plaice Box.

Although a negative effect of the Box cannot be completely ruled out, the observed trends do not provide clear support for the hypothesis of decreased food abundance as a result of the Plaice Box:

1. *Contemporary literature shows that there is no positive effect of bottom trawling on ecosystem productivity;*
2. *The decrease in growth rates was initiated before the establishment of the Plaice Box; the temporal trends in growth rate are not correlated with the trends in beam trawling effort.*
3. *Similar trends in the abundance and spatial patterns of Plaice were shown for areas outside the Box such as the Wadden Sea and the Dutch coastal zone southwards of the Box.*

Below these findings will be discussed in more detail.

1. *Contemporary literature shows that there is no relationship between bottom trawling and ecosystem productivity;*
   Within the scope of this evaluation no new data were collected on the impact of bottom trawling on the productivity of the ecosystem and on food availability for Plaice. The effect of trawling on the composition of the benthic community and especially of macrofauna has been subject of many studies, both in descriptive field studies and experimental studies (Kaiser & De Groot, 2000a; Schratzberger, Dinmore & Jennings, 2002a; Schratzberger & Jennings, 2002b). Most of these studies focus on the effect of bottom trawling on the structure of the benthic community, i.e. species and size composition. Generally speaking, intensively fished areas are characterised by smaller short-lived species, whereas undisturbed areas are characterised by larger long-lived sessile species. Although less well-studied, meiofauna (the fraction of benthic fauna smaller than 500 μm) are more abundant than macrofauna, but show a similar reaction to trawling as macrofauna (Schratzberger *et al.*, 2002b). Number of species, diversity and species richness of the meiofaunal species community were significantly lower as a result of trawling. Contrary to the hypothesis that trawling enhances productivity, several studies show that in areas subject to intensive trawling species diversity, biomass and production of benthic macrofauna is reduced (Collie *et al.*, 2000; Jennings *et al.*, 2001; Kaiser *et al.*, 2000b). Jennings et al. (2002) showed that trawling did not have a significant effect on the production by small infauna or polychaetes, the main food source for flatfish. However the production of larger infauna strongly decreased and the study showed that small polychaetes are less vulnerable to trawling disturbance. In conclusion, there is no evidence that bottom trawling would enhance total ecosystem productivity. However, total ecosystem productivity is not directly related to food availability for Plaice. To date there are no studies that quantify the effect of bottom trawling on the food availability for Plaice.
2. *The decrease in growth rates was initiated before the installation of the Plaice Box;*
   At present, growth rate of Plaice has indeed decreased but this decrease was already initiated before the Plaice Box was installed. The long-term trend showed that growth rates of Plaice peaked in the 1970s and started to decrease around 1980. In fact, since the closure of the Plaice Box in 1989, growth rate has not changed significantly.

3. *Similar trends in the abundance and spatial patterns of Plaice were shown for areas outside the Box such as the Wadden Sea and the Dutch coastal zone southwards of the Box.*
   Trends in the abundance of different year classes showed the same patterns inside the Plaice Box, in the Wadden Sea and in a reference area just south of the Box (chapter 3). Although the areas are not similar in their ecological function, differences in trends would be expected if the reduction in beam trawling in the Plaice Box would have had a negative effect. In the Wadden Sea beam trawling has always been forbidden. Although the area has not experienced a reduction in beam trawl effort as a result of the Box, trends for all age classes were similar to those inside the Box.

It was clearly shown that 1-group Plaice has partly moved out of the Plaice Box and that the importance of the Box has decreased. However, 1-group Plaice has also shifted offshore out of the Wadden Sea. It is not known whether they moved towards the Plaice Box. Moreover, patterns in the changed distribution of Plaice of different age groups followed a gradual pattern that had already started before the closure of the Box. This was most clear for 1-group Plaice in the Wadden Sea. Therefore it is unlikely that the closure of the Box caused these changes.

The change in distribution was less clear for Sole (Figure 3.4; 3.5 and Chapter 6). If Plaice would have been driven out of the Box by a reduction in food availability, the same pattern would be expected for Sole, given comparable diets of both species (Rijnsdorp & Vingerhoed, 2001).

In conclusion, no evidence was found for a negative effect of the Plaice Box on the growth rate, recruitment and spatial distribution of Plaice. However, it cannot be unambiguously proven that there is no effect of the Box on the spatial distribution of Plaice through a reduction in food availability. Published studies show an effect of trawling on benthic community structure. Based on literature, there is no evidence for a reduction in total benthic productivity as a result of reduced fishing intensity, but there is no information on the food availability for Plaice. Theoretically if food availability for Plaice is determined by a limited number of prey species that proliferate as a result of regular bottom turbation, trawling may have an effect.

9.2 Confounding effects of other developments

As indicated above, recruitment, spawning stock biomass and yield of North Sea Plaice have decreased dramatically over the past 15 years and in addition, growth rate and spatial distribution have significantly changed. However, as described in 9.1 these events are likely unrelated to the establishment of the Plaice Box. This rises the question what caused these changes.

Both the Plaice stock (SSB, recruitment) and the environment (temperature, nutrients) changed concurrently since the establishment of the Box. Therefore, it is difficult to disentangle the effects that caused changes in the Plaice stock. Below an outline is given of the possible confounding effects of environmental and biotic variables that might have attenuated any positive effect of the Plaice Box, and may even have caused changes in the life history of Plaice.

9.2.1 Changes in the environment

Large time-scale trends in environmental variables in the North Sea are evident and have been described in many studies. The mechanisms however are poorly understood. This is especially true for the so-called 'regime shifts' (Weijerman *et al.*, MS). The closing of the Plaice Box started (1989) one year after the year that was identified by Weiieman and Lindeboom as a regime shift in many biological time series. According to them, many time series also showed a sudden change in 1998.

Several independent time series have shown an ongoing increase in water temperature. Effects of a change in water temperature can be expressed in recruitment (effect on egg and larval survival), growth rate and spatial distribution. Apart from water temperature, the spatial distribution and growth of Plaice may also be affected by low oxygen concentrations but these hardly ever occur in the North Sea. Effects of changes in water temperature on fish abundance and distribution have been shown in many studies. North Atlantic Oscillation fluctuations have had differential effects on the ecosystems in the North Atlantic (Parsons & Lear, 2001). For several species such as gadoids (ICES, 1999), Herring *Clupea harengus* (Alheit & Hagen, 1997) and plankton (Planque & Fromentin, 1996) in the North Atlantic, indications of a link between population developments and long-term trends in the NOA have been described (Parsons *et al.*, 2001). Climatic change has had dramatic effects on community composition in Britain (Genner et al., 2004). Responses of species composition and the occurrence of warm-water species to increasing sea surface temperature were also observed in the English Channel (Hawkins et al., 2003). It has been suggested that effects of over-fishing such as the collapse of the northern cod stock, can be aggravated by adverse climatic conditions (Parsons *et al.*, 2001).

In the Northern hemisphere increasing temperatures seem to favour species that are at their northern limits of the distribution. The northward shift of many southern (warm-water) species as already described in (Piet *et al.*, 1998) has continued since then (Chapter 8). The abundance of southern species has been increasing steadily since the 1980s.

Several sources have shown that in recent years, nutrient concentrations, and with some delay, also primary production have decreased in the North Sea (Chapter 8). It cannot be proved that this has affected food availability for Plaice but the fact that both growth rate and condition factors were equally affected in both Plaice and Sole (Chapter 5) suggests that food availability has decreased.

In addition to an almost continuous increase in fishing mortality from 1970 to 1997, the characteristics of the fishery have also changed. New techniques such as twin-trawling for example, have developed, and the efficiency of gear types has increased. These developments are not expressed by the observed trends in fishing efforts. Additionally the Plaice Box is not a closed area. Fishing intensity in the Box has significantly decreased since 1995 but is still high.

Although the relationship between changes in the environment and the Plaice stock seem obvious, it is difficult to relate environmental changes to changes in the recruitment of Plaice. As described in Figure 9.1, there are several steps that might eventually link nutrient levels to the recruitment of Plaice (nutrients-primary production-secondary production-growth rate-recruitment). Most of these links are poorly understood. Also links between closely connected levels are difficult to interpret: a decrease in primary production does not necessarily lead to a decrease in secondary production. This is only the case if primary production is limiting for secondary production. Moreover, a decrease in secondary production is not always related to food availability for Plaice. Secondary production, for instance zoobenthos, is prey for a large variety of organisms, of which Plaice only uses a selection, and different organisms may show different reactions to changes in primary production or water temperature.

9.2.2 Changes in biotic variables

Apart from changes in environmental variables, changes in the biotic environment have also taken place. The diet of both young Plaice and Sole consists mainly of short-lived highly productive benthic organisms such as annelids. Bivalves and Echinodermata are of secondary importance. Among the annelids the polychaetes predominate. Important bivalve species are Spisula and Ensis. Diet does not differ between areas differing in trawling intensity (Rijnsdorp *et al.*, 2001). Recently, the composition of the benthic community the Wadden Sea changed rapidly as a result of sediment change due to intensive shellfisheries and a reduction in primary production (Brinkman & Smaal, 2003). In general, the density of bivalves decreased, while densities of polychaetes increased. Also in the Dutch coastal zone major changes took place. Spisula that occurred in dense banks just offshore the islands and North Sea coast disappeared (Craeymeersch & Perdon, 2004). Concurrently, densities of Ensis increased dramatically. Any changes in the distribution or abundance of benthic food organisms may therefore be expected to have an impact on flatfish distributions. Short-term changes which can effect benthos include severe winter weather and periods of oxygen deficiency (Beukema & Dekker, 2003; Honkoop & Van der Meer, 1997). Although, recovery appears to be rapid and biomass may reach pre-impact levels within two years, this can still affect food availability for flatfish if a significant proportion of the feeding area has been affected.

9.3 New hypotheses

During the evaluation several new hypotheses arose that may explain trends in the abundance and spatial distribution of Plaice. Below, these hypotheses are presented but it must be stressed that at present there is no evidence to support them.

- The complete disappearance of especially the 1-group Plaice from the Wadden Sea might be related to the rapid increase of Cormorants *Phalacrorax carbo* in this area since the 1980s (Fig 9.4, van Roomen et al. 2003, Dijksen et al., in prep). Young flatfish are an important prey and it was estimated that a considerable proportion of young Plaice might be taken by Cormorants, especially in years with low Plaice abundance (Leopold et al. 1998). Also numbers of another predator, Common Seal *Phoca vitulina* have increased since the population collapsed in the virus outbreak in the late 1980s. In 2002, however, numbers were nearly halved as a result of a new virus outbreak (Reijnders *et al.*, 2003). A recent study has shown that Common Seals predominantly feed in the North Sea, rather than in the Wadden Sea in recent years (Brasseur et al., 2004), which possibly reflects a food shortage in the Wadden Sea.
- The changed spatial distribution could be explained by a rise in water temperature. The difference in response between Plaice and Sole supports this hypothesis. An alternative might be that changes in fish predator populations have affected the distribution patterns. Populations of species such as Cod have decreased dramatically in the North Sea. If young Plaice favour the deeper waters, but were prevented from going there by the presence of potential predators, a decline in predator density might have induced the change in distribution.
- Along the same line of reasoning, the decrease in abundance of older Plaice may have caused the movement of juvenile Plaice towards deeper waters. If food competition between age groups or even inter-specific competition with e.g. Sole or Dab occurs, the distribution of juvenile Plaice might be affected.
- Apart from a change in predator or competitor distribution also prey distribution and preference for food species may have changed. Large annual variation in several benthic species is common and trends were observed recently. For instance *Ensis americanus* increased in the coastal zone, bivalves generally decreased in the Wadden Sea, while polychaetes have increased there (Leopold, 1998; Leopold et al., 2003).

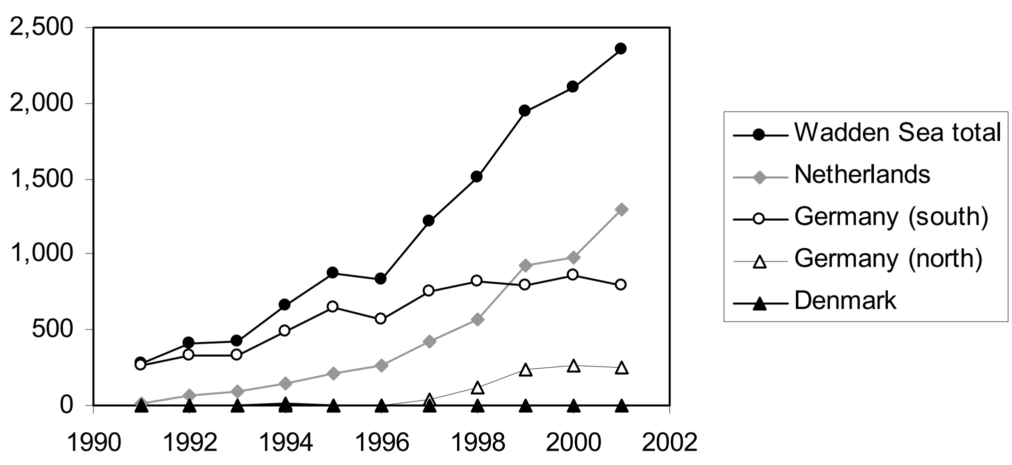

Figure 9.4 *Number of breeding Cormorants in the Wadden Sea (Dijksen et al., in prep).*

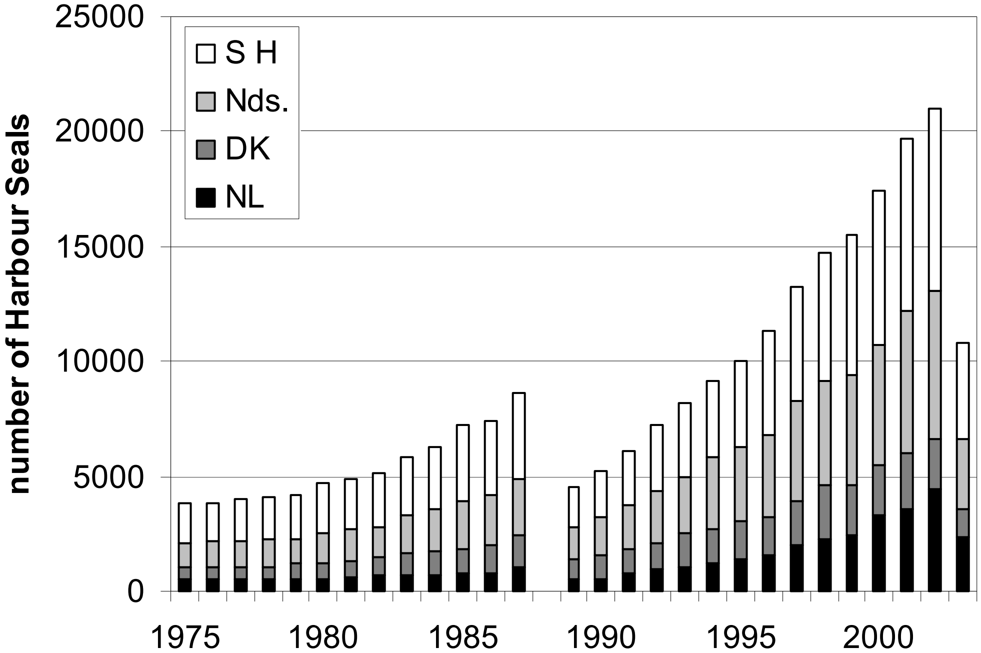

Figure 9.5 *Number of Harbour Seals in the Wadden Sea (Reijnders et al., 2003). SH=Schleswig-Holstein, Nds=Niedersachsen, DK=Denmark, NL=Netherlands.*

9.4 Recommendations

The Plaice Box was installed to improve recruitment of Plaice. However, no criteria were formulated to measure the effect of the Plaice Box. The lack of clear-cut objectives and criteria makes it very difficult to evaluate the effect of this management measure.

The following steps are suggested to improve the evaluation of any closed or partially closed area to be established in the future:

- The specific aims and objectives of the closure should be considered and well defined before measures are put in place;
- Relevant, measurable criteria should be considered / developed;
- A research program to monitor the effects, over a predetermined time scale, in a way that enables meaningful, statistically based evaluation should be put in place.

Such an evaluation can only be achieved within an experimental set-up, which allows for the separation of autonomous developments and the closure (with or without fishing) effects, for example a control area which differs from the treatment area only in terms of fishing intensity.

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Annex II. Terms of Reference

Terms of reference for ad-hoc expert working group on the Shetland and Plaice Box.

1. Identify the initial objectives and additional objectives for both Boxes related to the CFP;
2. Evaluate the effectiveness of the Shetland and Plaice Box by:
   - Analysis of the spatial distribution of the relevant species, preferably by age groups;
   - Analysis of the spatial distributions of fishing effort by the highest possible resolutions (e.g. by rectangle, by month or quarter, by fleet and by gear);
   - Definition of the key biological processes relevant to the functioning of both Boxes;
   - Analysis of the response of the fishing fleets and the relevant species to the existence of the Boxes;
3. Define measures for the performance of a Box;
4. Specify biological models that can be used to evaluate closed Boxes relative to the measures of performance defined above. Such models must contain components handling:
   - Migration of fish in and out of the Box, by age group;
   - Stability/instability of spatial distribution of fish over longer time periods;
   - Redistribution of effort caused by introduction of Boxes;
   - Change of fishing techniques and target species caused by introduction of Boxes;
5. List data needed to implement the models of point 4, and evaluate the possibilities to achieve these data. Evaluate the practical problems in parameter estimation;
6. If the models of 5) cannot be implemented as conventional statistical models, suggest hypothetical model, which are based on assumptions which may be verifiable;
7. Evaluate the economic consequences of the Shetland Box and the North Sea Plaice Box for relevant array of fleet segments of EU-countries[9];
8. Review existing bio-economic models with respect to the evaluation of closed Boxes[10];
9. Collate data needed for the economic evaluation:
   a. Catches by the relevant fleet segments and fishing areas;
   b. Costs by the relevant fleet segments biomass by fishing area.

[9] Preferably existing bio-economic models will be used because setting up completely new models will be too extensive. The working group must consider whether the economic analysis will be static comparative, rest on economic time series or both.

[10] A well-functioning model covering an array of fleet segments from relevant EU countries has been developed under the EU Concerted Action Q5CA-2001-01502. This model, entitled the EIAA-model, is designed to interpret the ACFM-advice and does thus include biomass and quota considerations. Furthermore, it is designed to utilise the collected economic data within the EU member countries. The working group may modify the EIAA-model to accommodate adaptability to the problem. These adjustments include determining the relevant fleet segments and the desegregation of fishing areas. The latter must be advised by the working group in order to secure relevant linkages between the biological and economic evaluation of the Shetland and North Sea Plaice Box.

Annex III. Trends in fishing effort and landings

III.1 Analyses and assumptions

Landings and effort data by statistical rectangle, year, month (quarter for Denmark), country and gear were made available by participating countries and were put into one dataset (Table III.1). Fleets were separated into two groups based on total engine power: ≤ 300 HP[11] (Exemption fleet or "Euro-cutters"); >300 HP.

Two units for effort were used: days at sea (d.a.s.): the number of days a vessel has been out of the harbour; and Hp days at sea: days at sea multiplied with the engine power of a vessel[12]. For landings, the total landings per species for Plaice, Sole, Dab, Whiting, Cod, Haddock, Nephrops and shrimps were available.

Table III.1. *Overview of effort and landings data available to the working group. The period of which data were available are indicated per country.*

Country	Effort data	Landings data
Belgium	-	2000-2002
Denmark	1989-2003	1989-2003
England	1989-2002	1989-2002
France	1999-2003	1999-2003
Germany	1989-2003	1989-2003
Netherlands	1990-2003	1990-2003
Scotland	1989-2002	1989-2002

Because Belgian landings data were available from three years only, and the proportion of Plaice landed by this fleet was smaller than 5 % of the total, Belgian data were not further used in the evaluation.

Of all data, it was determined whether it came from inside or outside the Plaice Box depending on ICES statistical rectangles, the type of gear and the HP of the vessel. In cases where the Plaice Box crosses an ICES rectangle (Figure III.1), the following assumptions were made:

- If a vessel >300 HP was fishing in that rectangle during a 'closed quarter', the landings and effort were allocated to the adjacent area outside the Plaice Box;
- If a vessel ≤ 300 HP was fishing in that rectangle the landings and effort were always allocated to the Plaice Box area. This implies an assumption of strict compliance with the Plaice Box regulations by the skippers and also that the exemption fleet will prefer to fish inside the Box rather than just outside or on the border. Support for this assumption is presented in the 1999 evaluation report and in (Rijnsdorp et al., 1998);
- In quarters the Box was open, effort and landing of beam trawlers>300 HP were distributed between the Box and outside the Box relative to the surface of the ICES rectangle in- and outside the Box;
- For all other gears, effort and landings were distributed between the Box and outside the Box relative to the surface of the ICES rectangle in- and outside the Box.

When trends in effort and landings in the Plaice Box were compared with those in the North Sea, data from the total North Sea were used (Figure III.1).

[11] Power is expressed here as horse power, HP, 1 HP=0.7355 KW.

[12] For German data, days were days fishing, and not days at sea.

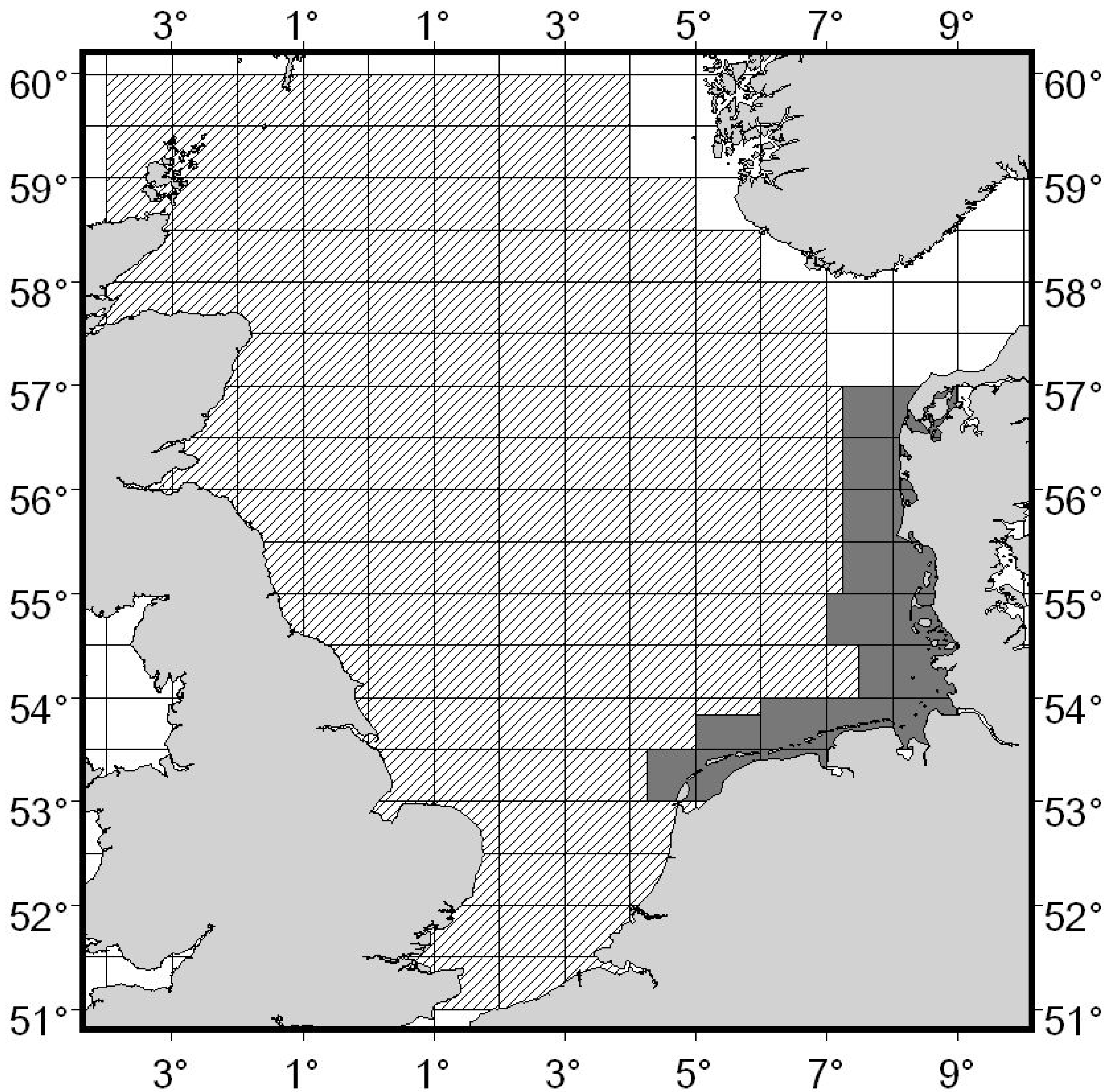


Figure III.1. *Map of the North Sea showing the Plaice Box (dark grey area) and the rectangles from which data representing the North Sea were selected (hatched rectangles).*

All gears were classified into six gear types: beam trawl, otter trawl, seine, shrimp trawl, gill net and others.

III.2 Results

III.2.1 Trends in effort

The closure of the Plaice Box had almost no effect on the effort of the vessels ≤ 300 HP whereas the effort of larger vessels decreased rapidly (Figure III.2). Since 1999 total effort in the Plaice Box seems to have stabilized in both categories. An apparent sharp increase in shrimp vessel effort is due to the fact that only from 2000 onwards that logbook recording is in force for this vessel category. Obviously, for beam trawlers >300 HP the contribution to the total effort has decreased and, in contrast to the pre-Box period, otter trawls are the most important gear type for this type of vessel. In the segment of the smaller vessels, the proportion of each gear type has hardly changed, except for the shrimp trawlers.

Beam trawling was mainly executed by German and Dutch vessels that accounted for ca. 95 % of the total beam trawl effort. In terms of HP days at sea, the total effort of the Dutch **beam trawlers** has further decreased since 1999 to 3 % of the pre-Box level (Figure 4.3). This decrease paralleled a general decrease in fishing effort in the Dutch beam trawl fishery over the entire North Sea. Of Danish, English and German beam trawlers, effort decreased since 1999 also (Figure III.4).

Trends in effort for the **otter trawl** varied strongly among countries (Figure (III.5). Effort of the Danish vessels decreased from 1989-1990 and remained rather stable since then. Effort of the English vessels was always low with a peak in 1996. Effort of German vessels decreased steadily from 1989 to 1994 and remained rather constant from 1995 onwards. Only the effort from the Dutch otter trawlers has increased since the closure of the Plaice Box to a level of two to three times the pre-Box level. This increase was mainly caused by vessels >300 HP. From 1995 to 2003, the contribution of Dutch vessels to otter trawling increased from almost 0 to 10-20 % of the total effort.

Gill nets and **seines** were mainly operated by Danish fishermen although the contribution of Dutch fishermen to the total seining effort in the Plaice Box has increased strongly since 1995. The gill netting effort showed a peak around the closure of the Plaice Box in 1995 (Figure (III.6). The effort with seines steadily decreased from 1989 to 1998 and this was mainly due to the decrease in effort of smaller vessels (Figure (III.7). The effort of larger vessels employing seines has increased since 1998.

III.2.2 Trends in landings

Since 1989, the total landings from the Plaice Box have decreased for both categories of vessels (Figure (III.8). From 1989-1995, the proportion of Plaice decreased rapidly in the landings from larger vessels. From 1999 onwards, however, the proportion of Plaice increased in the landings from the Plaice Box whereas the proportion of cod decreased during this period. Outside the Plaice Box, total landings have decreased for the larger vessels also but remained rather constant for the smaller vessels. In the smaller vessels, the proportion of cod in the total landings decreased rapidly from 1998 onwards. This decrease was caused by a sharp decrease in the cod stock and by this in cod landings. They dropped from a level of 20.000-25.000 ton in 1995-1999 to a level of 6600 ton in 2001-2002.

Denmark, the Netherlands and Germany land more than 90 % of the Plaice from outside the Plaice Box (Table (III.2). Total landings of Plaice from the Plaice Box decreased more rapidly than landings from the total North Sea. The area of the Plaice Box became less important for the Plaice landings. The proportion of Plaice from the North Sea that was landed from within the Plaice Box decreased from 11-13 percent in 1990-1995 to 5-7 % in 1999-2003 (Table III.2).

Table III.2. *Annual contribution of each country (as a percentage of the total) to the Plaice landings from the Plaice Box (column B). The total Plaice landings (ton) from the Plaice Box and the total landings from the North Sea are given in columns C and D. A value of 0 means <0.5, a value of '.' means no observation. Column E presents the Plaice landed from the Plaice Box as a percentage of all Plaice landed from the North Sea.*

A	B						C	D	E
Year	Percentage of total Plaice landings in the Plaice Box						Total Plaice Box	Total North Sea	% of Plaice from Plaice Box
	Eng	Bel	Dk	Ger	Nld	Sco	(ton)	(ton)	
1989	2	.	71	27	.	0	4813	50746	9
1990	1	.	31	21	47	0	13137	120307	11
1991	3	.	34	19	44	0	14769	113951	13
1992	6	.	38	22	34	0	9918	98152	10
1993	14	.	28	15	43	.	11697	88521	13
1994	3	.	48	19	29	.	9403	88040	11
1995	3	[13]*4*	58	13	22	0	5299	72631	7
1996	3	*4*	51	25	18	.	4754	65860	7
1997	4	*3*	47	28	17	.	4286	66119	6
1998	6	*3*	46	27	18	.	3367	55028	6
1999	1	*4*	46	21	27	0	4637	63173	7
2000	2	6	53	14	20	0	3266	68772	5
2001	1	4	59	17	14	0	4684	68422	7
2002	1	5	60	17	13	.	3459	56455	6
2003	.	.	75	11	12	.	2939	42609	7
Average	4	5	50	20	24	0	6695	74586	9

The proportion of Plaice caught in the different gear types has remained rather constant over time for the vessels ≤ 300 HP whereas in the larger vessels the importance of the otter trawl and gill nets has increased and that of the beam trawl has decreased (Figure (III.9). Outside the Plaice Box the importance of the beam trawl for Plaice landings has increased for vessels ≤ 300 HP whereas for larger vessels the proportion of Plaice landed by a beam trawl remained high (>90 %) over the whole period.

Obviously, landings of Plaice in the Dutch beam trawl fleet >300 HP decreased rapidly after the closure of the Plaice Box whereas those in the vessels ≤ 300 HP decreased steadily (Figure (III.10). Also outside the Plaice Box Plaice landings decreased but both inside and outside the Plaice Box a small peak in landings occurred in 1999. This was probably due to the strong 1996 year class that recruited to the fishery in that year.

In addition to a peak in landings, the landings per unit effort (LpUE) of Dutch beam trawlers ≤ 300 HP also increased in 1999 (Figure (III.11). Outside the Box, this peak occurred one year later which is probably caused by the offshore migration of the 1996 year class. Since 1990, LpUE of beam trawlers ≤ 300 HP has decreased inside the Plaice Box whereas it has increased outside the Plaice Box. LpUE of larger beam trawlers has decreased.

In comparison, for Sole, the LpUE in the Dutch beam trawl fleet dipped in 1997 after which it increased rapidly in beam trawlers ≤ 300 HP (Figure (III.12). In larger beam trawlers, LpUE for Sole was rather constant with a small dip in 1997 also.

[13] Numbers printed in italics were Belgian landings in Dutch auctions retrieved from the Dutch landings database.

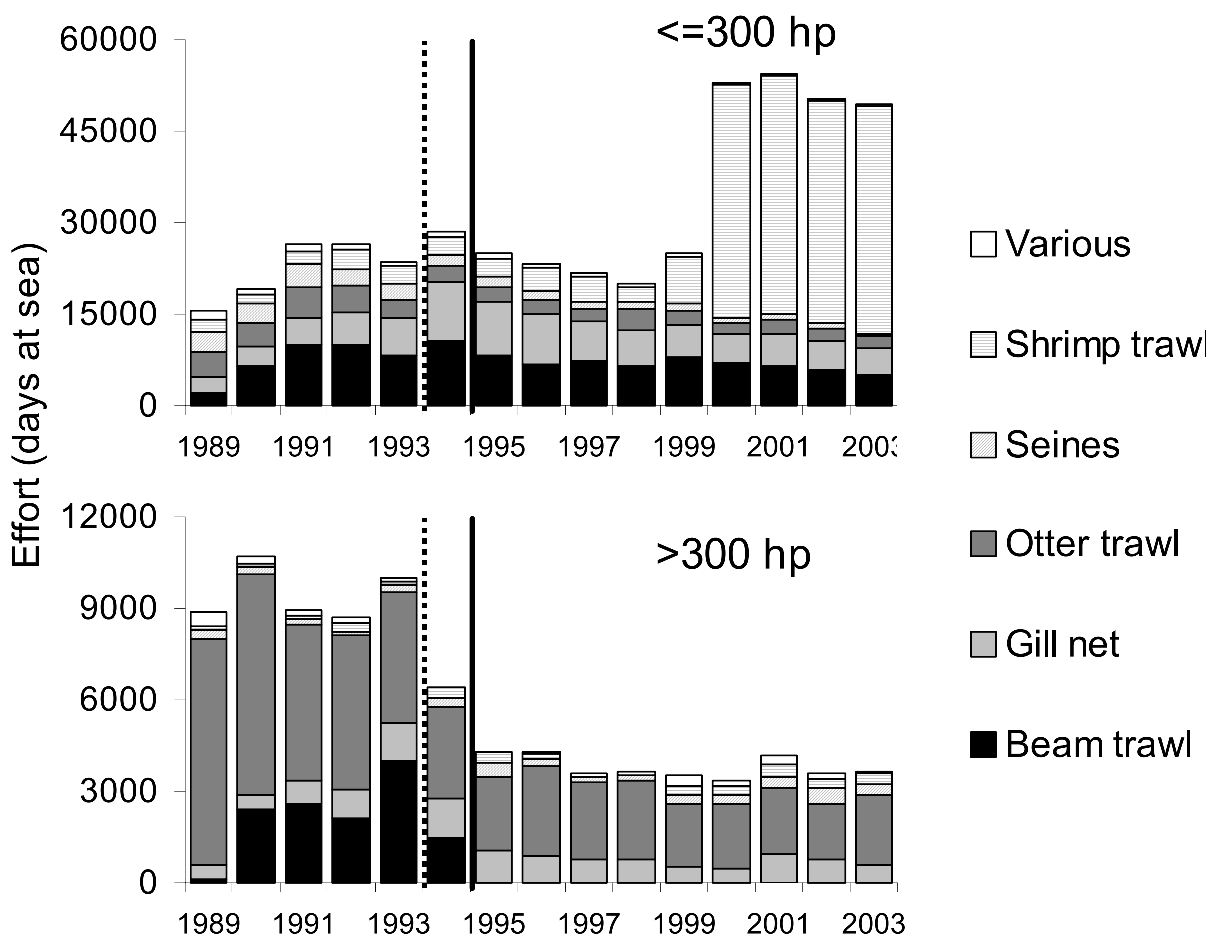


Figure III.2. *Trends in total effort inside the Plaice Box for all gear types for euro cutters (upper panel) and larger vessels (lower panel).*

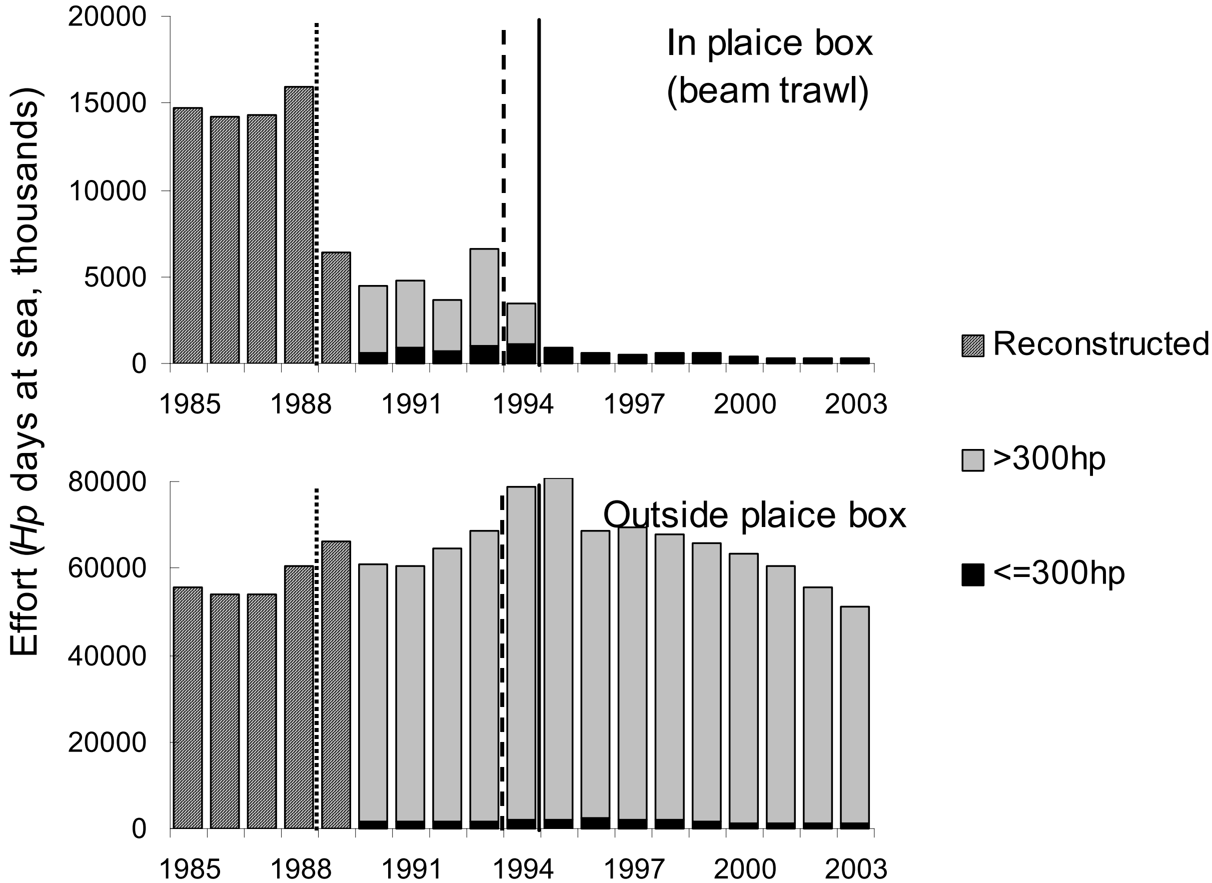


Figure III.3. *Trends in effort (Hp days at sea) of the Dutch beam trawl fleet for euro cutters ≤ 300 HP and larger cutters inside (upper panel) and outside (lower panel) the Plaice Box. Data up to 1989 were retrieved from the 1999 evaluation for which they were reconstructed. For these data, HP classes could not be distinguished.*

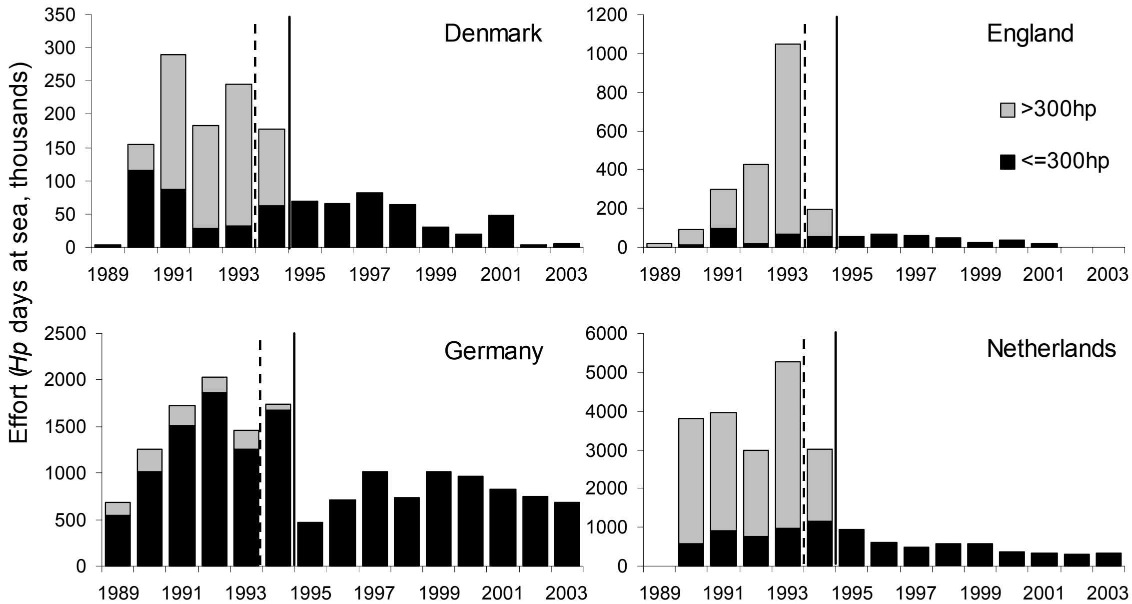


Figure III.4. *Trends in effort in bream trawling for euro cutters and larger cutters in the Plaice Box.*

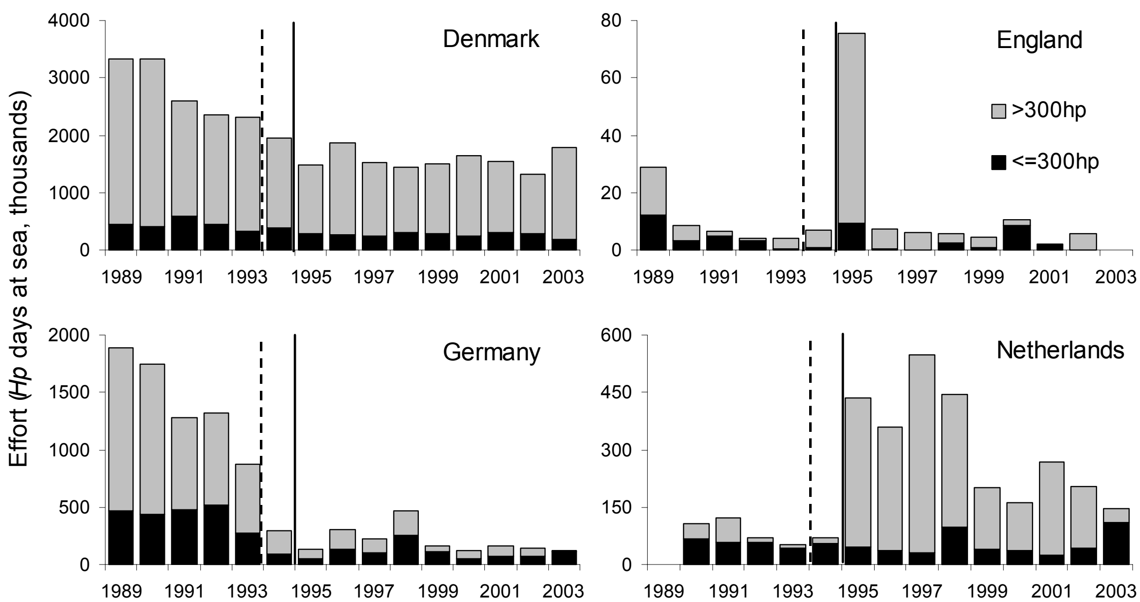


Figure III.5. *Trends in effort in otter trawling for euro cutters and larger cutters inside the Plaice Box.*

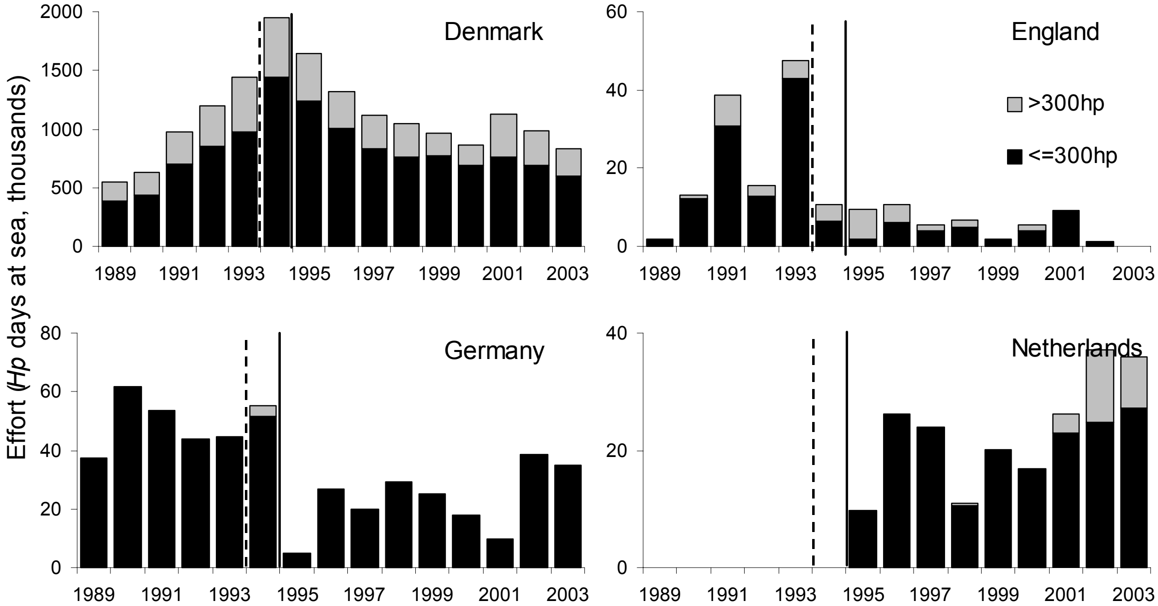


Figure III.6. *Trends in effort for gill netting by euro cutters and larger cutters inside the Plaice Box.*

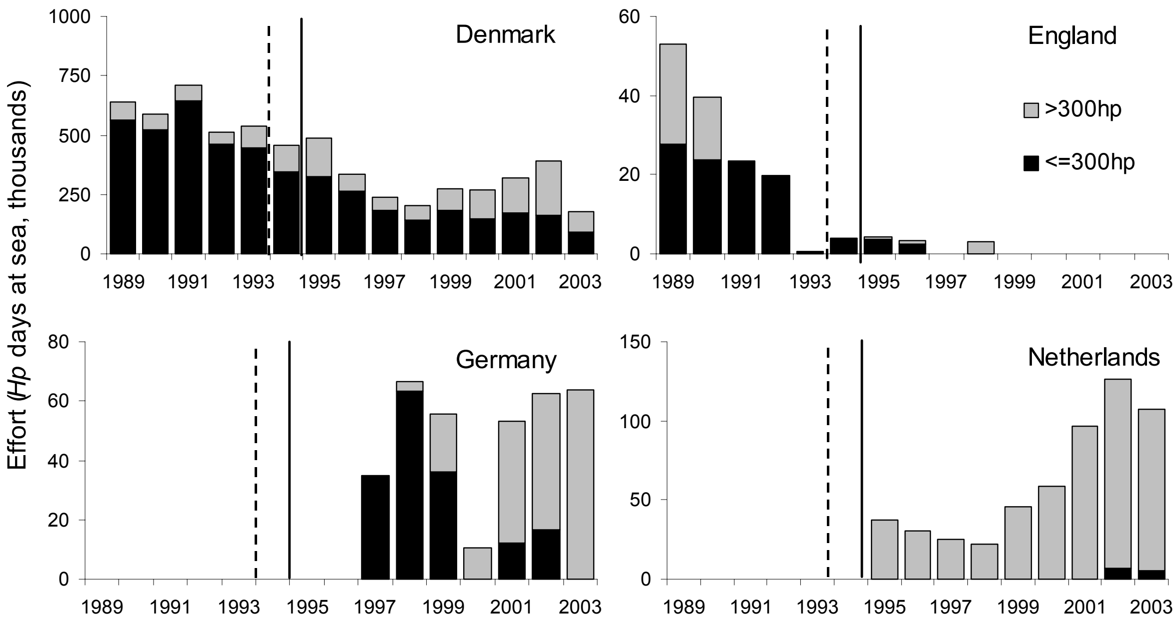


Figure III.7. *Trends in effort by seines for euro cutters and larger cutters inside the Plaice Box.*

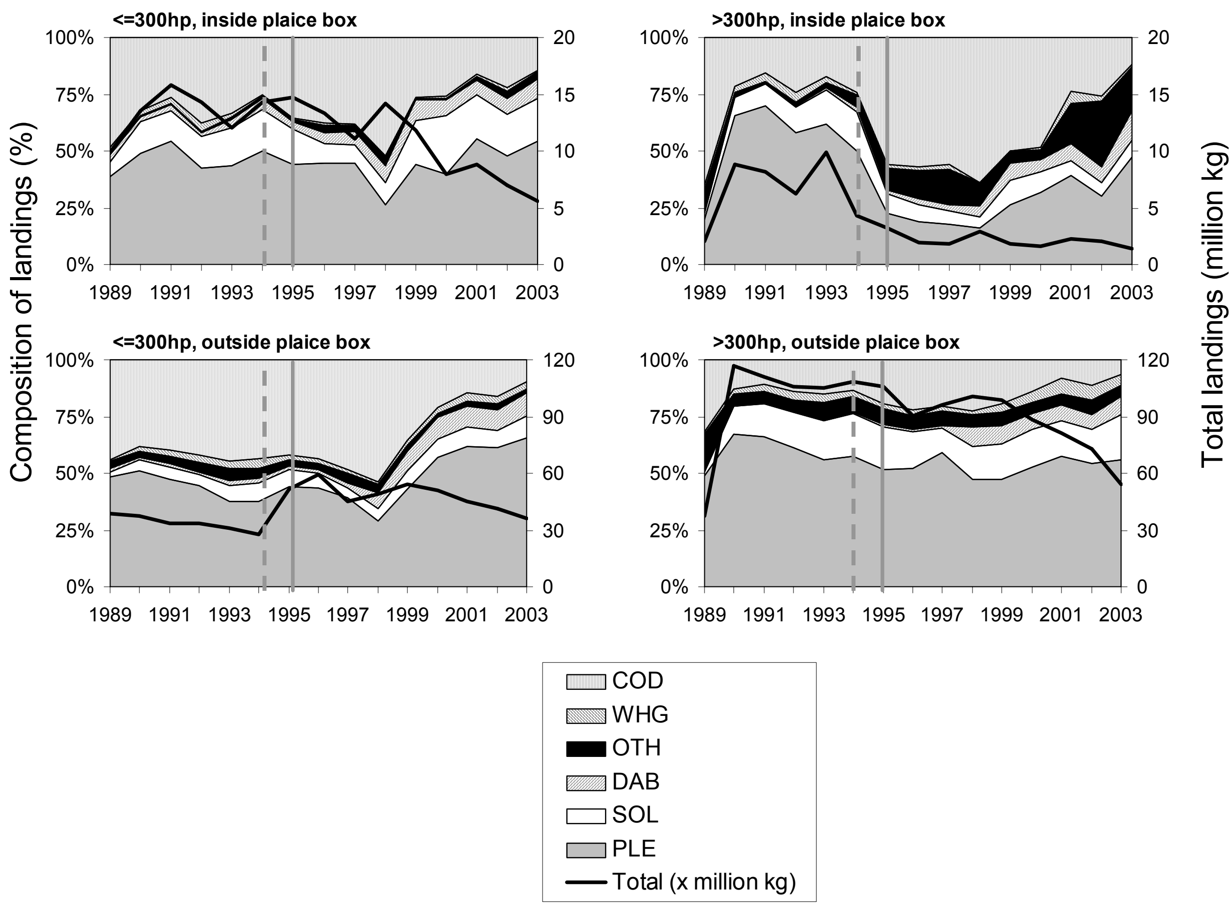


Figure III.8. *Total landings for six species (solid black line) and composition of the landings in- and outside the Plaice Box for euro cutters and larger vessels. Data are from a selection of species and thus do not present total landings from the North Sea.*

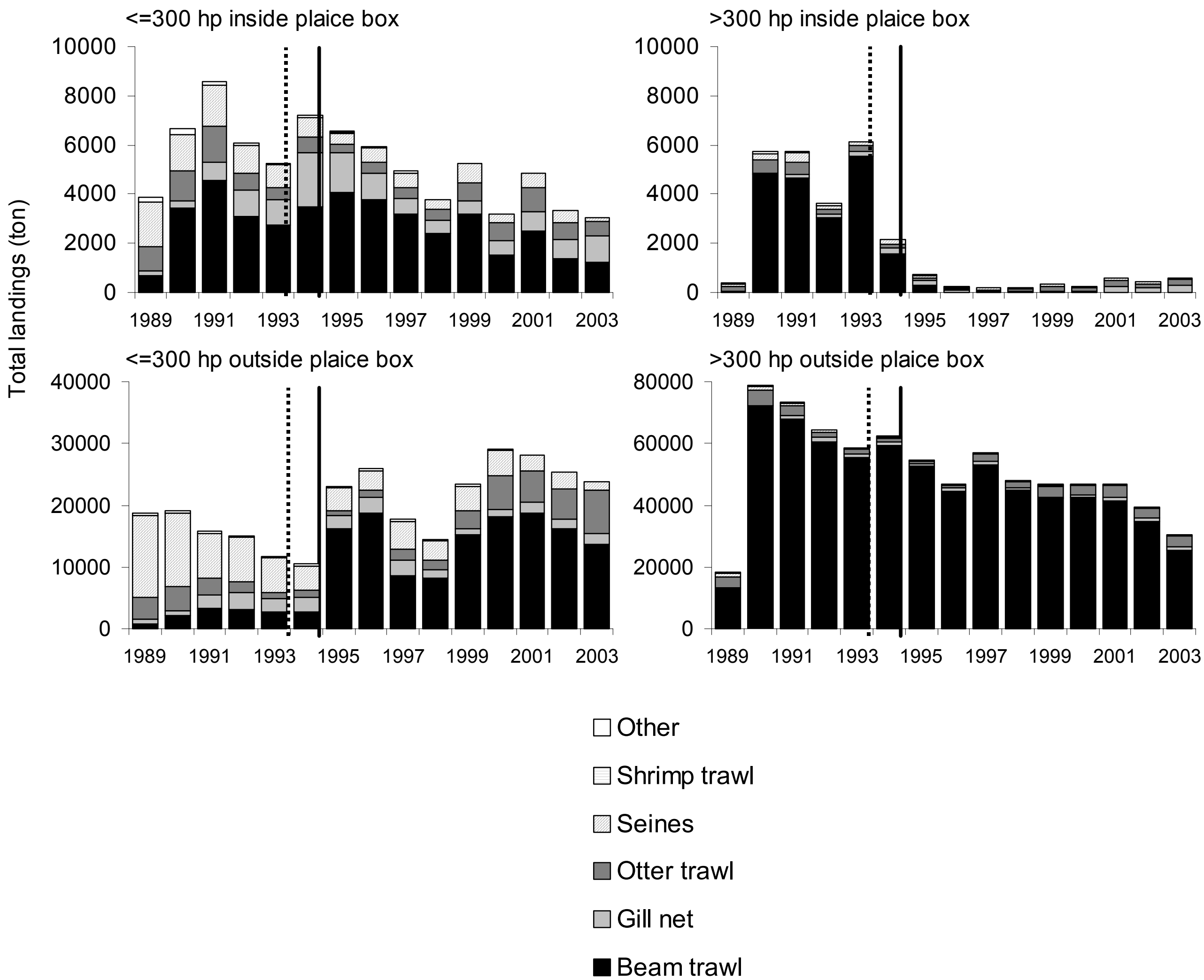


Figure III.9. *Total landings of Plaice (solid black line, right y-axis) and the proportion of the landings from each gear type (left y-axis), in- and outside the Plaice Box for euro cutters and larger vessels.*

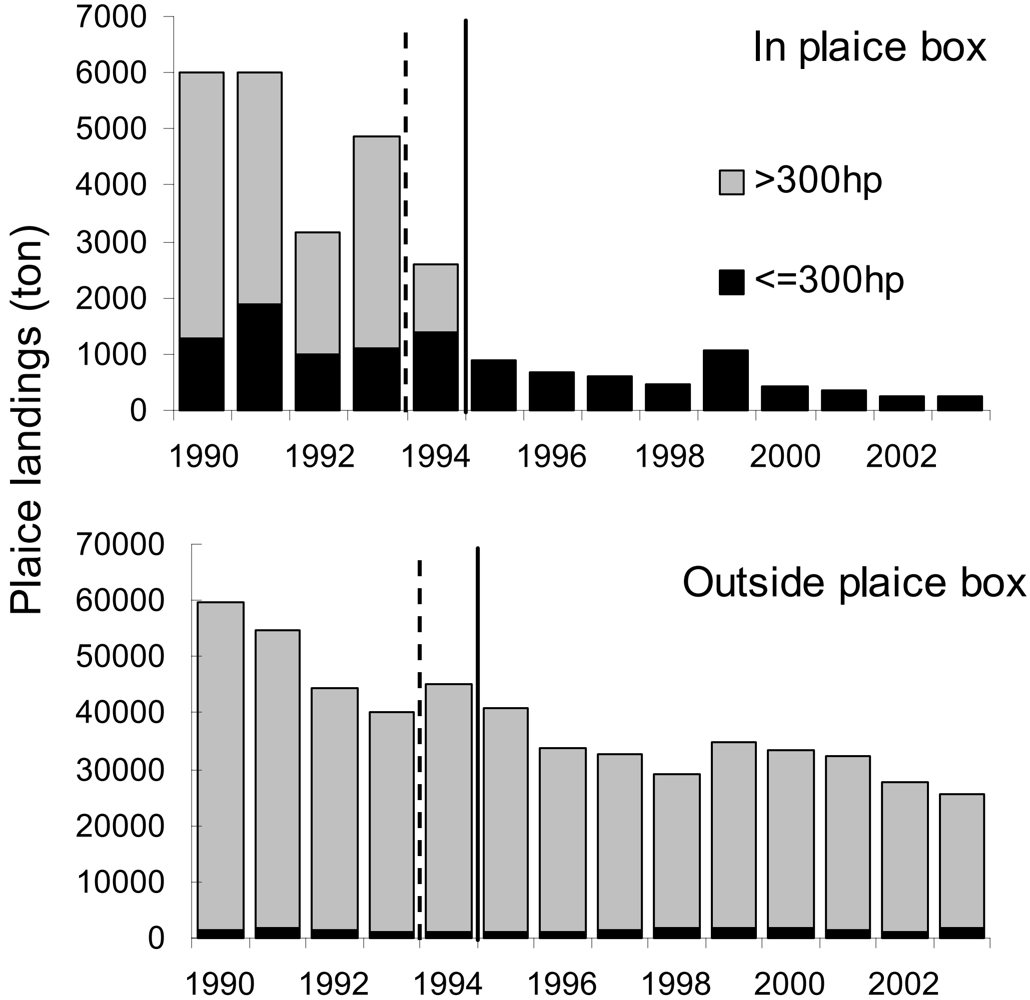


Figure III.10. *Total landings of Plaice in the Dutch beam trawl fishery, in- and outside the Plaice Box for euro cutters and larger vessels.*

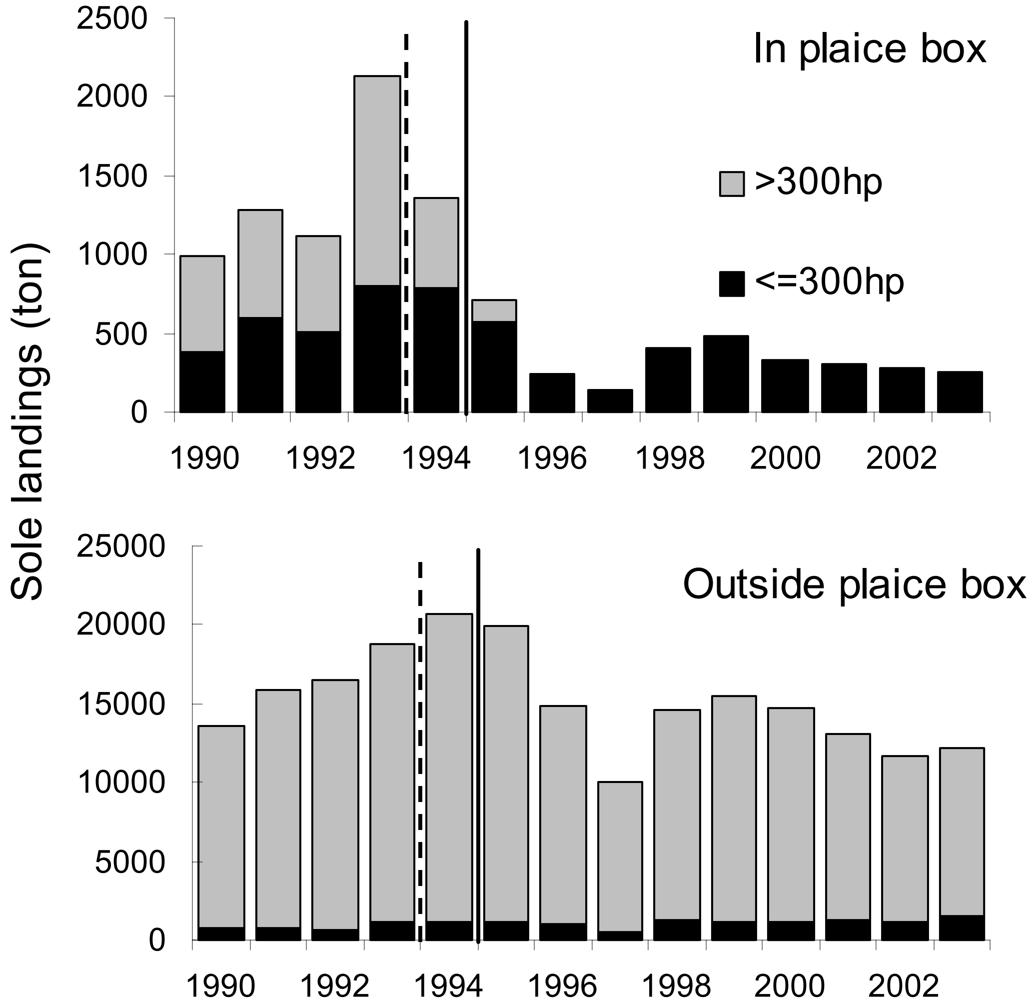


Figure III.11. *Total landings of Sole in the Dutch beam trawl fishery, in- and outside the Plaice Box for euro cutters and larger vessels.*

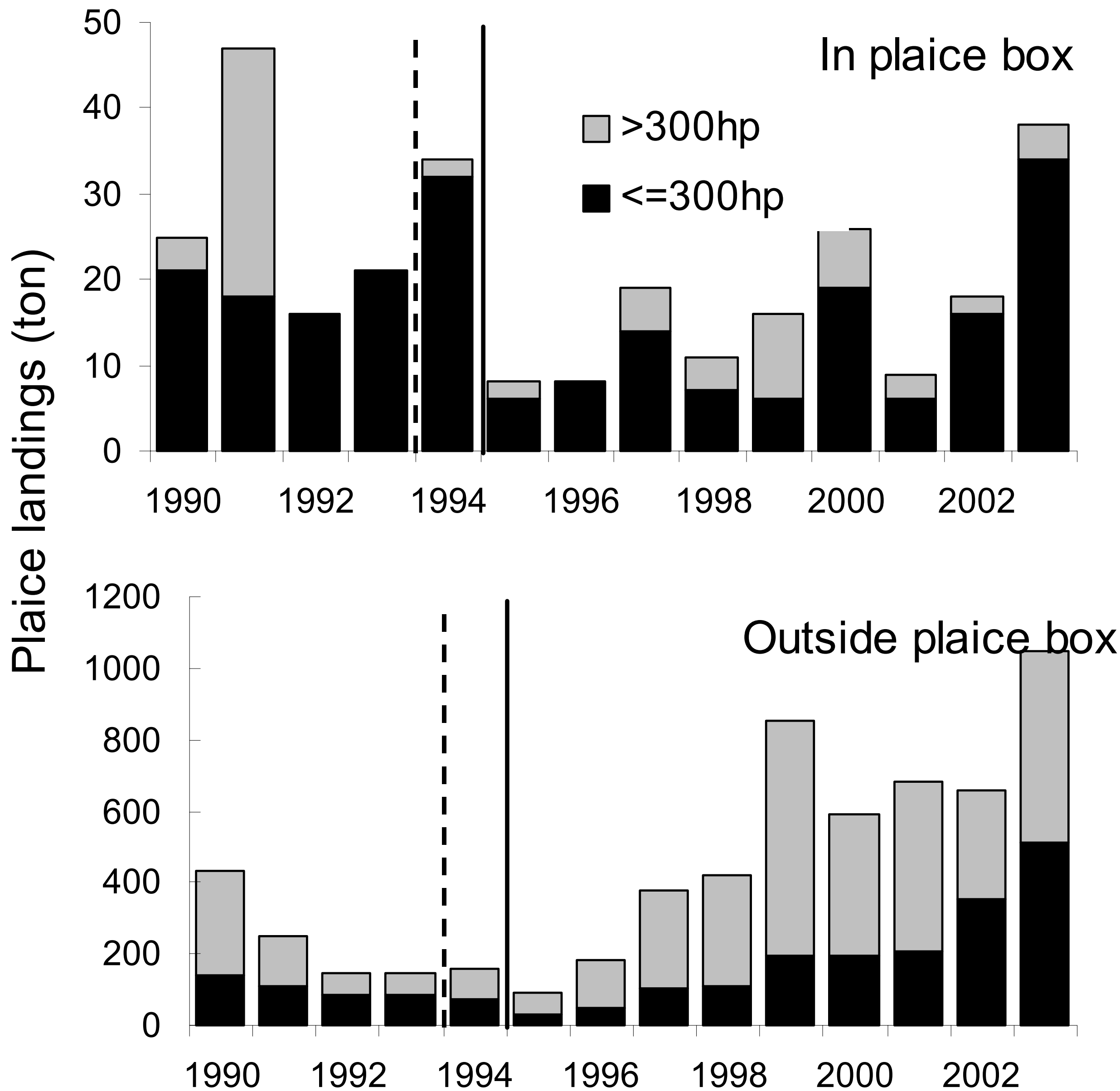


Figure III.12. *Total landings of Plaice in the Dutch otter trawl fishery, in- and outside the Plaice Box for euro cutters and larger vessels.*

Annex IV. Discard data.

Table IV.1. *Summary table of average number and weight (kg) per hour landed (L) and discarded (D) and percentage discarded (%D) for Plaice per period (from Van Keeken et al 2004). Mesh size is 80 mm.*

Period	Plaice Box	gear	Number			Weight		
			L	D	%D	L	D	%D
1969-1970		all			40			23
1975		all		130				
1976-1990		all	296	315	51	111	40	27
1976-1990	inside	all	219	754	78			
1976-1990	outside	all	332	148	31			
1999-2003	inside	≤ 300 HP	37	241	87	8	14	63
1999-2003	outside	>300 HP	212	704	77	55	56	50

Table IV.2. *Average catch of Plaice discards in the beam trawl fishery (numbers per hour fishing inside the Plaice Box. German data.*

Half Year	Mesh opening	
Periods	80 mm	100 mm
1993-1.H	238	169
1993-2.H	343	
1994-1.H	245	156
1994-2.H	454	176
1995-1.H	789	757
1995-2.H	619	
1996-2.H	691	573
1997-1.H	290	
1997-2.H		266
1998-1.H	942	
1998-2.H		360

Table IV.3. *Discard percentages of the beam trawl fisheries for Plaice. Mesh size is 80 mm.*

Year	Quarter	Weight			Numbers		
		Inside Germany W	Outside Germany W	Outside Netherlands W	Inside Germany N	Outside Germany N	Outside Netherlands N
1998	1						
1998	2	98			99		
1998	3	98			99		
1998	4		9			21	
1999	1		66			84	
1999	2	93	72		98	85	
1999	3	86	85	33	97	97	58
1999	4		47	25		77	50
2000	1		36	31		74	62
2000	2	93		60	99		83
2000	3	82	68	40	99	91	64
2000	4	82	63	18	99	80	40
2001	1		58	27		94	54
2001	2	85	33	68	99	54	76
2001	3		74			89	
2001	4						
2002	1			41			69
2002	2	49		60	87		85
2002	3			62			82
2002	4			68			81
2003	1		38	49		73	85
2003	2	57		62	81		84
2003	3		70	58		87	83
2003	4			61			81
Average		*82*	*55*	*48*	*96*	*77*	*71*
Stdev		*17*	*21*	*17*	*6*	*20*	*15*

Table IV.4. *Numbers of German discard trips per year and mesh size.*

Year	Number of trips			Number of hauls		
	100 mm	80 mm	Total	100 mm	80 mm	Total
1993	3	4	7	42	127	169
1994	4	3	7	130	132	262
1995	1	5	6	43	219	262
1996	2	1	3	79	36	115
1997	2	1	3	86	53	139
1998	1	3	4	42	67	109
1999	2	2	4	57	111	168
2000		10	10		325	325
2001		4	4		205	205
2002	1	1	2	43	34	77
2003		3	3		35	35
Total	16	37	53	522	1344	1866

Table IV.5. *Numbers of Dutch discard trips per period and Hp class.*

Period / Year	Number of trips			Number of hauls		
	≤ 300 Hp	> 300 Hp	Total	≤ 300 Hp	> 300 Hp	Total
1976-1990	1	50	51	10	1690	1700
1999		3	3		104	104
2000	2	13	15	74	420	494
2001	1	4	5	44	128	172
2002		6	6		172	172
2003	1	9	10	31	306	337
Total	5	85	90	159	2820	2979

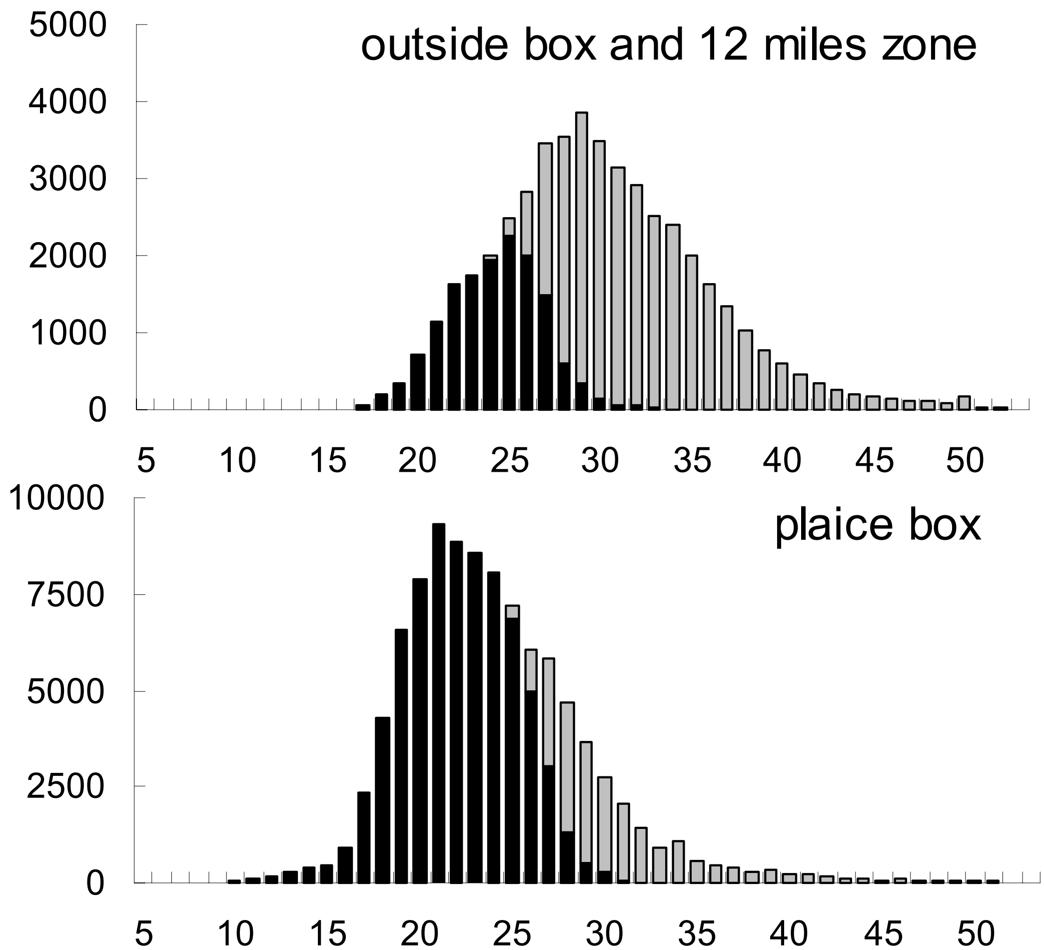


Figure IV.1. *Length frequency distributions of discards (black bars) and landings (grey bars) in- and outside the Plaice Box averaged over the period 1976-1990). Mesh size is 80 mm.*

Annex V. Maps with the spatial distribution of Plaice

V.1 Introduction to the maps

The maps in this Annex present the density of Plaice in and around the Plaice Box per age group and year. These densities were estimated from three Dutch beam trawl surveys that were executed from 1970-2003. Not all surveys were executed in each year:

- SNS (6 m beam trawl: 1970-2002);
- DFS (3 and 6 m beam trawl: 1970-2003);
- BTS (8 m beam trawl: 1985-2003).

The BTS extends further offshore than both other surveys and therefore, from 1985 onwards, the spatial distribution of Plaice is shown over a larger area.

For 1970-1995 densities are shown for each fifth year and for 1996-2003 for every year.

The densities are expressed as the numbers per 10000m^2 (1 hectare) swept area and are raw data, given for each haul.

There are six classes of densities (presented in the legend of each map) and the percentiles of the catch distribution over all years form borders of the classes:

1. No Plaice caught (density=0);
2. >0 and <=*P*25 (Between 0 and the 25 percentile);
3. >*P*25 and <=*P*50;
4. >*P*50 and <=*P*75;
5. >*P*75 and <=*P*90;
6. >*P*90.

V.2 Description of RIVO beam trawl surveys

SNS. The SNS was initiated in 1969 with the aim of establishing indices of abundance of Plaice and Sole at ages 0-3. The survey is conducted in September and October and uses a pair of 6-m beam trawls with 40 mm stretched mesh cod-ends. Each year 10 fixed transects (parallel or perpendicular to the coastline) along the Dutch, German and Danish coast are sampled with at least 4 hauls per transect. The positions of the stations are chosen such that the entire depth-range of the transect is covered.

DFS. The DFS was initiated in 1969 with the aim of developing abundance indices for ages 0-1 Plaice and Sole. The survey is conducted from September/October (estuaries) to October/November (coastal zone). In estuaries a 3-m shrimp net is used, while in the coastal zone a 6-m beam trawl is used, each with 20-mm stretched mesh cod-ends. Each year 200-300 hauls of 15 minutes are made along the Dutch, German and Danish coast, as well as the Westerschelde, Oosterschelde, Wadden Sea and the Eems-Dollard.

BTS (Piet, 2002). The BTS was initiated in 1985 and is carried out in international cooperation covering both inshore and offshore areas throughout the North Sea, Channel and western waters of the UK. The survey is conducted over five weeks during August and September. The fishing gear used to collect data for the North Sea Plaice and Sole indices is a pair of 8 m beam trawls rigged with nets of 120 mm and 80 mm stretched mesh in the body and 40 mm stretched mesh cod-ends. A total of eight tickler chains are used, four mounted between the shoes and four from the ground rope. The survey was designed to take between one and three hauls per ICES rectangle depending on the rectangle. The stations are allocated over the fishable area of the rectangle on a “pseudorandom” basis to ensure that there is a reasonable spread within each rectangle. No attempt is made to return to the same tow positions each year. Towing speed is 4 knots for a tow duration of 30 min and fishing occurs during daylight only. From the start of BTS in 1985 until present the same research vessel (RV "Isis") was used. At each station all fish species are measured and recorded together with physical/chemical variables such as surface and bottom temperature, depth and position in latitude and longitude.

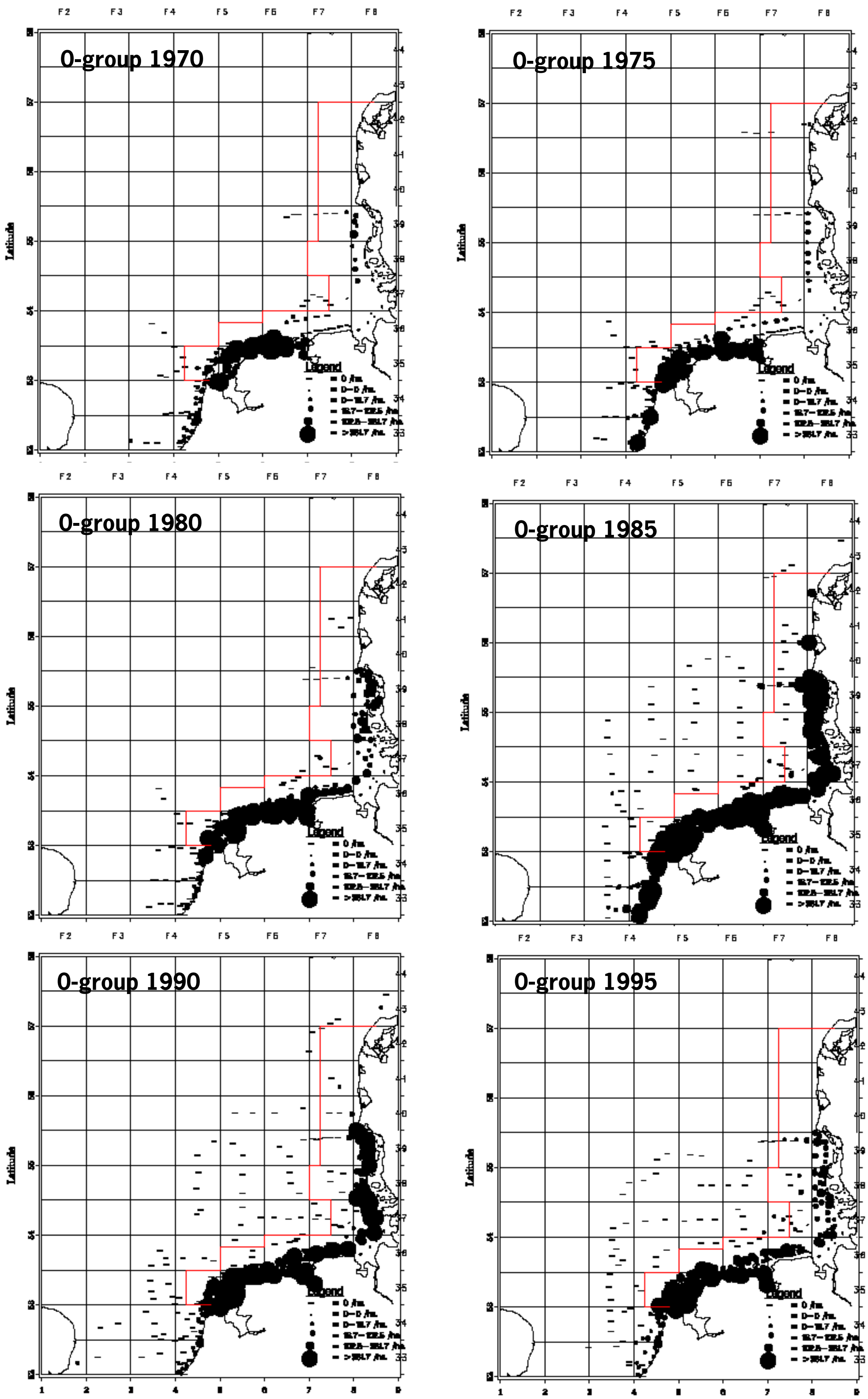


Figure V.1. *Distribution of the catch (number per ha) in the period 1970-1995 of 0-group Plaice.*

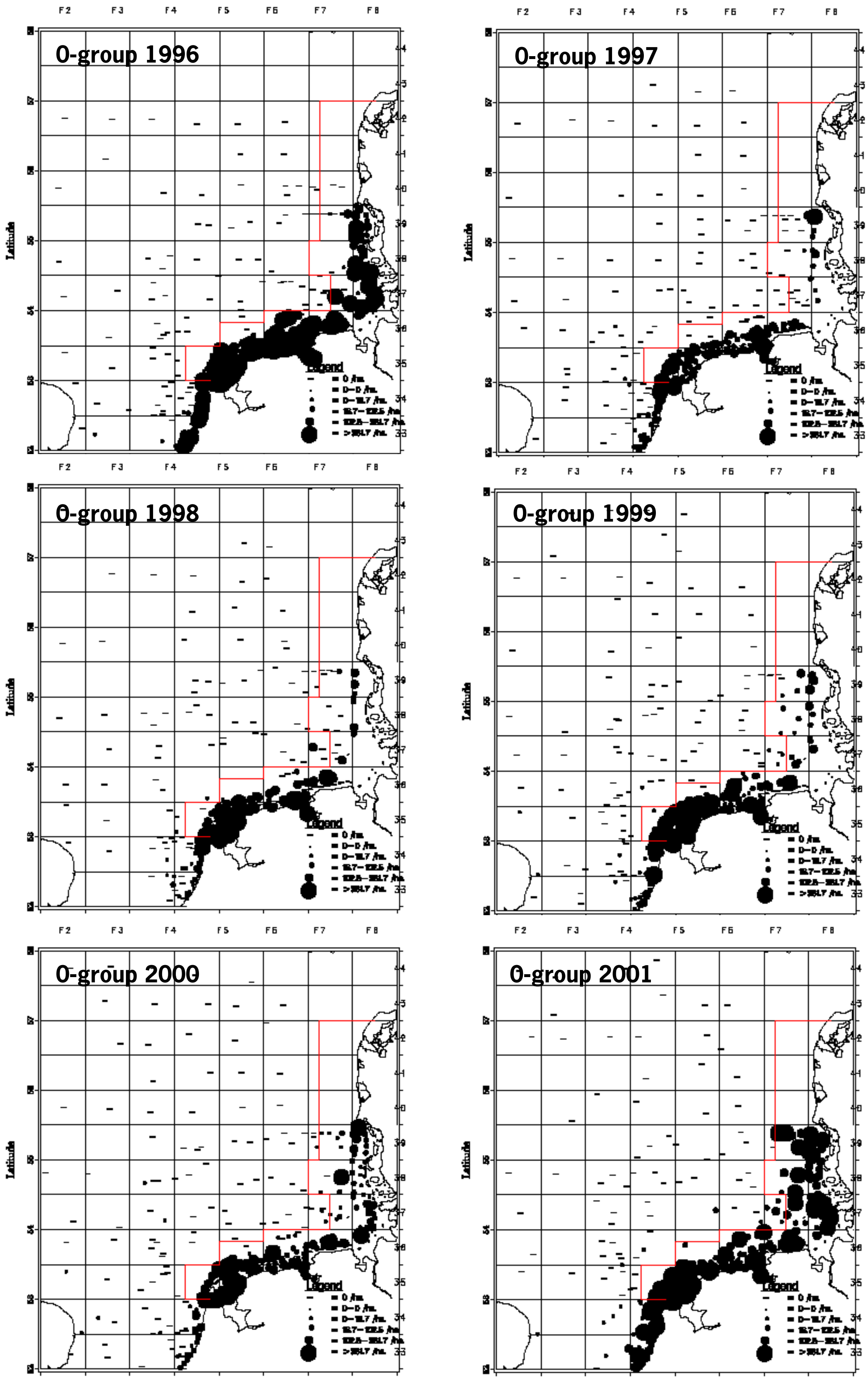


Figure V.2. *Distribution of the catch (number per ha) in the period 1996-2001 of 0-group Plaice.*

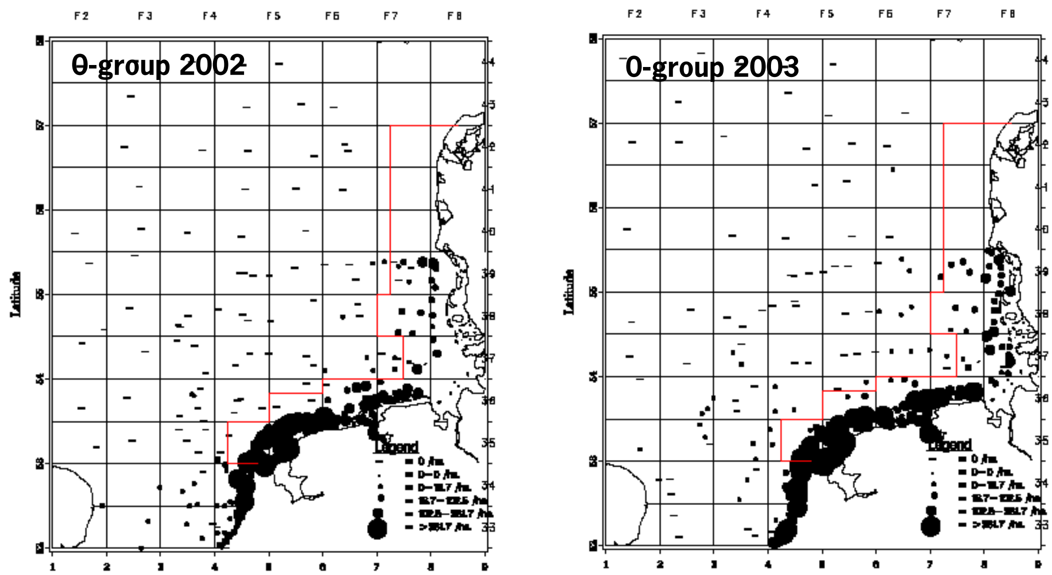


Figure V.3. *Distribution of the catch (number per ha) in the period 2002-2003 of 0-group Plaice.*

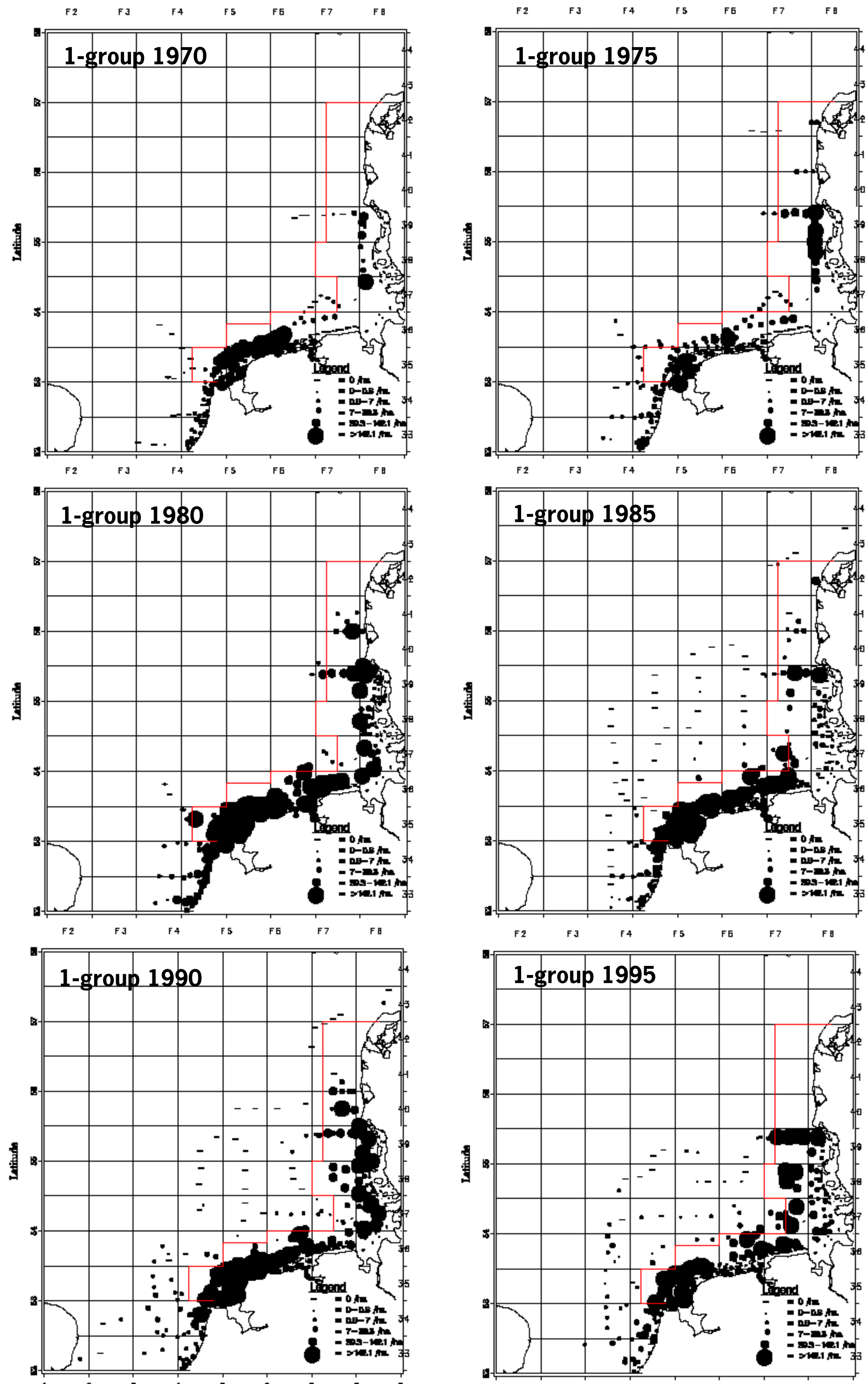


Figure V.4. *Distribution of the catch (number per ha) in the period 1970-1995 of 1-group Plaice.*

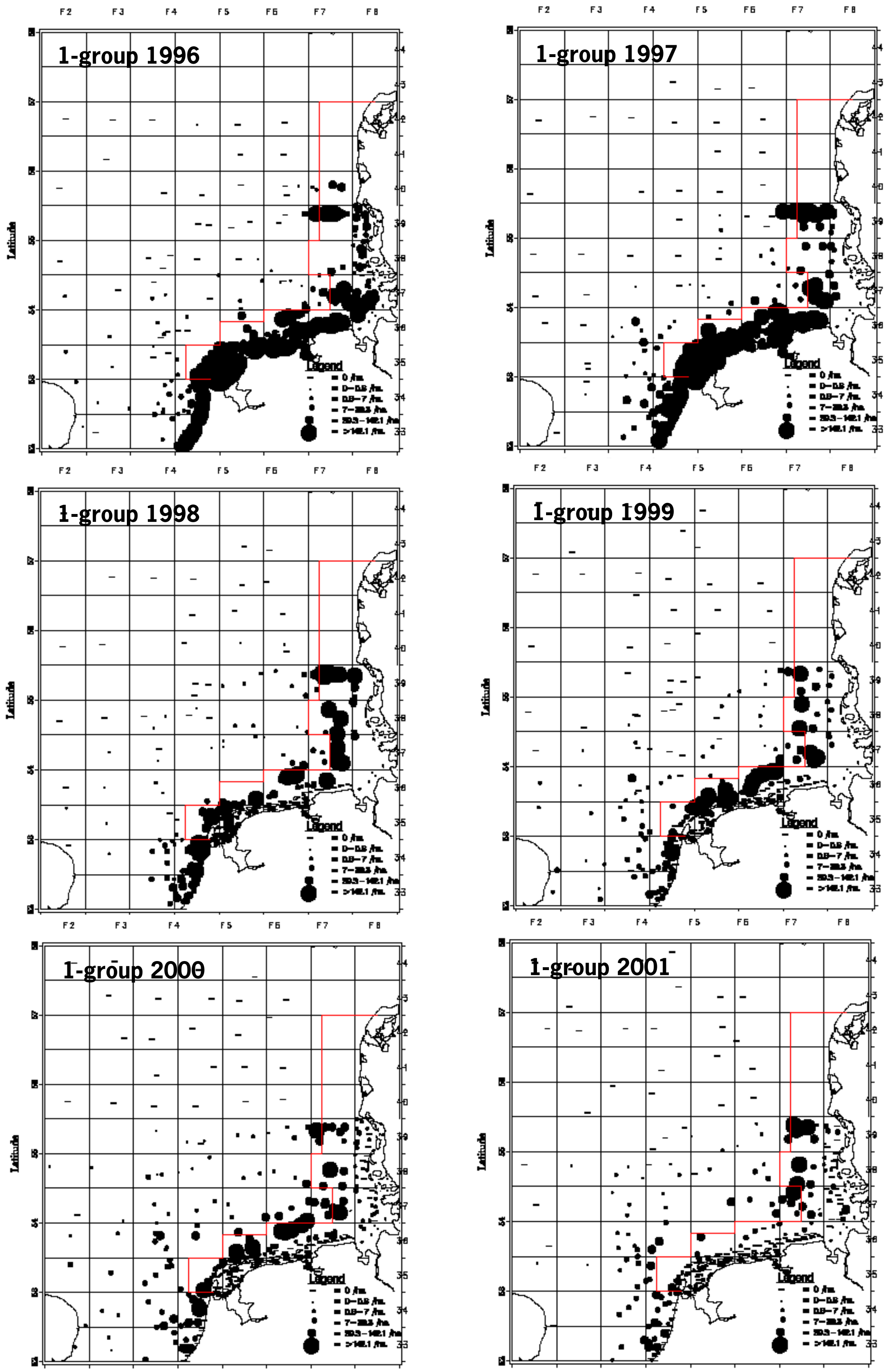


Figure V.5. *Distribution of the catch (number per ha), in the period 1996-2001 of 1-group Plaice.*

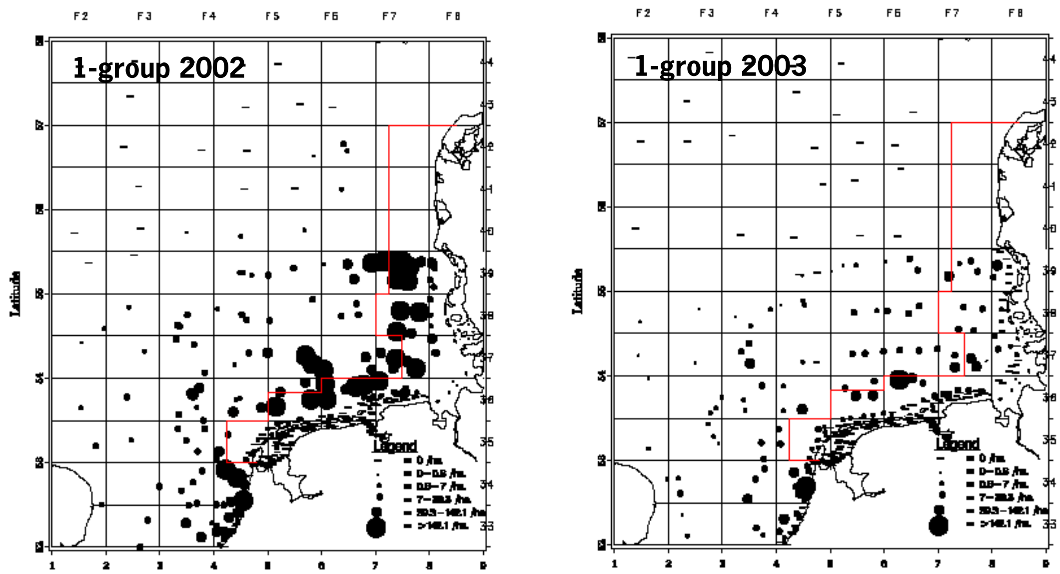


Figure V.6. *Distribution of the catch (number per ha), in the period 2002-2003 of 1-group Plaice.*

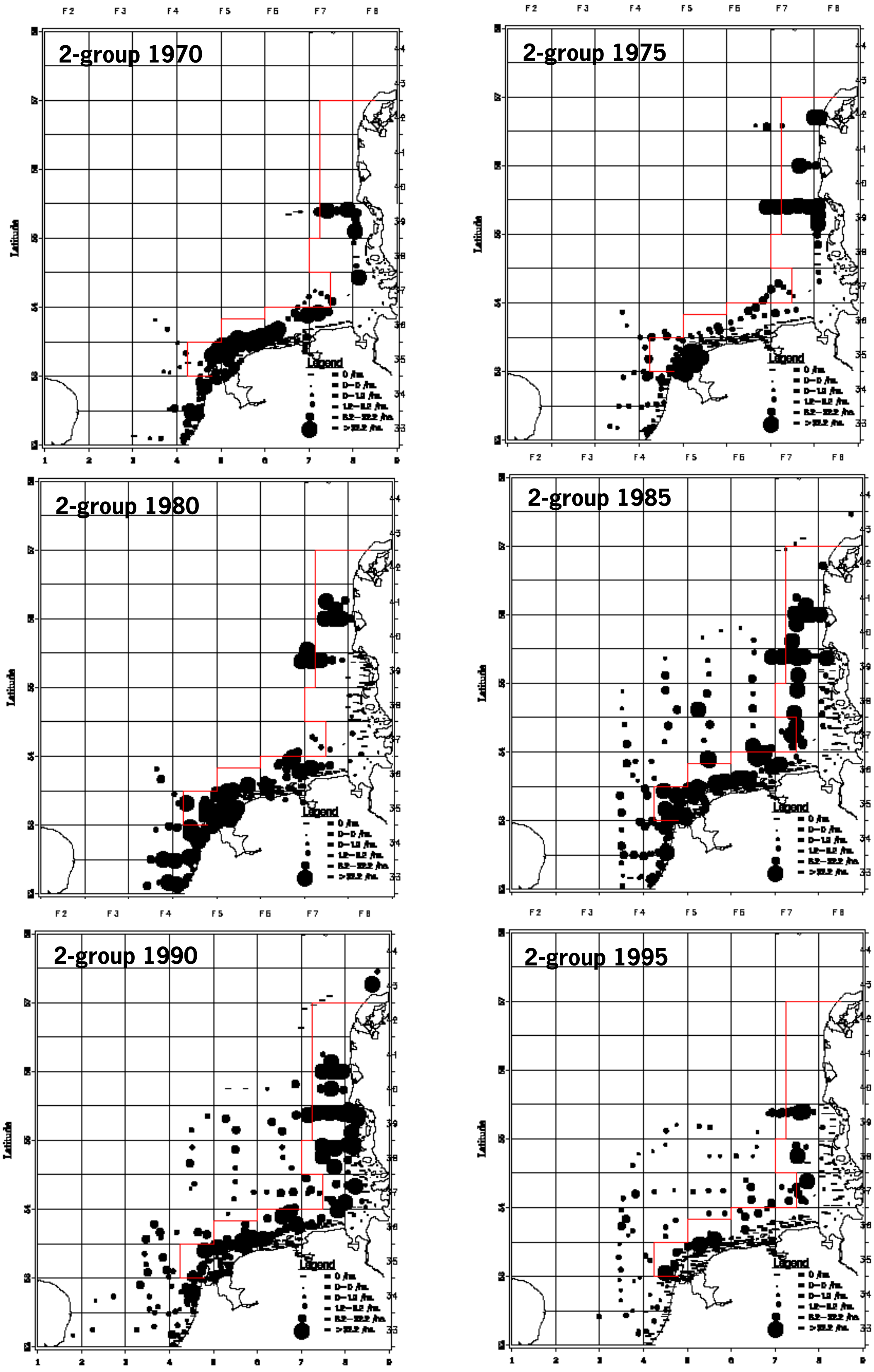


Figure V.7. *Distribution of the catch (number per ha) in the period 1970-1995 of 2-group Plaice.*

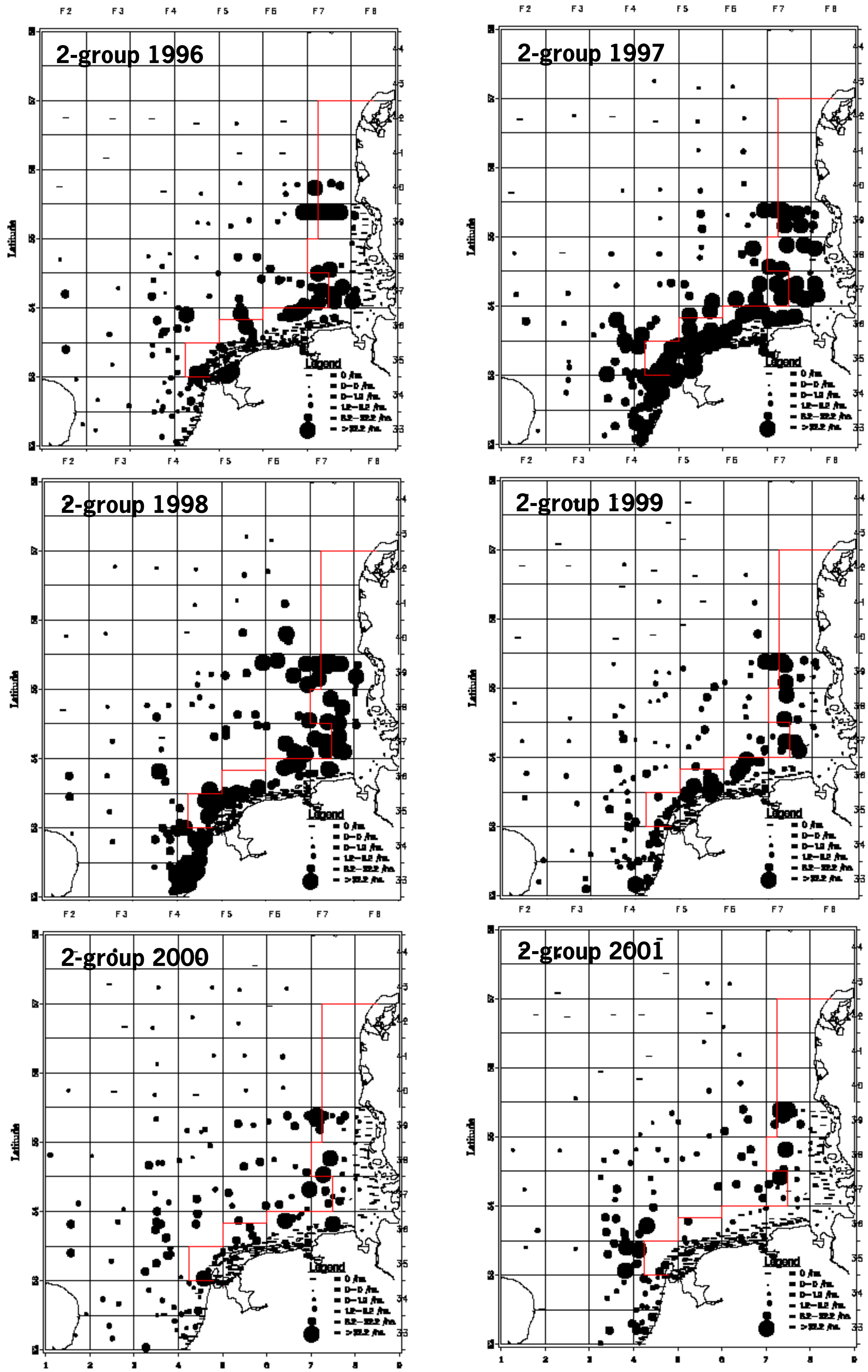


Figure V.8. *Distribution of the catch (number per ha) in the period 1996-2001 of 2-group Plaice.*

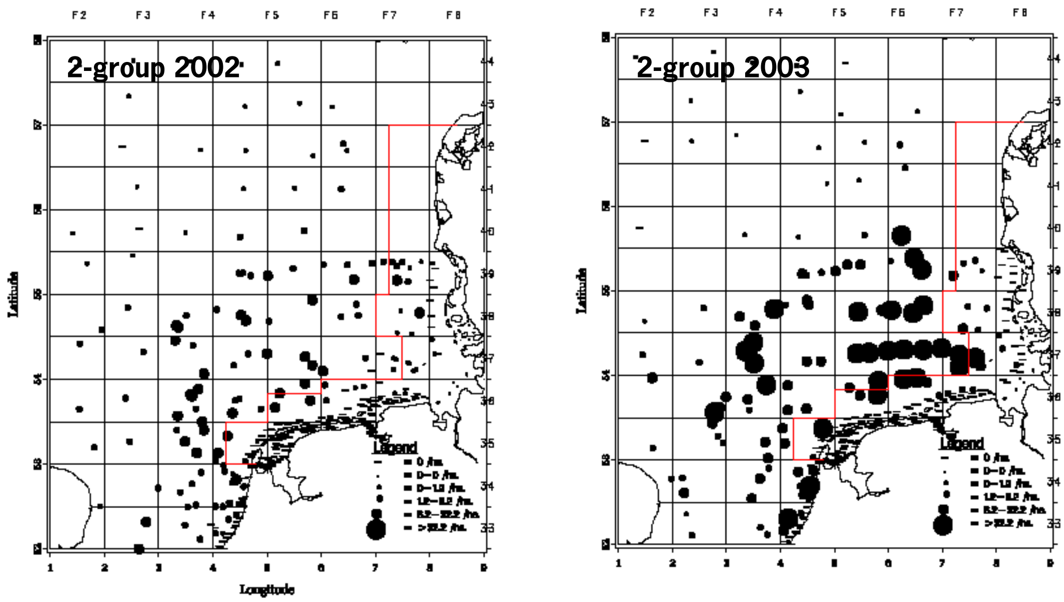


Figure V.9. *Distribution of the catch (number per ha) in the period 2002-2003 of 2-group Plaice.*

Annex VI. Maps with the spatial distribution of Sole

Introduction to the maps
The maps in this Annex present the density of Sole in and around the Plaice Box per age group and year. These densities were estimated from three Dutch beam trawl surveys that were executed from 1970-2003. Not all surveys were executed in each year:

- SNS (6 m beam trawl: 1970-2002);
- DFS (3 and 6 m beam trawl: 1970-2003);
- BTS (8 m beam trawl: 1985-2003).

The BTS extends further offshore than both other surveys and therefore, from 1985 onwards, the spatial distribution of Sole is shown over a larger area.

For 1970-1995 densities are shown for each fifth year and for 1996-2003 for every year.

The densities are expressed as the numbers per 10000m^2 (1 hectare) swept area and are raw data, given for each haul.

There are six classes of densities (presented in the legend of each map) and the percentiles of the catch distribution over all years form borders of the classes:

1. No Sole caught (density=0);
2. >0 and <=$P$25 (Between 0 and the 25 percentile);
3. >$P$25 and <=$P$50;
4. >$P$50 and <=$P$75;
5. >$P$75 and <=$P$90;
6. >$P$90.

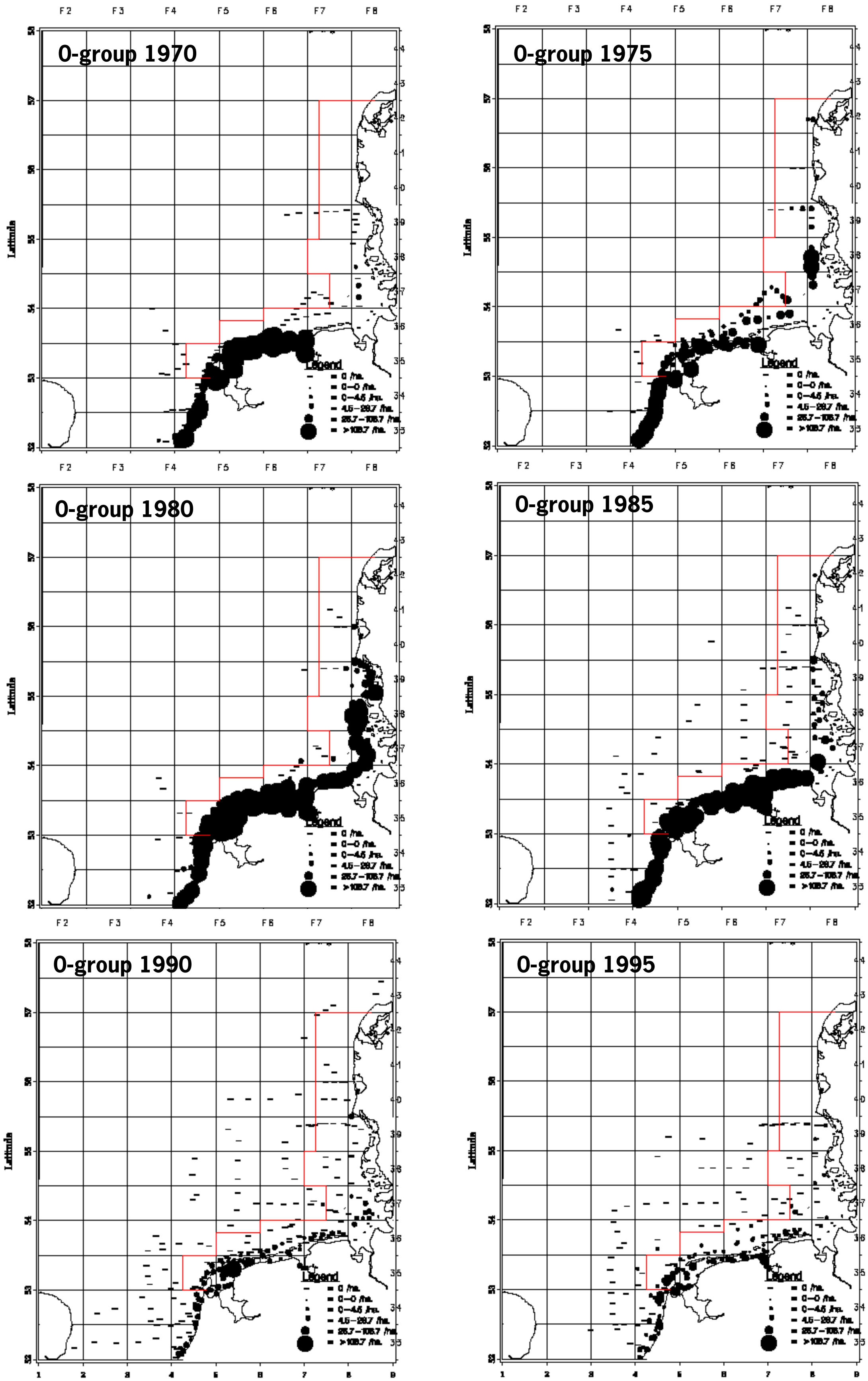


Figure VI.1. *Distribution of the catch (number per ha) in the period 1970-1995 of 0-group Sole.*

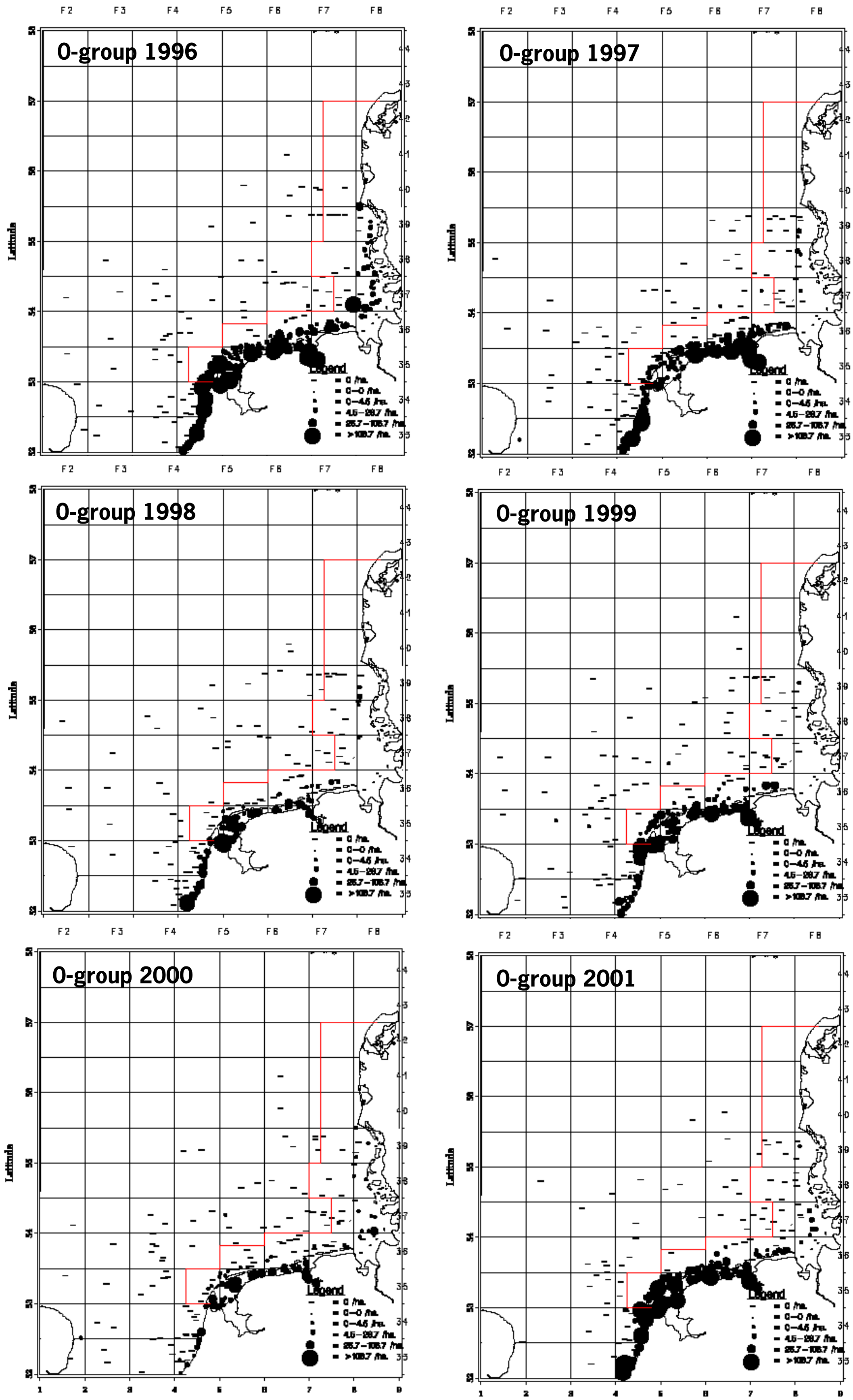


Figure VI.2. *Distribution of the catch (number per ha) in the period 1996-2001 of 0-group Sole.*

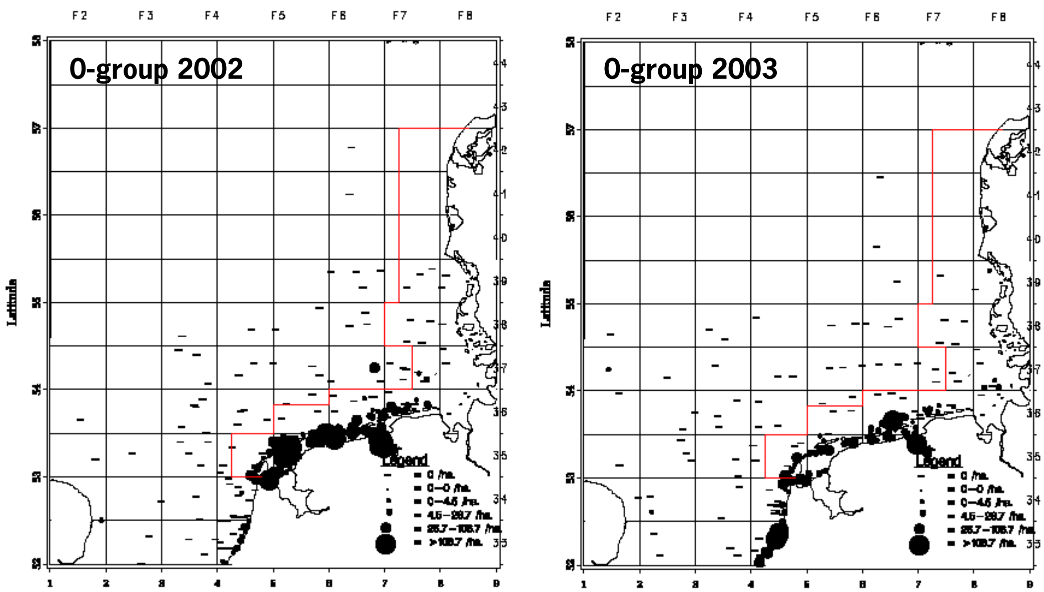


Figure VI.3. *Distribution of the catch (number per ha) in the period 2002-2003 of 0-group Sole.*

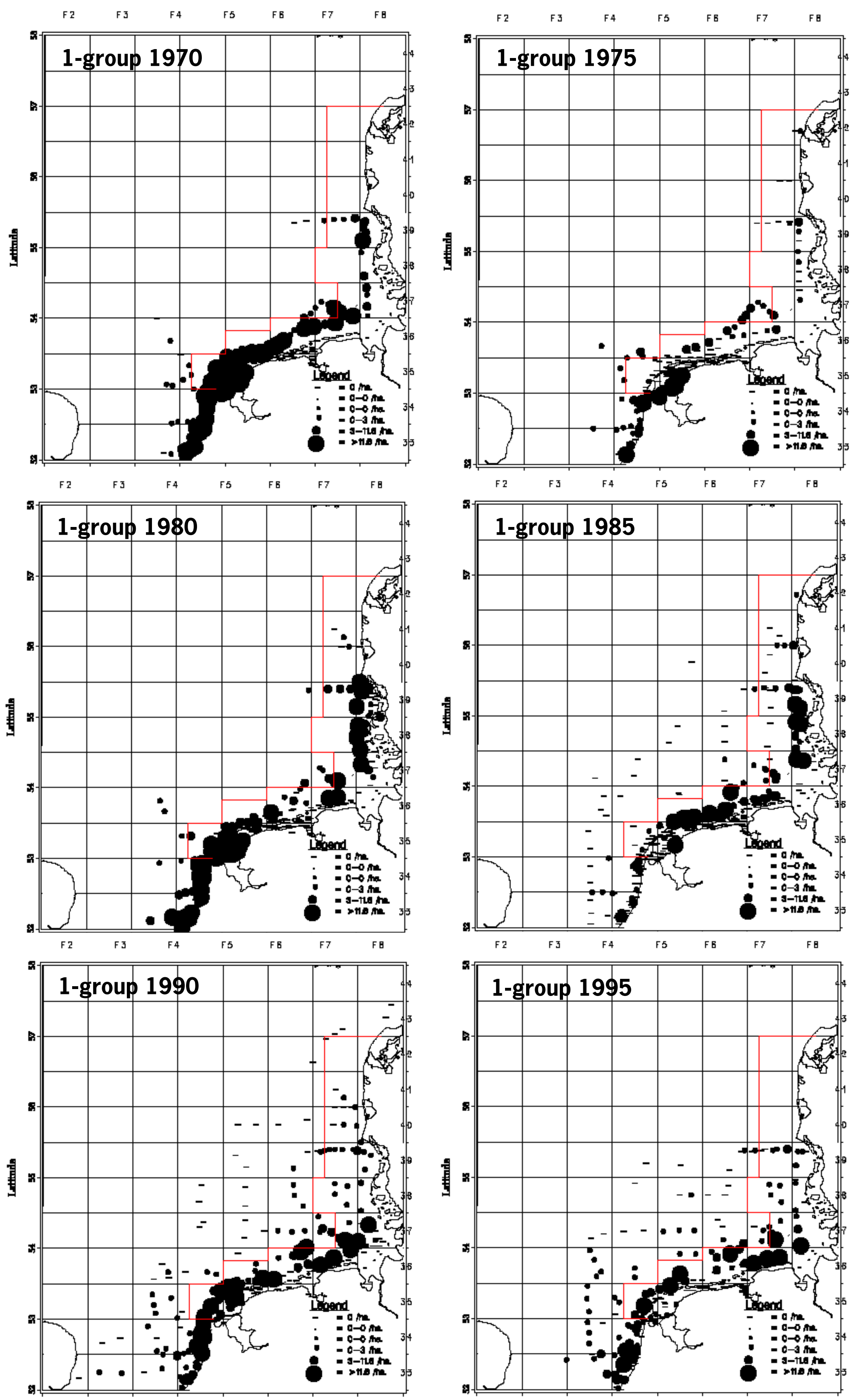


Figure VI.4. *Distribution of the catch (number per ha) in the period 1970-1995 of 1-group Sole.*

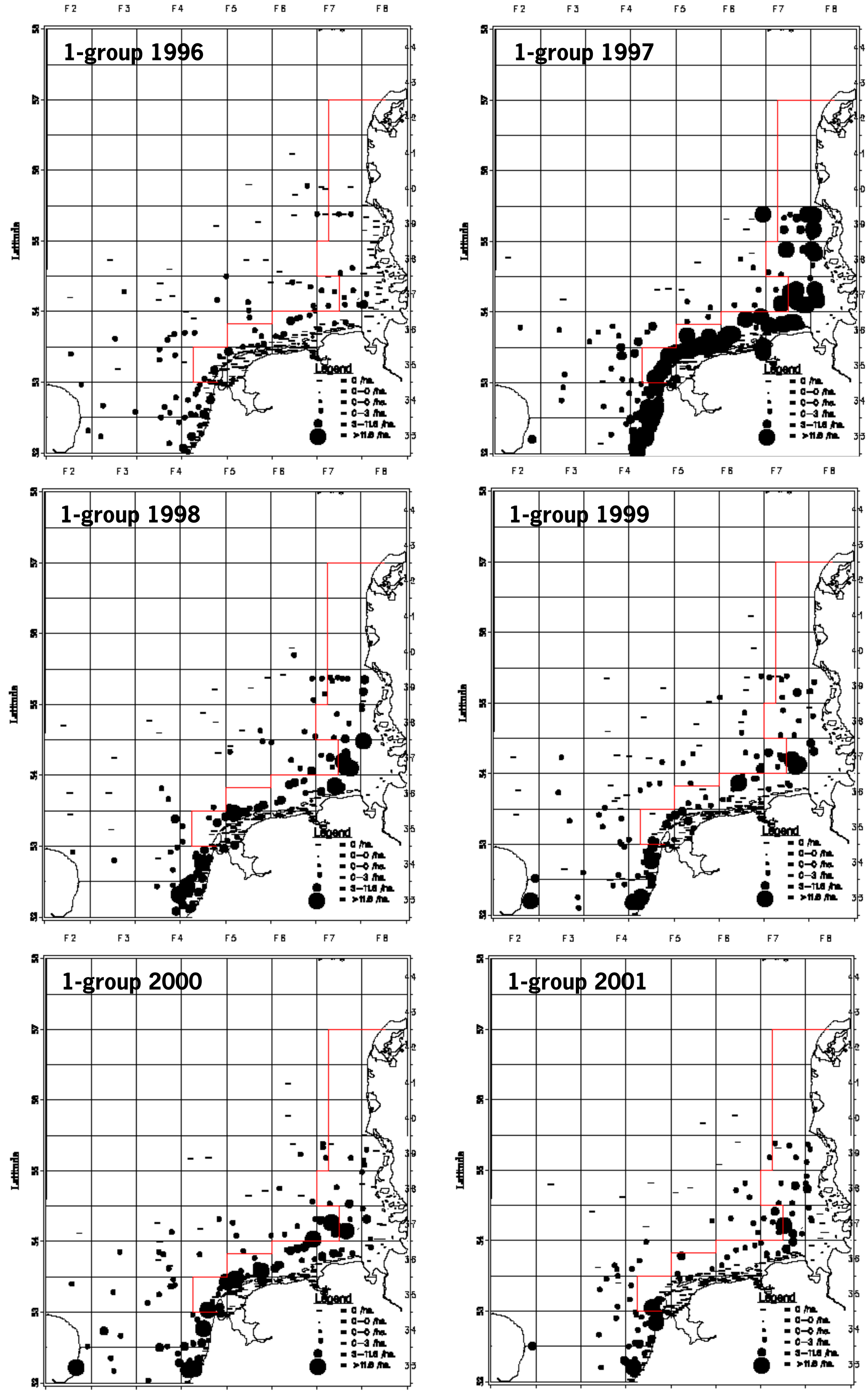


Figure VI.5. *Distribution of the catch (number per ha), in the period 1996-2001 of 1-group Sole.*

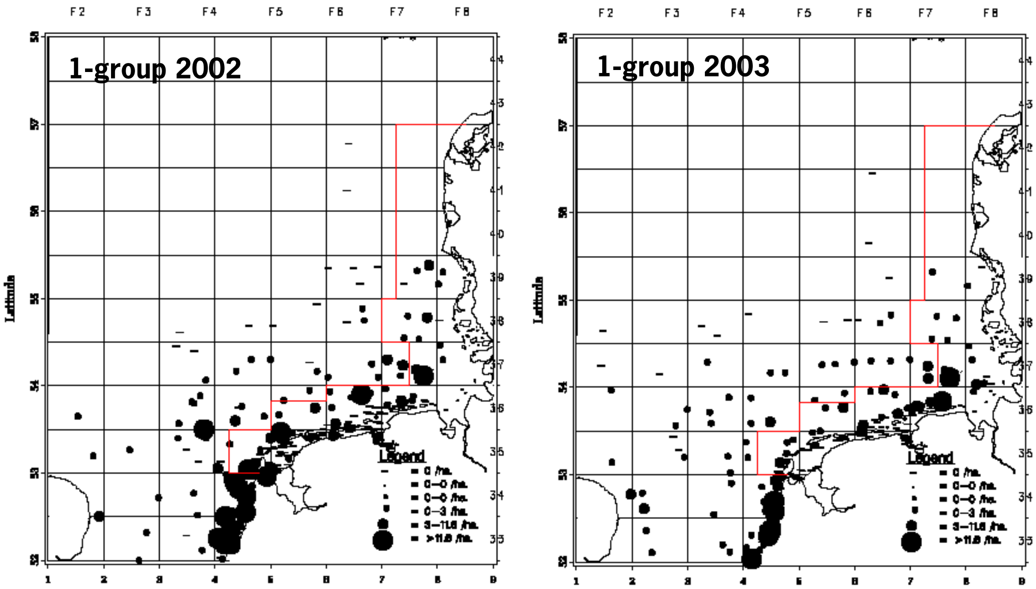


Figure VI.6. *Distribution of the catch (number per ha), in the period 2002-2003 of 1-group Sole.*

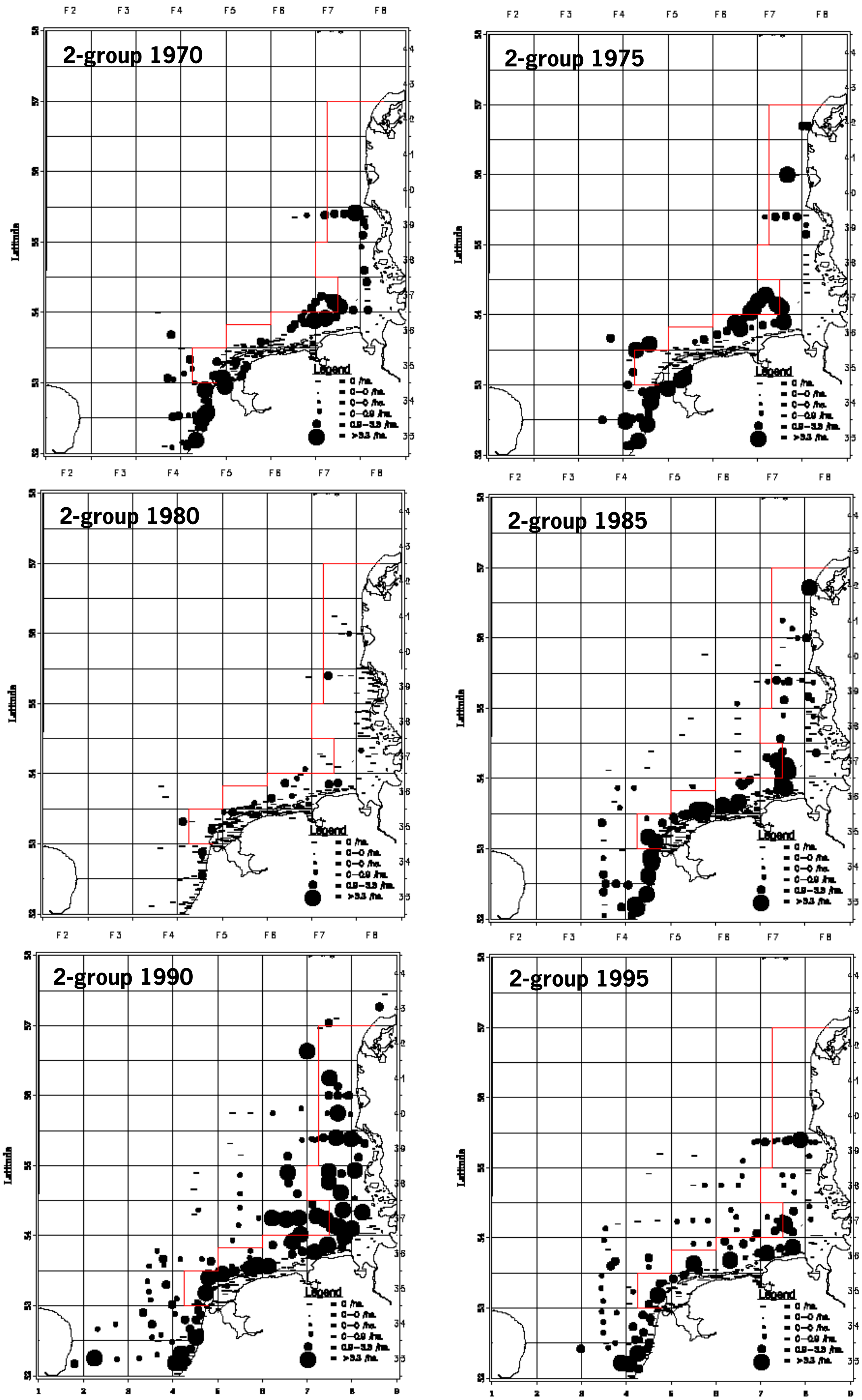


Figure VI.7. *Distribution of the catch (number per ha) in the period 1970-1995 of 2-group Sole.*

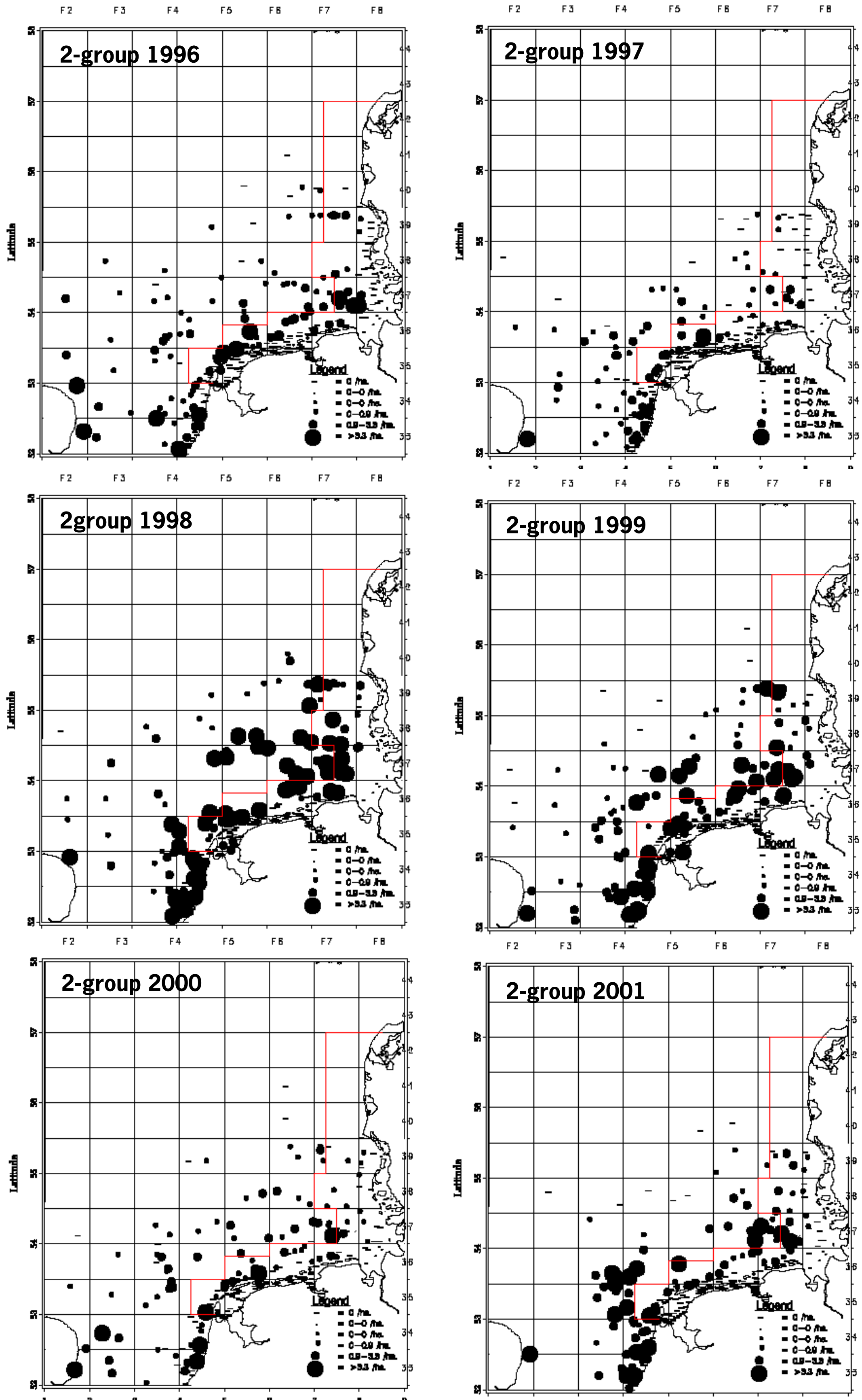


Figure VI.8. *Distribution of the catch (number per ha) in the period 1996-2001 of 2-group Sole.*

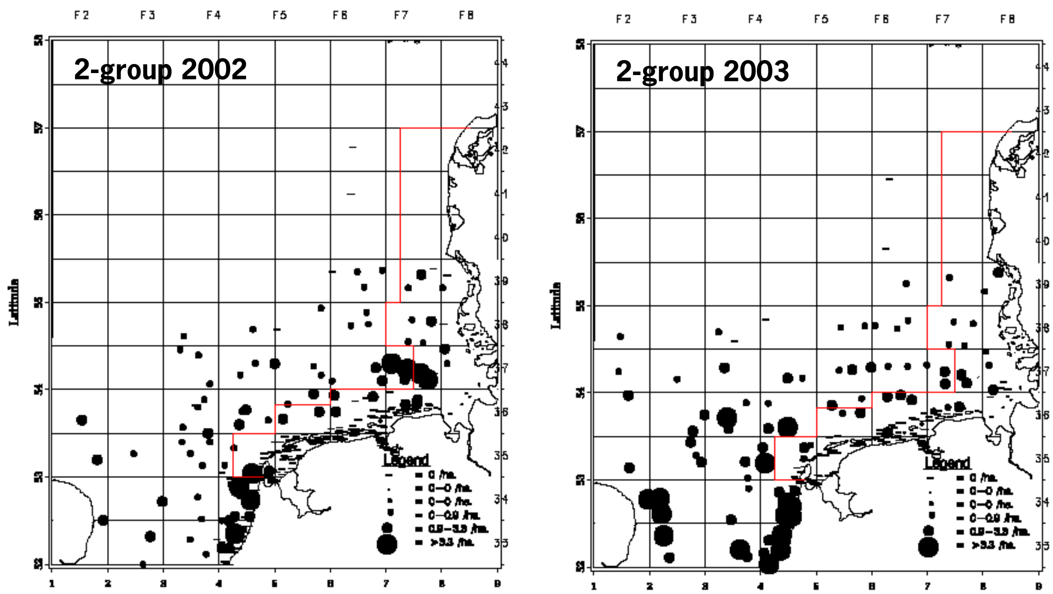


Figure VI.9. *Distribution of the catch (number per ha) in the period 2002-2003 of 2-group Sole.*

Annex VII. Maps with the presence-absence of Plaice

Introduction to the maps
The maps in this Annex present the presence or absence of Plaice in and around the Plaice Box per age group and year. This was estimated from three Dutch beam trawl surveys that were executed from 1970-2003. Not all surveys were executed in each year:

- SNS (6 m beam trawl: 1970-2002);
- DFS (3 and 6 m beam trawl: 1970-2003);
- BTS (8 m beam trawl: 1985-2003).

The BTS extends further offshore than both other surveys and therefore, from 1985 onwards, the presence-absence of Plaice is shown over a larger area.

For 1996-2003 presence-absence are shown for every year. Maps for <1996 are not shown as the major changes took place in the most recent years.

Presence-absence indicates whether Plaice of that age group was caught in a haul or not.

There are two classes of presence absence (presented in the legend of each map):

1. No Plaice caught (absent);
2. Plaice of that age group was caught (present).

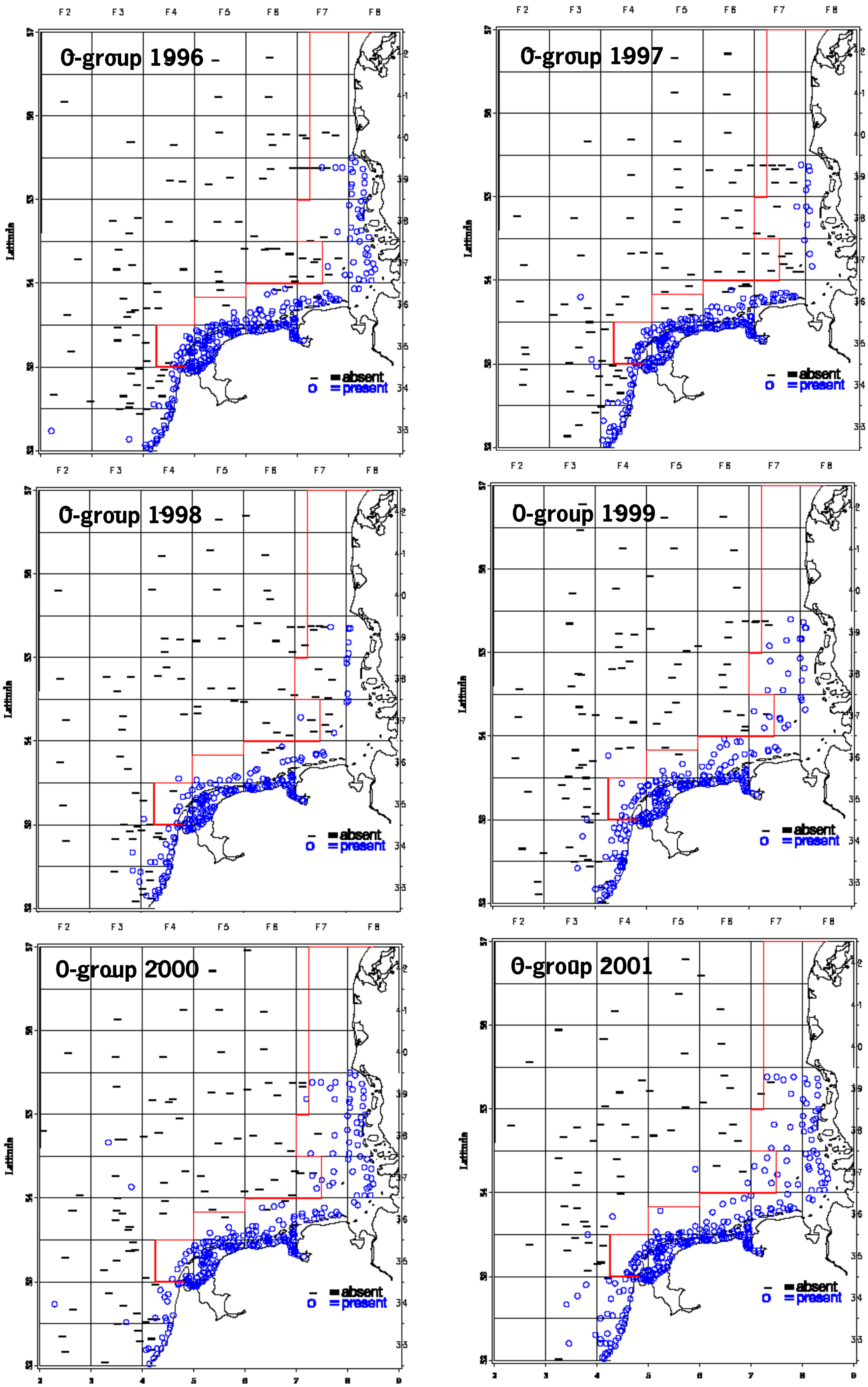
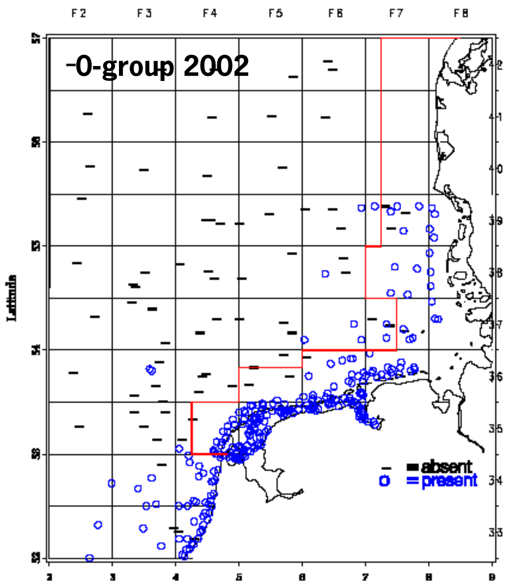


Figure XII.1. *Presence-absence of 0-group Plaice from 1996-2001.*



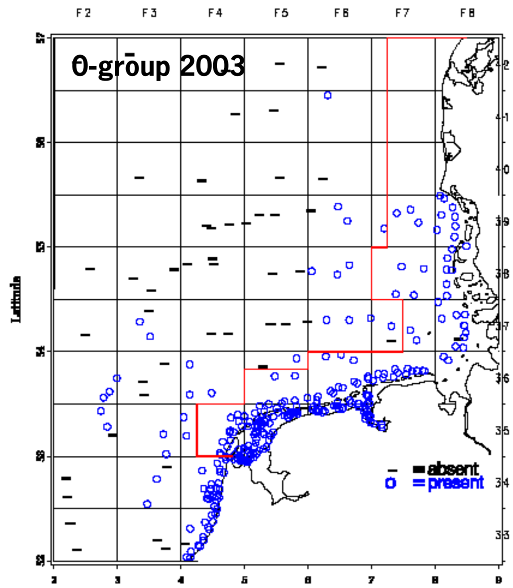


Figure XII.2. *Presence-absence of 0-group Plaice from 2002-2003.*

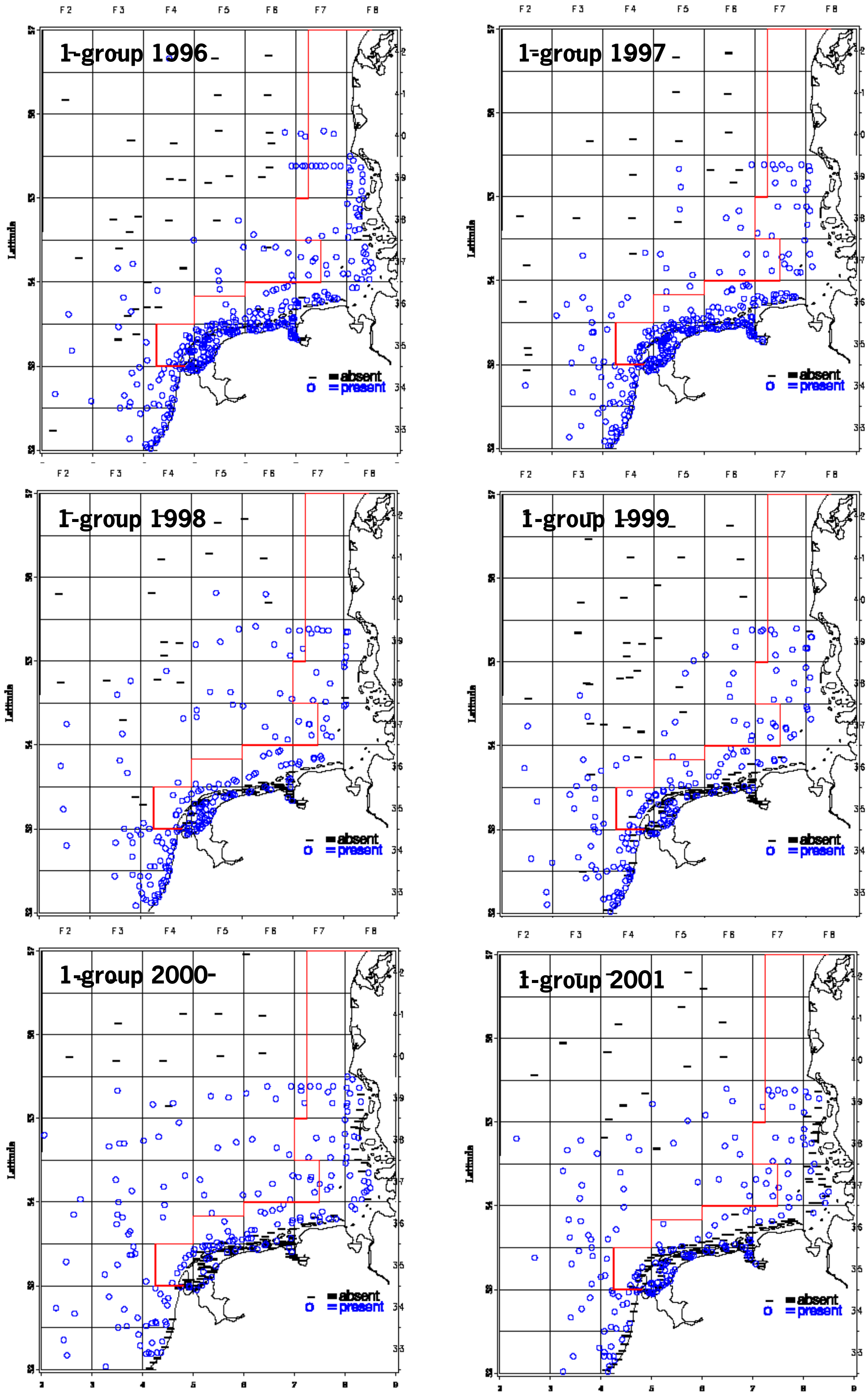


Figure XII.3. *Presence-absence of 1-group Plaice from 1996-2001.*

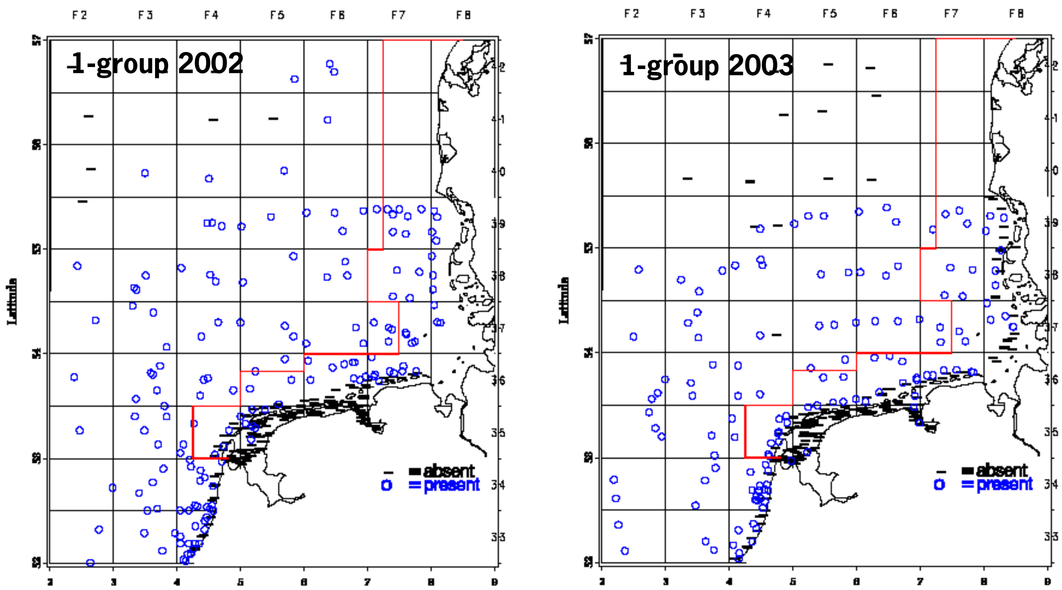


Figure XII.4. *Presence-absence of 1-group Plaice from 2002-2003.*

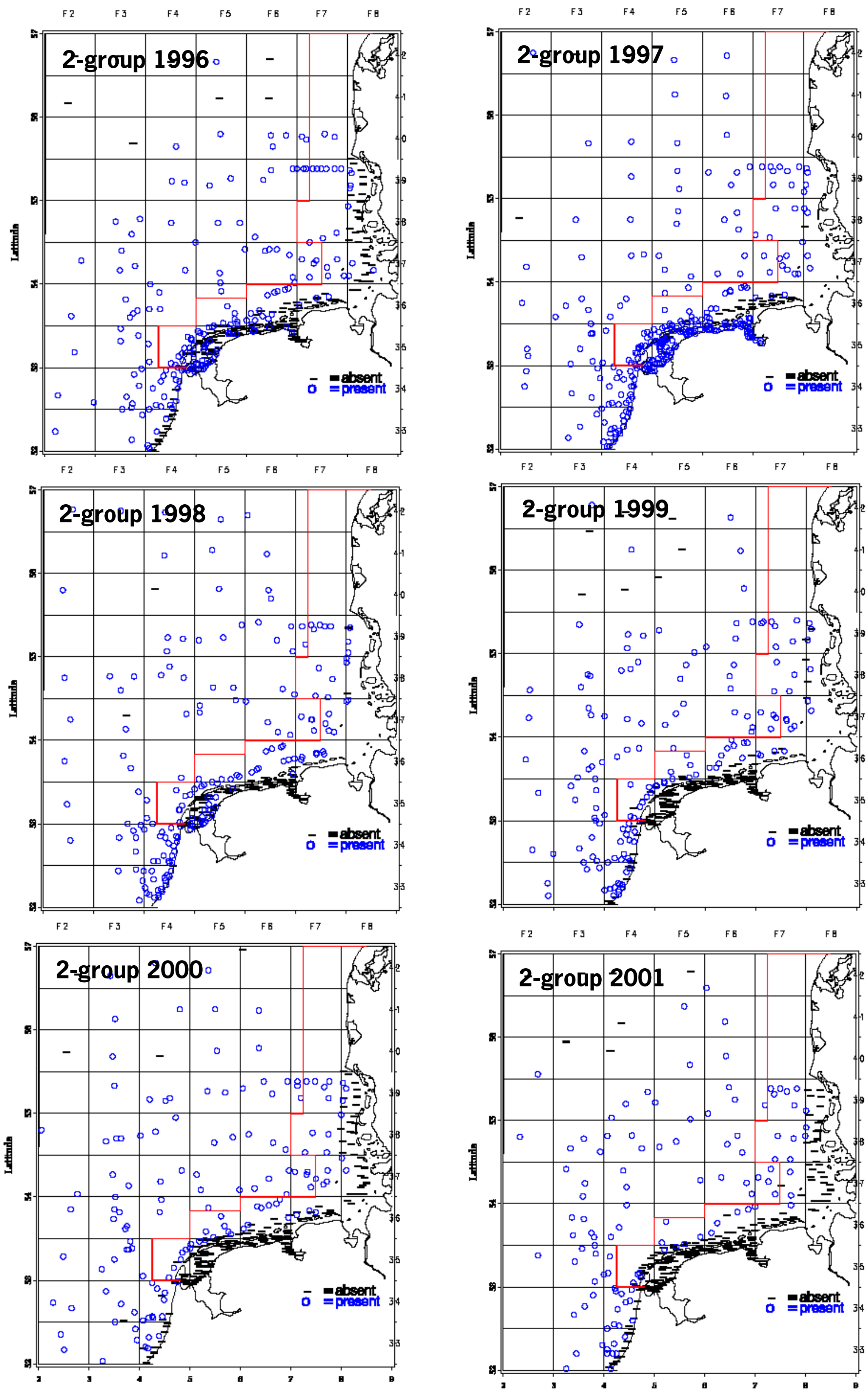


Figure XII.5. *Presence-absence of 2-group Plaice from 1996-2001.*

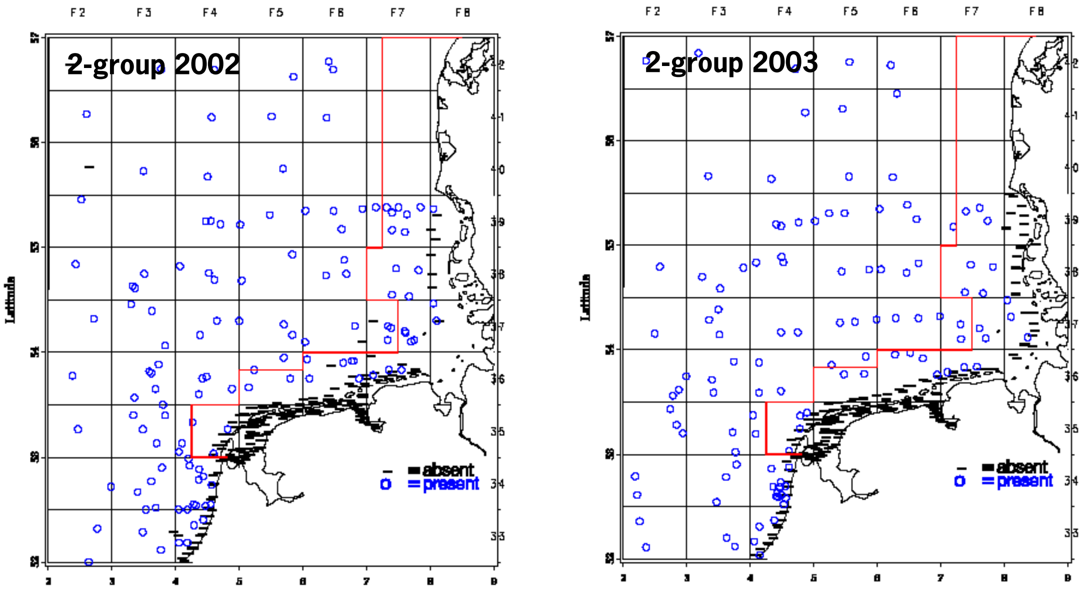


Figure XII.6. *Presence-absence of 2-group Plaice from 2002-2003.*

Annex VIII. Statistical analysis of the change in spatial distribution of Plaice

Before carrying out the actual analyses, the distribution of the data was investigated. Catch of Plaice, rescaled to numbers per 30 minutes haul in the three surveys operating in and out the Plaice Box, varied from 0 to more than 50 000 with intermediate values well represented and abundant hauls containing 0 or few Plaices. Data are analysed per age group: age 0, age 1, age 2 and age 3 plus. Numbers per haul were classified into age-specific classes using a class width of 50 for age 0, 20 for age 1, 10 for age 2 and 5 for age 3 plus.

The two parameters were chosen to quantify the effects of predictor variables:(i) the probability to catch 0 Plaice in a haul (P1) and (ii) the median of the numbers per haul (in classes). Predictor variables used in this study are:

Area	Plaice Box, Outside the Plaice Box and Wadden Sea
Year	1970-2003
Depth	0 – 5 m, 5 – 10m, 10 – 15m, 15 – 20m, 20 – 25m 25 – 30m, 30 – 50m and > 50m
Area Closure	area open (<1995), closed (>1995)

Table VIII.I. Results of logistic regressions analysing the probability to catch at least 1 Plaice for the different age groups and areas. Significant variables are printed in italics.

	OUTSIDE PLAICE BOX					INSIDE PLAICE BOX					WADDEN SEA				
	Df	deviance	% deviance explained	F	P(F)	Df	deviance	% deviance explained	F	P(F)	Df	deviance	% deviance explained	F	P(F)
age0															
Year	1	164	2.9	141	*0.0000*	1	299	8.6	308	*0.0000*	1	19	3.2	119	*0.0000*
Year^2	1	29	0.5	25	*0.0000*	1	9	0.2	9	*0.0028*	1	0	0.0	0	0.9221
Depth	6	1636	29.1	338	*0.0000*	5	1156	33.3	375	*0.0000*	3	18	3.0	38	*0.0000*
Closure	1	2	0.0	2	0.1573	1	9	0.3	15	*0.0001*	1	15	2.5	98	*0.0000*
Year*Depth	6	24	0.4	5	*0.0000*	5	31	0.9	10	*0.0000*	3	4	0.6	8	*0.0000*
			33.0					43.3					9.4		
age1															
Year	1	2	0.0	2	0.1400	1	236	10.5	386	*0.0000*	1	730	17.7	760	*0.0000*
Year^2	1	85	1.6	78	*0.0000*	1	95	4.3	164	*0.0000*	1	352	8.5	409	*0.0000*
Depth	6	90	1.7	14	*0.0000*	5	68	3.0	24	*0.0000*	3	3	0.1	1	0.2559
Closure	1	10	0.2	9	*0.0021*	1	6	0.3	11	*0.0010*	1	95	2.3	114	*0.0000*
Year*Depth	6	162	3.1	26	*0.0000*	5	56	2.5	21	*0.0000*	3	4	0.1	2	0.2067
			6.7					20.6					28.6		
age2															
Year	1	160	2.5	122	*0.0000*	1	535	12.5	466	*0.0000*	1	522	12.0	482	*0.0000*
Year^2	1	2	0.0	2	0.1739	1	11	0.3	9	*0.0021*	1	26	0.6	24	*0.0000*
Depth	6	809	12.8	119	*0.0000*	5	751	17.5	163	*0.0000*	3	18	0.4	6	*0.0008*
Closure	1	12	0.2	10	*0.0015*	1	13	0.3	15	*0.0001*	1	121	2.8	116	*0.0000*
Year*Depth	6	23	0.4	3	*0.0025*	5	32	0.7	7	*0.0000*	3	2	0.0	1	0.5840
			15.9					31.2					15.8		
age3															
Year	1	118	2.0	96	*0.0000*	1	196	4.7	161	*0.0000*	1	86	5.0	189	*0.0000*
Year^2	1	2	0.0	2	0.1637	1	0	0.0	0	0.5247	1	0	0.0	0	0.7859
Depth	6	932	15.7	150	*0.0000*	5	740	17.7	149	*0.0000*	3	5	0.3	4	*0.0112*
Closure	1	1	0.0	1	0.3705	1	38	0.9	38	*0.0000*	1	27	1.6	61	*0.0000*
Year*Depth	6	19	0.3	3	*0.0048*	5	53	1.3	11	*0.0000*	3	4	0.2	3	*0.0300*
			18.1					24.6					7.2		

Table VIII.2 Results of log-linear regressions analysing the mean number of Plaice per haul for the different age groups and areas. Significant variables are printed in italics.

	OUTSIDE PLAICE BOX					INSIDE PLAICE BOX					WADDEN SEA				
age0	Df	Deviance	% deviance explained	F	P(F)	Df	Deviance	% deviance explained	F	P(F)	Df	Deviance	% deviance explained	F	P(F)
Year	1	1853	0.2	7	*0.0078*	1	29295	1.4	46	*0.0000*	1	10912	0.5	16	*0.0001*
Year^2	1	7410	0.6	29	*0.0000*	1	24804	1.2	40	*0.0000*	1	185472	7.8	304	*0.0000*
Depth	6	133409	10.9	96	*0.0000*	5	242841	11.6	88	*0.0000*	3	64920	2.7	36	*0.0000*
Closure	1	6249	0.5	27	*0.0000*	1	662	0.0	1	0.2730	1	19878	0.8	34	*0.0000*
Year*Depth	6	35302	2.9	26	*0.0000*	5	148895	7.1	59	*0.0000*	3	11118	0.5	6	*0.0003*
			15.0					21.3					12.4		
age1															
Year	1	3006	0.5	25	*0.0000*	1	6887	0.4	14	*0.0002*	1	21692	3.0	108	*0.0000*
Year^2	1	20705	3.6	175	*0.0000*	1	47873	3.0	101	*0.0000*	1	100547	13.7	585	*0.0000*
Depth	6	4803	0.8	7	*0.0000*	5	73623	4.6	32	*0.0000*	3	4532	0.6	9	*0.0000*
Closure	1	6437	1.1	55	*0.0000*	1	8966	0.6	20	*0.0000*	1	32825	4.5	203	*0.0000*
Year*Depth	6	30873	5.3	47	*0.0000*	5	74723	4.6	35	*0.0000*	3	426	0.1	1	0.4513
			11.4					13.2					21.9		
age2															
Year	1	203	0.1	4	*0.0494*	1	12787	3.0	100	*0.0000*	1	5907	7.5	286	*0.0000*
Year^2	1	7293	2.9	143	*0.0000*	1	473	0.1	4	0.0539	1	5422	6.9	284	*0.0000*
Depth	6	25748	10.4	94	*0.0000*	5	63799	14.8	118	*0.0000*	3	192	0.2	3	*0.0179*
Closure	1	569	0.2	12	*0.0004*	1	471	0.1	4	*0.0368*	1	1919	2.4	104	*0.0000*
Year*Depth	6	3550	1.4	13	*0.0000*	5	20233	4.7	40	*0.0000*	3	50	0.1	1	0.4373
			15.1					22.7					17.1		
age3															
Year	1	1733	1.1	50	*0.0000*	1	1881	0.9	31	*0.0000*	1	361	4.9	184	*0.0000*
Year^2	1	4516	2.8	135	*0.0000*	1	640	0.3	11	*0.0012*	1	43	0.6	22	*0.0000*
Depth	6	36423	22.3	236	*0.0000*	5	52778	26.2	235	*0.0000*	3	125	1.7	22	*0.0000*
Closure	1	73	0.0	3	0.0908	1	1123	0.6	25	*0.0000*	1	35	0.5	19	*0.0000*
Year*Depth	6	913	0.6	6	*0.0000*	5	5746	2.8	27	*0.0000*	3	14	0.2	2	0.0596
			26.8					30.8					7.9		

Annex IX. Shift in the distribution of juvenile Plaice in relation to distance from shore

IX.1 Introduction

To test the hypothesis that there has been a shift in the spatial distribution of Plaice, trends in the occurrence of Plaice at different depths were analysed using Dutch survey data. The relationship between numbers of Plaice of different age groups and the distance from the coast was assessed employing data from the Sole Net Survey (SNS) that has been executed annually in the south-eastern North Sea since 1970.

IX.2 Material and methods

The SNS survey consists of more or less fixed stations on transects which run parallel or perpendicular to the coast in Dutch and Danish waters. Two transects were used that ran perpendicular to the coast (601, and transects 606 and 660 combined into 666, Figure X.1) to study the relationship between numbers and distance from the coast. The distance from the coast was determined by converting the differences in degrees between the longitude of the sampling stations and the longitude of the coast into kilometres. The longitude of the coast for transect 666 was specified as 4.8°E and for transect 601 as 8.35°E.

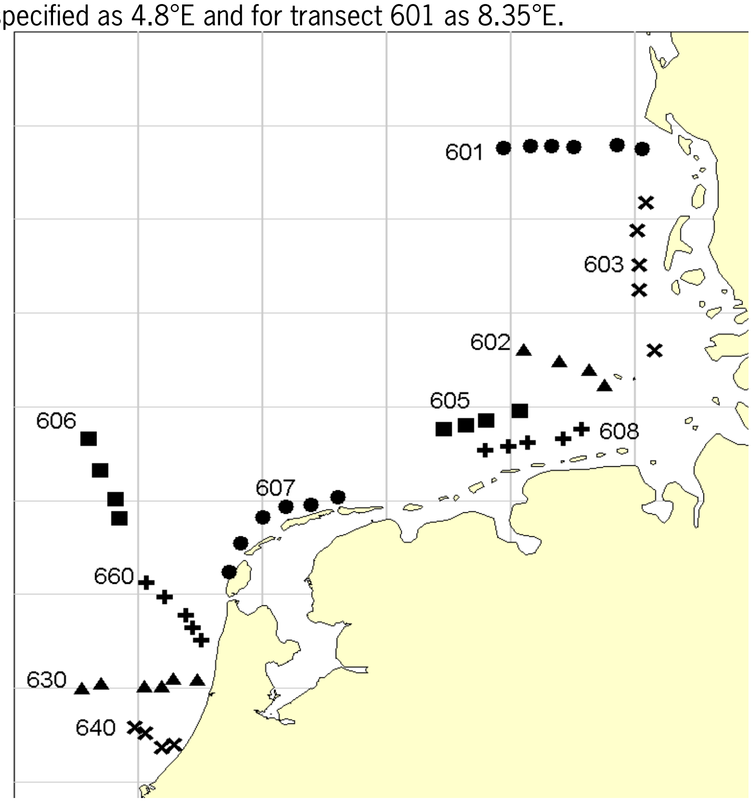


Figure IX.1. *Map of the transects of the SNS survey. In this analysis, transects 601 and 666 (combination of 606 and 660) were used.*

A general linear model of log-transformed catch rates (numbers $hour^{-1}$) was used for the statistical analysis of the variation in catch rates. The mean catch rate per year, region and depth class was estimated, for each age group and transect separately, using the following model:

$$\log(C_{R,A}) = A + D + YC + D*A + D*Y + D*Y*A\,, \qquad (1)$$

in which *C*= catch rate (numbers hour^{-1}), *R*= survey, *A*= age group, *D*= distance from coast (km), *YC*= year-class and *Y*= year, where *R*, *A* and *YC* are factors and *D* and *Y* are variates. *A* and *YC* correct for the difference in catch rate induced by age groups and year-classes. *D* represents the slope of the decline in numbers with distance. This slope is different for each age group which is accounted for by the parameter *D*A*. For age 1 and age 2 Plaice the parameter will be negative, as the numbers will decrease with increasing distance from the coast. The interaction term *D*Y* examines whether the slope of the numbers with distance has changed in time (*D*Y*). If this parameter is significant, the slope has changed over the years and it may be concluded that the distribution of Plaice over depth classes has also changed over years. A type 1 analysis was used to test whether the parameters included in the model significantly contribute to explain variation in catch rates.

IX.3 Results

All parameters included in the model contributed significantly to explaining variance in the catch rates (Table X.1). The total model explained 63% of the variance in catch rates for transect 601 and 60% for transect 666. The catch rates varied among different age groups and different year-classes.

The parameter *D*A* explained 20 and 10% for transect 601 and 666 respectively. The change of numbers over the distance varied between the different age groups. Table X.2 gives the estimates for the parameters, which describe the change in numbers over distance. For both transects the slope of the numbers with distance is steepest for age group 1. The term *D*Y* contributed significantly to the model, but explained only a small proportion (1.2) of the variance. The parameter estimate is positive, showing that the slope of the relationship with distance has become less steep. This effect is strongest for age group 1 and is most obvious in transect 601 (Table X.2, Figure 6.3, 6.4).

The slopes for age groups 0, 1 and 2 have become less steep in time (Figure 6.4). This effect was strongest for age group 1 and was most obvious in transect 601. In transect 666 the effect was also visible, though less clear. The change of slopes seems to have started around 1994

IX.4 Conclusion

In both transects a significant change in distribution pattern of juvenile Plaice was observed. The change was most obvious for age 1 Plaice 1. Plaice of this age group extended their distribution to locations further away from the coast because the relationship between numbers of Plaice and distance from the coast has become less negative. This extension was most obvious in transect 601. In transect 601 a similar effect was demonstrated for age group 0 and 2. The change in the spatial distribution of young Plaice seems to have started around 1994.

Table IX.1. *Statistical evaluation of the influence of age (*A*), distance from the coast (*D*), year-class (*YC*) and the interactions* D*A, D*Y *and* D*Y*A *on the catch rates of Plaice in transects 601 and 666.*

Area	*Source*	*SS*	*%*	*df*	*MS*	*F*	*p*
601	*A*	1861.1	23.5	4	465.3	202.09	<.0001
	D	371.3	4.7	1	371.3	161.27	<.0001
	YC	907.5	11.5	36	25.2	10.95	<.0001
	*D*A*	1580.6	20.0	4	395.1	171.63	<.0001
	*D*Y*	98.4	1.2	1	98.4	42.72	<.0001
	*D*Y*A*	182.2	2.3	4	45.5	19.78	<.0001
	Explained	5001.0	63.2	50	100.0		
	Unexplained	2912.4	36.8	1265	2.3		
	Total	**7913.4**	**100.0**				

Area	*Source*	*SS*	*%*	*df*	*MS*	*F*	*p*
666	*A*	2053.3	33.5	4	513.3	388.98	<.0001
	D	290.2	4.7	1	290.2	219.93	<.0001
	YC	568.1	9.3	36	15.8	11.96	<.0001
	*D*A*	648.3	10.6	4	162.1	122.81	<.0001
	*D*Y*	47.3	0.8	1	47.3	35.82	<.0001
	*D*Y*A*	86.0	1.4	4	21.5	16.30	<.0001
	Explained	3693.3	60.3	50	73.9		
	Unexplained	2428.2	39.7	1840	1.3		
	Total	**6121.5**	**100.0**				

Table IX.2. *Parameter estimates from the type I analysis per transect.*

		Estimate	**p**	**Estimate**	**p**
Parameter	*Age Group*	*601*		*666*	
D		-1.47252	0.0019	-1.32404	0.0001
*D*A*	0	-0.95936	0.0556	0.97048	0.0082
*D*A*	1	-3.25008	<0.0001	-1.74904	<0.0001
*D*A*	2	-0.45679	0.3452	-0.07762	0.8270
*D*A*	3	0.90725	0.0579	0.07423	0.8318
*D*A*	4	0		0	
*D*Y*		0.00075	0.0017	0.00067	0.0001
*D*Y*A*	0	0.00044	0.0814	-0.00051	0.0054
*D*Y*A*	1	0.00160	<0.0001	0.00086	<0.0001
*D*Y*A*	2	0.00022	0.3575	0.00003	0.8452
*D*Y*A*	3	-0.00045	0.0605	-0.00004	0.8408
*D*Y*A*	4	0		0	

Annex X. Changes in growth rates of Plaice and Sole

X.1 Statistical analyses

Length at age of Plaice and Sole were estimated from available research vessel surveys and market sampling data:

- DFS 0- and 1-group;
- SNS 1-, 2-, 3- and 4-group;
- BTS-ISIS 1-, 2-, 3-, 4-group;
- BTS-Tridens 2-, 3-, 4-group;
- Q1 market sampling data (age group 4 for Plaice and age group 3 and 4 for Sole; males and females separately);
- Back-calculated individual growth rates of female Plaice.

In order to extract a signal of the variation in growth of the age groups up to age 4, the length (L) at age (A) data were analysed in a generalized linear model:

L = A + M + A*M + YCLS,

using a log link function where A =age (variate), M = method (factor) and YCLS= birth year (factor).

X.2 Results analysis of variance

Table X.1. *Analysis of covariance of the length at age 0 – 4 in relation to age (A), year class (YCLS) and method (S: surveys DFS, SNS, BTSi, BTSt; back calculations and market sampling). Data range analysed: 1958-2003.*

	Plaice					Sole				
	SS	df	MS	F	P	SS	df	MS	F	P
A	1876.87	4	469.22	7731.30	<0.001	620.19	4	155.05	2679.51	<0.001
S	26.95	6	4.49	74.01	<0.001	51.89	5	10.38	179.36	<0.001
A*S	17.14	12	1.43	23.54	<0.001	4.21	10	0.42	7.28	<0.001
YCLS	34.30	50	0.69	11.30	<0.001	19.17	50	0.38	6.63	<0.001
Error	35.87	591	0.0607			27.83	481	0.0579		
Total	1991.14	663				723.29	550			

Table X.2. *Results of the analysis of covariance of length at age in relation to age (A), method (S: surveys DFS, SNS, BTSi, BTSt; back-calculation; market sampling), crowding (C), eutrophication (DIP) and seabed disturbance (TBB). The contribution of the covariables was tested against the full model (type3). A substantial part of the explained variance (colinearity) could not be ascribed to a single covariate.*

	Plaice					Sole				
	SS	df	MS	F	P	SS	df	MS	F	P
A+S+A*S	1695.53	22	77.07	1036.56	<0.001	494.45	19	26.02	370.32	<0.001
C	9.30	1	9.30	125.14	<0.001	0.74	1	0.74	10.49	<0.01
DIP	14.94	1	14.94	200.97	<0.001	3.46	1	3.46	49.18	<0.001
TBB	0.26	1	0.26	3.47	0.063	0.02	1	0.02	0.22	0.636
Colinearity	30.74					45.01				
Error	41.12	553	0.074			31.06	442	0.07		