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Changes in the demersal fish assemblage in the south-eastern North Sea following the establishment of a protected area ("plaice box")

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This paper studies the effect of the reduction in the trawling effort of large beam trawlers (>300 hp) in the coastal waters of the south-eastern North Sea following the establishment in 1989 of a protected area, the "plaice box", using data from annual beam trawl surveys carried out since 1985. Two different aspects of the demersal fish assemblage were analysed: (1) the size distribution using multiple analysis of variance; and (2) the species composition using multivariate techniques such as principal component analysis, multidimensional scaling and multiple analysis of variance.

It is shown that the overall size structure of the commercially exploited fish species was affected by the change in trawling effort whereas that of the non-target species was not. In particular, the abundance of commercial fish within the marketable size-range of 25–40 cm increased when fishing effort was reduced.

Multiple analysis of variance showed that, in contrast to the size structure of the fish assemblage, the species composition was not significantly affected by the change in fishing effort. However principal component analysis does indicate that after the closure of the "plaice box" a considerable proportion of the variation in the abundance of the large fish ($\geq$25 cm) over the years can be explained by a higher abundance in the "box" area than in the reference area of most fish species, including the two main commercial species plaice and sole. Other trends that were observed during the study period both within and outside the closed area were: (1) a decrease of the relative abundance of plaice and (2) a general increase of species richness due to the influx of southerly species.

Key words: species composition, size structure, reduction trawling effort.

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Introduction

In 1989, legislation was introduced (Council regulation (EEC) No. 4193/88), establishing a closed area in the North Sea: the "plaice box" (Fig. 1). It was decided that the box should be active from 1 April to 30 September. When active the following regulations applied to the area:

(1) No fishing inside the "box" was allowed within 12 miles of the coast by vessels exceeding 8 m overall using beam and otter trawls (Council regulation (EEC) No. 3094/86).
(2) No fishing inside the "box" was allowed by beam trawlers and otter trawlers exceeding 300 hp (221 kW).
(3) Fishing by other vessels was permitted provided that they were:
   - on an authorized list and then engine power did not exceed 300 hp, even if fishing with beam trawls
   - not on a list but fishing for shrimp
   - not on a list but fishing with other trawls using 100 mm mesh, even if engine power exceeds 300 hp, provided catches of plaice and sole which exceed 5% by weight of the total catch on board were discarded immediately.

The "box" was intended to cover the major distribution area of juveniles of the main commercial demersal fish species such as plaice, sole and, to a lesser extent, cod. However, for specific age-groups of other,

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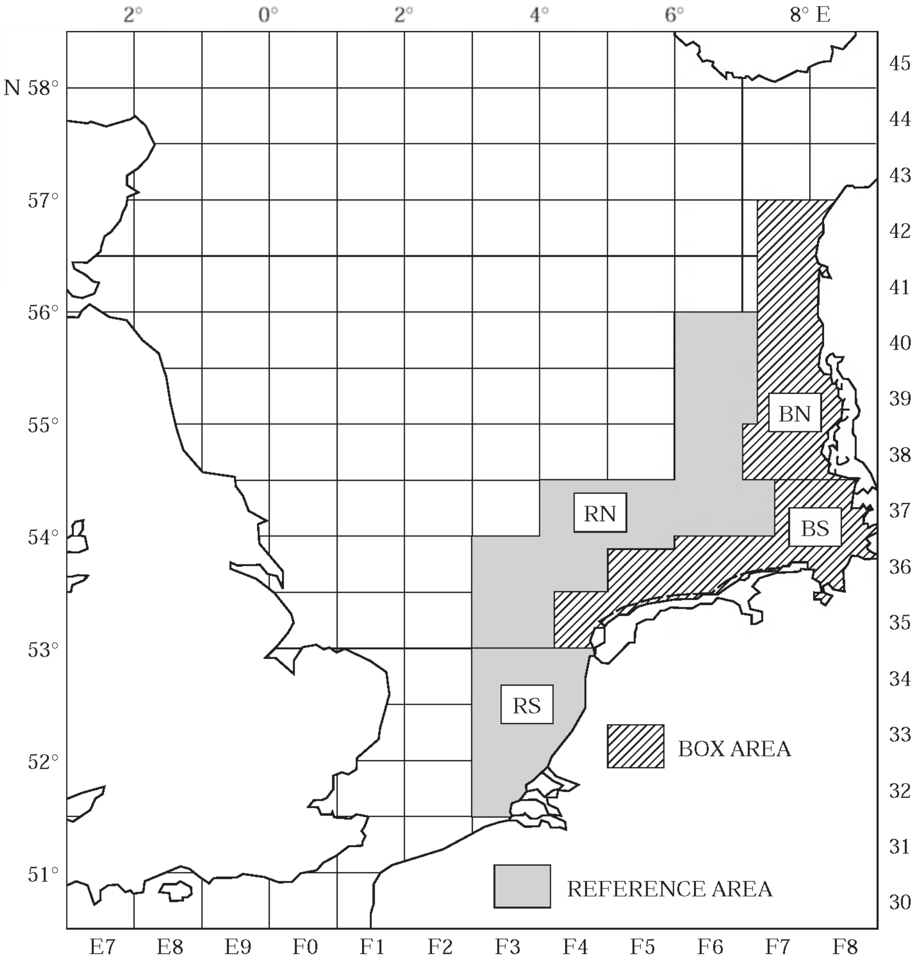

Figure 1. Position of the plaice box (B) and reference area (R) with their respective sub-areas.

non-target, species occurring in the "box" a reduction of fishing mortality was expected as well. In contrast an increase in mortality of age groups outside the "box" was expected as a result of the displacement of the fleets to them.

Greenstreet and Hall (1996) showed the subtle changes in community parameters in the demersal fish catches in the northern North Sea that were likely to be related to changes in fishing effort. Rijnsdorp *et al.* (1996) compared size spectra and community parameters of research vessel bottom trawl catches in the 1980s with those of the period 1906–1909 and showed that at present there are relatively fewer large fish and that species diversity has decreased. Rice and Gislason (1996) presented evidence of changes in the size spectrum and species diversity spectrum since 1970 that were related to an overall increase in fishing effort.

The null hypothesis addressed in this paper is that (1) the size distribution, (2) the species composition and (3) total number of species in the beam trawl catches are similar before and after establishment of the "box" as well as inside and outside of the closed area. The alternative hypothesis expects an increase in the "box" after closure of the area of the relative abundance of (1) the larger size groups and (2) commercial species which are retained in the commercial gears and (3) an increase in species richness.

Material and methods

To study the effect of beam trawl effort on the fish community two areas (Fig. 1) and two periods were distinguished. Period 1 (1985–1988) was the period before the closure of the "plaice box", period 2 the period after the closure (1989–1994). During the second period fishing effort of large beam trawlers (>300 hp) inside the area had decreased whereas fishing effort in the reference area had increased. From 1985 onwards beam trawl surveys were carried out by the Netherlands

Table 1. Number of hauls per (sub)area per year.

Year	Box BN	Box BS	Reference RN	Reference RS
1985	12	5	14	8
1986	8	10	13	8
1987	9	9	17	13
1988	9	10	17	14
1989	9	11	17	16
1990	17	14	23	16
1991	17	12	24	16
1992	13	15	18	15
1993	17	13	23	16
1994	14	16	19	16

in these areas each year during the third quarter. For these surveys an 8 m beam trawl was used with eight tickler chains and 40 mm stretched mesh. Haul-duration was 30 minutes and towing speed was 4 knots. The number of hauls differed between years and areas (Table 1). The data from these surveys were used to study possible effects of a redution of effort on the dermersal fish assemblage caused by the introduction of the "box". In the present study three diffeent aspects of the demersal fish assemblage were analysed: (1) size spectrum; (2) species composition; and (3) species richness.

Size spectrum

The size-structure of the demersal fish assemblage was characterized by distinguishing eight size-classes. The effect of area or period on the number of fish in one or more of the eight size-classes was analysed using "analysis of variance" (ANOVA) and "multiple analysis of variance" (MANOVA). Changes in depth distribution between the areas were accounted for by selecting only hauls conducted at positions where the depth was between 10 and 40 m as well as by including depth as a covariate in the ANOVA and MANOVA models. Since the effect of the introduction of a closed area was expected to occur primarily on the commercial species the fish assemblage was divided into commercial and non-target species (Table 2). A general linear model was used to analyse the effect of area and period on the number of commercial and non-target fish caught per haul and per size-class.

Table 2. Characterization of species with regard to commercial fishery.

Commercial species		Non-target species	
Dicentrarchus labrax	Bass	*Agonus cataphractus*	Hooknose
Gadus morhua	Cod	*Anguilla anguilla*	Eel
Glyptocephalus cynoglossus	Witch	*Arnoglossus laterna*	Scaldfish
Melanogrammus aeglefinus	Haddock	*Aspitrigla cuculus*	Red gurnard
Merlangius merlangus	Whiting	*Buglossidium luteum*	Solenette
Merluccius merluccius	Hake	*Callionymus* spp.	Dragonet
Microstomus kitt	Lemon sole	*Ciliata mustela*	Five-bearded rockling
Molva molva	Ling	*Coryphaenoides rupestris*	Roundnose grenadier
Mugilidae	Grey mullets	*Cyclopterus lumpus*	Lumpsucker
Mullus surmuletus	Red mullet	*Eutrigla gurnardus*	Grey gurnard
Pleuronectes platessa	Plaice	*Gaidropsurus vulgaris*	Three-bearded rockling
Scophthalmus maximus	Turbot	*Galeorhinus galeus*	Tope
Scophthalmus rhombus	Brill	*Gasterosteus aculeatus*	Three-spined stickleback
Solea solea	Sole	*Gobiidae*	Gobies
		Hippoglossoides platessoides	Long rough dab
		Limanda limanda	Dab
		Microchirus variegatus	Thickback sole
		Myoxocephalus scorpius	Bullrout
		Phrynorhombus norvegicus	Norwegian topknot
		Platichthys flesus	Flounder
		Raja brachyura	
		Raja clavata	Roker
		Rhinonemus cimbrius	Four-bearded rockling
		Scyliorhinus caniculus	Lesser-spotted dogfish
		Syngnathidae	Pipefishes
		Trachinus vipera	Lesser weever
		Trigla lucerna	Tub gurnard
		Trisopterus luscus	Bib
		Trisopterus minutus	Poor cod
		Zoarces viviparus	Eelpout

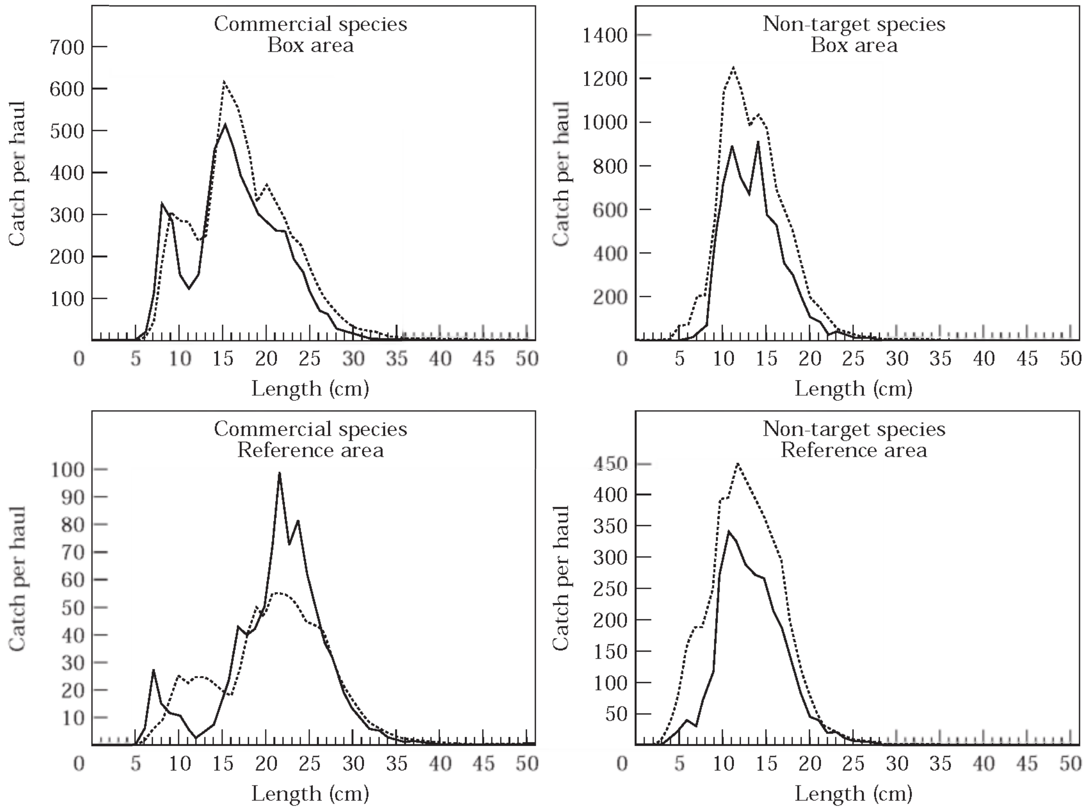

Figure 2. Length-frequency distributions of commercial and non-target species per area, per period. Period 1=1985–1988 (solid line), Period 2=1989–1994 (dashed line).

Species composition

In this study several approaches were used to determine a possible effect of fishing effort on the species composition. These approaches involved the use of multivariate techniques and the determination of species richness. For the multivariate techniques the fish community was divided into assemblages consisting of "small" (<25 cm) and "large" (≥25 cm) fish while species richness was determined for the entire assemblage. For the analyses involving multivariate techniques the 10 most abundant species in an assemblage were selected and together these made up more than 98% of the fish density in that assemblage.

Multivariate analyses provide statistical methods for study of joint relationships of variables in data that contain interrelations (James and McCulloch, 1990). One attribute of these methods is that they can reduce the patterns in those data to a smaller number of axes while preserving most of the information in the higher dimensionality data. In the present study the multivariate methods of analysis of variance (ANOVA) and multiple analysis of variance (MANOVA), non-metric multi-dimensional scaling (MDS) and principal component analysis (PCA) were applied. For the analyses using multivariate techniques the numbers caught were logarithmically transformed.

To explore differences in community structure between periods and areas as well as the interaction between them, ANOVA and MANOVA were used. Community structure can differ between goegraphically different areas depending on, for example, habitat (inshore vs. offshore) or latitude. Apart from the difference in fishing effort the box area and reference area also differed with respect to latitude as well as habitats included. Therefore the "box" and reference areas were each divided into two sub-areas allowing comparison of effects other than those caused solely by the difference in fishing effort. The sub-areas were chosen in such a manner that sampling effort was more or less evenly distributed between them and that effects of habitat or latitude could be constrasted without confounding effects of differences in fishing effort. The observed differences between the different sub-areas helped to put the differences between the box and reference area into perspective. Unfortunately the distribution of sampling effort did not allow a complete statistical design to determine the relative contributions of these effects

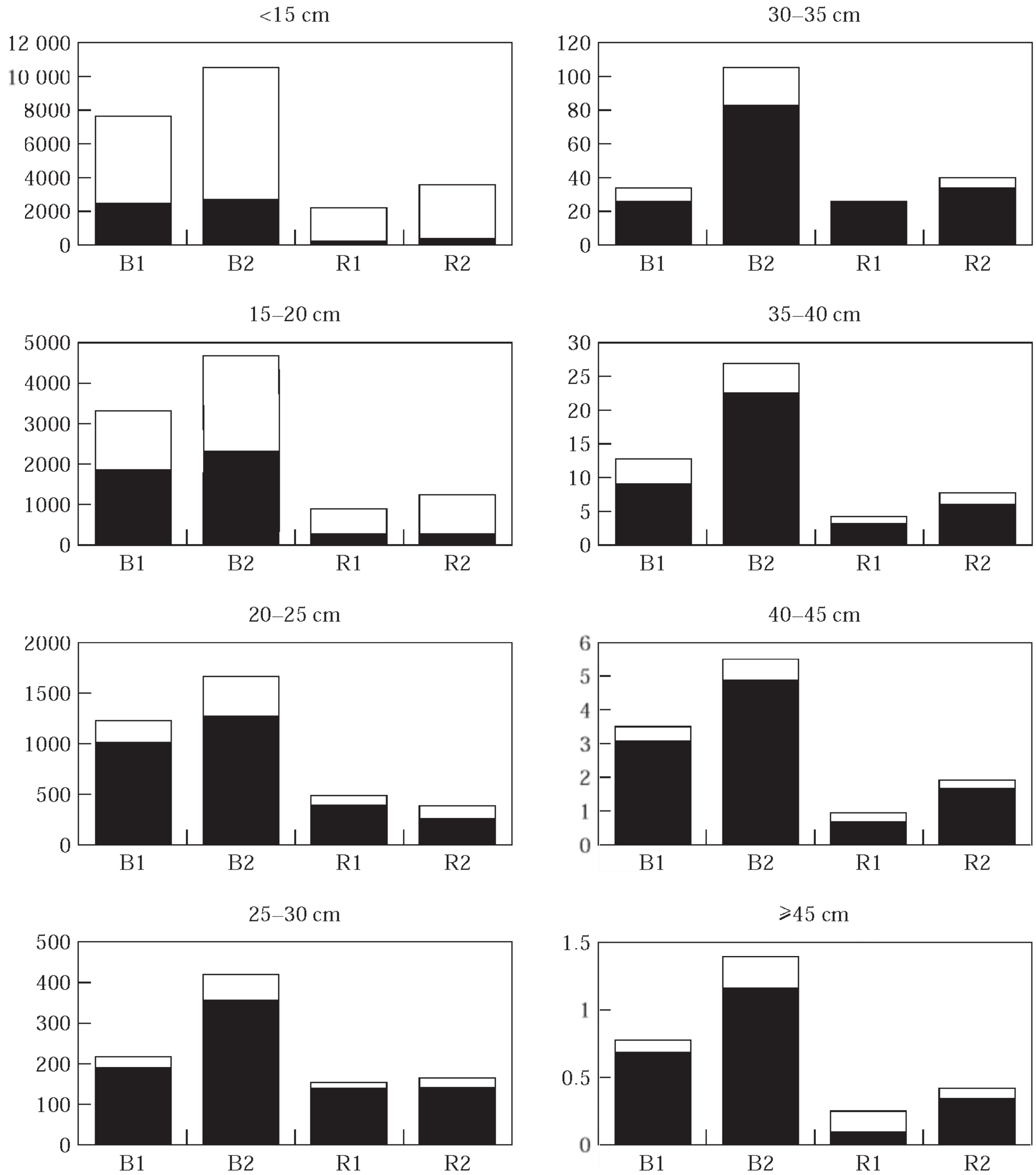

Figure 3. Number of commercial (dark) and non-target (light) fish caught per haul for eight size-clases. Characters along x-axis indicate box (B) and reference (R) area, numerals indicate periods. Period 1=1985–1988, Period 2=1989–1994.

simultaneously. The differences in species composition between (sub-areas before and after the closing of the box area are represented using MDS. PCA was used to help explain the variation between years and between the "box" and reference areas.

Species richness as determined by the total number of species caught in a survey in a specific area or during a specific period can depend on the sampling effort. Because sampling effort differed between the "box" and reference area as well as between years, the bootstrap technique (Efrom and Tibshirani, 1993) was used to determine the relation between sampling effort and species richness by area and by period respectively.

Results

Size structure

Length-frequency distributions of commercial and non-target species in and outside the closed area on the one hand as well as before and after closure of this area on the other (Fig. 2), show that in general fish density was

Table 3. Results of the analysis of the effect of the closure of the box on the number of fish per size-class. Indicated are the p-values of ANOVA per size-class and MANOVA (Total) for the overall size structure. Significant values ($p \leq 0.05$) are in bold.

Class	Size (cm)	Commercial species Area	Period	Area*Period	Non-target species Area	Period	Area*Period
L0	<15	**0.00**	0.50	0.52	**0.00**	0.26	0.71
L1	15–20	**0.00**	0.62	0.92	**0.00**	0.26	0.64
L2	20–25	**0.00**	0.27	0.59	**0.00**	0.16	0.32
L3	25–30	**0.00**	0.44	0.11	**0.00**	**0.03**	0.16
L4	30–35	**0.01**	**0.00**	**0.01**	**0.05**	**0.02**	0.27
L5	35–40	**0.00**	**0.00**	0.09	0.25	0.88	0.57
L6	40–45	**0.00**	0.12	0.77	0.92	0.86	0.57
L7	≥45	**0.02**	0.71	0.33	0.52	0.22	0.34
Total		**0.00**	**0.00**	**0.02**	**0.00**	0.28	0.24

higher in the "box" area and that especially the "small" (<25 cm) fish of the commercially exploited species were found there. Except for the "large" commercial species in the reference area the number of fish caught per haul was higher after closure of the box (Period 2).

Results of the MANOVA testing for an area or period effect on the number of fish in various size-classes show a significant effect ($p<0.01$) of the area on the number of both commercial and non-target species whereas only for the commercial species was significant effect of the period ($p<0.01$) or the interaction between period and area ($p<0.05$) detectable (Table 3).

The results of the ANOVA show that only for the commercial species between 30 and 35 cm was a significant ($p<0.05$) interaction between area and period observed (Table 3). The differences between periods and areas in the number of fish of a specific size-class caught per haul are presented in Figure 3.

Species composition

The results of the ANOVA (Table 4) show for several species of both the "large" and the "small" fish assemblages significant differences in abundance between either the two areas, or between the periods before and after establishment of the closed area. However, only for large whiting *Merlangius merlangus* was there a significant interaction. Results of the MANOVA process on the overall species composition did not show a significant interaction for any of the assemblages (Table 4).

Multi-dimensional scaling characterizes the various assemblages by their position in the two-dimensional plane (Fig. 4). For the large fish assemblage the main difference between areas before the closure of the "box" was apparently based on the distinction between inshore coastal areas (BN, BS, RS) and offshore areas (RN), whereas that after the closure of the "box" was based on the distinction between southern (BS, RS) and northern (BN, RN) geographic areas. In contrast, for the small fish assemblages only minor temporal differences were observed while the distinction between "box" and reference areas and between the northern and southern areas appeared to be equally important. The different direction of change of the RS area compared to the other areas suggests other factors determined the species composition there.

Table 4. Results of the analysis of the effect of the closure of the box on the number of fish per species. For each assemblage only the 10 most abundant species were selected. Indicated are the p-values of ANOVA per species and MANOVA (Total) for the overall species compostion. Significant values ($p \leq 0.05$) are in bold.

Species (large)	Area	Period	Area*Period
P. platessa	**0.05**	0.45	0.09
S. solea	0.52	**0.00**	0.46
L. limanda	0.12	0.10	0.29
M. merlangus	**0.00**	**0.02**	**0.03**
P. flesus	**0.00**	0.44	0.25
T. lucerna	0.06	**0.00**	0.67
S. maximus	**0.00**	**0.00**	0.61
S. rhombus	0.14	**0.00**	0.84
G. morhua	0.71	0.89	0.63
E. gurnardus	0.11	**0.01**	0.07
Total	**0.00**	**0.00**	0.39
Species (small)	**Area**	**Period**	**Area*Period**
L. limanda	0.06	0.64	0.62
P. platessa	**0.00**	**0.05**	0.15
Callionymus spp.	0.98	0.25	0.38
B. luteum	0.08	**0.00**	0.06
M. merlangus	0.40	**0.00**	0.22
A. cataphractus	**0.00**	0.55	0.18
A. laterna	0.16	**0.00**	0.84
S. solea	**0.01**	**0.03**	0.73
E. gurnardus	0.41	**0.02**	1.00
Pomatoschistus spp.	**0.01**	**0.02**	0.83
Total	**0.00**	0.06	0.31

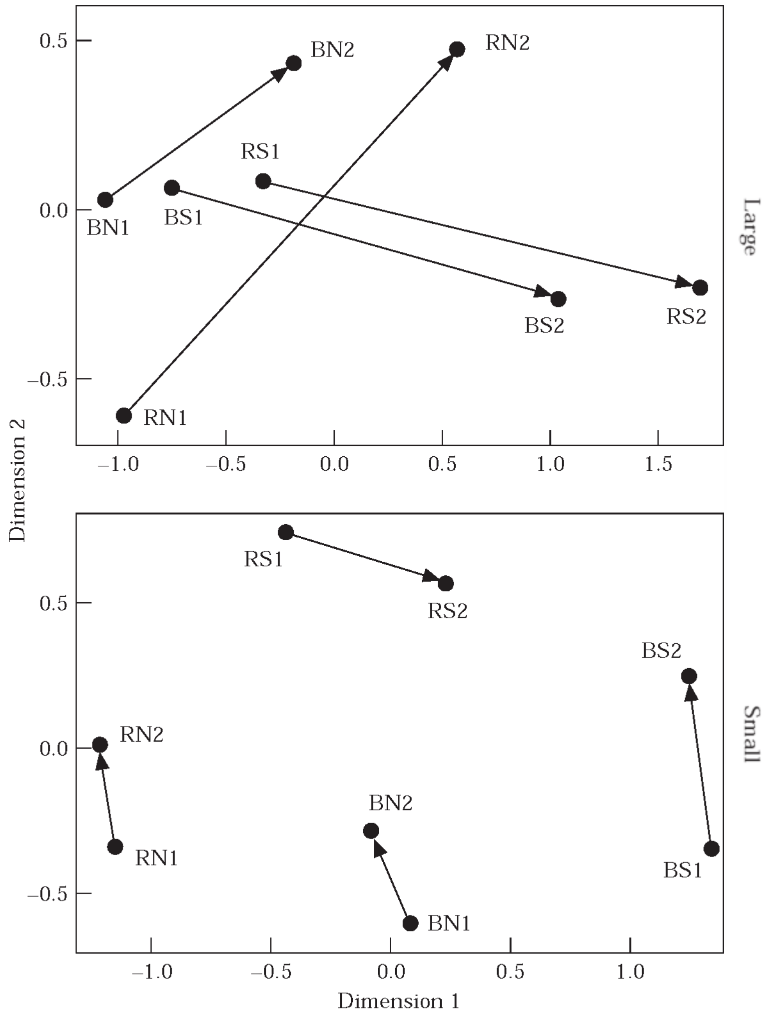

Figure 4. Multidimensional scaling output for the "large" and "small" fish assemblages distinguishing differences in the assemblage composition between box (B) and reference (R) area, northern (N) and southern (S) subarea as well as periods before (1) and (2) closure of the box area.

For the variation in the composition of the "small" and the "large" fish assemblages three principal components axes (PCA) were extracted explaining 75% and 84% respectively, of the variation between years as well as between the "box" area and the reference area (Table 5 and Fig. 5). After closure of the "box" the first PCA of the "large" fish assemblage shows a difference between that area and the reference area caused by a higher abundance in the former of all species except for the flounder *Platichthys flesus* and hooknose *Agonus cataphractus*. The second PCA of the "large" fish assemblage mainly distinguishes the "box" area and the reference area by the relatively high abundance of flounder *Platichthys flesus* in the former and the relatively high abundance of whiting *Merlangius merlangus* in the latter. The third PCA suggests that after the closure of the "box" the abundance of plaice *Pleuronectes platessa*, and, to a lesser extent, cod *Gadus morhua*, increased there. The two most important PCAs of the "small" fish assemblage either distinguish between the two areas or explain a specific temporal patern. The temporal patterns, however, do not differ between the "box" and the reference area. The first PCA indicates abundance of scaldfish *Arnoglosuss laterna*, solenette *Buglossidium luteum* and dragonet *Callionymus spp.* is higher in the "box" than in the reference area. The second PCA reflects a trend of an increasing abundance in both areas of small plaice *Pleuronectes platessa* and hooknose *Agonus cataphractus*. The third PCA, with high opposite loadings of whiting *Merlangius merlangus* and grey gurnard *Eutrigla gurnardus*, shows similar trends in the "box" and reference areas but a somewhat larger variation in the former.

Table 5. Loadings, eigenvalues and explained variance of the main three principal components for the logarithmically transformed numbers of the "large" and the "small" fish assemblages.

Species (large)	Principal components 1	2	3
P. platessa	−0.55	−0.01	−0.58
S. solea	−0.84	0.24	0.29
L. limanda	−0.73	0.32	−0.22
M. merlangus	−0.68	−0.57	−0.09
P. flesus	0.43	0.65	0.39
T. lucerna	−0.86	0.39	0.12
S. maximus	−0.87	−0.19	0.08
S. rhombus	−0.87	0.28	0.28
G. morhua	−0.17	0.52	−0.49
E. gurnardus	0.47	0.57	−0.29
Eigenvalue	4.7	1.8	1.1
Total variance (%)	46.8	17.7	10.6
Cumulative variance (%)	46.8	64.5	75.1

Species (small)	Principal components 1	2	3
L. limanda	0.57	0.67	0.34
P. platessa	−0.07	0.94	−0.24
Callionymus spp.	0.83	0.22	0.21
B. luteum	0.84	−0.34	−0.15
M. merlangus	0.73	−0.07	0.49
A. cataphractus	0.30	0.85	−0.33
A. laterna	0.89	−0.29	−0.04
S. solea	0.69	0.56	−0.04
E. gurnardus	0.78	−0.24	−0.41
Pomatoschistus spp.	0.61	−0.61	−0.22
Eigenvalue	4.6	3.0	0.8
Total variance (%)	45.9	30.5	8.1
Cumulative variance (%)	45.9	76.4	84.4

The bootstrap technique was used to determine the species richness per area, per period depending on the number of hauls (Fig. 6). Before the closure of the "box" there was no difference between it and the reference area. After closure, species richness in both areas was significantly ($p<0.05$) higher and a significant ($p<0.05$) difference between the two areas was observed. However, in contrast to expectations, the number of species in the reference area was higher than in the "box". The main "new" species in the assemblage after closure were, among others: lesser spotted dogfish *Scyliorhinus canicula*, lumpsucker *Cyclopterus lumpus*, three-spined stickleback *Gasterosteus aculeatus*, red gunard *Aspitrigla cuculus*, bass *Dicentrarchus labrax* and tope *Galeorhinus galeus*.

Discussion

The main object of this programme of work was to determine whether fishing effort affects the size distribution or the species composition of the demersal fish assemblage. Assuming that since the establishment of the plaice box fishing effort within this area has decreased relative to that outside of the box, we stratified our survey data on a temporal and area basis where any significant interaction between these parameters would indicate an effect of beam trawling effort on the fish assemblage. However, for the period between 1989 no statistics are available on the distribution of fishing effort of the Dutch fleet, which contributed almost 60% of the total international catch of North Sea plaice and sole (Anon., 1994). Comparison of the distribution after 1989 shows that the beam trawl effort of the larger vessels (>300 hp) has shifted to slightly deeper waters outside the plaice box (Anon., 1994). This conclusion is corroborated by the detailed effort data collected by automated position recording devices showing that beam trawl effort was highly concentrated along the borders of the "box" (Rijnsdorp *et al.*, 1994). To what extent the fishing effort of larger vessels inside was replaced by that of smaller vessels belonging to the exception fleet remains to be assessed. However, it is believed that the effort of small beam trawlers (<300 hp) inside the "box" has increased (Anon., 1996).

The overall size structure of the commercial fish species was shown to be affected by the trawling effort. In particular the abundance of fish within the size-range of 25–40 cm increased when trawling effort was reduced. Least effect was observed for size-class 0 (<15 cm). When interpreting the effect of trawling effort on the various size-classes it should be realized that fish smaller than 15 cm are not caught by the commercial beam trawl fishery and that the minimum landing size of the main commercial species is about 25 cm (van Beek, 1990). Fish between 15 and 25 cm are generally discarded. The fact that only the marketable size-classes of the commercial species were affected, whereas the smallest size-class not caught by commercial fisheries was least influenced, confirms the conclusion that size-structure depends on the fishing effort.

Because only the fish larger than 25 cm were affected by the beam trawl fishery, the assemblage was split into a "large" fish assemblage and a "small" fish assemblage for the multi-variate analyses. The composition of the "large" fish assemblage throughout the survey period is most likely to be affected by the fishing effort whereas the composition of the "small" assemblage is mainly governed by variation in recruitment of the individual species.

In contrast to the size structure of the fish assemblage, the species composition of both the "small" and "large" assemblages was not significantly affected by the reduction in fishing effort. However, the principal component analysis does indicate that a considerable proportion of the variation in the abundance of the large fish over the years can be explained by an increased abundance of

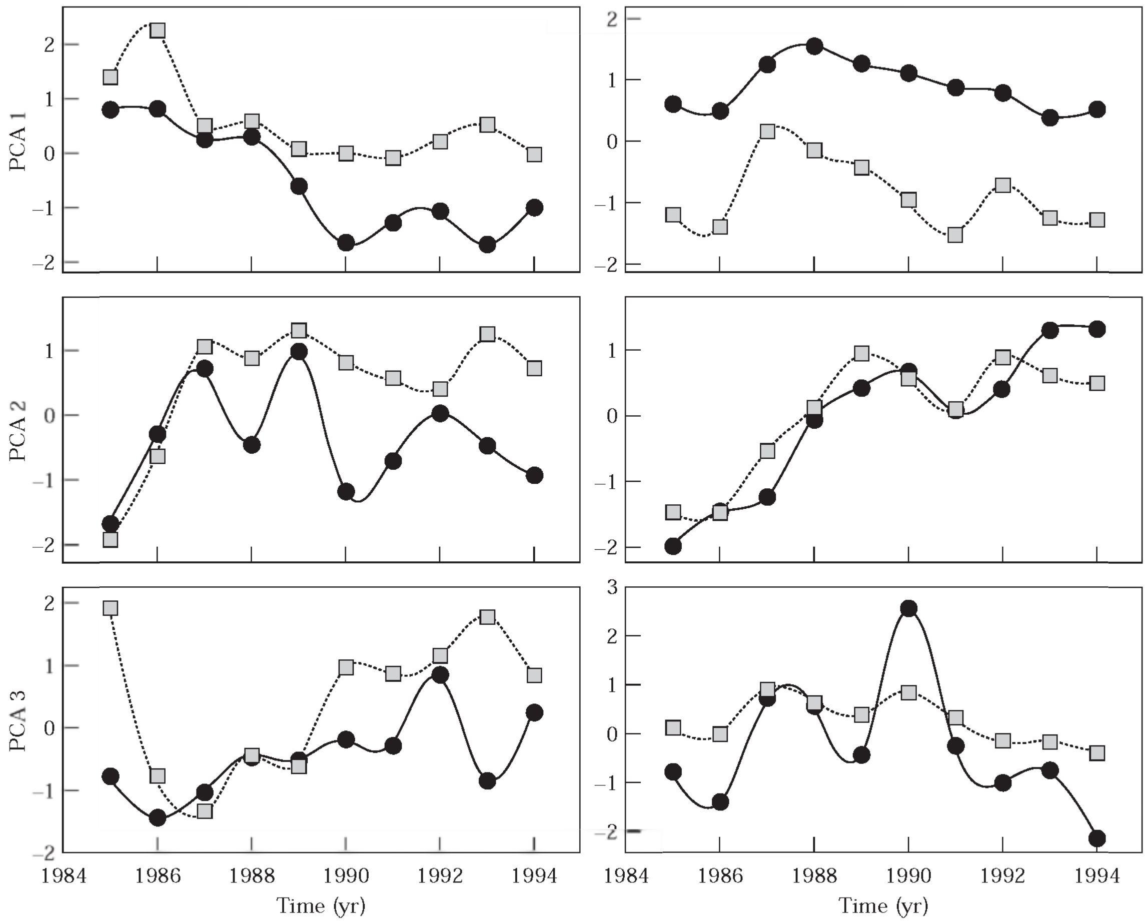

Figure 5. Values of the three most important Principal Component Axes (PCAs) during the survey period in the box (●) and reference (□) area for the "large" and "small" fish assemblages.

most fish species, including the two main commercial species plaice and sole, in the box area after its closure. The fact that this was not observed for any of the principal components of the small fish assemblage only confirms that the observed changes in the box area might be caused by a reduction of fishing effort there.

Other trends that could be observed throughout the survey period but did not differ between the two areas are:

- A decrease of the relative abundance of plaice, most probably due to the high level of fishing mortality and to the decrease in the level of recruitment. The latter is likely to be related to a decrease in growthrate.
- A general increase of species richness due to the influx of southerly species. This trend was most probably caused by the overall increased inflow of Atlantic water therough the Strait of Dover (Corten and van de Kamp, 1996) during the survey period. The observation that species richness increased stronger in the reference area is probably caused by the fact that the reference area covers the southernmost areas closer to the Strait of Dover.

Because of the apparent influence of factors other than fishing effort on the composition of the fish assemblage both the "box" and the reference area were divided into different parts. This allowed an evaluation of the contribution of these factors to the observed differences between the two areas. The outcome of the analysis using multi-dimensional scaling shows that at least part of the differences between the box and the reference area can be attributed either to the difference between inshore and offshore areas or between southern and northerly areas.

In conclusion therefore it would seem that although the size structure was affected by the beam trawling effort the species composition was not. Although several temporal trends could be determined, of which at least one could be attributed to the fishing effort, the scale of the different areas did not allow the establishment of any significant effect.

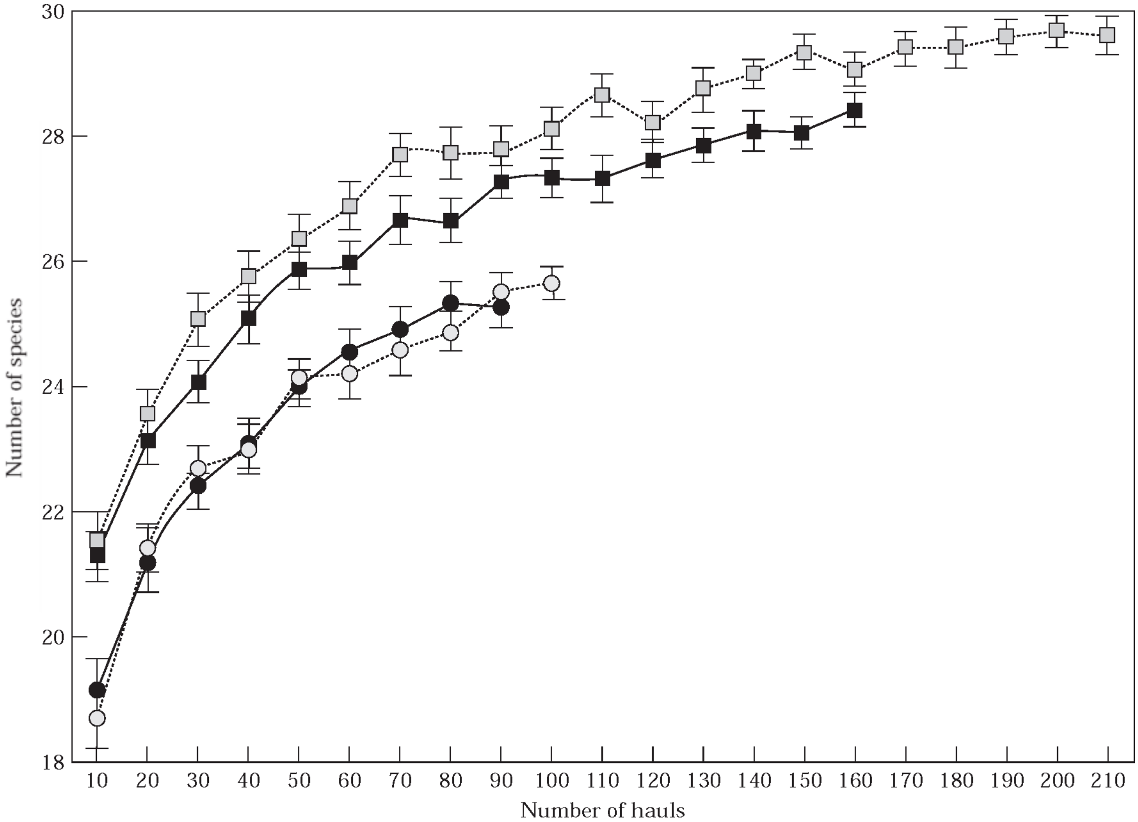

Figure 6. Species richness (number of species) with increasing number of hauls per area and per period. Box area, 1985–1988 (●): box area 1989–1994 (■): reference area, 1985–1988 (◎): reference area 1989–1994 (❑).

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