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Monitoring juvenile stocks of flatfish in the Wadden Sea and the coastal areas of the southeastern North Sea*

F. A. van Beek[1], A. D. Rijnsdorp[1] & R. de Clerck[2]

[1] *Netherlands Institute for Fishery Investigations; P. O. Box 68, 1970 AB IJmuiden, The Netherlands*
[2] *Fisheries Research Station; Ankerstraat 1, Oostende, Belgium*

ABSTRACT: Results are presented of an on-going monitoring program, started in 1970, of the demersal fish population in the Wadden Sea, Scheldt estuary, and along the continental coast between the Belgian-French border and Esbjerg. Particular attention is given to long-term trends in overall abundance and annual variations in spatial distribution of 0- and 1-group plaice and sole in relation to year-class strength and to variations in growth rate. Recruitment level in both plaice and sole appeared to be higher in the 1980s than in the 1970s. The most important nursery areas for plaice are the German Bight and the Wadden Sea, and the relative contributions of these areas to the total plaice stock in different years are relatively stable. In contrast, the most important nurseries for sole are along the continental coast, and the contribution of different parts of these nurseries vary considerably from year to year. Abundant year-classes of sole can originate from northern as well as from southern parts of the nurseries. Relations between survey results and year-class estimates from Virtual Population Analysis (VPA) for plaice are better compared to sole. No trends have been observed in mean length at age 0 and 1 during the years the surveys have been carried out. It is concluded that the quality of the continental coastal area and the Wadden Sea as nursery area for plaice and sole has not declined during the period of investigation.

INTRODUCTION

The importance of the estuaries and the shallow coastal waters along the eastern coast of the southern North Sea as a nursery area for juvenile flatfish was recognized at the beginning of this century (Johansen, 1913, 1922; Bückmann, 1934a, 1934b, 1953; Tåning, 1943, 1951; Ursin, 1958). The first attempt to quantify the importance of the Wadden Sea for the recruitment of the North Sea stocks of plaice and sole was made by Zijlstra (1972). To this end, he analysed the results of a Demersal Young Fish Survey (DYFS) in the Wadden Sea and the adjacent shallow coastal waters, conducted by the Netherlands in 1969 and 1970. The survey area has been extended through the cooperation of the Fishery Research Institutes of the Netherlands, Belgium and the Federal Republic of Germany, and now encompasses the shallow coastal waters from the Belgian-French border (51° 00′ N) up to Esbjerg (55° 30′ N) including the Scheldt estuary and the Dutch and German Wadden Sea. This survey has been continued up to the present day. Annual reports have been published in Annales Biologiques (Volumes

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26–36) under the title of "Young Fish and Brown Shrimp Surveys along the Continental Coast of the North Sea". At present the main purpose of the survey is to estimate the year-class strength of juvenile North Sea plaiçe and sole as early as possible for use in the preparation of the annual fishery management advice.

Mainly due to the impact of river discharges, the coastal and estuarine areas in the southeastern North Sea are heavily polluted (Salomons et al., 1988). This could affect the quality of the area as nursery for plaice and sole via the level of recruitment or growth rate. An increase in growth rate of both species of juveniles and adults has been reported (de Veen, 1976; Bannister, 1978; Rauck & Zijlstra, 1978; Rijnsdorp, 1984; van Beek, 1988). The causes of these changes in growth are not yet understood, although an increase in food availability due to eutrophication has been mentioned as one of several contributing factors.

In this paper, the question of the relative importance of the Wadden Sea and shallow coastal areas as nurseries for North Sea plaice and sole will be re-addressed. An attempt is made to quantify the relative contribution of the different parts of the nursery areas along the continental coast in regard to the total recruitment of North Sea plaice and sole. Absolute abundance cannot be estimated, as data on gear efficiency is not available. Secondly, the relation between survey estimates of year-class strength and recruitment to the fishery will be analysed. Finally, the growth of juveniles is considered.

MATERIALS AND METHODS

Survey design

Flatfish surveys in estuarine and coastal areas pose special problems as a consequence of changes in distributions of fish in relation to the tides. For instance, part of the 0- and 1-group plaice migrate onto the tidal flats in the estuaries during high tide, and concentrate in the tidal channels during low tide (Kuipers, 1973; Berghahn, 1986a, 1986b). In the coastal areas, juvenile plaice also exhibit a tidal migration (Gibson, 1973).

The sampling stations of the Demersal Young Fish Surveys (DYFS) were stratified by geographical area (Table 1 and Figure 1), but the stations were not evenly distributed over the depth zones. The minimum depth sampled was determined by the depth of the research vessel and was generally more than 2 m. Before analysis of the data the observed depth was corrected to the depth relative to the mean low water line. In the estuaries, only the tidal channels were sampled. In the course of the years, some changes have been applied to allocate the stations more evenly over the different depth zones, in particular the coastal areas. Also, since 1978, the number of stations fished in the shallow coastal area of the Federal Republic of Germany and Denmark has been increased.

Survey period and gear

The DYFS were conducted in spring (April–May) and autumn (September–October) from 1969 up to the present by research vessels and chartered commercial vessels. In the estuaries, a 3-m beam trawl is used and in the coastal areas a 6-m beam trawl. Both trawls are rigged with a shrimp net with bobbin rope and one tickler chain and a mesh size in the cod end of 10 × 10 mm. Towing speed is 3 knots and haul duration is 15 min. Details

Table 1. Overview of the subareas studied

	Surface area 0–20 m km²	Approx. number of stations	Starting year	Responsible country
Estuaries				
Scheldt	610	61	1969	Netherlands
Wadden Sea				
– Netherlands	1453	108	1969	Netherlands
– FRGermany	1559	variable	1978	FRGermany
– Denmark	281			
Coastal areas				
Belgium	2058	33	1971	Belgium
Netherlands	7613	113	1969	Netherlands
FRGermany	5766	18 (52)	1969 (1978)	Netherlands
Denmark	2118	6 (22)	1969 (1978)	Netherlands

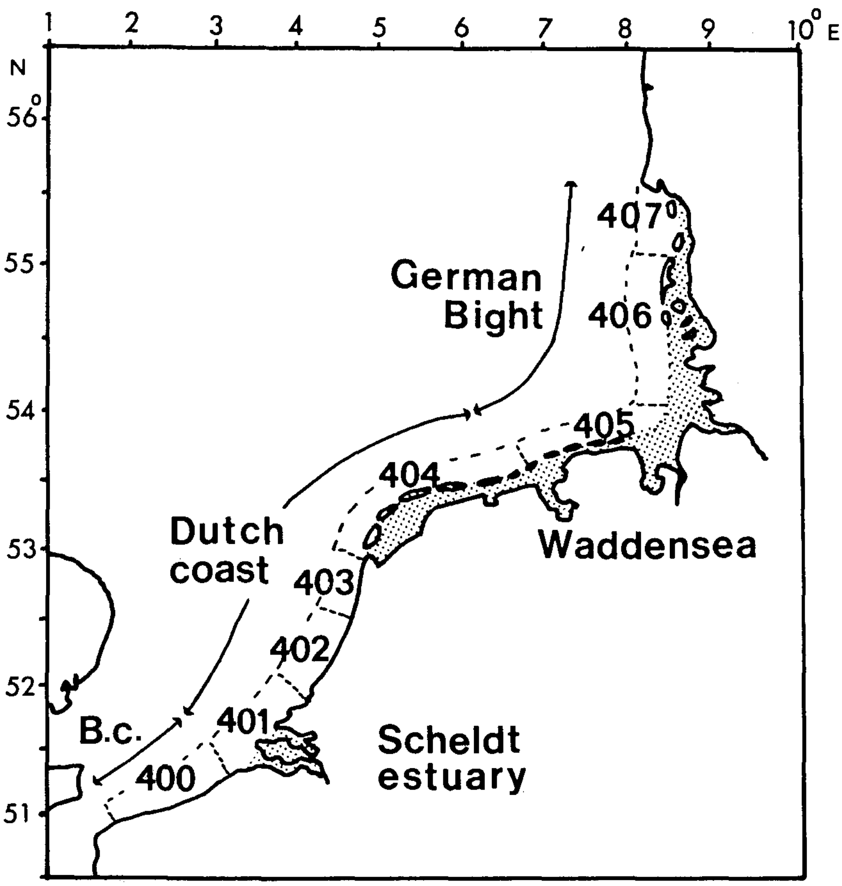


Fig. 1. Map of survey areas of the Demersal Young Fish Survey (DYFS) and the areacodes of the subareas. Estuarine areas are hatched

on the gear are given by Boddeke et al. (1971). In the present paper, only autumn data from the Netherlands and Belgium will be analysed since the spring data and the data from the Federal Republic of Germany are not yet available on computer.

From each haul, the length distributions of all fish species were recorded. For age determinations the otoliths of 4–6 fish per cm group were collected for plaice and sole in each subarea, except in the German Wadden Sea. The total number of otoliths collected each year was about 2000 in plaice and 750 in sole.

RESULTS

Distribution and abundance

Plaice

The overall abundance index of 0- and 1-group plaice in the total survey area is given in Table 2. The index was calculated from the density by subarea and depthzone, weighted over the surface area of the depth zones. As no data for the Danish and German Wadden Sea were available, it is assumed that the total Wadden Sea is 2.5 times the size of the Dutch Wadden Sea and that the densities in these areas are equal. This assumption is supported by data in Annales Biologiques (van Beek et al., 1980). Also in Table 2, the year-class strength at age 1 from Virtual Population Analysis (VPA) from commercial

Table 2. Abundance index (numbers · 1000 m^{-2}) of juvenile plaice and sole in the nursery areas along the continental coast between 51° 00′ N and 55° 30′ N and the estuaries of the Scheldt and the Wadden Sea, and the estimate of year-class strength from VPA (from Anon., 1989)

Year class	Plaice 0-group	Plaice 1-group	Plaice VPA millions	Sole 0-group	Sole 1-group	Sole VPA
1969	–	3.3	370	–	0.96	141
1970	7.6	0.9	283	14.3	0.05	42
1971	5.7	3.3	233	9.0	0.08	77
1972	2.7	5.0	538	0.4	0.20	106
1973	3.1	2.2	449	4.3	0.25	111
1974	3.0	2.4	330	0.8	0.10	42
1975	5.0	4.0	322	6.6	0.18	115
1976	9.8	6.3	467	3.4	0.22	140
1977	4.8	4.0	423	1.3	0.03	47
1978	12.4	10.9	435	4.4	0.03	12
1979	20.9	10.4	647	21.1	1.87	155
1980	5.9	8.9	412	20.4	0.65	149
1981	30.0	15.6	994	13.9	0.64	153
1982	23.2	11.0	580	16.4	0.87	138
1983	23.0	7.5	651	4.9	0.42	72
1984	13.8	5.2	466	8.1	0.09	66
1985	32.8	17.2	1063	10.8	0.39	111
1986	9.9	10.6	–	3.6	0.26	–
1987	21.6	5.5	–	29.3	0.73	–
1988	21.7	–	–	2.1	–	–

landing statistics (Anon., 1989) is given. The survey estimate of 0- and 1-group abundance index shows a significant positive relation with the VPA estimate of year-class strength (Fig. 2).

The average contribution of subareas to the overall abundance index is given in Table 3. The Wadden Sea and the coastal areas in the German Bight contribute most to

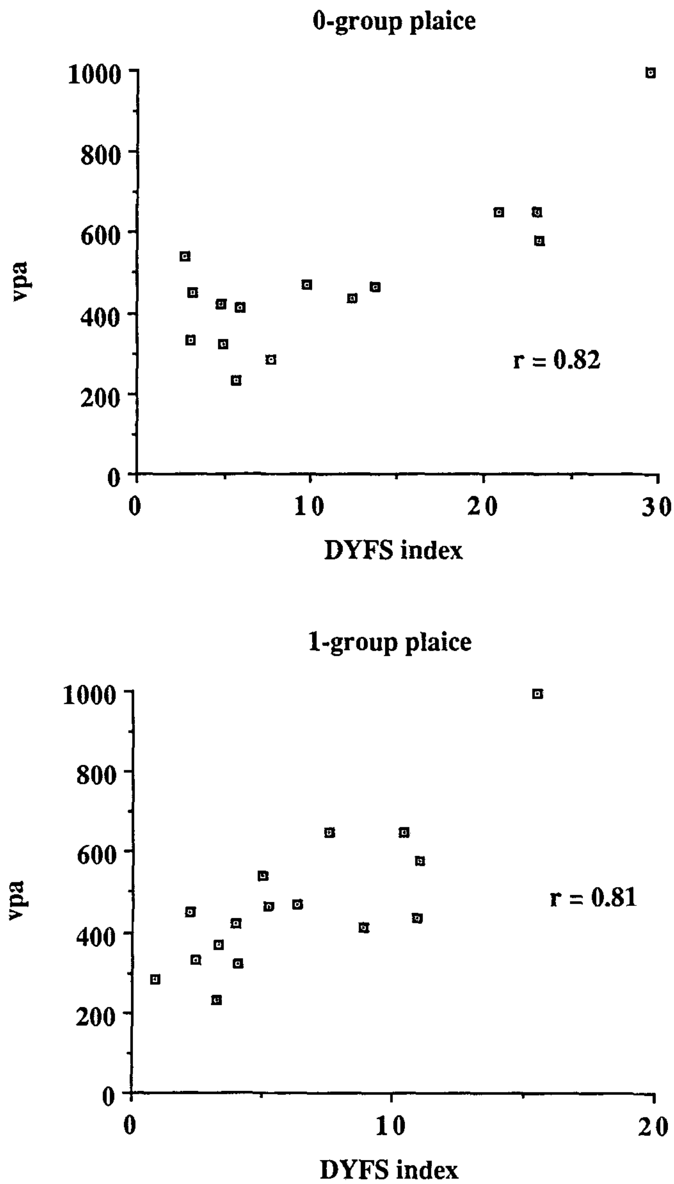


Fig. 2. North Sea plaice, the relation between DYFS recruitment index of 0- and 1-group plaice and VPA year-class estimate at age 1

the 0-group plaice with an average contribution of respectively 49 % and 37 %. In the autumn of the following year, an important part of the 1-group plaice have left the estuaries and are predominant in the coastal areas, especially in the German Bight (66 %). This shift in distribution coincides with a shift in the depth-distribution (Table 4).

The annual variations in the contribution of subareas to the overall abundance index of 0- and 1-group plaice are shown in Figure 3 and appear to be relatively constant. The recruitment of plaice thus originate each year from the same areas. The slight increase in the average contribution of the German Bight in 0-group and the slight decrease in 1-group is probably related to the increase and reallocation of sampling in the coastal area towards the shallow depth zones since 1978.

Table 3. Average contribution (%) of the continental nursery areas to the overall abundance index of 0- and 1-group plaice and sole in the period 1970–1987

	Plaice				Sole			
	0-group		1-group		0-group		1-group	
	mean %	sdev	mean %	sdev	mean %	sdev	mean %	sdev
Belgian coast	0.9	0.9	1.3	3.5	12.4	10.6	16.3	14.6
Scheldt estuary	0.9	1.2	1.2	1.9	0.8	0.6	4.0	3.5
Dutch coast	13.3	8.5	12.2	6.4	31.8	20.6	29.9	18.0
Wadden Sea	48.6	18.5	19.8	10.2	20.7	13.5	13.1	16.4
German Bight	36.5	17.5	65.7	12.9	35.5	23.1	38.4	23.5
Total	100.0		100.0		100.0		100.0	

Table 4. Distribution of 0- and 1-group plaice and sole ($N \cdot 1000\ m^{-2}$) by depthzone (m below mean low water line) in the period 1978–1982

	0–2 m	2–5 m	5–10 m	10–20 m
0-group plaice				
Scheldt estuary	–	6.8	3.7	3.0
Dutch Wadden Sea	55.1	46.0	47.5	11.7
Coastal areas	42.5	37.6	22.5	21.3
1-group plaice				
Scheldt estuary	–	2.1	2.8	2.9
Dutch Wadden Sea	5.8	14.9	12.8	5.4
Coastal area	6.8	2.4	11.7	9.2
		0–5 m	5–10 m	10–20 m
0-group sole				
Scheldt estuary		4.0	5.2	4.9
Dutch Wadden Sea		14.6	17.3	7.1
Coastal areas		24.5	37.3	13.1
1-group sole				
Scheldt estuary		0.22	1.61	1.70
Dutch Wadden Sea		0.35	0.77	0.47
Coastal areas		0.30	0.70	0.44

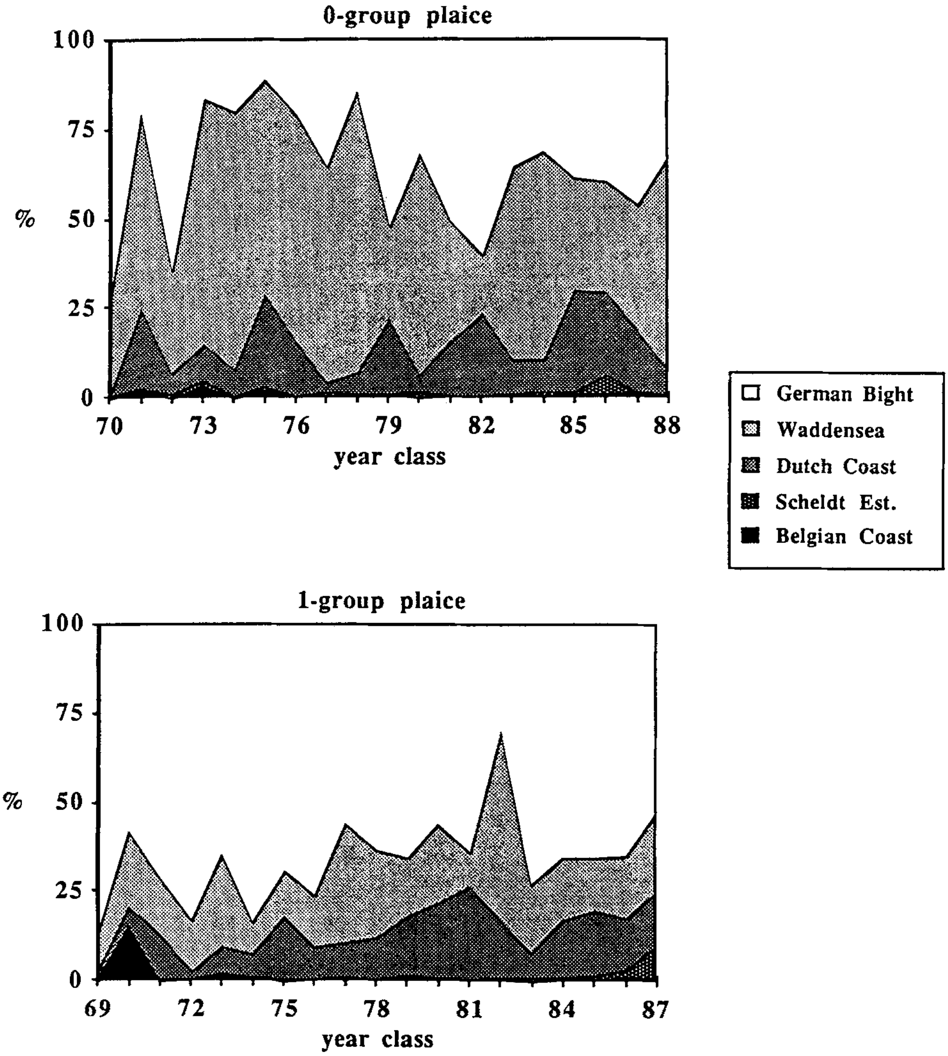


Fig. 3. North Sea plaice, annual variation in the contribution of different parts of the continental nurseries to the DYFS index

In order to compare the annual differences in the distribution of 0- and 1-group plaice, a detailed analysis was made of the distribution of plaice over the shallow coastal zone between 51° 00′ N to 55° 30′ N (subareas 400–407; Fig. 1), using data for the period 1978–1987. The relative density in each subarea was calculated from the ratio of the observed density over the annual mean density of the total area. The relative density of 0- and 1-group plaice shows similar patterns with an increase from the Southern Bight towards the German Bight (Fig. 4). The decrease in the relative density in subarea 406 (Sylt) is probably related to the dispersion of plaice over the rather extended shallow waters. The coefficient of variation is generally low in the subareas with the highest

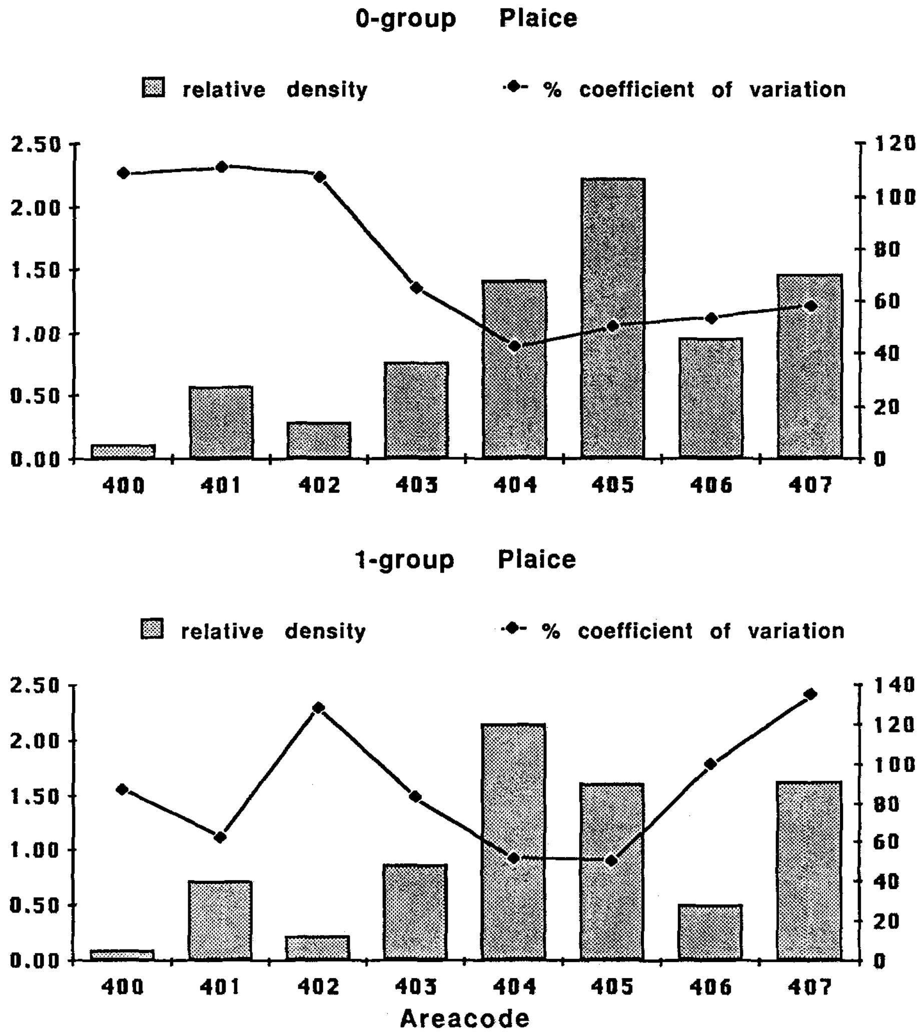
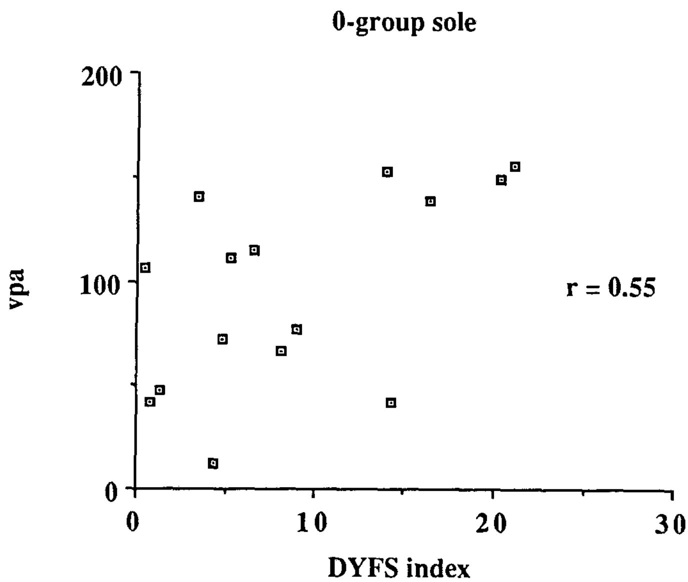


Fig. 4. North Sea plaice, average relative density and coefficient of variation of the coastal areas from the Belgium (areacode 400) to Esbjerg (areacode 407) in the period 1978–1987

densities (40–60 %). A striking feature of the distribution pattern is the local peak in plaice density in the coastal area bordering the Scheldt estuary (subarea 401) coinciding with a local low in the coefficient of variation.

Sole

The overall abundance index of juvenile sole in the total continental nursery area is calculated according to a method similar to that described for plaice, and is given in Table 2 together with the VPA estimates of year-class strength at age 1. Both 0- and 1-group survey estimates show a positive correlation with VPA year-class strength (Fig. 5). The relations are not very precise and the survey can indicate a poor year-class that appears



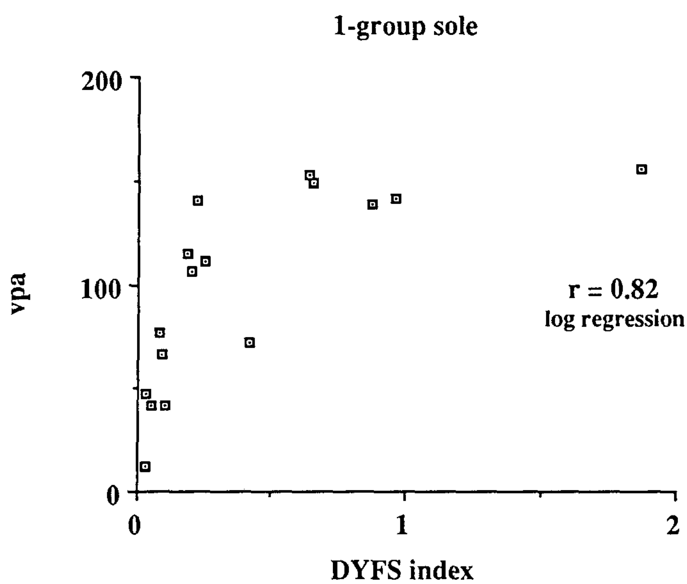


Fig. 5. North Sea sole, the relation between DYFS recruitment index of 0- and 1-group sole and VPA year-class estimate at age 1

in the VPA to be an average year-class, or an average year-class that appears to be poor in the VPA. The relation between survey estimate and VPA estimate improves slightly in 1-group sole.

The contribution of the estuaries and the different coastal areas to the overall abundance index is also given in Table 3. On average the juvenile soles show a less marked preference for estuarine areas in comparison with plaice and they also prefer slightly deeper water (Table 4). The Wadden Sea and Scheldt estuary together contribute on average only 20 % to the total abundance index of 0-group sole. The other 80 % are distributed in the shallow coastal areas. In 1-group soles the contribution of estuarine areas is further reduced.

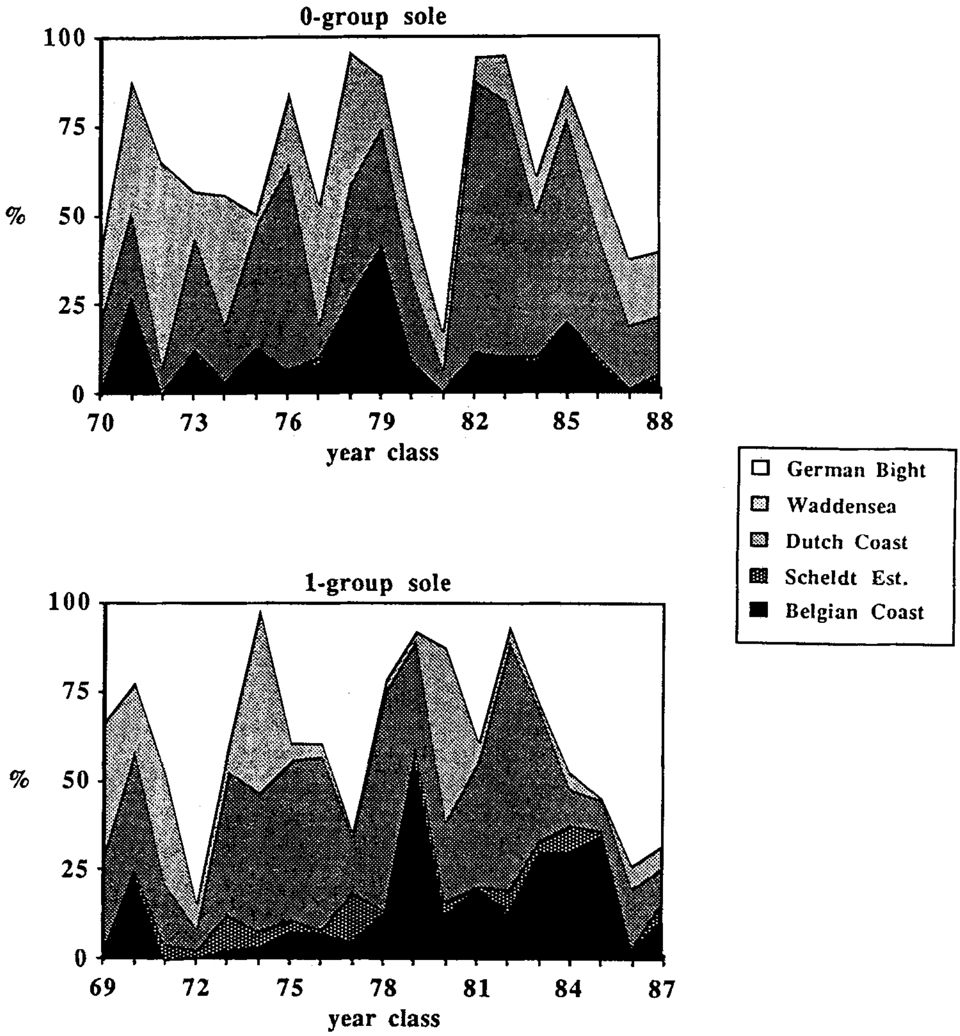


Fig. 6. North Sea sole, annual variation in the contribution of different parts of the continental nurseries to the DYFS index

The distribution of the juvenile soles within the continental nursery area appears to be rather variable (Fig. 6). Some year-classes have as 0-group a southern distribution (e.g. 1979), others a central (e.g. 1975, 1976, 1982, 1983) or northern (e.g. 1981, 1987). However, in some year-classes the contribution to the 0- and 1-group production can change markedly between areas. As 0-group, year-class 1981 was particularly abundant in the German Bight, but as 1-group, the main part of this year-class was distributed along the Belgian and Dutch coast. In year-classes 1983, 1984 and 1985 the contribution of the Belgian coast increased substantially.

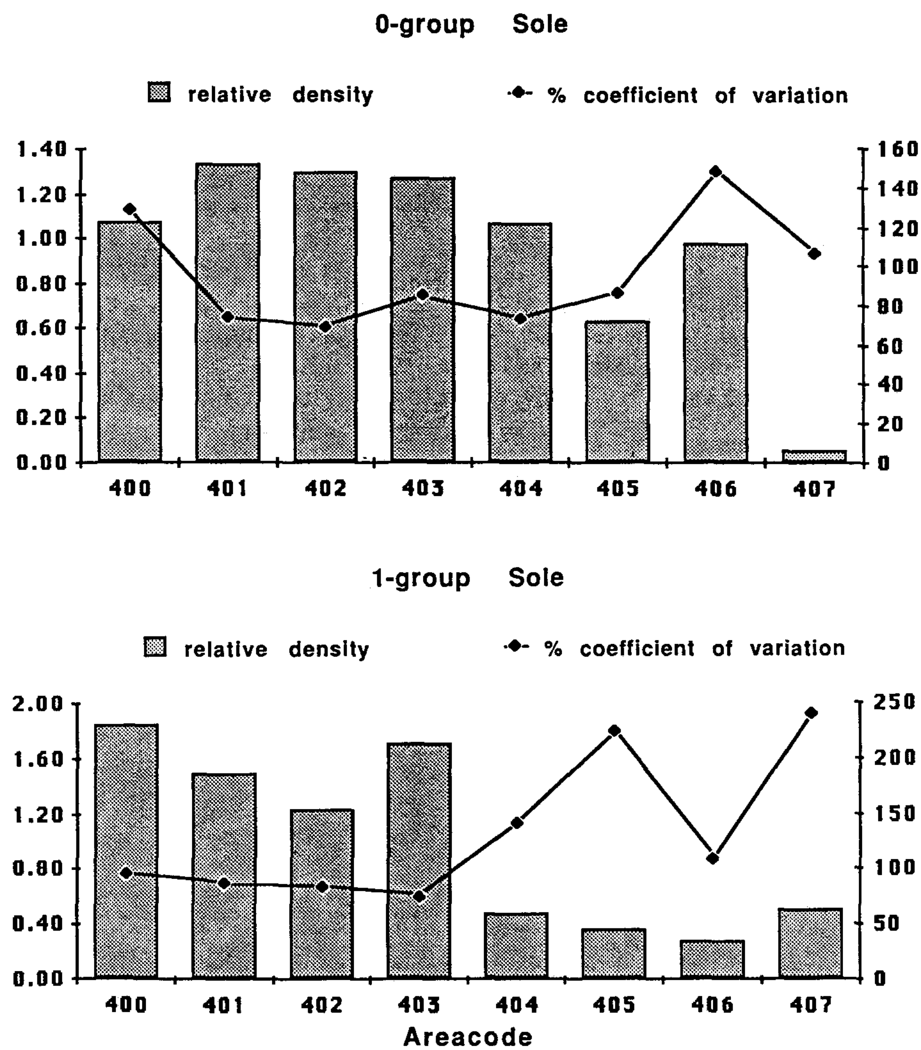


Fig. 7. North Sea sole, average relative density and coefficient of variation of the coastal areas from the Belgium (areacode 400) to Esbjerg (areacode 407) in the period 1978–1987

The geographical distribution within the continental nursery area does not appear to be related with the year-class strength as indicated by the VPA. The 1-group distribution of the strong year-classes 1969, 1976, 1979, 1980, 1981, 1982 and 1987 does not differ substantially from the distribution of the poor year-classes 1970, 1971, 1974, 1977 and 1978.

A detailed analysis of the distribution of juvenile sole in the period 1978–1987 over the coastal area between 51°00′ N and 55°30′ N (subareas 400–407; Fig. 1) shows that the relative density of 0-group sole from the Belgian coast (400) up to Sylt (406) does not differ significantly. Only the density along the Danish coast (407) is much lower. The coefficient of variation, indicating the annual variation in the contribution of each subarea to the total, decreases from 120 % along the Belgian coast to 80 % along the Dutch coast and increases again to above the 100 % in the German Bight and Danish coast (Fig. 7). In 1-group sole the relative density in the areas north of the Dutch Wadden islands and in the German Bight is substantially reduced compared to the relative density of 0-group. Along the Belgian coast and the southern coast of the Netherlands the coefficient of variation is at about the same level as in 0-group sole but increases in the more northern areas.

Growth

The mean length of 0- and 1-group plaice and sole was calculated for the whole survey area (Fig. 8). In this calculation both the differences in the abundance index between areas as well as between depth zones have been taken into account.

In both plaice and sole the mean length at age 0 and 1 in the surveys shows substantial variability between years but does not show a particular trend over the survey period between 1970 and 1986. Also the length at age 4, as obtained from the market sampling of adult fish in commercial landings, does not show a trend between 1970 and 1986.

DISCUSSION

Distribution and abundance

In the present analysis of the DYFS, only relative abundance indices of juvenile plaice and sole were calculated, because data on the gear efficiency were not available. In addition, the DYFS did not sample the tidal flats and the very shallow waters and, therefore, may have lead to biassed results for species showing a strong preference for the very shallow waters or tidal flats. This bias will be small in 0- and 1-group soles, as they do not have a preference for tidal flats or very shallow waters (Riley et al., 1981; Berghahn, 1986b), but will be substantial in 0-group plaice, as they show a strong preference for very shallow water and tidal flats (Kuipers, 1973; Zijlstra et al., 1982; Berghahn, 1986a, 1986b). The order of magnitude of the bias in 0-group plaice is indicated by Zijlstra et al. (1982), who showed that in the western Wadden Sea the density in the 4–8 m depthzone was half the density in the 0–3 m depthzone, and by Berghahn (1986a) who showed that between 7–20 % of the 0-group plaice in the German Wadden Sea were permanently living in the tidal channels. It can also not be ruled out that part of the 0-group plaice that are distributed over the shallow coastal areas in September–October have actually settled in the Wadden Sea in spring, and left the area after a period of summer growth. This implies that the contribution of the estuarine areas

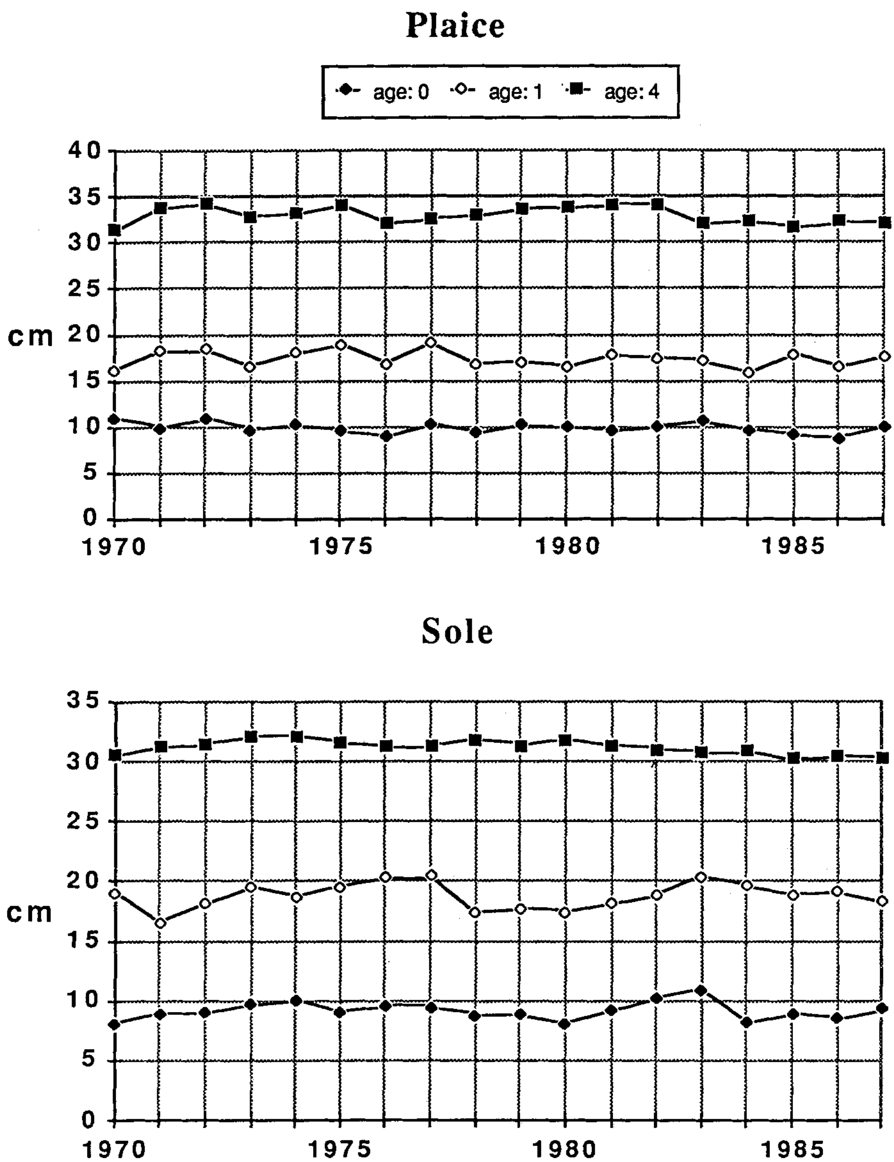


Fig. 8. Length of 0- and 1-group plaice and sole in the continental nursery area (DYFS) and length at age 4 in the commercial catch of Dutch beam trawlers (from Rijnsdorp, 1984; van Beek, 1988)

to the total production of 0-group plaice has been underestimated. In 1-group plaice this bias is probably less, as these fish have already migrated to slightly deeper water (Kuipers, 1973; Riley et al., 1981). Although the abundance index estimates from the survey are biased for 0-group plaice, they nevertheless show a significant correlation with the VPA estimates and thus do reflect differences in absolute abundance.

Also the length at age might be influenced if the largest plaice of a year-class are distributed in deeper waters. A comparison of the mean length at age of 0-group plaice in the western Wadden Sea in 1973 corresponded closely with the mean length observed in 0-group plaice on the tidal flats (Kuipers, 1977); DYFS: 9.8 cm compared to the tidal flats: 10.1 cm. It can therefore tentatively be concluded that the bias in mean length will not be substantial.

The increase in abundance of juvenile plaice from the Belgian coast towards the German Bight can be explained by the spatial distribution of egg-production and the drift of eggs and larvae. Egg production occurs throughout the eastern English Channel and the southern and south eastern North Sea (Harding et al., 1978). The eggs drift on the residual current parallel to the continental coastline towards the German Bight. In the German Bight an eddy occurs which will on average entrain the eggs and larvae. The chance that larvae will be unable to find a suitable nursery area is therefore rather small. If larvae are not able to enter a tidal inlet, they will drift to the next tidal inlet and will have another chance to settle successfully. As the pelagic stage of eggs and larvae is relatively long (90–130 days), it is likely that the offspring of one spawning group will become dispersed over a relatively large nursery area and that a particular tidal inlet will receive larvae of different ages and from different origins. Rijnsdorp et al. (1985) suggested that the bimodality in larval immigration in the western Wadden Sea might be related to the larvae originating from the eastern English Channel and the Southern Bight.

The increase in abundance of juvenile plaice in the coastal area in front of the Scheldt estuary might indicate that the strong tidal flows or river discharge enhance the possibilities for plaice larvae to reach the shallow coastal waters and the estuaries. Once in the reach of a tidal current which enter the estuaries, plaice larvae were shown to ride the inflowing tides when entering the estuaries (Creutzberg et al., 1978; Rijnsdorp et al., 1985; van der Veer et al., 1988).

In plaice, it has been shown that the level of larval immigration into the estuaries was already positively correlated with subsequent 0-group abundance (Creutzberg et al., 1978; Rijnsdorp et al., 1985). It has even been suggested that year-class strength may already be determined at the end of the egg stage (Brander & Houghton, 1982). The significant correlation between the 0- and 1-group survey index and the VPA estimates, and the correspondence between the 0- and 1-group distribution corroborates these observations.

The DYFS indices indicate that recruitment in North Sea plaice is at a considerably higher level since the late 1970s compared to earlier years. This overall increase in recruitment in recent years has also been observed in the VPA. For the moment, no explanation for the higher level of recruitment can be given.

In contrast with plaice, the distribution of 0-group sole within the continental nursery area was rather variable from year to year and the coefficients of variation were generally much higher than in plaice (compare Figures 4 and 7). The variability in the spatial distribution of juvenile soles can be related to the timing of the spawning season and the location of the spawning areas. Eggs are mainly produced between April and July in the coastal areas and spawning activities are restricted to certain hot spots. Centres of high egg production occur along the Belgian coast, west of Texel and in the German Bight (Anon., 1986). At ambient temperatures between 10 and 15 °C the development rate is fast and larvae become demersal within 1 month after fertilization (Fonds, 1975). This implies that the time in which pelagic eggs and larvae float freely on the currents is rather short compared to plaice. The local abundance of 0-group soles is, therefore, likely to reflect the spawning success of one local spawning group. However, over a period of 10 years (1978–1987) the relative spawning success, measured as 0-group abundance, was almost equal for the coastal areas up to 55°00′ N, but measured as 1-group, the success of the spawning in the areas along the Dutch and German Wadden Sea was reduced considerably. This decrease can at least partly be related to a number of severe winters in which the temperature in the southern North Sea but especially in the German Bight was reduced well below the average conditions. Millner et al. (1988) have indicated that the mortality between the 0- and 1-group increased with lower winter temperatures. Also adult sole suffer from an increased mortality rate during winters in which the water temperature drops below a level of 3 °C (Woodhead, 1964).

In sole, the relation between 0-group abundance and subsequent year-class strength, although significant, is not very precise but improves in 1-group. The VPA estimate of year-class strength is based on the total number of fish of a year-class which have subsequently entered the fishery and have been caught. The vulnerability of sole, in both juveniles and adults, towards low winter temperatures may disturb a relation between abundance of juvenile soles and subsequent recruitment to the fishery if the extra mortality is not included in the VPA.

In the present paper, only the relative importance of the continental nursery area between 51° 00′ N and 55° 30′ N could be studied. However, other nursery areas do also contribute to the total recruitment of the North Sea plaice and sole. For plaice, nursery areas occur along the English and Scottish east coast in the open sandy bays (Riley et al., 1981). The contribution of the English nursery areas was estimated to be on average 9 % (range: 4–18 %) (Anon., 1985). In the shallow coastal waters along the west coast of Jutland north of 55° 30′ N, generally high densities of juvenile plaice are observed (van Beek et al., 1986). The contribution of this area is probably substantial although no quantitative estimate can be made at present.

For sole, the coastal area along the English east coast is an important nursery area (Millner et al., 1988) and the contribution to the total recruitment was estimated to be on average 30 % (range: 8–43 %) (Anon., 1985). The coastal area Jutland north of 55° 30′ N is of no importance for sole (van Beek et al., 1986).

The North Sea sole stock in the late eighties is at a historical low level and fishery biologists fear that the level of spawning stock biomass could be near the level at which a collapse of recruitment may occur (Anon., 1989). As the North Sea sole stock is composed of several substocks the stock-recruitment relations may be different and it is possible that recruitment collapse might occur in one of the substocks. The contribution of the different subareas to the total recruitment, however, do not indicate that recruitment is at present below the average level shown in the period 1970–1980. Table 2 even indicates that recruitment in the 1980s is at a slightly higher level than in the 1970s.

Growth

In North Sea plaice and sole an increase in growth rate was reported in the 1960s and early 1970s (de Veen, 1976; Bannister, 1978; Rijnsdorp, 1984; van Beek, 1988). The relation of these changes to the eutrophication of the North Sea, in particular of the coastal and estuarine areas, is not at all clear. The present data do not indicate an increase in growth rate of 0- and 1-group plaice and sole since 1970, although the nutrient levels have continued to rise (Bennekom et al., 1975; Gerlach, 1987). Thus, the growth rate of juvenile flatfish does not correlate with the level of eutrophication. However, it cannot be excluded that prior to 1970 the growth of juvenile plaice and sole increased (Rauck & Zijlstra, 1978) in relation to eutrophication and contributed to the increase in length at age of adult fish. A more detailed treatment of the growth of juvenile plaice and sole will be given in a separate paper.

CONCLUSIONS

From the results of the DYFS for the period 1970–1987 it can be concluded that the quality of the continental coastal area and the Wadden Sea as nursery area for plaice and sole has not declined. The overall recruitment in both plaice and sole has been at a higher level in the recent 10 years, although the causal factors involved in this increase are unknown. Also, there are no indications that the contribution of certain subareas to the overall recruitment has changed or that the growth rate in juvenile plaice and sole has changed.

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