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Spatial and Temporal Changes in the Southern Species Component of North Sea Bottom Fish Assemblages

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With 5 Text-Figures and 3 Tables

Keywords: North Sea, bottom fish assemblage, southern species, temporal changes.

Abstract

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A survey series was started in 1987 to monitor changes in North Sea fish assemblages and to investigate the meso-scale natural variability in catch rates of individual species. The survey began in four areas (boxes) of 10×10 nm, but has been extended to 10 boxes. The boxes are distributed throughout the North Sea.

Randomly located trawl tows were conducted in each box during summer, using standard trawls and standard procedures. Data were available from nearly 2500 hauls. In total 85 species occurred in the catches, of which 37 were southern, 34 northern and 14 intermediate species.

The results indicate southern species migrate into the North Sea by two paths: through the Straits of Dover along the coast into the German Bight and by the Fair Isle current between Orkney and Shetland Isles into the north-western North Sea. The faunal exchange between both seems to be very low.

The highest percentages of southern species were found in the boxes south of the line, which runs north of the Dogger Bank from 54°30'N at the English coast to 56°N at the Danish coast. The location of this line approximates to the northern boundary of the transition area between thermal stratified (Northern and Central North Sea) and thermal homogenous water masses in the Southern North Sea and the German Bight. The lowest proportions of southern fish species were observed in the centre of the North Sea north of the Dogger Bank, rather than in the northern areas.

Only in the German Bight a significant temporal increase in the frequency of southern fish species was noted. This appears to be determined by the winter conditions, for they are related to the comparatively high number of mild winters during the recent decade combined with a dominance of south-westerly winds, which increase the inflow of water through the Straits of Dover. The water temperatures in summer seem to be not relevant for the increasing abundance of southern species.

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Introduction

The fish fauna of the North Sea is connected with the boreal fauna of the North Atlantic through the entrance between Scotland and Norway, with the Baltic Sea fauna through Skagerrak and Kattegat and with the southern Lusitanian fauna through the Channel. The immigration of southern fish species is related to the strength of currents and the amount of water that passes through the entrances. This is true for the pelagic early life stages but also for adult fishes, which are able to extend their range of distribution with the water masses.

Anecdotal observations by fishermen on southern species, concern about global warming and the relatively high number of mild winters in recent years intensify the discussion on changes in the North Sea fish fauna towards an increase of the southern faunal component. Earlier periods of increasing abundance of southern species in the North Sea were described by several authors during recent decades. During the periods 1948-1952 and 1958-1960, episodes of increasing abundance of anchovy (*Engraulis encrasicolus*, Linné 1758) and pilchard (*Sardina pilchardus*, Walbaum 1792) in the southern North Sea were observed (Aurich 1953; Postuma 1978). Corten & van de Kamp (1996) identified two periods of increased abundance of southern species in the southern North Sea, one in the mid-1970s and one around 1990. This was explained by temporary climatic changes. Rogers & Millner (1996) investigated changes in abundance of English inshore demersal fish populations and found a positive correlation between mean surface water temperatures and the presence and absence of Lusitanian species at the South Coast (English Channel).

Since 1987, a research programme has been carried out in the North Sea to sample the fish fauna intensively within small target areas. The objectives of the programme were to study the species composition of the fish fauna and to obtain information on abiotic factors like characteristics of water masses, sediment, weather and light, which may influence species distribution. For this investigation, data sets collected over the last 12 years up to 1999 are used to detect possible changes within the groundfish assemblages in the North Sea.

Material and Methods

Survey Description

The location of the ten sampling areas ('boxes') of 10×10 nm currently covered by the survey programme is shown in Fig. 1. Initially, boxes A-D were sampled by the R/V *'WALTHER HERWIG'*, which was replaced in 1994 by *'WALTHER HERWIG III'*. In 1999, two boxes in the north (L and M) were added. The boxes labelled E, F, K and H were fished by the smaller research vessel *'SOLEA'*, while both vessels operated in box A for reasons of comparison of the data sets.

Since 1986, a total of 2499 standardised hauls have been made within the sampling areas during summer; the 'Solea' boxes in July and the 'Herwig' boxes from June to August. The number of hauls per year and box are listed in Tab. 1. During daylight hours, a minimum of 20 hauls was made in each box over three days (2 to 5). However, due to technical problems or bad weather conditions, in some years less than 10 hauls were completed.

The duration of the hauls was 30 minutes at a speed of four knots for *'WALTHER HERWIG'* and 3.5 knots for *'SOLEA'*. On both *'WALTHER HERWIG'* and *'WALTHER HERWIG III'*, a GOV standard trawl was used (Anon. 1999), whereas *'SOLEA'* was equipped with a smaller but similar otter trawl. The position and direction of the hauls within each area were randomly selected on a daily basis to avoid a bias caused by currents and tides on the catches. Fig. 2 represents a typical example (box B sampled during 4 days in 1996). On board the vessel, the catch was sorted, identified to the species level, weighted, counted and measured.

Table 1. Number of hauls per box and year.

Year	A	B	C	D	E'	F	H	K	L	M
1986				41						
1987	29	13	27	80						
1988	26	17	25	42						
1989	36	22	25	24	25	25				
1990	36	23	25	17	8	28				
1991	50	25	27	26	28	28	27	24		
1992	55	24	24	24	28	21	23	19		
1993	51	15	11	20	27	23	25	27		
1994	49	19	31	39	19	26	27	27		
1995	44	19	21	24	21	26	26	24		
1996	41	29	23	27	28	26	17	28		
1997	35	22	15	19	6	18	25	26		
1998	50	19	20	19	17	20	25	23		
1999	24	14	23	28	10	27	34	30	20	23
sum	**526**	**261**	**297**	**430**	**217**	**268**	**229**	**228**	**20**	**23**
Total 2499										

Definition of Southern Species

Eighty-five fish species were present in the catches. The species were allocated to one of three different categories, based on the location of the area of distribution, as shown in the FNAM-fish atlas (Whitehead et al. 1984)

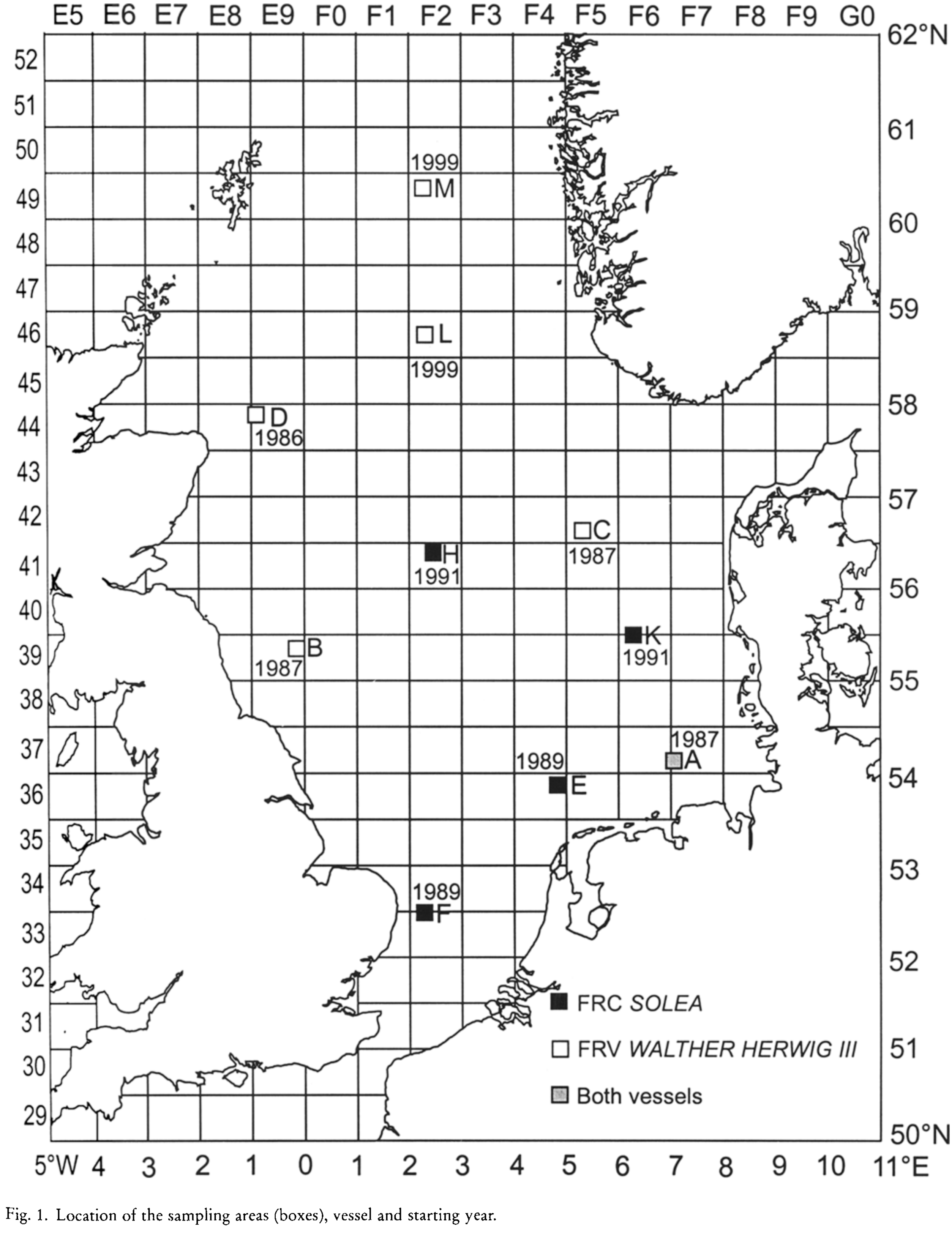

Fig. 1. Location of the sampling areas (boxes), vessel and starting year.

in relation to the North Sea. On this básis, 37 species were selected belonging to a southern category and 34 species to a northern category. A third intermediate category containing 14 species was used to obtain a clearer separation between the first two categories. Except for two widely distributed species, the 37 species of the southern category in this investigation also belong to the 'Lusitanian fauna', defined by YANG (1982; see Tab. 2).

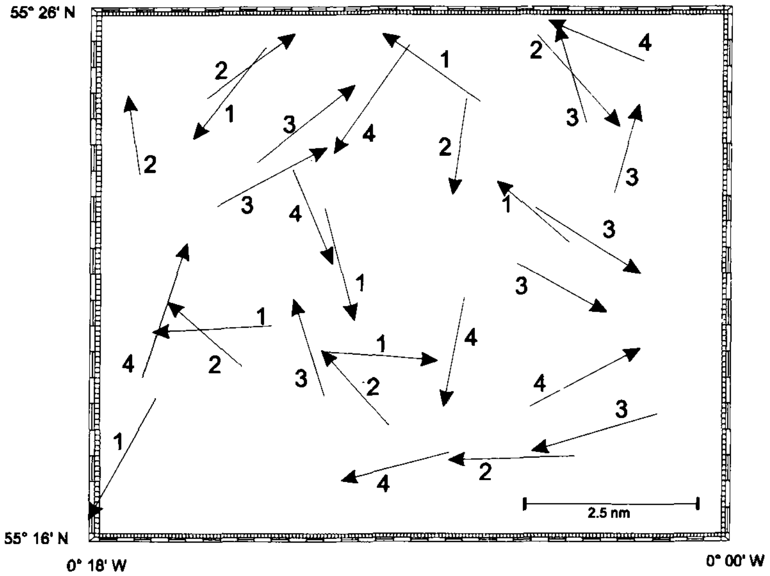

Fig. 2. Distribution of hauls within box B (1996). – The hauls taken at each of the 4 days are marked by numbers.

Results

The Hydrographic Conditions

The hydrographic conditions in the North Sea during summer depend on water depth, tidal currents, wind and solar radiation. These factors not only influence the horizontal distribution of temperature and salinity, but also define the occurrence, strength and depth of thermoclines, which characterise and separate the water masses vertically.

In the German Bight and south of the Dogger Bank, the water usually is mixed down to the bottom, which results in high bottom temperatures during summer. This is true for the boxes A, E and F and partly K. The biggest seasonal difference in bottom temperature in box A during the investigation period was 9°C (from 4.5°C in January to 13.3°C in July), whereas in the northern boxes only moderate seasonal variation in temperature near the bottom was observed due to one or two persistent thermoclines. In 1994, bottom temperature in box D in January was even one degree higher than the bottom temperature in June (6.7°C). In summer, the depth of the mixed layer mainly depends on wind stress. Strong winds over several days can increase the thickness of the mixed layer to 15-25 m, but complete mixing is not observed in deeper areas.

Spatial Differences in the Southern Species Component

The number of southern species (%) in the bottom fish assemblages is significantly correlated with the bottom temperature, as shown in Fig. 3. But this figure also demonstrates big differences in the portion of southern species (up to 22%) with changing bottom temperatures in a range of only 2°C; indicating that the distribution of southern species is not only dependent on temperature.

As expected, the highest percentage of southern species (up to nearly 50%) was found in the southern North Sea and in the German Bight (Tab. 3; boxes F, E, A). To the north of box A to C, the share of southern species, averaged over the whole time series, decreases from 47% (box A) to 32% in box K and 19% in box C.

Box D in the northwestern North Sea is strongly influenced by the inflow of Atlantic water from between the Orkney and Shetland Islands. The highest value (33%) of southern species in the bottom fish assemblages in the northern North Sea was found in that box. It decreased southwards (28% for box B) as well as northwards (22% and 25% for boxes L and M, respectively). The lowest value of 13% was detected in box H in the centre of the North Sea (Tab. 3).

Temporal Changes in the Southern Species Component

During the last decade (1989-99), significant trends in the total number of species were found in the boxes A, C and H. Negative trends in the boxes C and H are related to the decrease of the northern species component whereas the southern component remained unchanged. The positive trend in the number of species in box A (Fig. 4) depends on the highly significant increase of the southern species component in the German Bight. The number of southern species increased from 10 at the beginning of the time series (1987) to 14 in 1999, with a maximum of 17 species in 1997.

A positive trend in abundance of southern species can also be demonstrated by an increasing number of hauls in which a certain southern species occurs in relation (%) to the total number of hauls (frequency, MAGURRAN 1988). For the three southern species, tub gurnard (*Trigla lucerna*, LINNÉ 1758), red mullet (*Mullus surmuletus*, LINNÉ 1758) and pilchard (*Sardina pilchardus*), Fig. 5 shows a much higher frequency in the hauls in the late 1990s, compared to earlier years.

Table 2. Allocation of the 85 fish species to the 3 categories; compared to the classification of YANG (1982). – N=northern category; S=southern category; U=undefined category; A=Atlantic fauna; B=Boreal fauna; L=Lusitanian fauna.

Species	Category	YANG (1982)	Species	Category	YANG (1982)
Agonus cataphractus	N	B	*Alosa alosa*	S	L
Ammodytes marinus	N	B	*Alosa fallax*	S	L
Anarhichas lupus	N	B	*Aphia minuta*	S	L
Argentina silus	N	B	*Argentina sphyraena*	S	L
Brosme brosme	N	B	*Arnoglossus laterna*	S	L
Chirolophis ascani	N	B	*Aspitrigla cuculus*	S	L
Ciliata mustela	N	B	*Buglossidium luteum*	S	L
Clupea harengus	N	B	*Callionymus lyra*	S	L
Cyclopterus lumpus	N	B	*Callionymus maculatus*	S	L
Gadiculus argenteus thori	N	L	*Dicentrarchus labrax*	S	L
Gadus morhua	N	B	*Echiichthys vipera*	S	L
Glyptocephalus cynoglossus	N	B	*Engraulis encrasicolus*	S	L
Hippoglossoides platessoides	N	B	*Eutrigla gurnardus*	S	L
Hippoglossus hippoglossus	N	B	*Galeorhinus galeus*	S	L
Hyperoplus lanceolatus	N	B	*Helicolenus dactylopterus dact.*	S	A
Limanda limanda	N	B	*Lepidorhombus whiffiagonis*	S	L
Lumpenus lampretaeformis	N	B	*Microchirus variegates*	S	L
Melanogrammus aeglefinus	N	B	*Mullus surmuletus*	S	L
Merlangius merlangus merl.	N	L	*Mustelus asterias*	S	L
Micromesistius poutassou	N	A	*Mustelus mustelus*	S	L
Microstomus kitt	N	B	*Raja brachyura*	S	L
Molva molva	N	B	*Leucoraja circularis*	S	L
Myxocephalus scorpius	N	B	*Raja clavata*	S	L
Phrynorhombus norvegicus	N	B	*Raja montagui*	S	L
Pollachius pollachius	N	L	*Leucoraja naevus*	S	L
Pollachius virens	N	B	*Sardina pilchardus*	S	L
Raja radiata	N	B	*Scomber scombrus*	S	A
Rhinonemus cimbrius	N	B	*Scophthalmus rhombus*	S	L
Salmo salar	N	A	*Scyliorhinus canicula*	S	L
Salmo trutta	N	B	*Solea solea*	S	L
Sebastes viviparus	N	B	*Spondyliosoma cantharus*	S	L
Micrenophrys lilljeborgi	N	B	*Sprattus sprattus*	S	L
Trispoterus esmarkii	N	B	*Trachinus draco*	S	L
Trisopterus minutus min.	N	L	*Trachurus trachurus*	S	L
			Trigla lucerna	S	L
Belone belone	U	L	*Trisopterus luscus*	S	L
Gasterosteus aculeatus	U	B	*Zeus faber*	S	L
Lampetra fluviatilis	U	B			
Lophius piscatorius	U	L			
Merluccius merluccius	U	L			
Myxine glutinosa	U	A			
Petromyzon marinus	U	B			
Platichthys flesus	U	L			
Pleuronectes platessa	U	L			
Pomatoschistus minutus	U	L			
Psetta maxima	U	L			
Raja fullonica	U	B			
Squalus acanthias	U	A			
Syngnathus rostellatus	U	L			

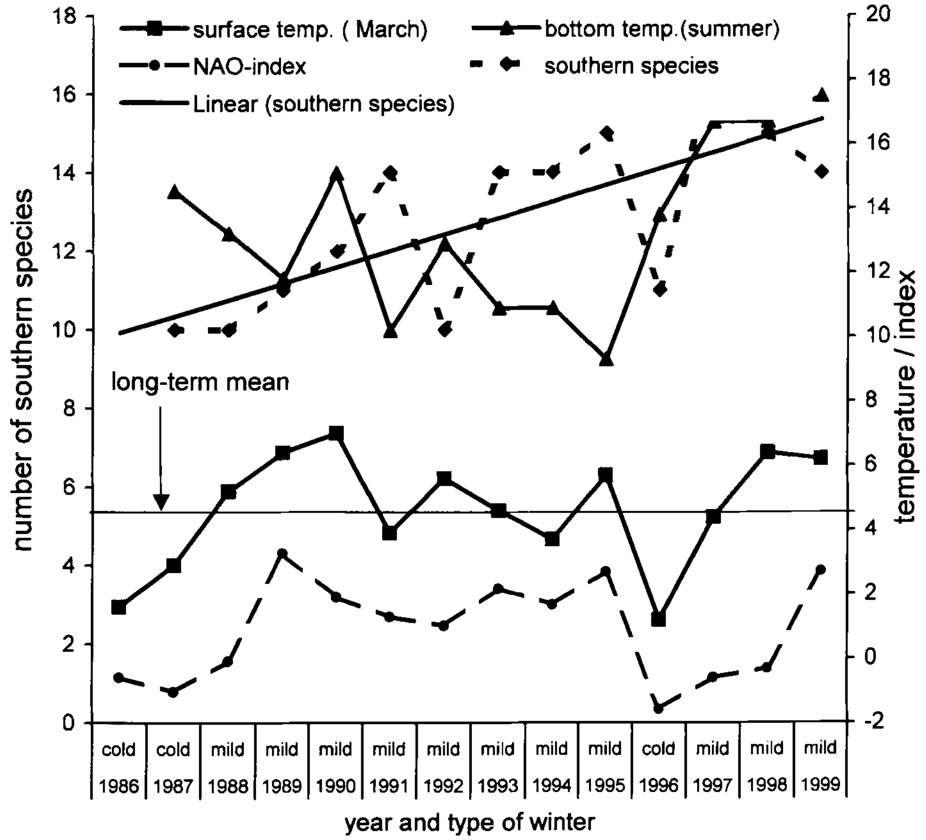

Fig. 3. Number of southern species (%) in relation to mean bottom temperatures for all boxes in 1999 (boxes are marked by letters).

Table 3. Mean number of southern species (%) per box.

	Box A	Box B	Box C	Box D	Box E	Box F	Box H	Box K	Box L	Box M
mean no. of species	27.2	23.5	23.3	30.9	21.9	20.1	18.7	20.8	23.0	20.0
mean no. of southern species	12.8	6.7	4.5	10.2	10.6	9.5	2.6	6.8	5.0	5.0
% of southern species	47	28	19	33	48	47	13	32	22	25

Discussion

A total of 224 fish species has been recorded in the North Sea (Yang 1982). The present investigation is based on only 85 of them. This small number is not only an effect of the position (only offshore) and size of the small boxes or the short duration of investigation, but also a gear effect. The qualitative and quantitative species composition in a haul strongly depends on the type of gear used. The GOV-trawl is a high opening bottom trawl with a light ground rope and a head-line around 5 m above the bottom. Thus, the net is constructed to catch fish, which live close to the bottom or a few meters above the bottom like haddock, cod and whiting. Flatfishes and small bottom living species like dragonets, sandeels and Gobiids are only partly caught by the trawl, for they are able to escape under the fishing-line or through the larger meshes in the first part of the net (Dahm & Wienbeck 1996). Only the part of the pelagic species like herring, mackerel and horse mackerel, which occur in the 5 m layer above the bottom, is caught.

Bootstrapping simulations of the sampling in the box areas showed that about eight hauls are necessary to record more than three quarters of the fish species in a box, while an average of 20 hauls covered more than 90% of the fish species (unpubl. data). For most of the

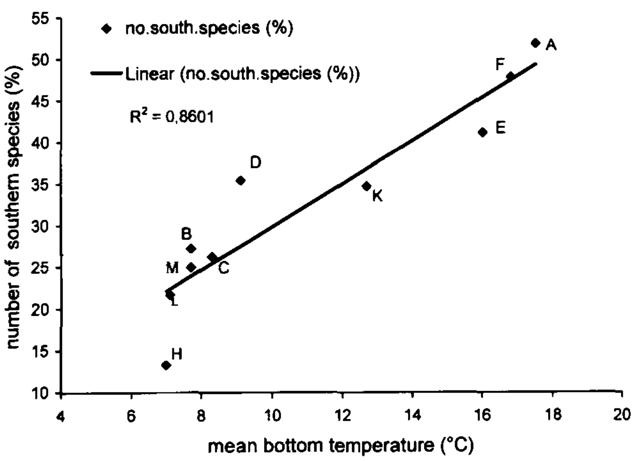

Fig. 4. Box A (German Bight). – Annual variation in the number of southern species, bottom temperatures during trawling, preceeding winter (March) surface temperatures and in the NAO-Index.

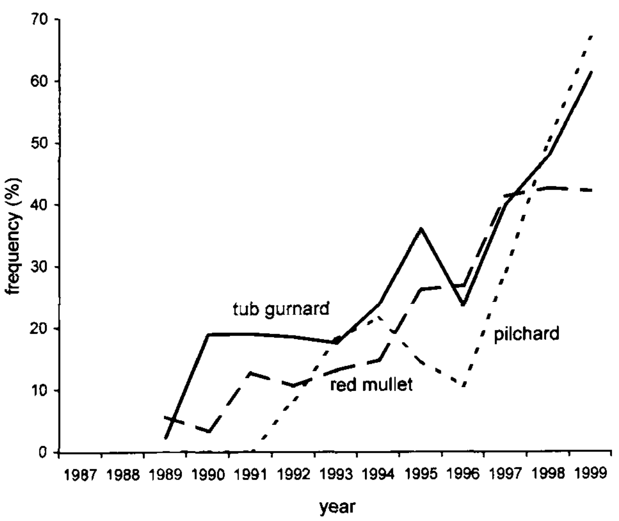

Fig. 5. Box A (German Bight). – Annual changes in frequency (3-times running mean) of the southern species red mullet (*Mullus surmuletus*), tub gurnard (*Trigla lucerna*) and pilchard (*Sardina pilchardus*).

boxes, around ten hauls were found to provide a sufficient precision in biomass estimates (PEARSON correlation of >0.9 between original and bootstrapped biomass values) for gadoid species (STRANSKY 1998).

The North Sea is an open system, which is connected with adjacent areas through the Skagerrak and the English Channel. The northwestern and northern boundaries are defined by depth. YANG (1982) defined the fish fauna of the North Sea belonging to three different faunal associations; 66 of the 224 species are boreal (the distribution of these species is centred north of the English Channel), 110 are Lusitanian (the distribution of these species is centred south of the English Channel) and 48 species belong to the Atlantic fauna (these species are widely distributed in the Atlantic Ocean). For this investigation, the separation of species into categories was done by using the most recent distribution maps of North-Atlantic fishes in the FNAM-Fish atlas (WHITEHEAD et al. 1984) and by assessing the geographical location of the species or subspecies specific distribution areas relative to the North Sea and not the English Channel.

The species of the southern category all belong to the Lusitanian fauna, except the two species *Helicolenus dactylopterus dactylopterus* (DELAROCHE 1809) and *Scomber scombrus* (LINNÉ 1758), which YANG (1982) has assigned to the Atlantic fauna (Tab. 2). The centre of distribution areas of both species is clearly situated south of the North Sea.

Using cluster analysis based on mean catches in weight of the English ground fish survey in summer, DAAN et al. (1990) separated three fish communities within the North Sea: the shelf edge, the central and the southern association. They found the major division between the southern and the central one along the 40 m depth contour, which separates the stratified and mixed water masses. According to OTTO et al. (1990), the transitional area between thermal stratified and thermal homogenous water masses is situated further south and this is more in accordance with the results of this study. The northern boundary of this area defined by OTTO et al. (1990) separates the southern boxes F, E, and A from the northern boxes. Box K, with a mean depth of 42 m, is situated within this transitional area. This explains the intermediate portion of southern species of box K relative to box A in the south and box C in the north.

The surprisingly low portions of southern species in the boxes B and H illustrate that, not only is temperature an important factor, but also the distance of the boxes to the entrances of the North Sea and the bottom currents, which support or hamper the faunal exchange between areas. In most years the temperature at the bottom in box D in summer is nearly 1°C higher compared to B and H. Looking at the currents of the North Sea (BECKER 1990), boxes B and H have no connections to the water masses coming from the Channel and flowing along the coasts of Belgium and the Netherlands into the German Bight. Boxes D, B and H are exposed to the influence of Atlantic water masses entering between Orkneys and Shetland Islands into the North Sea (Fair Isle Current). The larger distance between the northern entrance and box B compared to D could explain the lower portion of southern species in box B. The very low portion in box H can only partly be explained by the distance to the entrance. The position of box H in the centre of the North Sea within the area of weak and variable bottom currents (BECKER 1990) could be responsible for this finding.

The increase in the southern component of the fish fauna in the German Bight over the last decade could have been produced by a strong inflow of warm and hyaline Atlantic water through the Straits of Dover, by a series of mild winters, or by both. BECKER et al. (1992) identified extremely high salinity levels in the early 1990s in the southern North Sea and the eastern English Channel, which indicated such a strong inflow.

Changes in windstress are presumably the main cause of long-term variability. The rate of inflow through the

Straits of Dover is mainly a function of the north/south component of the wind (SALOMON & BRETTON 1993), with a maximum inflow at southerly winds.

The general air-circulation over the North-Atlantic is described by the North Atlantic Oscillation Index (NAOI), which is the normalised pressure difference between Iceland and the Azores, measured during the winter months December to March. Positive NAO anomalies are associated with strong southwesterly winds and higher temperatures in Western Europe. The southwesterly winds intensify the inflow of Atlantic water into the southern North Sea and high air temperatures reduce surface cooling.

According to REID et al. (1998), the NAO-Index increased from 1988 to 1990 to a very high positive level and remained positive until 1995. In 1996, the index was very low and in 1997 on a medium level (Fig. 4). In this figure, also the mean surface temperatures in March for the German Bight, the actual bottom temperatures during fishing and the number of southern species in box A during summer are shown. These three variables are not correlated with each other. But the mean March surface temperatures correspond quite well with the NAO-Index, for there are normal to warm winters from 1988 to 1997, only interrupted by the cold winter in 1996, which could be responsible for the decrease in southern species in box A during the following summer.

The nearly constant portions of southern species over the period in the southern area (box F) and in the area off the coast of the Netherlands (box E) point out that the German Bight is an area where the north- and eastwards migration of the species stops, where the southern species will accumulate and where they can stay over months or by chance where they could pass a mild winter without leaving the area.

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