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EcoShape

The importance of the surf zone for fish and brown shrimp in The Netherlands;

A literature review

EcoShape – Building with Nature

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Authors:	L.R. Teal (IMARES) O.A. van Keeken (IMARES)
Project manager:	M.J. Baptist (IMARES)
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P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00

Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00

Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 57
1780 AB Den Helder
Phone: +31 (0)317 48 09 00
Fax: +31 (0)223 63 06 87
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 167
1790 AD Den Burg Texel
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 62
E-Mail: imares@wur.nl
www.imares.wur.nl

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Summary

Human activity in the North Sea is increasing, involving more motorised cargo shipping, and rapidly expanding construction and operation of oil platforms and wind farms. Furthermore, the North Sea is used on a large scale for fisheries, military purposes and the extraction and suppletion of sand. Sand suppletion is used in the Netherlands to protect the beaches along the coast. In recent years, underwater sand levees or sand suppletion near shore has been performed for coastal protection. It has been suggested that new areas created as the result of sand suppletion offshore can create new opportunities for fish, because of an increase of the suitable habitat.

The aim of the literature review was to provide the necessary information required for the design of a survey, investigating the role of the shallow coastal area and the potential of newly created shallow areas. The focus was therefore on determining specific factors (season, depth, temperature, substrate, food etc.) which may influence the distribution and habitat suitability of a range of selected species and would therefore need to be monitored during the proposed survey. Unpublished measurements carried out by RIVO in the 1970s, as well as published information were used to summarise available knowledge.

The study describes the spatial and temporal patterns of fish species most common along the Dutch coast, and their habitat preferences. Using available data, nine species were selected for the literature study, consisting of commercially interesting fish species (plaice, sole, turbot, brill, sprat) and brown shrimp, as well as less commercial species that are abundant (lesser weever) and important prey items for e.g. birds (sand goby, sand eel, pipefish). The coastal zones of the Dutch part of the North Sea form important habitat for these species and are particularly important as nursery habitat for some commercial species (e.g. plaice, sole), which settle in the area before migrating further offshore as they grow. Others (e.g. sprat, brown shrimp) inhabit the area all year round.

Because all species encountered in this area are used to the seasonality of a temperate environment, they are generally adapted to a range of temperatures and are only likely to be affected when these exhibit extreme peaks. In terms of substrate, however, all species show a particular preference for a specific range of grain sizes, ranging from fine sand (e.g. turbot, plaice, sole) to medium/coarse sand (sandeel) and floating seaweed (pipefish). Substrate is often a key factor in determining the settlement of larvae in a particular area. It was further concluded, that strong seasonal as well as diel migration patterns need to be taken into account during the survey design in order to represent all species in a consistent manner.

1 Introduction

Human activity in the North Sea is increasing, involving more motorized cargo shipping, and rapidly expanding construction and operation of oil platforms and wind farms (Lindeboom *et al.*, 2008; Paramor *et al.*, 2009). Furthermore, the North Sea is used on a large scale for fisheries, military purposes and the extraction and suppletion of sand. These anthropogenic activities are sources of disturbance for the abiotic and biotic environment. Activities, specifically uncontrolled activities, may have unexpected, unwanted and possibly even irreversible effects on the marine ecosystem.

Sand suppletion is used in the Netherlands to protect the beaches along the coast, whereby sand is added onto the beach to strengthen and enlarge the beach. In recent years, underwater sand levees or sand suppletion near shore has been performed for coastal protection. It has been suggested that new areas made by sand suppletion offshore can create opportunities for fish, since they can enhance the habitat suitability.

Knowledge of the spatial distribution, seasonal patterns and specific habitat requirements of fish species is critical for assessing the extent to which these newly created habitats can be beneficial for fish communities. To assess this, fish occurrence and distribution in the coastal area is investigated. Knowledge on habitat requirements and preferences for species that inhabit the coastal zone can be helpful in enhancing or creating new habitats that are most suitable for the fish community. Because of the direct coupling between nursery size and population size (Rijnsdorp & Van Leeuwen 1992, MacKenzie et al. 2000) enhancing juvenile habitat and nursery grounds can be beneficial to the recruitment of a population.

The aim of this literature study is to summarise information which will be used to design and set up a survey aimed at investigating the role of the shallow coastal zone and the potential of newly created shallow areas in enhancing fish habitat. The review will focus specifically on spatial and temporal patterns (occurrence and distribution) of fish species most common along the Dutch coast, as well as specific environmental preferences, such as depth, temperature, substrate food requirements, etc. which influence the habitat choice of selected species. The results will provide the necessary information on the best times of year for sampling the fish community in order to represent the main users consistently, as well as which environmental parameters are most important to monitor during the survey.

2 Data

Most of the information presented here was found in the peer-reviewed literature. However, we also made use of existing survey data, both from the RIVO coastal survey and from the "NJN Strandwerkgroep".

RIVO data on fish abundance in the shallow North sea coast were obtained from the beach/coastal zone survey carried out by RIVO along the Dutch coast between 1974 - 1985. A total of 610 hauls were carried out between 1974 and 1985 across 17 areas. The survey consisted of hauls with a 2 meter beam trawl from a rubber boat (1974 - 1981), the Krab (1975 by the Wadden islands) and the Stern (1977, 1980 in Wijk aan Zee, Parnassia and Noordwijk). During this period 75 hauls were carried out from the beach using a push-net. Due to the weather dependence of sampling, most hauls (231) were done during quarter 3, quarter 2 (189 hauls) and quarter 4 (148 hauls), while, quarter 1 is relatively underrepresented (42 hauls). The survey effort is therefore subject to large seasonal and regional bias. All data are available in the IMARES database and have been quality checked according to standard procedures.

Data on fish abundance in the shallow coastal area along the Dutch coast were also available from the StrandWerkGroep (Beach Working Group) of the "Nederlandse Jeugdbond voor Natuurstudie" (NJN: Youth Organization Nature Studies) and published in their magazine (Sepia). During a weekend in September-October in 1998, 1999 and 2000, hauls were carried out with small trawls at six or seven different locations along the Dutch coast (Table 2.1 a, b, c).

These combined data give an overview for which species the coastal area might be important. Species were selected for this literature study based on both datasets. The selection consists of commercially interesting fish species plaice *(Pleuronectes platessa)*, sole *(Solea solea)*, turbot *(Psetta maxima)*, brill *(Scophthalmus rhombus)*, sprat *(Sprattus sprattus)* and brown shrimp *(Crangon crangon)*, as well as less commercial species that are abundant, i.e.lesser weever *(Echiichthys vipera)* and important prey items for e.g. birds, i.e. sand goby *(Pomatoschistus minutus)*, sandeel *(Ammodytidae sp.)*, pipefish *(Syngnathidae sp.)*.

Table 2.1a. Results from the trawling by StrandWerkGroep NJN in 1998 (20th of September). Data are numbers caught during the survey.

Species	Castricum	IJmuiden	Zandvoort	Noordwijk	Scheveningen
Ammodytidae		15	7	1	
Brill	4	10			
Dab		1			
Dragonet			1		
Grey mullet				5	
Lesser weever	18	1		1	
Plaice	16	1		2	
Sand goby	15	1			
Sandeel	1				
Sole			1		
Sprat	46	30	1	151	2
Sygnathidae	16	1		85	

Turbot	43	8	75	10

Table 2.1b. Results from the trawling by StrandWerkGroep NJN in 1999 (9th of September). Data are numbers caught during the survey.

Species	Bergen aan Zee	Castricum	Zandvoort	Scheveningen	Hoek van holland	Brouwersdam
Ammodytidae					1	
Anchovy				3		
Brill					1	1
Dab	1					
Glass-eel				50		
Lesser weever	7	3		5	1	
Plaice	9			2	2	1
Sand goby	21					173
Sand-smelt						1
Seabass						7
Brown shrimp	1400	13	60	540	115	4
Sole	3			4	2	
Sprat	975		47	1300	45	2
Sygnathidae	72		20	450	1	1
Turbot	5			1		
Whiting				6		

Table 2.1c. Results from the trawling by StrandWerkGroep NJN in 2000 on 1st of October. X = species present during the survey.

Species	Schiermonnikoog	Castricum	Zandvoort	Noordwijk	Scheve-ningen	Hoek van holland	Brouwersdam
Ammodytidae		x	x			x	
Anchovy		x					
Brill			x			x	
Dragonet							x
Lesser weever			x		x		
Plaice				x	x		
Sand goby		x	x			x	x
Sand-smelt					x		
Scaldfish				x			
Seabass				x			

Brown shrimp	x	x	x	x	x	x	x
Sole							
Sprat	x	x	x	x	x	x	
Sygnathidae			x	x	x		
Turbot		x					

Figure 2.1. Map of the locations sampled by the StrandWerkGroep NJN.

3 Plaice

3.1 Introduction

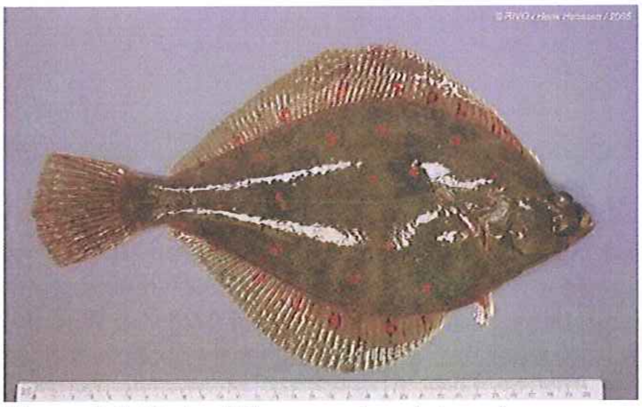


Figure 3.1. Plaice (*Pleuronectes platessa).*

The distribution of plaice ranges from the western Mediterranean Sea, along the coast of Europe as far north as the White Sea and Iceland, with occasional occurrences off Greenland (Nielsen, 1986). Plaice is a demersal boreal species that can reach a maximum length of a meter (Yang, 1982; Ellis *et al.*, 2002; Ellis *et al.*, 2008). It can reach an age of 50 years (although due to fishing pressure this age is not reached anymore) and matures at an age of 2 to 5 years; males mature earlier than females (Rijnsdorp, 1989). Plaice is a determinate batch spawner, which spawns pelagic eggs and shows seasonal migration from feeding areas to spawning areas. Plaice is an important commercial species in European waters, especially for the Dutch beam trawl fleet, and has been exploited for centuries. It is therefore also one of the best studied flatfish species in the North Sea.

The Dutch part of the North Sea has been shown to be a very important nursery area for juvenile plaice (Table 3.1, Rijnsdorp *et al.*, 1985; Teal *et al.* 2009), but the Dutch EEZ is also of importance for eggs, larvae and adult plaice (Taylor *et al.*, 2007; van Damme *et al.*, 2009). Due to the ontogenetic shifts in distribution and size-dependant distributions throughout the North Sea it can be assumed that the habitat requirements of plaice change throughout their life-cycle.

Table 3.1. Summary of the importance of the Dutch EEZ for different life stages of plaice at different times of the year. Eggs and larvae information is provided on a monthly basis, juvenile and adults on a quarterly basis. Importance levels (none or close to none = white; low = yellow; medium = orange; high = red; grey = unknown) relate to the extent of the distribution of each life stage within the Dutch EEZ and are based on best estimates from current knowledge (from Teal *et al.* 2009).

Month	1	2	3	4								
Eggs	*Med*	*Med*	*Med*									
Larv		*Med*	*Med*	*Med*								

ae		🟧	🟧	🟧								
Juveniles	*Med*			*High*			*High*			*Med*		
Adults	*Med*			*Med*			*Med*			*Med*		

3.2 Temporal patterns

Plaice spawn during the winter and eggs can be found in the plankton in the southern North Sea from December through to March/April, although the peak spawning period is usually late January to early February (Ehrenbaum, 1905; Russel, 1976; van Damme *et al.*, 2009) with potential recent shifts to an earlier end of spawning being observed in relation to sea temperature rise (Teal *et al.*, 2008). Time to hatching of eggs is temperature-dependent and can take between 7-14 days (at 10°C) up to 20-21 days (at 6°C; Fox *et al.*, 2003; Bolle *et al.*, 2009).

Larvae occur in the plankton between February and April and metamorphosing larvae (stages 4 and 5) enter the nursery areas in March and April (Rijnsdorp *et al.*, 1985). Following metamorphosis and settlement, 0-group plaice spend their first growing season in the shallow waters of estuaries and sandy beaches (Gibson *et al.*, 1973; van der Veer, 1986). In the Wadden Sea juvenile plaice can occur from February onwards (van der Veer and Witte, 1993), although seasonal variation in abundance depends on the exact location within the Wadden Sea (intertidal, sub-littoral or tidal channels). It has further been observed that juvenile plaice move offshore during the winter and back inshore the following spring (de Veen, 1978), which may be related to either avoiding cold temperatures, food or both.

Seasonal distribution patterns are also related to the age and size of the plaice. Juvenile plaice show a mainly coastal distribution (Figure 3.1), while older plaice gradually leave the shallow coastal waters and move into deeper waters further offshore (Figure 3.2; Wimpenny, 1953; Rijnsdorp and van Beek, 1991). Adult plaice undergo seasonal migrations between feeding grounds in the North during the summer and spawning grounds in the South during the winter (Greer Walker *et al.*, 1979; Metcalfe and Arnold, 1997; Hunter *et al.*, 2003).

3.3 Spatial patterns

The main spawning area of plaice is distributed around a number of hotspots in the southern North Sea (Harding *et al.*, 1978), including the Southern Bight and the central part of the southern North Sea, which overlaps with Dutch waters. Large concentrations of eggs are found on the south-western flanks of the Dogger bank (Heessen and Rijnsdorp, 1989; Taylor *et al.*, 2007) and in the area around and south of Fisher Banks (in the German bight; Taylor *et al.*, 2007; Munk *et al.*, 2009). Eggs are also found more sporadically off the coastal currents in other areas, as well as being abundant in the English Channel (Taylor *et al.*, 2007). Observations indicate that spawning is related to hydrographic features in the North Sea (Bolle *et al.* 2009), with peak abundances of eggs being found in areas of stronger frontal gradients (Munk *et al.*, 2009).

Coastal and inshore waters of the North Sea represent essential nursery areas (Table 3.1), with the most important areas in the German Bight and the Wadden Sea. These nurseries contribute the majority (50-90%) of the recruits to the North Sea plaice stock (Kuipers, 1977; Zijlstra, 1972; van Beek *et al.*, 1989). 1-group plaice also show a mainly coastal distribution while older plaice gradually leave the shallow coastal waters and move into deeper waters further offshore (Wimpenny, 1953; Rijnsdorp and van Beek, 1991). Two- and 3- group plaice are thus found progressively further offshore as well as further north (Figure 3.2). A positive relationship between depth and age/size of plaice can therefore be expected.

A study by Zijlstra *et al.* (1974) in the Dutch Wadden Sea showed that 0-group plaice are most abundant in the shallow, mainly intertidal, parts of the area (< 3m deep, Table 3.2). In the 0–3 m depth zone, plaice appear in the hauls from April onwards and abundances decrease from July onwards, with a dip in June. In the 4-8 m zone and the 9-20 m zone, 0-group plaice are not observed until May. After July densities in deeper water tend to increase, indicating a gradual migration to greater depths (Zijlstra *et al.*, 1974). Similar findings of a preference for shallower waters was found in an analysis of beach/coastal zone survey data. Although the differences were not significant ($p = 0.124$), the probability of plaice occurring increased slightly with an increase in depth (Figure 3.3; RIVO data 1974-1988). Again, this relationship is likely to be season-dependent due to the offshore migrations occurring in the winter as the fish grow.

Table 3.2: Distribution of 0-group plaice (numbers per 1000 m^2) at various depth ranges around high tide during the course of the 1974 season (number of hauls in parentheses). Data from Zijlstra *et al.* (1982).

Month	0-3 m	4-8 m	9-20 m
March	0 (18)	0 (15)	0 (8)
April	10.6 (28)	0 (16)	0 (6)
May	9.7 (14)	0.1 (15)	0.1 (10)
June	3.5 (13)	0.1 (11)	0.1 (7)
July	7.3 (18)	0.6 (16)	0.2 (9)
August	5.0 (23)	2.4 (11)	0 (9)
September	1.7 (9)	0.6 (9)	1 (1)
November	0.4 (19)	0.4 (7)	0.6 (17)

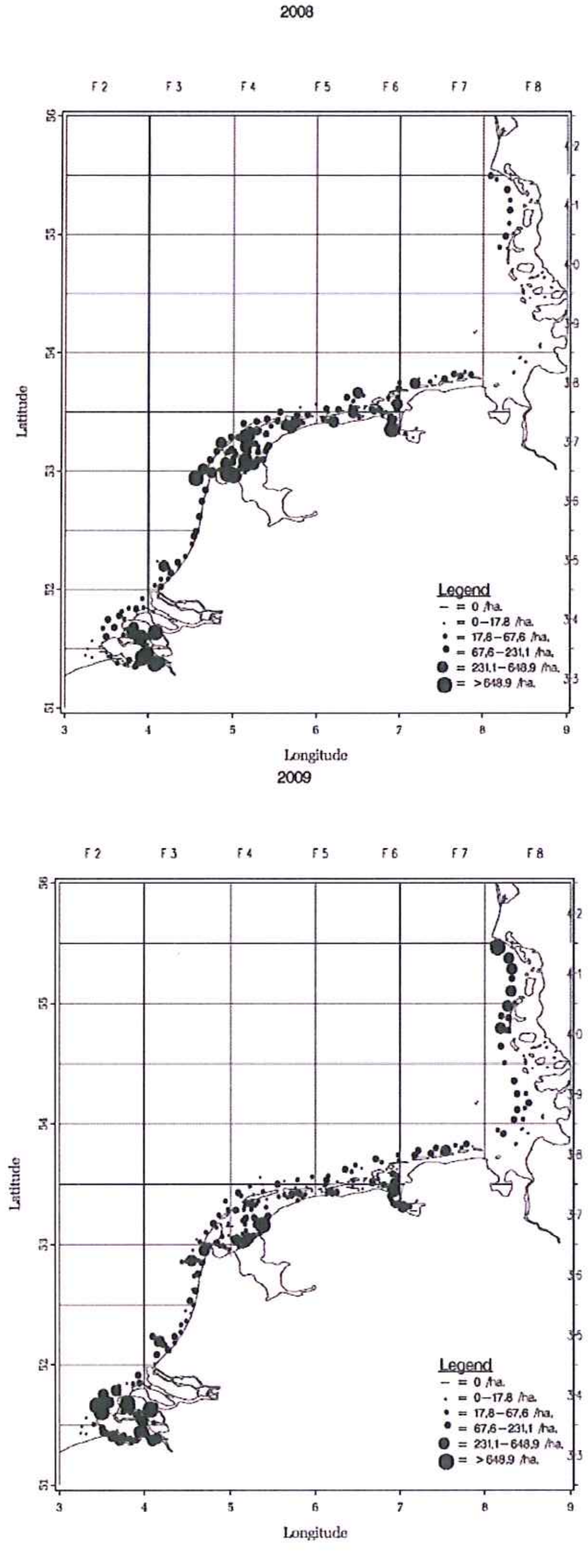


Figure 3.1. Number per ha for juvenile plaice in the quarter 3 DFS survey in 2008 and 2009 (IMARES unpubl.).

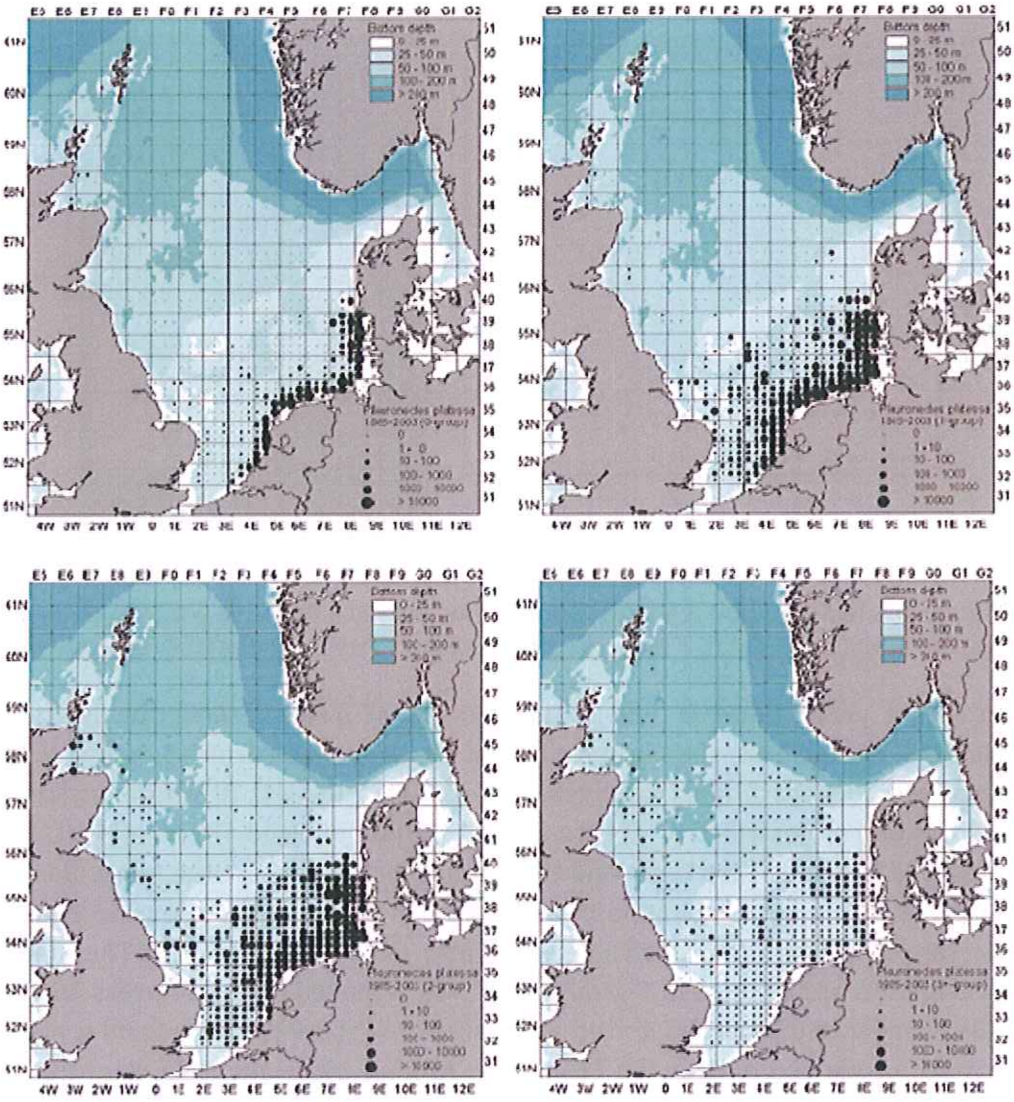


Figure 3.2. Average annual catch (number per fishing hour) for 0-, 1-, 2- and 3+ group plaice in the quarter 3 BTS survey, 1985-2003 (from ICES FishMap).

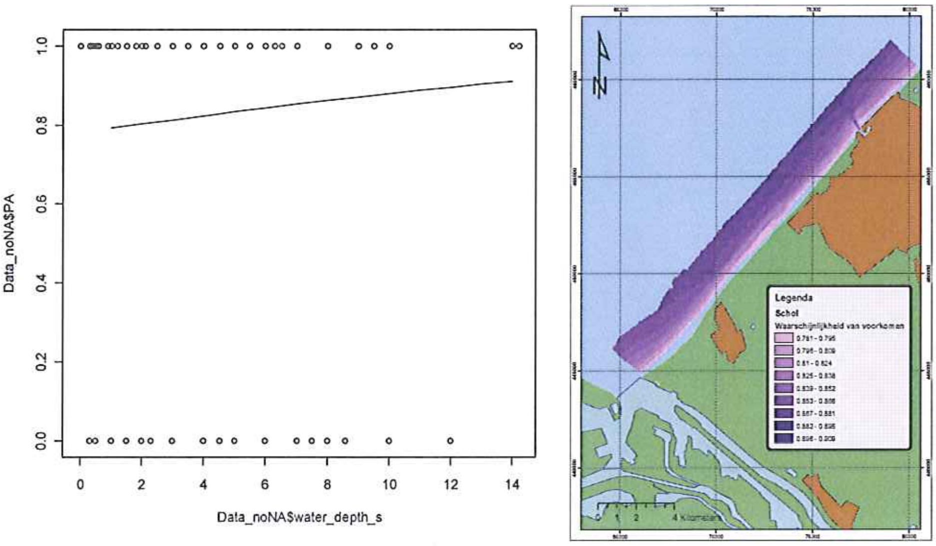


Figure 3.3. Relation between probability of occurrence of plaice with depth in the Dutch coastal area (RIVO data). X axis= depth in meters, Y axis =probability of occurrence.

In recent years, however, the spatial pattern of plaice distribution has shown some changes. An offshore shift in distribution of plaice has occurred, which was apparent already before the 1980s (Van Keeken *et al.*, 2007) and it is therefore questionable if the distribution as described by Zijlstra *et al.* (1974) is still valid. Distributional changes were observed in the German Bight and throughout the area where the Plaice Box (a technical measure to reduce exploitation of plaice within a specified are considered as importnat nursery grounds) was constructed, but also in the Wadden Sea. The shift in spatial distribution was clearest in 1-group Plaice which moved to deeper areas further offshore. The abundance of both undersized and marketable plaice decreased and showed the same pattern inside and outside the Plaice Box. Around 1990, about 90 % of the under-sized plaice occurred in the Plaice 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 (Grift *et al.*, 2004) and this shift has reduced the effectiveness of e.g. the Plaice Box as a technical measure to protect the under-sized plaice from discarding, since an increased proportion of the population of undersized plaice is moving offshore (Figure 3.4 & 3.5) to the more heavily exploited areas (Grift *et al.*, 2004; van Keeken *et al.*, 2007). The reasons for the offshore movement are hypothesised to be related to temperature (van Keeken *et al.*, 2007; Teal *et al.*, 2010).

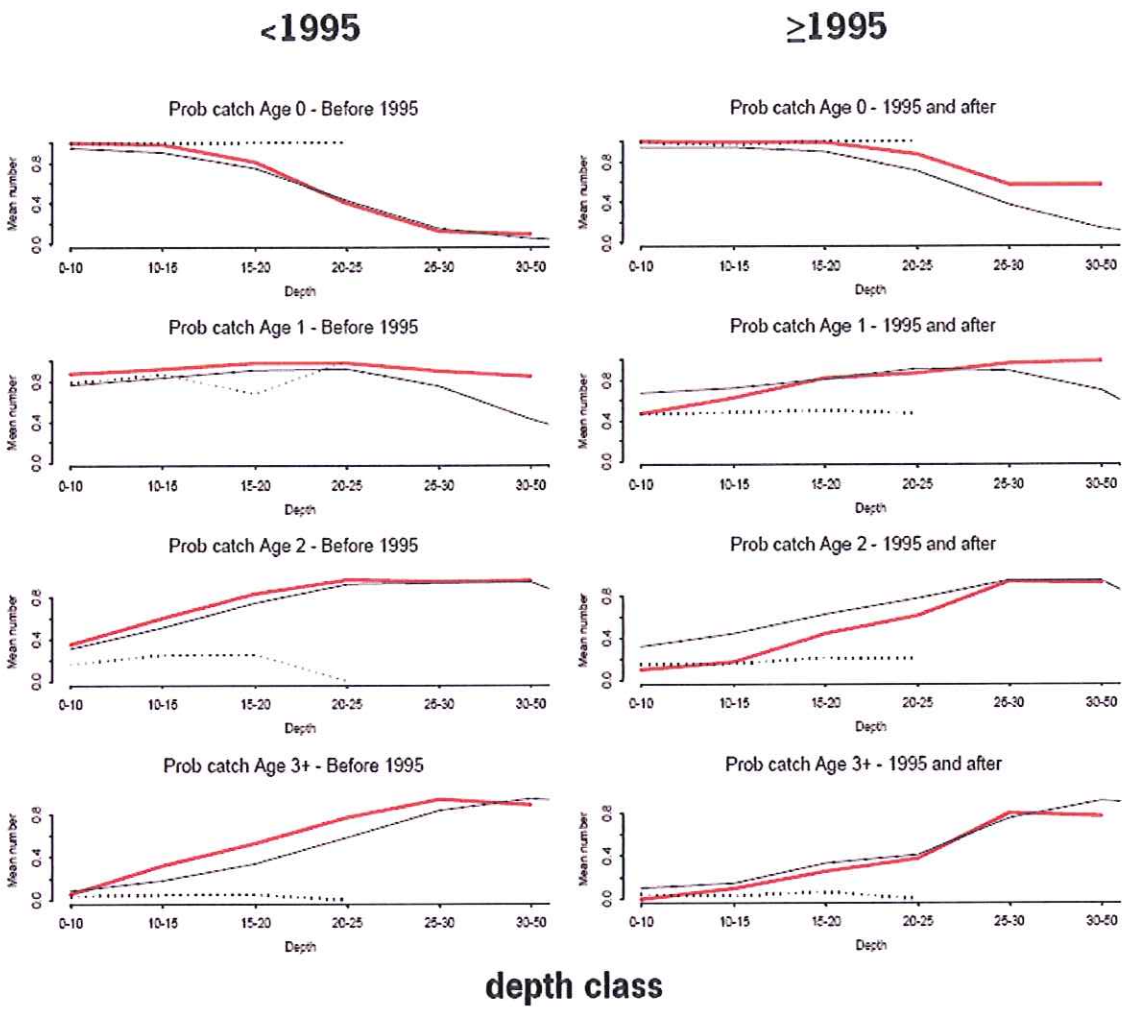


Figure 3.4. Probability to catch at least one Plaice per age group in relation to depth before 1995 (left) and from 1995 onwards (right). Bold line=Plaice Box, thin line=outside Plaice Box, dotted line=Wadden Sea (from Grift *et al.* (2004)).

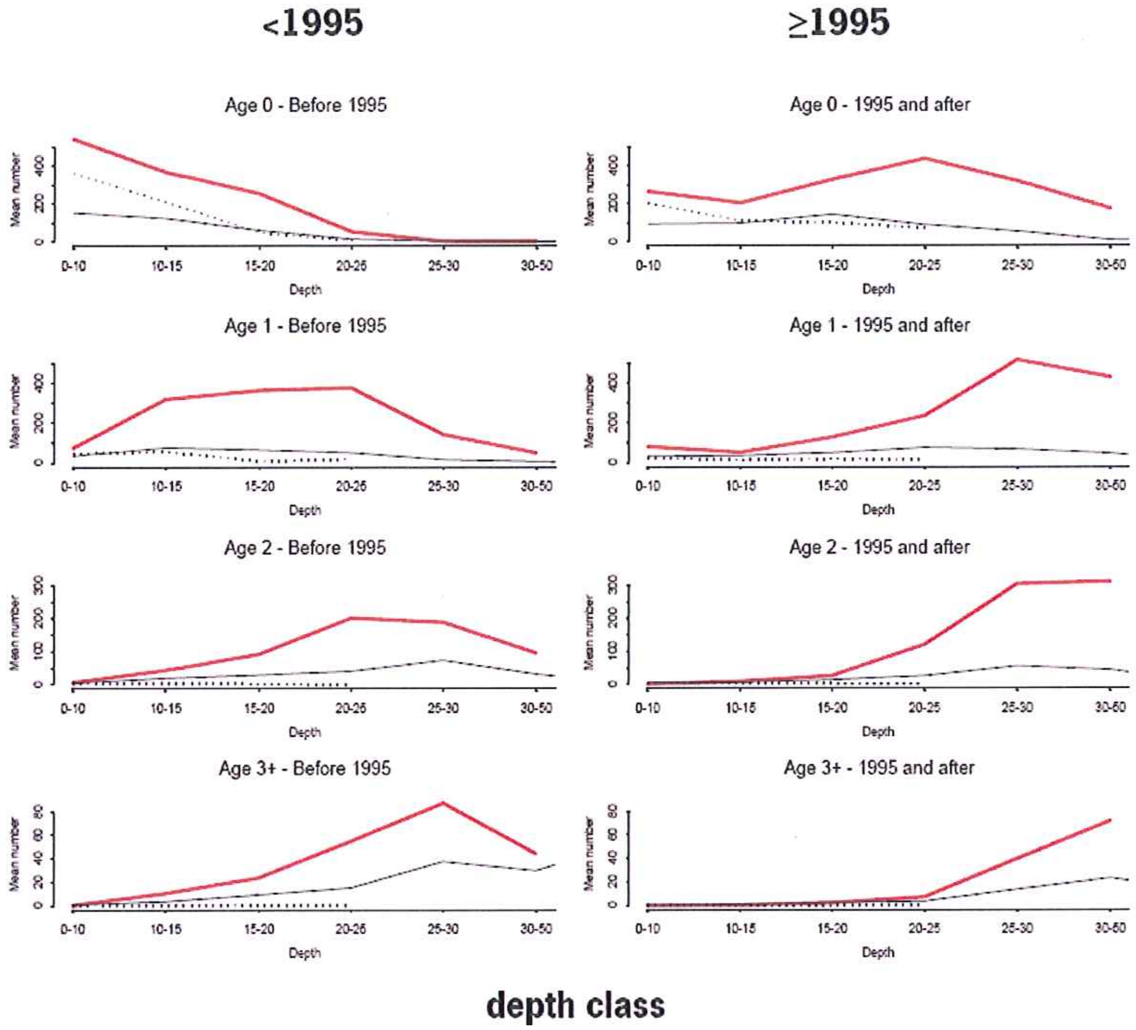


Figure 3.5. Mean catch rate per age group in relation with depth. Before 1995 (left) and from 1995 onwards (right). Bold line=Plaice Box, thin line=outside Plaice Box, dotted line=Wadden Sea (from Grift *et al.* (2004)).

3.4 Temperature

Plaice, as all fish, are ectotherms, and therefore temperature has a significant effect on physiological processes, making temperature a key determinant of habitat quality. The optimum temperature of a fish, however, depends on the food availability, as well as the size of fish. As ration levels reduce, the most efficient temperature for growth decreases, reflecting the lower metabolic coasts at lower temperatures. Substantial evidence also exists in a number of fish species, including plaice (Kuipers and Fonds, 1978; Fonds *et al.* 1992), that small (juvenile) fish grow well in, and will select for, a larger range of temperatures than larger (older) fish (e.g. Fonds *et al.*, 1992; Portner & Farrell, 2008), although the evidence of the underlying mechanisms is not clear. A commonly accepted assumption is that the decrease in optimal temperature of plaice is approximately 1°C per 10 cm increase in fish size (Van der Veer *et al.*, 2009, based on Fonds pers. comm.).

The relationship between growth and temperature (at *ad lib* food conditions) for different size classes of plaice is shown in Figure 3.6. For the juvenile plaice at 10 cm length, optimum temperature is found at ± 22°C, at 25 cm length this reduces to ± 20°C and at 40 cm length to ± 17°C.

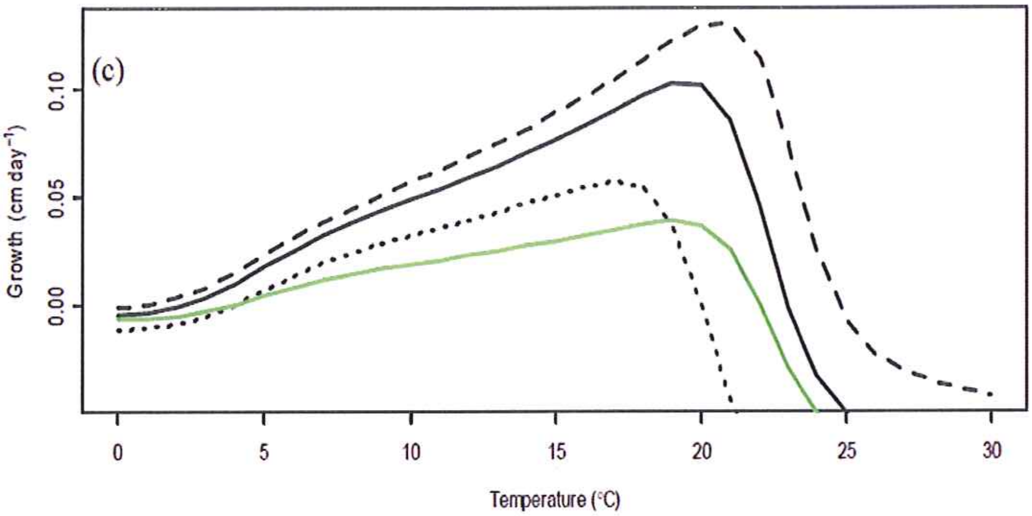


Figure 3.6. Growth curves predicted for plaice with a total length of 10 cm (dashed line), 25 cm (solid line, and 40 cm (dotted line) using Dynamic Energy Budget models at maximum feeding conditions. The green line represent the growth curve of a 25 cm plaice where feeding is at half the maximum rate (from Teal *et al.*, 2010).

3.5 Sediment

Flatfish (Pleuronectiformes) are uniquely adapted for a benthic lifestyle and substratum type is a major factor in determining their distribution (Burke *et al.*, 1991; Rogers, 1991; Jager *et al.*, 1993; Gibson, 1994, 1997; Wennhage & Pihl, 1994). Plaice are known to prefer sandy substrate, where they are able to bury themselves, over more coarse pebble or gravel substrate (Riley and Holford, 1965; Nasir and Poxton, 2001).

Sediment characteristics are also thought to be an important factor during larval settlement. In the western Wadden Sea, larvae settle in the same main areas each year, which are associated with a sediment consisting of fine sand with a moderate silt content (1.5 – 8%; Zijlstra *et al.* 1982). Riley and Holford (1965) report that suitable substrates range from very fine to coarse sand (> 500 mm) and that preference within this range is dependent on size of the plaice: newly-metamorphosed plaice settled on very fine sand and were able to bury in coarse sand later in their first year. The relationship between body size, grain size and burying ability in juvenile plaice (18 – 190 mm total length) was further investigated by Gibson and Robb (1992), who found a negative asymptotic relationship between sand grain size and the ability to bury for most size classes studied.

Preferences for older fish have also been studied in laboratory experiments. Gibson and Robb (2000) used plaice ranging from 40 – 50mm to test their preference towards four different sediment types: fine (<0.5 mm), medium (>0.5 and <1 mm), coarse (>1 mm and <2 mm) and very coarse (2–4 mm) and found a significant preference of plaice for the fine sand. Similarly, a study by Nasir and Poxton (2001) on a slightly smaller size class of plaice (mean total length 28.5 ± 6.7 mm) showed a significant preference for very fine (62-125 µm) sand. Whilst previous studies report a positive relationship between size and grain-size preference for newly-metamorphosed plaice (Riley and Holford, 1965; Gibson and Robb, 1992), Gibson and Robb (2000) found no significant size-dependence preferences for fish ranging from 16.5 to 104.5 mm. Instead, a preference for the two finest sediment types (fine, < 0.5 mm, and medium, > 0.5 and < 1mm) was observed across the range of sizes tested. Results of laboratory experiments were consistent with results found in field observations (Gibson and Robb, 2000).

3.6 Other factors

Food: Braber and de Groot (1993) report that juvenile plaice feed mainly on the polychaete worms *Pectinaria* and *Nereis*, and on *Macoma baltica* siphons. Older stages also feed on the worms *Arenicola* and *Lanice*. This is the most important food type till about 30 cm. Braber and de Groot (1993) reported that larger plaice mainly feeds on molluscs as *Macoma, Angulus, Ensis, Spisula, Donax* and *Venus*. The second most important food items of plaice are crustaceans, mysids, brown shrimp and hermit crabs. Occasionally echinoderms (*Asterias*) and fish were found in the stomachs. Rijnsdorp and Vingerhoed (2001) reported however that compared to the beginning of the 20th century, the preponderance of polychaetes has increased in recent years and that of bivalves has decreased.

Overall, there is a great variety in the food preference of this species. Polychaetes and molluscs are the most important phyla. Which of the two is preferred, mostly depends on their availability on the feeding ground. Their abundance is correlated with the bottom structure and the time of the year. Crustaceans are important especially in older plaice. First only mysids are eaten, but later on also decapods, like brown shrimps and hermit crabs. In British waters echinoderms play also an important role; not, however, in Dutch coastal waters (Braber and de Groot, 1993).

Laboratory experiments also show that food availability can influence the settlement of newly-metamorphosing plaice, which settle more frequently where more food is present (Figure 3.7; Wennhage and Gibson, 1996)

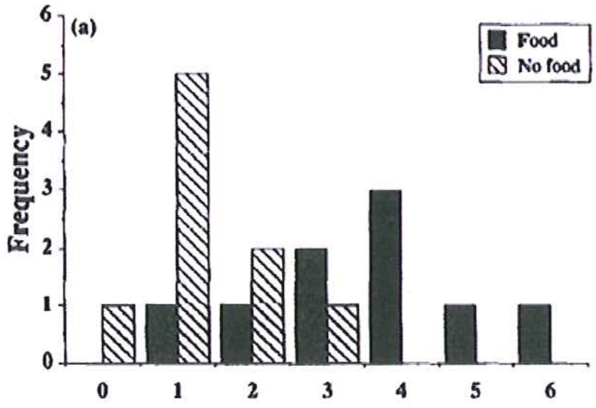


Figure 3.7. Frequency distribution of the number of newly metamorphosed plaice in the replicate trays of substrata with and without a benthic food supply (n = 9; from Wennhage and Gibson, 1996).

Predation: Laboratory experiments show that the presence of a predator (*Crangon crangon*) can influence the settlement of newly-metamorposing plaice. Presence of predators reduced the amount of time the plaice spent on the bottom (Figure 3.8; Wennhage and Gibson, 1996).

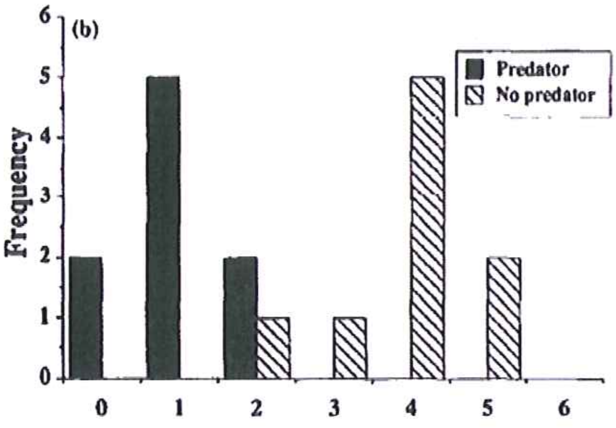
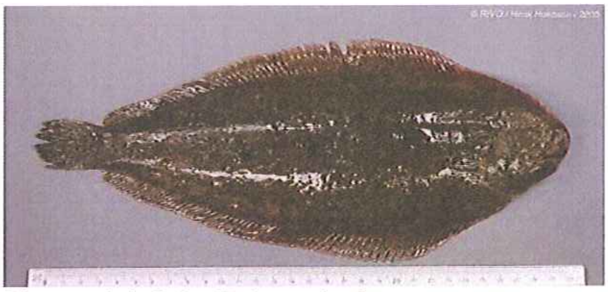


Figure 3.8. Frequency distribution of the number of newly metamorphosed plaice in the replicate trays of substrata with and without *Crangon crangon* as a potential predator (n = 9; from Wennhage and Gibson 1996).

4 Sole

4.1 Introduction



Picture 4.1. Sole *(Solea solea).*

The geographical range of sole extends from the northwest African coast and Mediterranean in the south to the Irish Sea, southern North Sea, Skagerrak and Kattegat in the north. They are sometimes caught in low numbers around Scotland and occasionally even along the southern coast of Norway (Wheeler *et al.*, 1969), but as a southern species, the North Sea is the northern limit. Sole is mainly found in the southern and eastern North Sea, south of the line from Flamborough to North Jutland. This line corresponds to the position of a steep temperature gradient that, in summer and autumn, divides the North Sea into a cold stratified northern section with bottom temperatures of about 7ºC and a warm mixed southern section with bottom temperatures of up to 17ºC. Sole tend to occupy shallow, sandy and sandy/muddy habitats which are widespread in the North Sea. The Dutch part of the North Sea is of medium importance for all life stages of sole in relation to their North Sea population and distribution (Table 4.1)

As for plaice, older and bigger individuals tend to occur in deeper waters than the juveniles (Figure 4.1), but they remain largely restricted to waters < 50m deep (ICES FishMap). Sole are batch spawners and females produce between 700 and 800 eggs per gram body weight, which corresponds to about 350,000 eggs for a 35 cm fish (Rijnsdorp *et al.*, 1992).

Table 4.1. Summary of the importance of the Dutch EEZ for different life stages of sole at different times of the year. Eggs and larvae information is provided on a monthly basis, juvenile and adults on a quarterly basis. Importance levels (none or close to none = white; low = yellow; medium = orange; high = red; grey = unknown) relate to the extent of the distribution of each life stage within the Dutch EEZ and are based on best estimates from current knowledge (from Teal *et al.* 2009).

Month			3	4	5	6						
Eggs			*Med*	*Med*	*Med*							
Larva				*Med*	*Med*	*Med*						

e				
Juveniles	*Med*	*Med*	*Med*	*Med*
Adults	*Med*	*Med*	*Med*	*Med*

4.2 Temporal patterns

Spawning takes place from spring to early summer and egg distribution studies have reported first spawning in March in the Southern Bight, developing northwards along coastal areas as the season progressed (van Beek, 1989). Peak spawning has been shown to occur in April or May (van Beek, 1989; van der Land, 1991). Following these peak spawning times and an egg development time of approximately 2 weeks (Knijn *et al.* 1993; Bolle *et al.*, 2005), larvae can be expected to show peak abundances between May and June.

Settlement of metamorphosing larvae occurs at a size of around 10-12 mm, at which point they settle into coastal areas and estuaries of the southern North Sea (Figure 4.1). As plaice, sole migrate offshore as they grow (Figure 4.2). In terms of daily patterns, it is generally accepted that sole feed mainly at night on the basis of anatomical and other evidence (Mackie *et al.*, 1980). De Groot (1971) concluded that feeding behaviour is primarily mediated by chemosensory mechanisms.

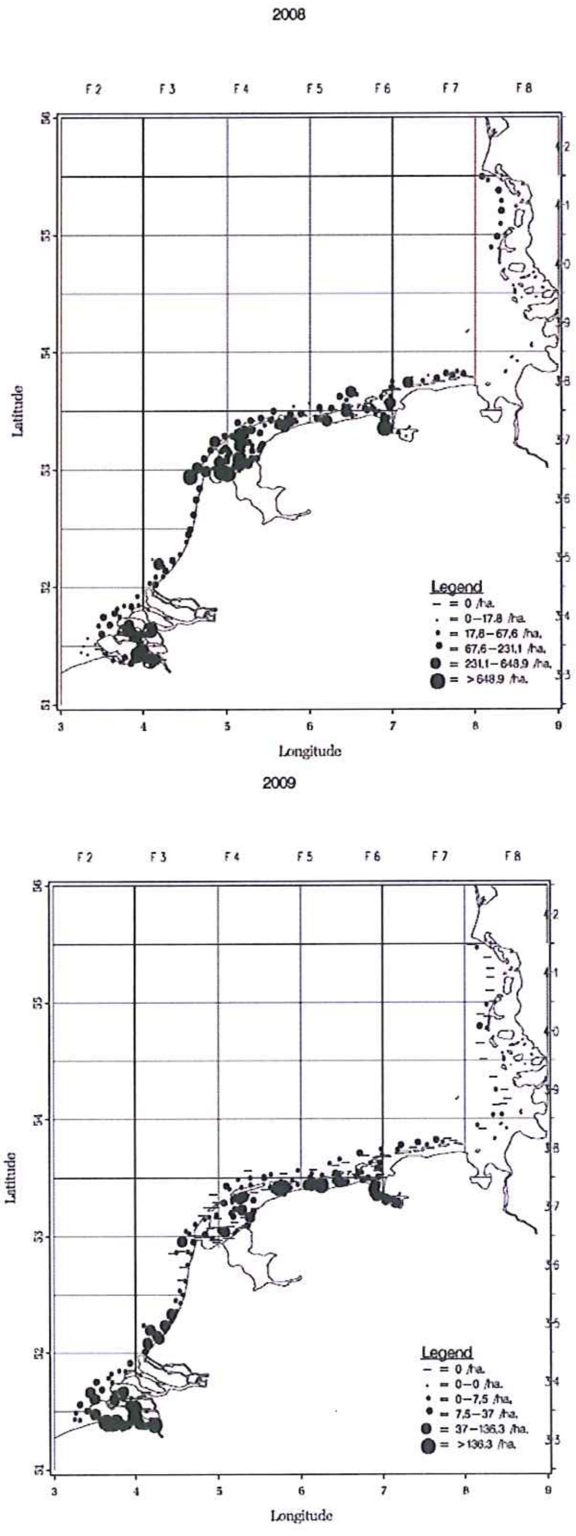


Figure 4.1. Number per ha for juvenile sole in the quarter 3 DFS survey in 2008 and 2009 (IMARES unpubl.).

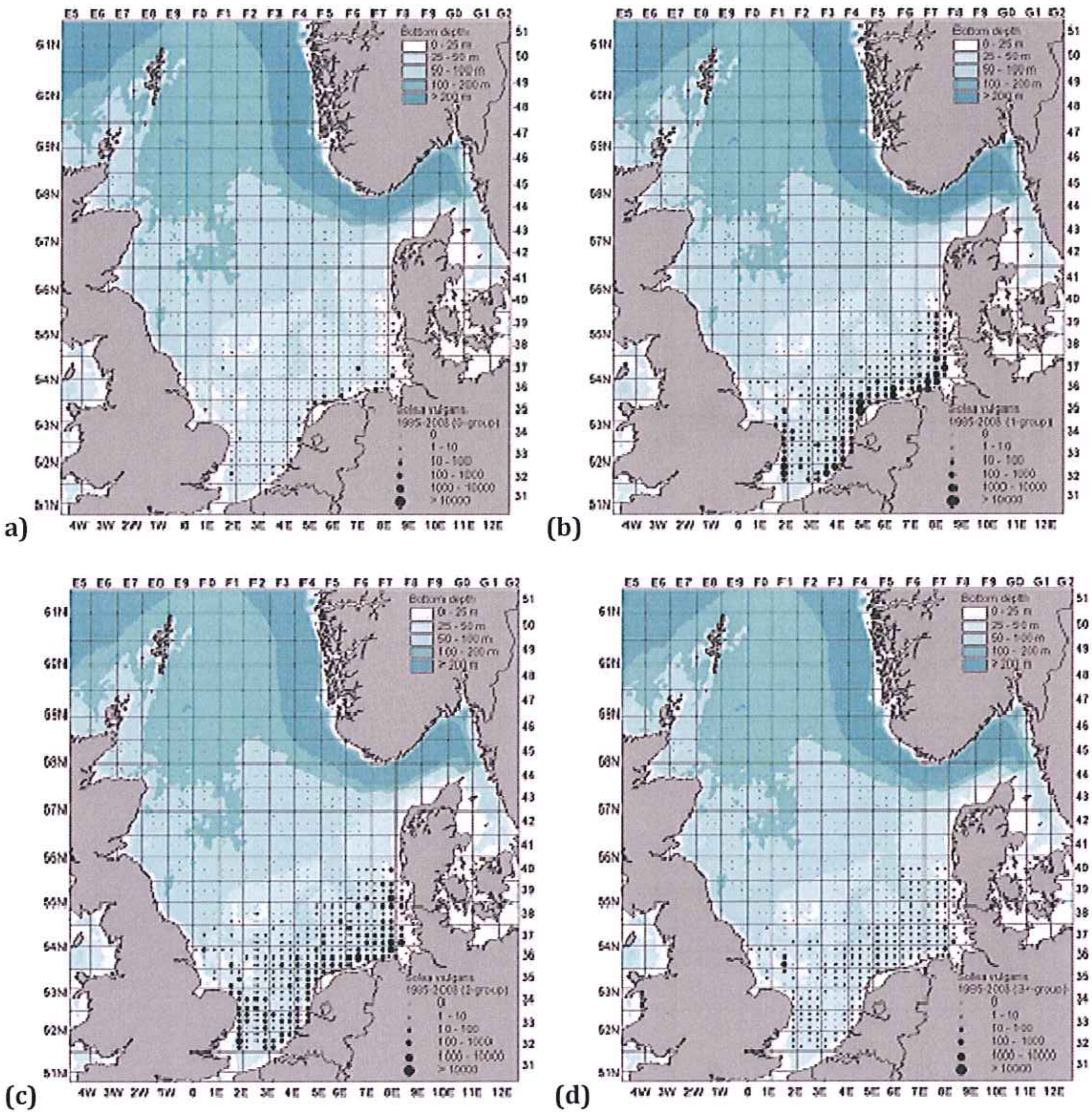


Figure 4.2. Average annual catch (number per fishing hour) for (a) 0-group, (b) 1-group, (c) 2-group and (d) 3-group sole in the quarter 3 BTS survey, 1985-2003 (from ICES FishMap).

4.2 Spatial patterns

Spawning of sole on the North Sea occurs mainly in southern areas in the English Channel and along the coast of Belgium, the Netherlands, Germany and Denmark. Within the spawning area (Figure 4.3), which is usually within the 30 m depth contour, highest egg densities occur in the Helgoland Bight and off the Danish coast (between 55° and 56° N), as well as off the Belgian Coast (van der Land, 1991; Bolle *et al.*, in prep). Passive transport of the larvae then occurs over short distances (Bolle *et al.,* 2005; Bolle *et al.,* 2009) and their spatial distribution will overlap with that of eggs and 0-group sole in the shallow coastal areas, including estuaries. Sole larvae live near the bottom (below a depth of 10-15m; Russell, 1976).

Unlike plaice, the intertidal areas along the southern coasts do not function as settlement areas and do not provide an important nursery area for 0-group sole (e.g. Balgzand, van der Veer et al. 2001, Dollard, Jager et al. 1993). Instead 0-group sole migrate into the subtidal and relatively deeper parts of the coastal areas where their distribution within the continental nursery areas can be quite variable between years (van Beek et al. 1989). The Dutch coast, Scheldt estuary and the Wadden Sea remain important nursery grounds for sole (van Beek et al. 1989).

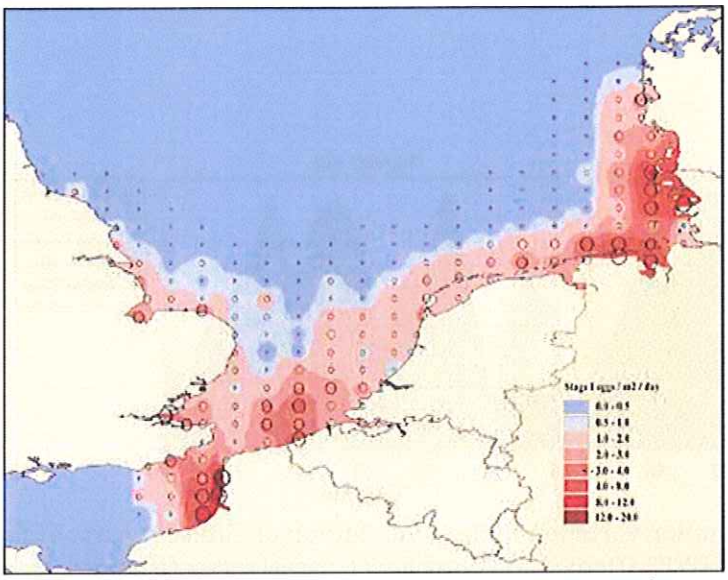


Figure 4.3. Spawning areas of *Solea solea* in the southern North Sea based on the occurrence of stage-I eggs (from Bolle *et al.* in prep).

Van Beek *et al.* (1989) investigated the contribution of the estuaries and the different coastal areas around The Netherlands to the overall abundance of sole and plaice. Data were used from a survey conducted in spring (April-May) and autumn (September-October) from 1969 until the end of the 1980's. Juvenile soles showed on average a less marked preference for estuarine areas in comparison with plaice and they also prefer slightly deeper water. The Wadden Sea and Scheldt estuary together contribute on average only 20% to the total abundance index of 0-group sole (Table 4.2), and other 80% is distributed in the shallow coastal areas. In 1-group sole the contribution of estuarine areas was further reduced.

Table 4.2. Distribution of 0- and 1-group plaice and sole (N/1000 m^2) by depth zone (m below mean LLWS)

Age group	Area	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	0.2	1.6	1.7
	Dutch Wadden sea	0.4	0.8	0.5
	Coastal areas	0.3	0.7	0.4

The distribution of the juvenile sole within the Dutch nursery areas appeared to be rather variable (Figure 4.4). Some year-classes showed 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, depending on the year-classes, the contribution to the 0- and 1-group production varies markedly between areas. For example, year-class 1981 was as 0-group 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. Year-classes 1983, 1984 and 1985 showed substantial increase of the contribution of the Belgian coast to the abundance index.

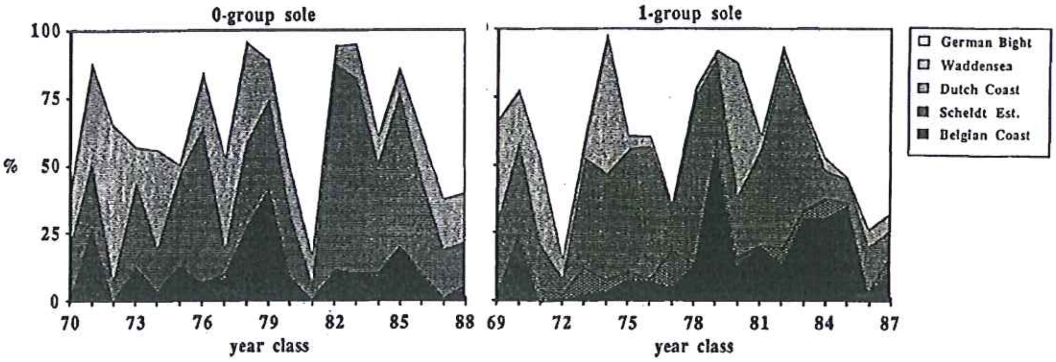


Figure 4.4. North Sea sole, annual variation in the contribution of different parts of the continental nurseries to the DYFS (Demersal Young Fish survey) index (from van Beek *et al.* 1989).

Van der Veer *et al.* (2001) used data from 1975-1982 and 1991-2000 to study the function of intertidal flats in the western Dutch Wadden Sea as nursery area for sole. Settlement occurred from May onwards, the timing being inversely related to water temperature in spring. Maximum densities were found in June, after which densities decreased due to migration into deeper waters. From the end of August onwards no 0-group sole occurred on the intertidal flats. Growth appeared to be density independent. The intertidal area only functioned as an important area of settlement for 0-group sole and as a nursery area for a relative short period during the first month of settlement.

A study of Le Pape *et al.* (2003) on juvenile sole in the Bay of Biscay (France) showed however that 0-group sole were concentrated in a few limited coastal sectors close to the shore near the main river mouths and in protected bays. Habitat variability was related to hydroclimatic conditions and did not significantly affect the contribution of the different bathymetric or sediment classes to the sole stock. A highly important role of very shallow (<5 m depth) areas in providing nursery grounds for sole was found (Figure 4.5). They considered areas deeper than 20 meter unsuitable as nursery area for sole during summer.

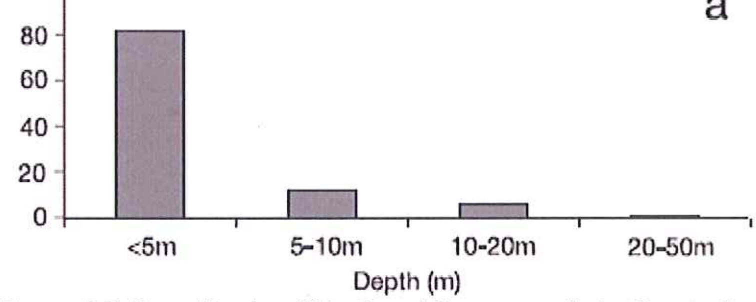


Figure 4.5. Contribution (% of total 0-group sole in the study area) of the different habitats according to bathymetry (Le Pape *et al.*, 2003) .

Eastwood *et al.* (2003) estimated the limits to the spatial extent and suitability of sole nursery grounds in the Dover Strait. In this area catch densities were generally highest within waters of approximately 3–20 m depth, at temperatures between 16–18°C, and at salinities greater than 33 psu. Highest catch densities in the Eastern English Channel were located in the shallow, higher salinity waters, and at temperatures between 16–18°C. In contrast to the pattern of distribution in the Dover straight, a clearer and more pronounced decrease in catch density with depth was seen in the Eastern English Channel. In addition, the relationship between catch density and both salinity and temperature in the Eastern English Channel differed from the relationship seen in the Southern North Sea, as a relatively constant mean catch density was found over the entire temperature and salinity range. However, the absence of robust estimates at the extreme upper and lower limits complicates the interpretation of overall trends in catch density across the entire range of temperatures and salinities encountered. A model made by Eastwood *et al.* (2003) predicted catch densities to decrease with depth and to be higher over sediments containing < 30% gravel. Variation in catch density over the temperature range was predicted to be minimal, albeit for a slight decrease in warmer waters.

RIVO data (RIVO data 1974-1988) show depth had a significant positive effect ($p < 0.001$) on the probability of sole occurring (Figure 4.6).

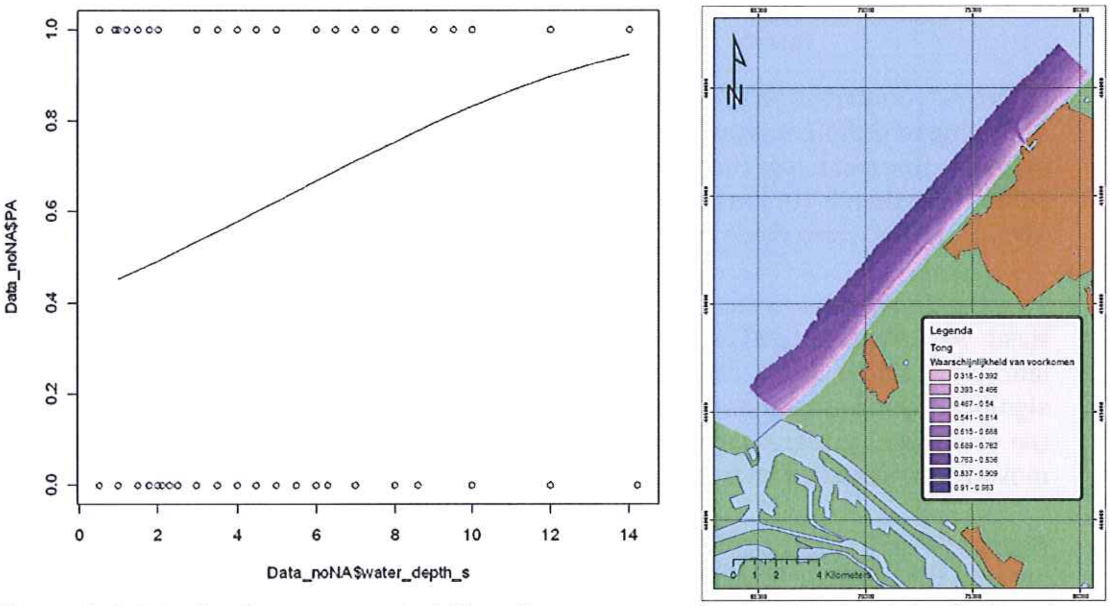


Figure 4.6. Relation between probability of occurrence of sole with depth in the Dutch coastal area (RIVO data). X axis= depth in meters, Y axis =probability of occurrence.

4.3 Temperature

Teal *et al.* (2008) investigated the effect of rising seawater temperature on growth of 0-group sole in the south-eastern North Sea for the period 1970 to 2004 using annual autumn pre-recruit survey data and frequent surveys on a nursery ground. Autumn length showed an increasing trend in sole. Increasing winter temperatures significantly increased the growing period of sole and growth rates increased with higher summer temperatures. Compared to experimental growth rates at ambient temperatures and unlimited food, observed growth rates were close to experimental values until mid-June but were much lower in July to September, suggesting food limitation in summer. The higher temperatures observed since 1989 positively affected the quality of the shallow coastal waters as a nursery area for sole.

Herderson and Seaby (2005) used a 24-year time series of monthly samples to investigate the factors correlated with long-term variation in the abundance and growth of sole in Bridgwater Bay in the Bristol Channel, England. Sole were found to be highly seasonal in their growth and only increased in length during the months of May to August inclusive. In recent years, there has been an approximately exponential increase in sole abundance that is highly positively correlated with seawater temperature during the early part of the season.

4.4 Sediment

Le Pape *et al.* (2003) studied juvenile sole abundance in the Bay of Biscay (France) in relation with sediment type. They made distinction in five grain size classes and showed that 0+ sole had a preference for mud (Figure 4.7).

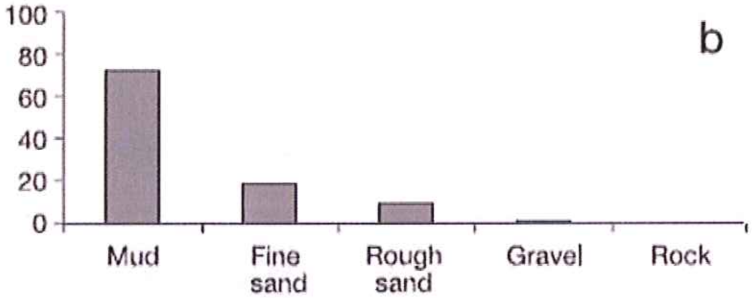


Figure 4.7. Contribution (% of total 0-group sole in the study area) of the different habitats according to sediment type (Le Pape *et al.*, 2003) . mud: more than 5% of less than 5 10 -5 m grains, fine sand: less than 15% of more than 2 10-3 m grains, rough sand: from 15 to 50% of less than 2 10-3 m grains, gravel: mean grain more than 2 10-3 m and less than 50% of pebble, rock: more than 50% of pebble.

Nasir and Poxton (2001) investigated substratum preferences of young sole in the laboratory under different levels of illumination. Settlement on a sandy substratum was significantly more frequent than on other substrata and the particle size of the sand affects the settlement preferences. Some of the sole settled initially on gravel and pebbles, but moved onto sand in a later stage.

Rogers (1992) studied sole abundance in relation to habitat characteristics in a nursery area on the coast of North Wales, UK. The distribution of juvenile sole during July (1988 and 1989 year classes) showed that juveniles were concentrated close inshore. This distribution also closely corresponded to the distribution of sediment median grain diameter less than 0.2 mm. Both juvenile sole and fine substrate occurred in a coastal strip to the southeast of the area near the mouth of the River Clwyd, and also in a discrete area close to the mouth of the River Dulas. Fish catches at stations used for determining sediment distribution indicated that high fish catch densities, i.e. greater than approximately 10 fish per 10^{-3} m^{-2}, did not occur in coarse substrates (MD > 2.3 ø (>0.20 mm)). The converse was not always true, however, as there were stations where substrate type appeared suitable (MD < ca. 0.20 mm), with low fish densities. The patchiness of the substrate within a nursery area is therefore likely to be of great significance to the distribution of juvenile sole. Sediment type alone should only be cautiously used as an indicator of site suitability. In this study, the use of the substrate as a single variable, while oversimplifying a complex system, can be justified by the limited geographical extent of the survey area, and the relatively restricted number of interrelated variables used. The occurrence of a few fine and homogeneous substrates which appear suitable, but which do not support a dense nursery population confirms that the nursery is a complex multivariate system.

Eastwood *et al.* (2003) also found that the catch density of juvenile sole was strongly related to the character of the seabed sediments with a decline in mean catch density from muddy through to gravelly sediments. However from different studies it appears that the exact range of depths and sediments that characterise a sole nursery ground has yet to be clearly defined. Since the maximum depth of a sole nursery ground would appear to be highly variable and location dependent, it seems unlikely that this can be considered a reliable generic definition. Rather than depth acting as a direct influence on the distribution of juvenile sole, it is probable that some other, interrelated factor, or a combination of factors, is responsible. Variations in depth will result in different environmental conditions between shallow and deeper waters. These could include physical factors, such as light penetration, temperature, salinity, local hydrodynamics, and substrate type, in addition to important biological factors, such as prey availability and predation risk.

4.5 Other factors

Density dependent growth: Rogers (1994) studied the effect of population density on growth for juvenile sole, occupying a nursery ground on the North Wales coast from 1988 to 1993. There was no evidence from this study that the growth rates of five consecutive year classes of sole on the North Wales coast nursery ground were influenced by cohort density. For example, the growth rates of the 1989, 1991 and 1992 year classes ranged from 0.54 to 0.57 $mm.d^{-1}$, and the mean length of the 1-group population from the strong 1989 year class was not significantly different from that of the 1990 year class, which had been almost absent from the nursery ground as 0-groups. The conclusion that there was no relationship between juvenile growth rates and the corresponding year-class strength, complements similar results that have been obtained from juvenile and adult sole in the North Sea (Rijnsdorp *et al.*, 1991).

The mean length of the 1988 year class in May 1989 (94 mm) was significantly lower than those of later year classes, even though the total number of days elapsed between the back-calculated date of settlement and the measurement of 1-group population mean length (369 d) was the largest of all years investigated. It appeared that a severe bloom of the colonial alga *Phaeocystis pouchetii* may have been associated with the reduced growth rate of juvenile sole in 1988. Stronger 1-group year class (e.g. 1989 and 1991) occurred at a greater mean distance offshore than weaker year classes (e.g. 1988 and 1992), indicating that strong year classes become widely dispersed in the nursery (van der Land, 1991).

Food: Nicolas *et al.* (2007) investigated the relation between benthic macrofauna and habitat suitability for juvenile sole in the Vilaine estuary (Bay of Biscay, France) nursery ground. In terms of prey availability, 0 and 1 group sole feed primarily on polychaetes, amphipods, and small bivalves (Eastwood *et al.*, 2003) all of which are found in close association with sandy and muddy substrates. The abundance of 0 group sole was correlated with an index of the benthic invertebrates biomass and, more specifically, with the biomass of suspension feeders. This result was reinforced by a one-dimensional spatial statistical analysis, which pointed out the similar distribution of invertebrate macrobenthos and juvenile sole along the upstream/downstream gradient of the estuary. Moreover, the inter-annual variations of abundance and distribution of juveniles were synchronous with those of the macrobenthos.

5 Turbot

5.2 Introduction


Picture 5.1. Turbot (*Psetta maxima*).

The geographical range of turbot extends from the Mediterranean and North Atlantic Ocean in the south to the Irish Sea, North Sea, Skagerrak and Kattegat in the north (Wheeler, 1969). Turbot is a demersal boreal species that lives in sandy and rocky habitat. It can reach a maximum length of 100 cm. Turbot is a determinate batch spawner and spawns between April and August at 10-80 meters depth. Important spawning grounds in the North Sea are found around the Aberdeen Bank and the Turbot bank in the North, and to the north of the Dogger Bank in the south (Knijn *et al.*, 1993). Eggs and small larvae are transported in the plankton until larvae settle at a length of about 25 mm. Turbot disperses to deeper water at older age.

Although turbot is only landed in small quantities (~5000t/year), turbot is extremely valuable food fish, which fetches a higher unit price than almost any other fish taken from the North Sea (Knijn *et al.*, 1993). Declining catches, together with high commercial value and high growth rate in intensive culture has made turbot a promising candidate for marine fish culture (Imsland *et al.*, 1996).

5.3 Temporal patterns

Spawning of turbot occurs during spring/summer (Jones, 1974). The embryonic development time is then very temperature sensitive and is doubled when water temperature is increased from 12 to 16 ºC (Gibson and Johnston, 1995a). Contrary to e.g. Pleuronectidae, turbot has a swim bladder during its larval stage (Evseenko, 1981) which has important implications for the transport of larvae from offshore spawning grounds to coastal nursery areas (Riley *et al.*, 1981). Time between hatching and metamorphosis varies according to ambient temperatures, but even with a constant temperature large plasticity in development time occurs. For a North Sea batch reared at 14-16 ºC metamorphosis was completed at day 45 for the first individual but not until day 72 for the last (Jones, 1973a). This variation in time from hatching to metamorphosis has the potential to influence the distribution of newly settled turbot since metamorphosis and settlement coincide for turbot like for most other flatfish (Nash and Geffen, 2005).

Turbot settlement in the coastal nurseries may occur from June/July until September at a size of around 3 cm (Jones, 1973b; Gibson and Johnston, 1995b).

5.4 Spatial patterns

In the North Sea, the turbot's main distribution area is found to be to the west of Denmark and in the Skagerrak and Kattegat (Knijn *et al.,* 1993). Compared with the distribution in winter, the centre of occurrence during the summer is situated further inshore, with juveniles more inshore compared to the adults (Figure 5.1, Heessen *et al.,* 2010).

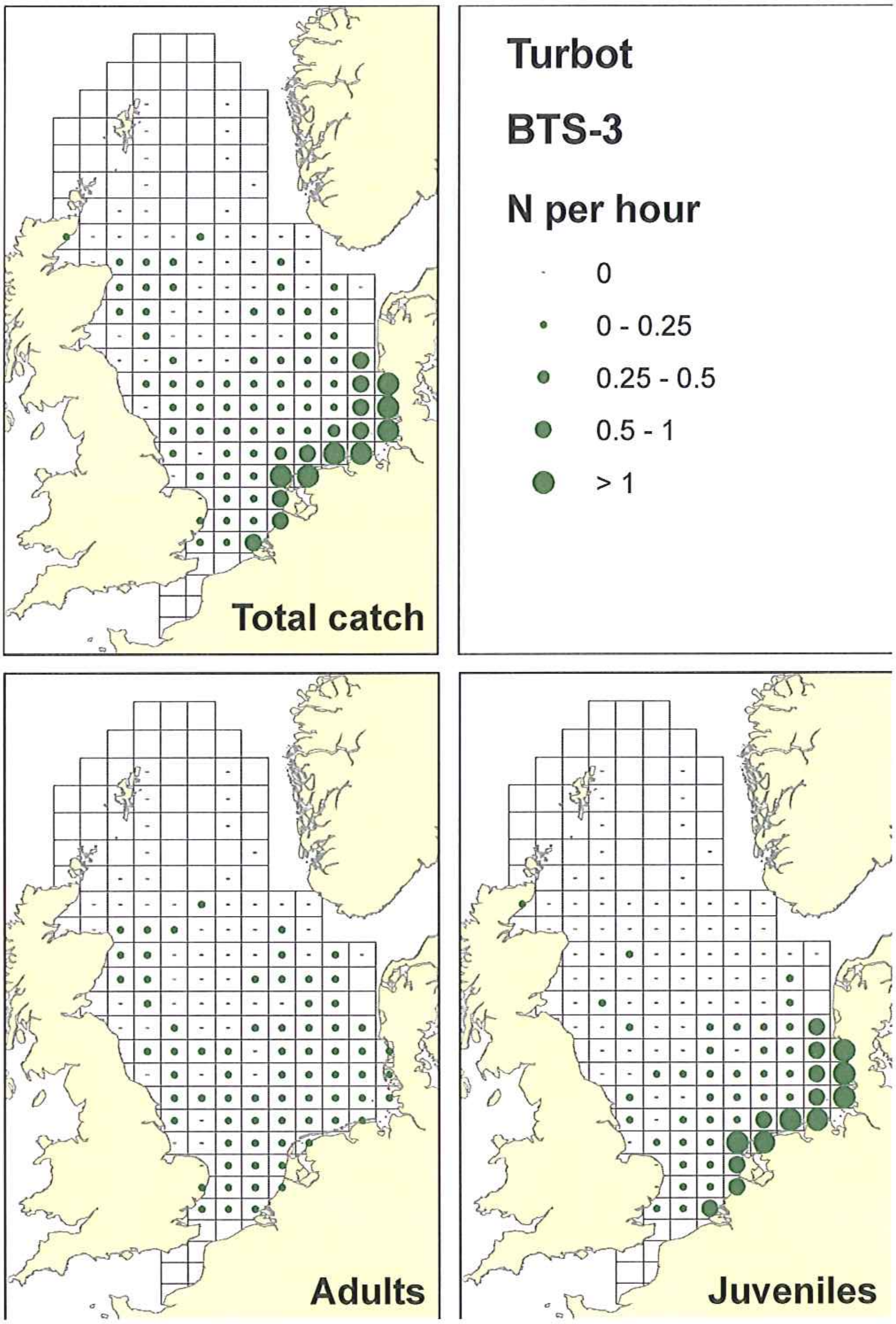


Figure 5.1a. Average annual catch rates from the BTS survey (numbers per fishing hour) in quarter 3 in the years 1985 – 2008 (from Heessen *et al.,* 2010).

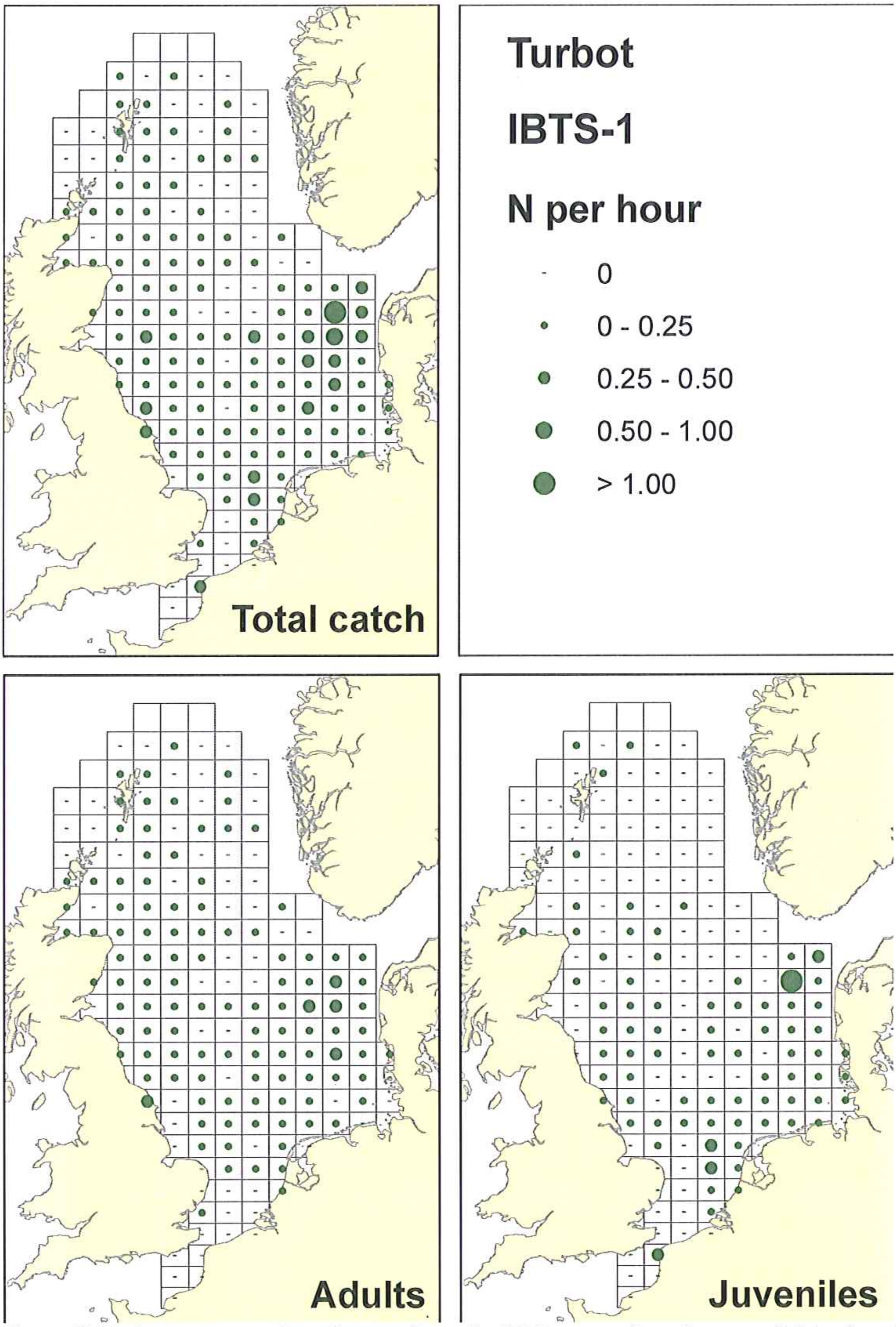


Figure 5.1b. Average annual catch rates from the IBTS survey (numbers per fishing hour) in quarter 1 in the years 1970 – 2009 (from Heessen *et al.*, 2010). Note that the IBTS survey is not ideal for sampling turbot due to the gear used.

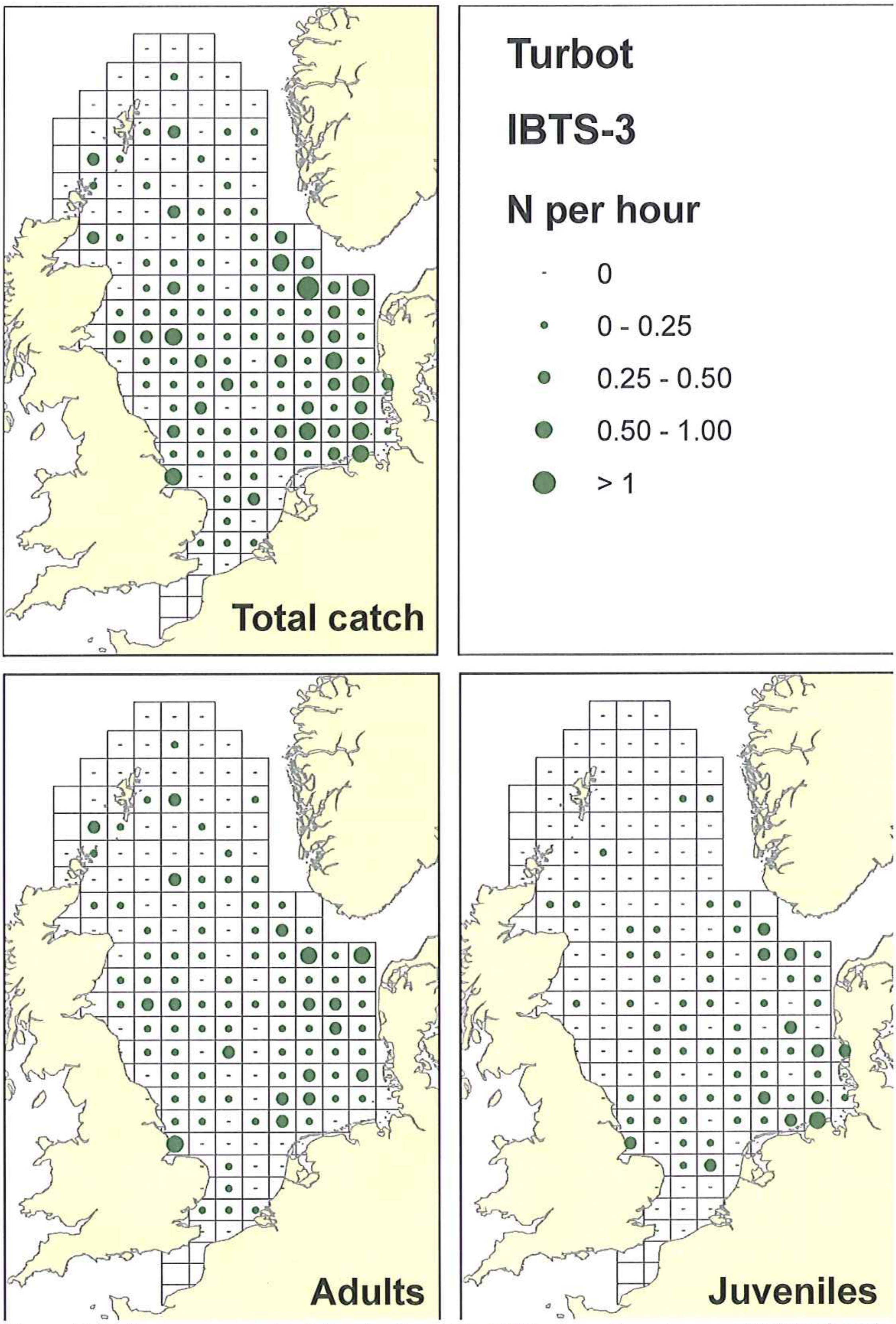


Figure 5.1c. Average annual catch rates from the IBTS survey (numbers per fishing hour) in quarter 3 the years 1985 – 2008 (from Heessen *et al.*, 2010). Note that the IBTS survey is not ideal for sampling turbot due to the gear used.

In the inshore areas of the Dutch coastal zone, which have been sampled by push nets in a coastal survey programme, depth showed a significant negative effect ($p < 0.0001$) on the probability of turbot occurring (Figure 5.2; RIVO data 1974-1988).

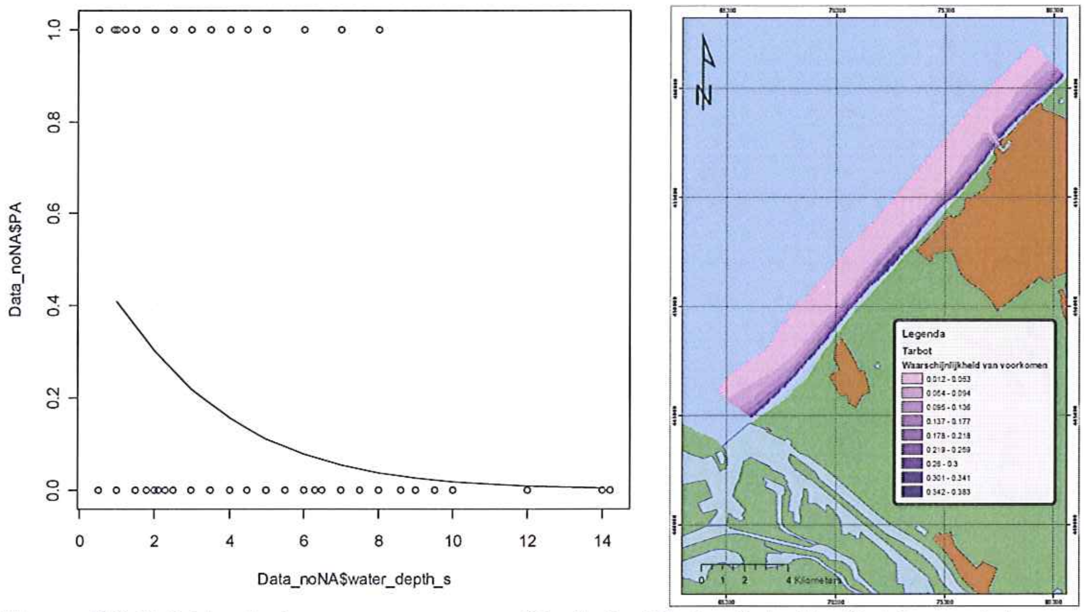


Figure 5.2. Relation between occurrence of turbot with depth in the Dutch coastal area (RIVO data).
X axis= depth in meters, Y axis =probability of occurrence.

Although depth is shown to have a negative effect on turbot occurrence based in the beach sampling data, it should be noted that depending on season and therefore size/life stage of the turbot, the relationship between occurrence and depth may change. The lifecycle of turbot can be divided into three ontogenetic stages which are characterized by a change in distribution and habitat association (Figure 5.3). After the planktonic egg and larval stages, the metamorphosed turbot settle in coastal zones (Riley *et al.*, 1981). After settling the juveniles remain in the shallow coastal zone but gradually increase their preferred depth as they increase in size. At around the age of 3-4 years, depending on sex, turbot matures and undergoes offshore spawning migrations.

Figure 5.3. A schematic overview of the lifecycle of turbot. Stage Ia shows the spawning, which takes place offshore. The eggs and larvae (Ib and Ic) are planktonic. Larvae are transported to the coast by wind driven current. Stage II is the juvenile stage in the nursery. There is seasonal determined migration between shallow and deeper waters and

as the size of turbot increases and mature (stage III) they gradually move to deeper waters (from Sparrevohn, 2008).

5.5 Temperature

Growth of turbot has been shown to have a positive relationship with temperature between 8 to 17°C, after which a plateau is observed from 17 to 20°C (Burel *et al.*, 1996). However, laboratory experiments also suggest that the optimum temperature of turbot is size-dependant, e.g. juvenile turbot in the size range 25–75 g show optimum growth between 16 and 19°C, but this optimal temperature for growth decreased rapidly with increasing size, and is between 13 and 16°C for 100 g turbot (Figure 5.4, Imsland *et al.*, 1996). These findings confirm that turbot exhibit ontogenetic variation in temperature optimum, which might partly explain different spatial distribution of juvenile and adult turbot in ocean waters.

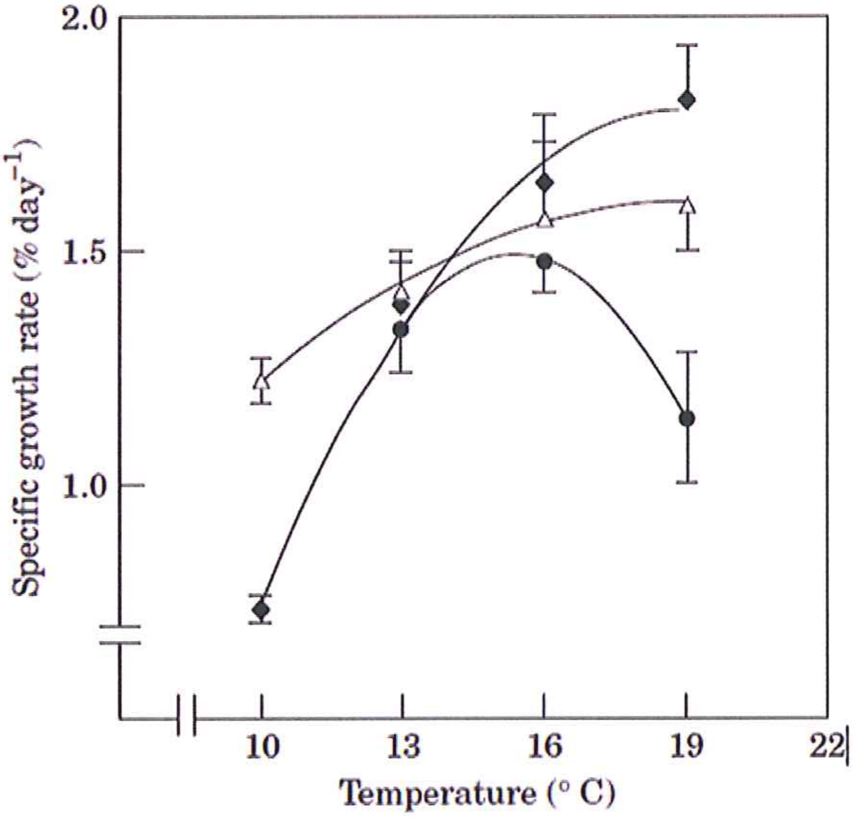


Figure 5.4. Changes in growth rate with temperature for three different sizes of juvenile turbot. The lines represent the least squares second-order polynomial fit to the data: G = aT2 + bT + c where G = specific growth rate, T – temperature, and a, b and c are constants determined by the regression. Vertical lines indicate standard error of mean. ◆ 25 – 30g; G = -0.013T2 + 0.487T – 2.854, small fish, n = 1- for each point. △ 45 – 50g; G = -0.005T2 + 0.182T – 0.061, medium fish, n = 20 for each point. ● 70 – 75g; G = -0.012T2 + 0.392T – 1.800, large fish, n = 20 for each point (from Imsland *et al.* 1996).

5.6 Sediment

Florin and Lavados (2000) looked at habitat preferences of turbot and found a preference for sandy sites, versus gravel (Table 5.1). The total number of turbot in the samples however, was very low (n = 5).

Table 5.1. Total number of flatfish caught in different habitat types, number of fish with empty stomachs within brackets (from Florin and Lavados, 2000).

Species	Substrate	Wave exposure		
		Extremely sheltered	Sheltered	Exposed
Flounder	Gravel	1	3	1
	Sand	6	31 (1)	16 (2)
	Soft		1	
Turbot	Gravel	1		
	Sand	4 (3)	19 (6)	1

In laboratory experiments, Nasir and Poxton (2001) tested the settlement of turbot (mean length 22.2 ± 5.4 mm) on 3 different substrates: sand (0.062 - 1mm), gravel (1 - 2mm) and pebbles (2 - 8mm) and found a strong and significant preference for sand over the other two substrates. In a second experiment, they then tested the preference between very fine (62 - 125 µm), fine (125 - 250 µm), medium (250 - 500 µm) and coarse 500 - 1000 µm) sand. A strong and significant preference was found for very fine sand (Nasir and Poxton, 2001).

5.7 Other factors

Salinity: Although adult turbot are found in seawater, there is some evidence that turbot, like many marine fish species, uses estuaries as nursery grounds for the juveniles. Kuhlman & Quantz (1980) observed that the best viable hatch of Baltic turbot occurred at 17°C and at a salinity of 1‰.

Short- and long-term effects of salinity changes have also been studied in juveniles (Waller, 1992; Gaumet *et al.*, 1994, 1995), where results show that this species is relatively euryhaline in the range 10–35‰; osmoregulatory disturbances are observed only below 6‰ (Burel *et al.*, 1996).

Exposure: Florin and Lavados (2000) looked at habitat preferences of turbot and found a strong preference sheltered versus exposed sites (Table 5.2).

Table 5.2. Total number of flatfish caught in different habitat types, number of fish with empty stomachs within brackets (from Florin and Lavados, 2000).

Species	Substrate	Wave exposure		
		Extremely sheltered	Sheltered	Exposed
Flounder	Gravel	1	3	1
	Sand	6	31 (1)	16 (2)
	Soft		1	
Turbot	Gravel	1		
	Sand	4 (3)	19 (6)	1

Food: The turbot is a voracious predator. Young turbot feed on a variety of benthic prey (e.g. polycheate worms, mysids), but at a length of approximately 20cm they switch to a diet consisting almost entirely of fish. Sandeels, gobies, herring, sprat, cod, whiting, haddock, Norway pout, dab and long rough dab, dragonets and lesser weever are only a few of the many species taken (Knijn *et al.* 1993).

Florin and Lavados (2000) calculated a preference index for dominating food items found in Baltic Sea turbot (chironomids, amphipods, gobies and mysids), which revealed a significant preference for mysids and a tendency for a preference of gobies, while chironomids and amphipods were eaten in proportion with their occurrence.

The proportion of fish and mysids in the diet increased with size while chironomids and *B. pilosa* decreased (Figure 5.5). The diet of turbot with a total length over 40 mm significantly differed from the diet in smaller size groups (ANOSIM: >40 mm vs. (31–40 mm): R = 0.31, p = 0.01; >40 mmvs. (21–30 mm): R = 0.24, p = 0.04; (31–40 mm) vs. (21–30 mm): R = -0.04, p = 0.51).

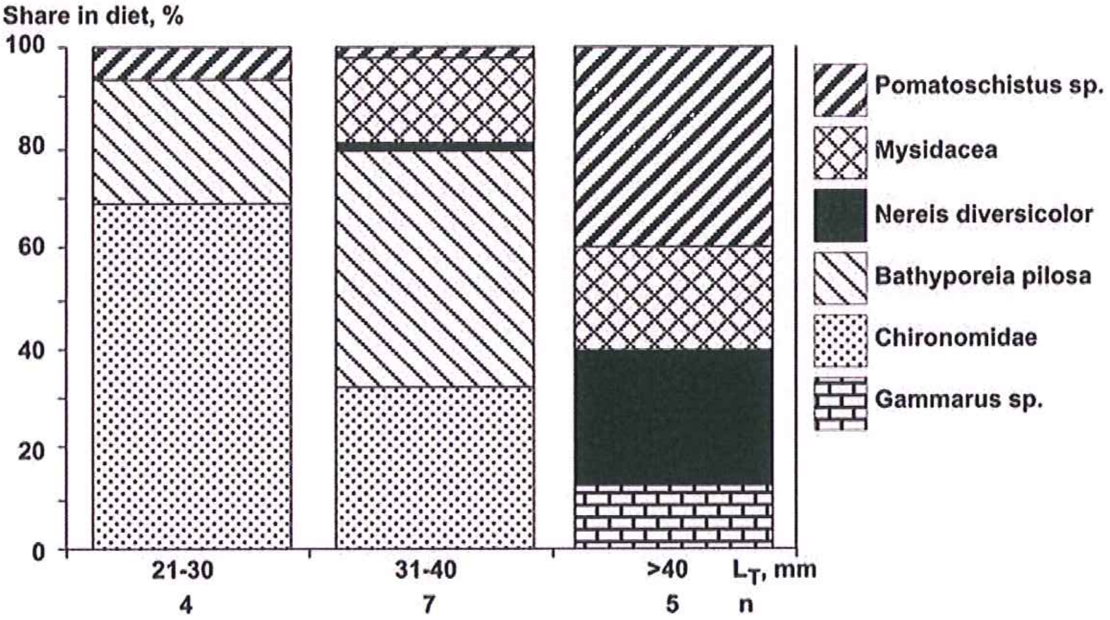


Figure 5.5. Diet composition in different size classes of turbot. n = number of individuals in each size group.

6 Brill

6.1 Introduction

Picture 6.1. Brill (*Scophthalmus rhombus*).

The biogeographical range of brill extends from the Mediterranean and North Atlantic Ocean in the south to the Irish Sea, North Sea, Skagerrak and Kattegat in the north (Wheeler, 1969). Brill is a demersal boreal species that usually lives in sandy habitat and can reach a maximum length of 75 cm. It is very similar to turbot in appearance, life cycle and distribution. Brill is a determinate batch spawner and spawns between March and August. Eggs and small larvae are transported in the plankton until larvae settle at a length of about 12-25 mm. Juvenile brill lives in the shallow coastal areas during the first two years, after which it moves to deeper water.

Brill is of moderate commercial importance, taken as bycatch in the fishery for sole and plaice. An average yearly catch of 1000 t was landed during the period 1960–1985 (Knijn *et al.* 1993).

6.2 Temporal patterns

The spawning period of brill overlaps with that of turbot, and can occur between March and August. Newly hatched young appear in the very shallow waters of the Dutch coast in July and August. 1–2 year old brill share this shallow strip of the sea with the 0-group specimens, but most brill have moved to deeper waters by the age of 3 (Knijn *et al.* 1993)

6.3 Spatial patterns

Brill is mostly caught in the southern part of the North Sea as well as in the Skagerrak and Kattegat. Only few specimens are caught in the northern North Sea, relatively isolated form the main concentration in the south (Figure 6.1; Heessen *et al.*, 2010).

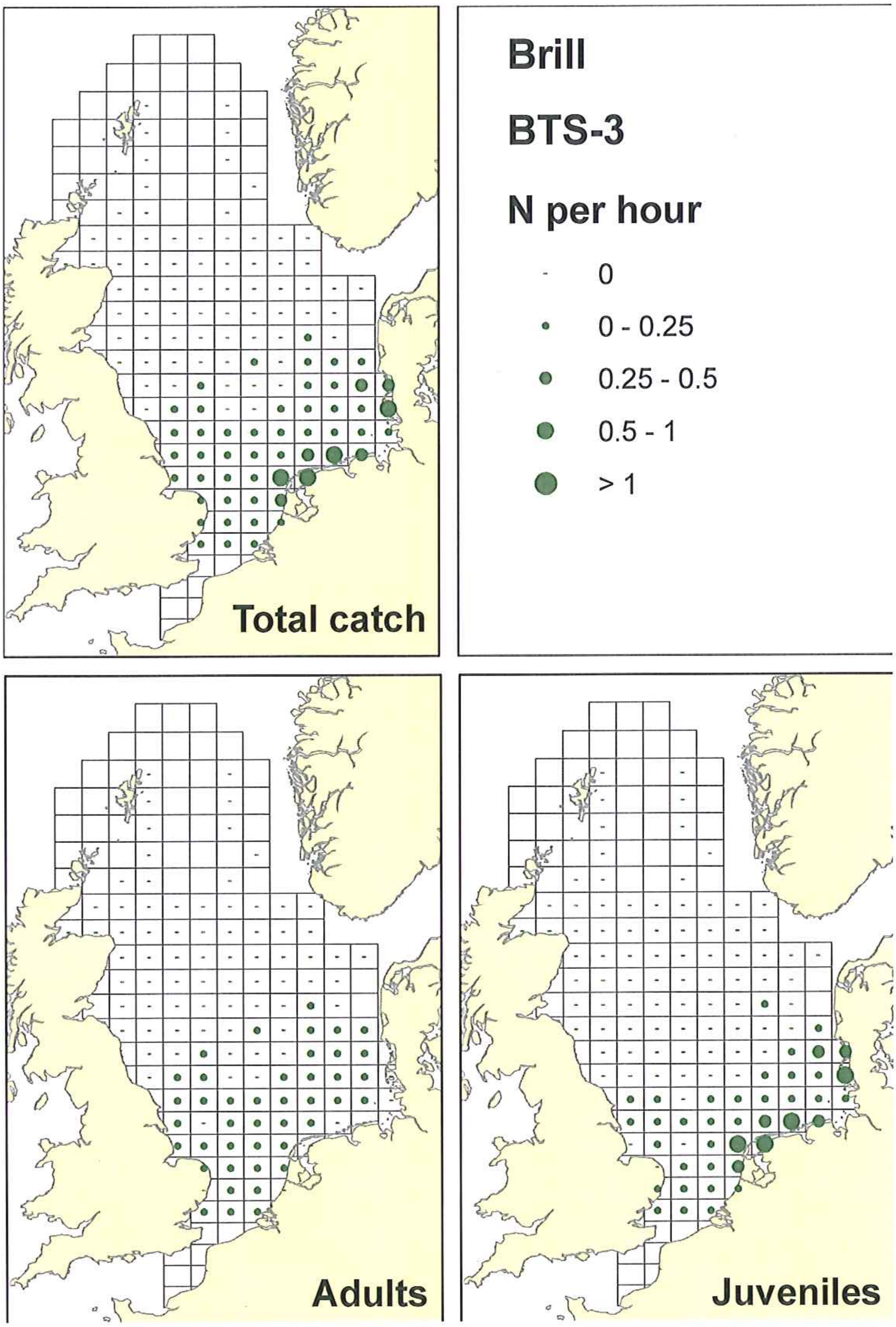


Figure 6.1a. Average annual catch rates from the BTS survey (numbers per fishing hour) in quarter 3 in the years 1985 – 2008 (from Heessen *et al.*, 2010).

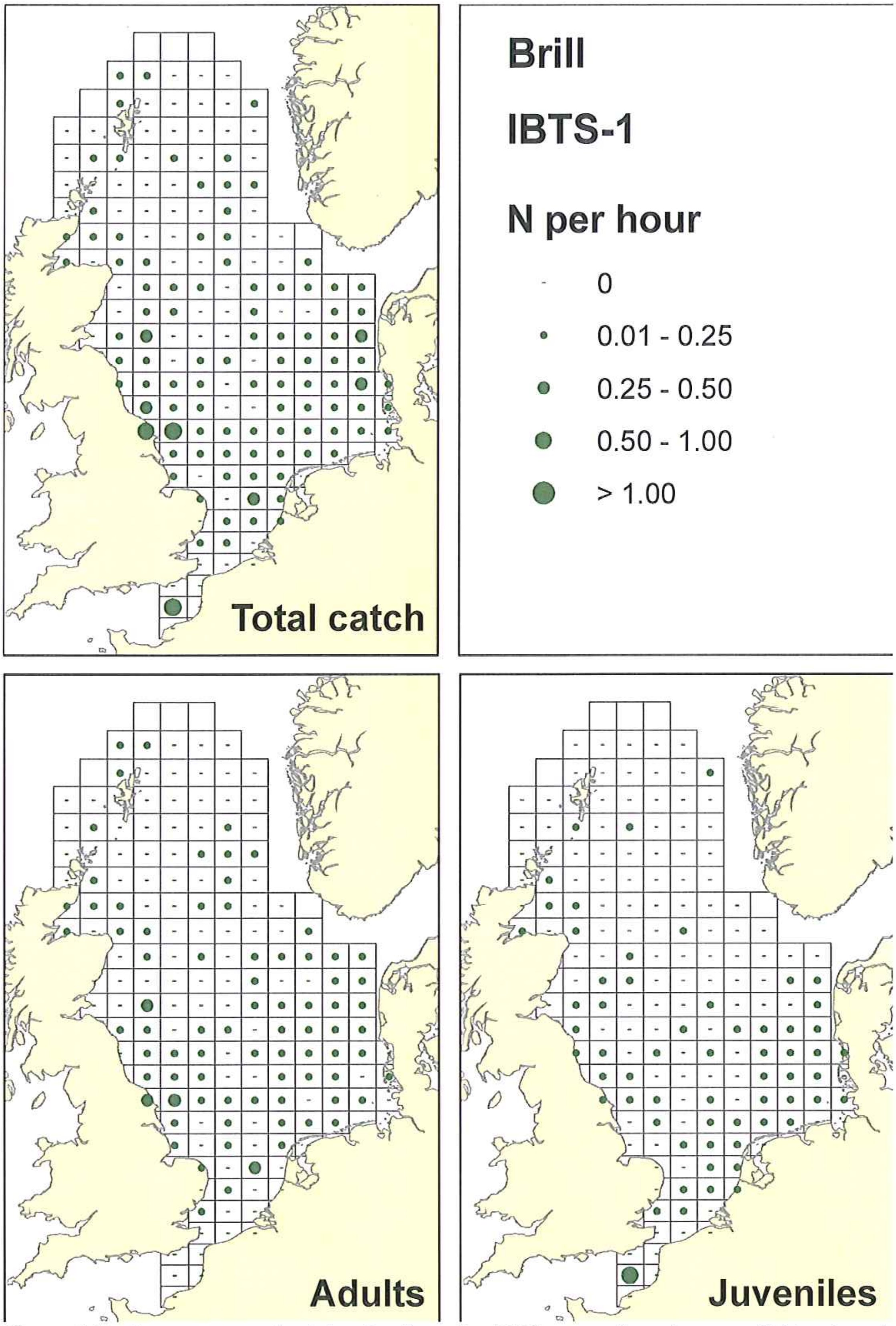


Figure 6.1b. Average annual catch rates from the IBTS survey (numbers per fishing hour) in quarter 1 in the years 1970 – 2009 (from Heessen *et al.*, 2010). Note that the IBTS survey is not ideal for sampling brill due to the gear used.

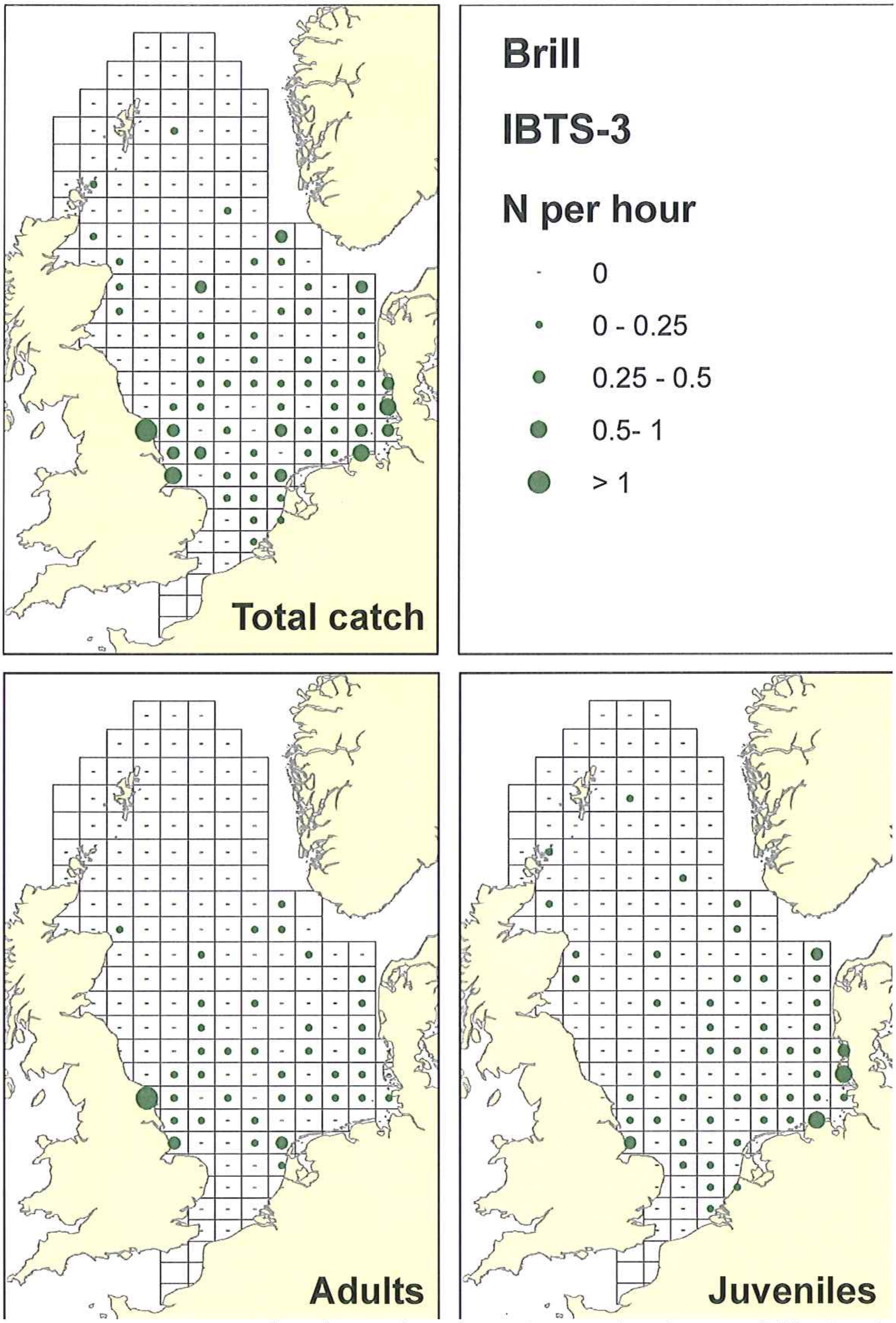


Figure 6.1c. Average annual catch rates from the IBTS survey (numbers per fishing hour) in quarter 3 the years 1985 – 2008 (from Heessen *et al.*, 2010). Note that the IBTS survey is not ideal for sampling brill due to the gear used.

6.4 Temperature

Temperature preferences of brill can be assumed to be similar to those of turbot due to their very similar life styles and distribution patterns.

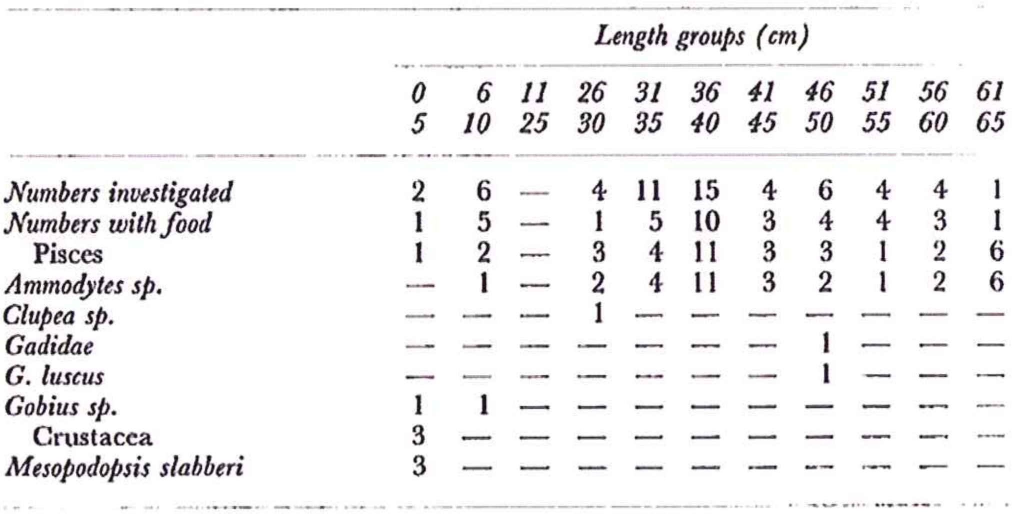
6.5 Sediment

Substrate preferences of brill can be assumed to be similar to those of turbot (fine sand) due to their very similar life styles and distribution patterns.

6.6 Other factors

Food: Like turbot, brill is an active predator which feeds largely on fish. Gobies, sandeel, gadoids, and clupeoids are important prey for brill in the southern North Sea. Juveniles already feed on fish and adults rely mostly on sandeel (Table 6.1; Braber and de Groot, 1973; Knijn *et al.*, 1993).

Table 6.1. Occurrence of principal food items in the stomachs of brill of different length groups (from Braber and de Groot, 1973).



	Length groups (cm)										
	0	*6*	*11*	*26*	*31*	*36*	*41*	*46*	*51*	*56*	*61*
	5	*10*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*	*65*
Numbers investigated	2	6	—	4	11	15	4	6	4	4	1
Numbers with food	1	5	—	1	5	10	3	4	4	3	1
Pisces	1	2	—	3	4	11	3	3	1	2	6
Ammodytes sp.	—	1	—	2	4	11	3	2	1	2	6
Clupea sp.	—	—	—	1	—	—	—	—	—	—	—
Gadidae	—	—	—	—	—	—	—	1	—	—	—
G. luscus	—	—	—	—	—	—	—	1	—	—	—
Gobius sp.	1	1	—	—	—	—	—	—	—	—	—
Crustacea	3	—	—	—	—	—	—	—	—	—	—
Mesopodopsis slabberi	3	—	—	—	—	—	—	—	—	—	—

7 Lesser weever

7.2 Introduction

Picture 7.1. Lesser weever (*Echiichthys vipera*).

Lesser weever is distributed in the Eastern Atlantic Ocean and the North Sea. In the North Sea the lesser weever is restricted to the southern and south-eastern regions off the coasts of Belgium, Holland, Germany and Denmark, and it occurs all along the British coast (Creutzberg and Witte, 1989). Lesser weever can reach a maximum length of 16 cm and lives in the shallower coastal area up to 30 meters deep, mostly on sandy bottoms (Wheeler, 1969). During daytime it usually buries itself into the sediment, while during night time it emerges from the sand and is more active. Spawning takes place from June to August and the eggs are pelagic. Egg development takes 9-10 days in summer. The young probably leave the plankton at a length of 13-15 mm. The postlarvae are found concentrated near the surface. Its food consists of, amongst others, amphipods, isopods, brown brown shrimp, young swimming crabs, gobies, clupeoids, young sandeels and small flatfishes; bivalves and polychaetes are also eaten (Wheeler, 1969). Creutzberg and Witte (1989) reports that lesser weever can also be a very selective feeder on fish of which 94% are gobies (*Pomatoschistus* sp). The fish is familiar because of the venom glands on the first dorsal fin and the gill cover.

7.3 Temporal patterns

During winter, survey catches of lesser weever were lower compared to the summer (Lewis, 1980; Creutzberg and Witte, 1989). Although migration cannot be excluded, it is most probable that lesser weever buries itself deeper in the sand during winter.

7.4 Spatial patterns

Wheeler (1969) gives the bathymetric distribution as extending from low water mark down to a depth of 50 m. The data suggest that lesser weever is more active on the flood, than the ebb tide. This would only appear to apply in sub-littoral areas. In the littoral zone the fish actively move down the beach on the ebb. Preliminary laboratory observations suggest that the activity patterns of this fish are affected by tidal periodicity.

7.5 Temperature

The temperature distribution data suggests that the lesser weever either moves into deeper water in winter as the temperature falls, but more likely buries itself in the sand (Lewis, 1980; Creutzberg and Witte, 1989). The critical temperature is probably about 5°C since no fish were caught when the water temperature was at or below this value (Lewis, 1980).

7.6 Sediment

Lesser weever occurs in shallow water on sandy substrata (Wheeler, 1969 in Lewis, 1976), moving onto the beach with the flood tide, and leaving with the ebb. Some individuals may remain buried in the beach during the low tide period. Creutzberg and Witte (1989) found that at sites with a grain size lower than 165 µm not a single lesser weever was caught during their research (Figure 7.1). The highest densities were found at median grain sizes ranging from 250 to 300 µm.

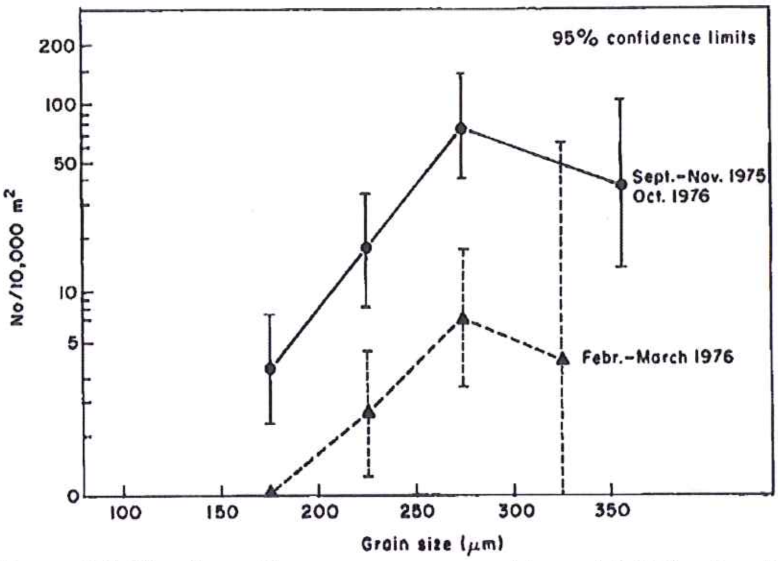


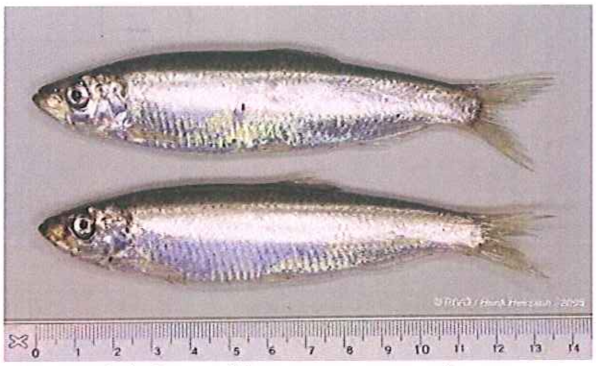
Figure 7.1. Number of lesser weever caught per 10 000 m2, with 95% confidence limits, in autumn 1975 and 1976 (circle) and in winter 1976 (triangle) in relation to the median grain size of the sediment (mean of 50 pm classes). The y-axis is based on a log (x+ 1) transformation.

7.7 Other factors

Light intensity: The numbers of lesser weever caught in clear and turbid waters by day and by night, suggests that light is an important factor determining the activity of this fish. Preliminary observations in the laboratory indicate that the fish are active at low light intensities. High light intensity, such as that produced by bench lamp provided with a 100 watt bulb, placed in close proximity to the fish causes them to bury themselves in the sand (Lewis 1980).

8 Sprat

8.1 Introduction



Picture 8.1. Sprat (*Sprattus sprattus*)

Sprat is a Lusitanian pelagic species (Yang, 1982; Ellis *et al.*, 2002; Ellis *et al.*, 2008) and is widely distributed in the coastal waters and inshore areas of Europe and North Africa, ranging from Morocco to Norway, including the Mediterranean, Black, Baltic and North Sea. Within the North Sea, sprat occurs throughout the southern and eastern/western parts. Sprat is one of the five clupeid species in the North Sea and can reach a maximum length of 19 cm and an age of 6 years (Muus and Nielsen, 1999). Sprat mature at an age of 1-2 years (Muus and Nielsen, 1999; ICES, 2009) and is an indeterminate batch spawner. Sprat are highly mobile, rely on a short, plankton-based food chain, are highly fecund and have plasticity in growth, survival and other life history characteristics. These biological characteristics make them sensitive to environmental forcing and highly variable in their abundance (Hunter and Alheit, 1995). As a small pelagic schooling fish, sprat can respond quickly to climate variation (Hunter and Ahheit, 1995) and changes in abundance are usually accompanied by changes in their distribution (Alheit 1997).

The importance of the Dutch EEZ for the different life stages of sprat is summarised in Table 8.1. The highest North Sea egg and larvae concentrations are found in the Dutch EEZ and German Bight and it has been estimated that the Dutch EEZ is of medium importance for eggs of North Sea sprat (Teal *et al.* 2009). For the larvae of sprat, it is known that large concentrations of larvae are found on the EEZ, but the extent of the full larval population is unclear. Although the spread of juveniles and adults is wider than the Dutch EEZ, a large part of the population occurs here (Teal *et al.*, 2009).

Table 8.1. Summary of the importance of the Dutch EEZ for different life stages of sprat at different times of the year. Eggs and larvae information is provided on a monthly basis, juvenile and adults on a quarterly basis. Importance levels (none or close to none = white; low = yellow; medium = orange; high = red; grey = unknown) relate to the extent of the distribution of each life stage within the Dutch EEZ and are based on best estimates from current knowledge (from Teal *et al.*, 2009).

Month												
Egg	🟧	🟧	🟧	🟧	🟧	🟧						

s	🟧	🟧	🟧	🟧	🟧	🟧						
Larvae				▨	▨	▨	▨	▨				
Juveniles	High			High			High			High		
Adults	High			High			High			High		

8.2 Temporal patterns

Spawning takes place in the North Sea from January to July, although sprat are also thought to spawn until September (Torstensen, IMR, Norway, pers. comm. in Taylor *et al.*, 2007), mainly in the south-eastern sector and in the Skagerrak (Munk and Nielsen, 2005). Sprat larvae occurred from April to August in daily samples of the Helgoland roads station (54°11.18 N and 07°54.00 E), in the years 2003-2005 (Malzahn and Boersma, 2007).

Catches from a power station in the UK, show that juvenile sprat are found in the Thames estuary the whole year round, however, highest catches occur in winter (Figure 8.1; Power *et al.*, 2000). A similar pattern was observed in the Dutch coastal zone, which has been sampled by push nets in a coastal survey programme (RIVO data 1974-1988).

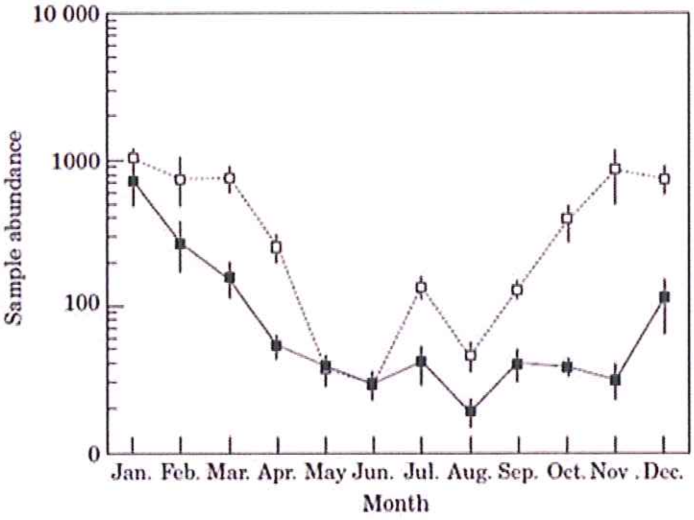
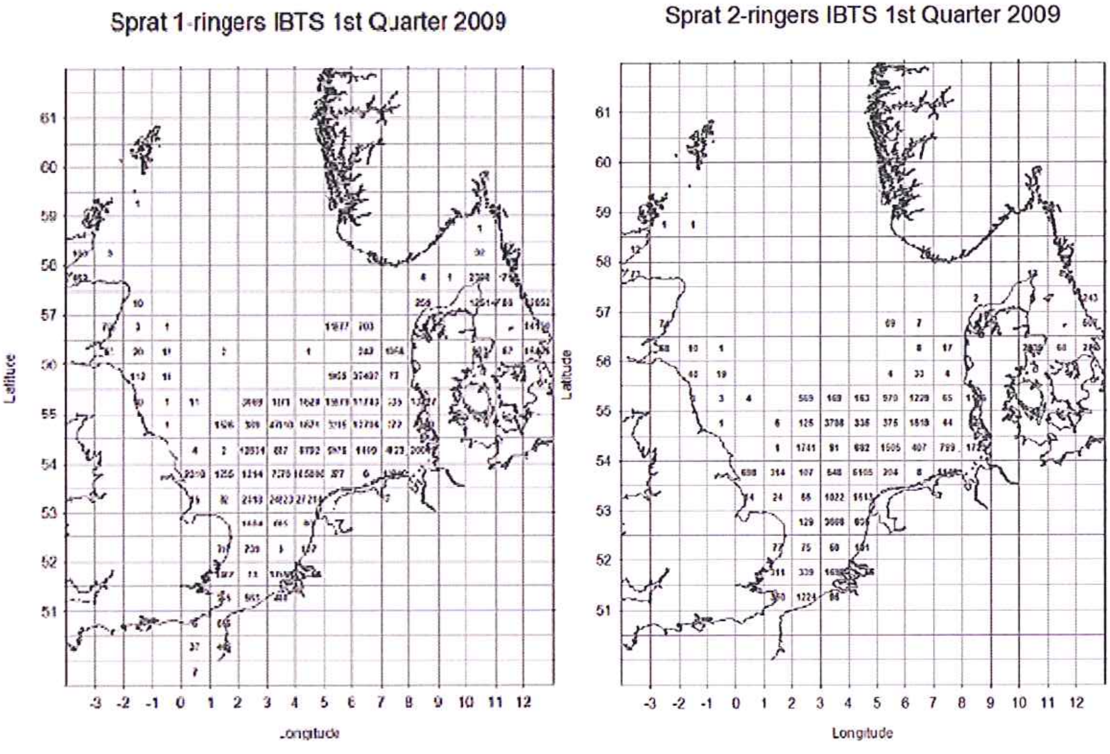


Figure 8.1. Seasonal catches of sprat (solid) and herring (dashed) in the West Thurrock power station in the estuary of the Thames (from Power *et al.*, 2000).

8.3 Spatial patterns

Sprat spawn in a wide area of the North Sea and spawning seems to occur mainly offshore close to the transition between stratified and mixed waters (frontal zones; Munk, 1991, 1993). Sprat eggs have been found throughout the Dutch EEZ (van der Land, 1990). The spatial distribution and growth of sprat larvae is closely related to hydrographic features (ICES, 2007). Sprat larvae were found in low densities in areas similar to their egg distribution during the 2004 ichthyoplankton survey (Taylor *et al.*, 2007). Most of the larvae were found in coastal areas (Munk, 1993).

Juvenile sprat occur at least throughout the southern part of the North Sea (Figure 8.2). It is not likely that their distribution extends much further north, given the overall distribution of sprat in 1991-2004 (Figure 8.3). Juvenile sprat occur widely around the coast of Britain, particularly in estuaries, which serve as nursery areas (Wheeler, 1969). Adult sprat are found almost exclusively in the eastern and southern parts of the North Sea, with highest abundances mainly in the central southern part (Figure 8.3). A similar distribution is shown in commercial catches of sprat (ICES, 2009a). Besides the North Sea, sprat also inhabits the estuarine areas bordering the North Sea (Power *et al.*, 2000).


Sprat 1-ringers IBTS 1st Quarter 2009

Sprat 2-ringers IBTS 1st Quarter 2009

Figure 8.2. Distribution of 1 and 2-ringers in February 2009 (ICES, 2009a)

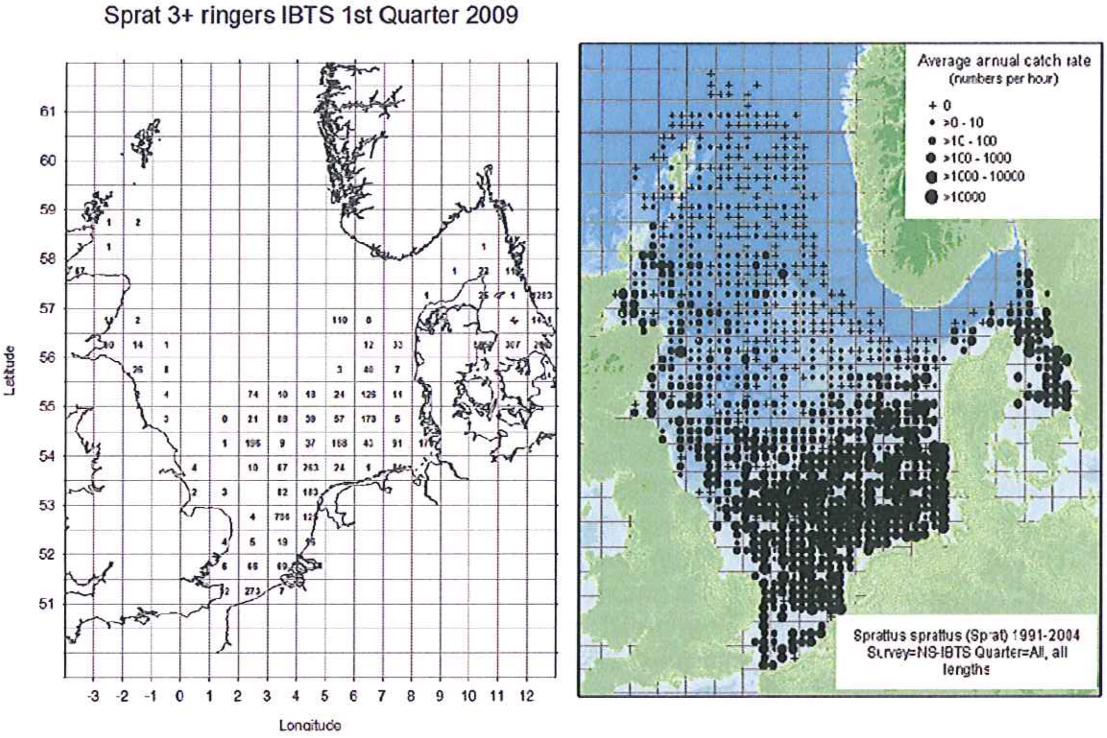


Figure 8.3. Distribution of 3-ringers in February 2009 (ICES, 2009a) and of sprat in the IBTS averaged over 1991-2004 in the North Sea and Division IIIa (from ICES fish atlas).

In the inshore areas of the Dutch coastal zone, which have been sampled by push nets in a coastal survey programme, depth showed no significant effect ($p < 0.124$) on the probability of sprat occurring (Figure 8.4; RIVO data 1974-1988). Although sprat is a pelagic species, it is assumed that in such shallow waters the beam trawl used during this survey is still able to collect reliable information on sprat (de Boer *et al.,* 2001). Although depth had no significant effect on the probability of occurrence, a decline in densities was evident at depths below 6m. These higher densities in shallower waters may be related to juvenile nursery grounds or popular adult habitat in estuarine areas.

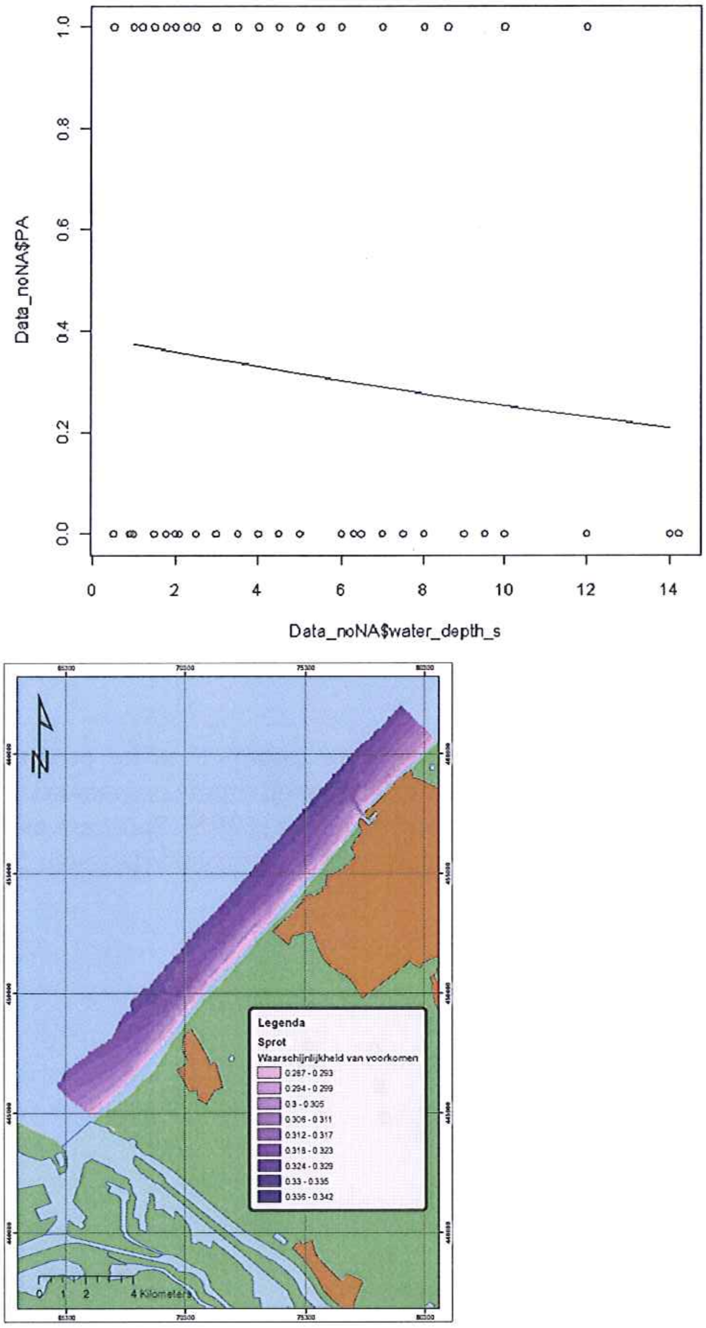


Figure 8.4. Relation between occurrence of sprat with depth in the Dutch coastal area (RIVO data).

8.4 Temperature

Due to the wide distribution and the seasonal changes at high latitudes, sprat experiences pronounced temperature fluctuations. In the Baltic Sea, Arrenhius and Hansson (1993) assume that sprat follow the yearly cycle of adult herring and thus experience temperatures between 2 and 16°C (Figure 8.5).

Cardinale *et al.* (2002) found no significant effect of temperature on the condition factor of sprat (Figure 8.6), which was related more to zooplankton biomass and salinity.

In the Thames estuary, the optimal temperature for sprat was calculated at 6.4°C and steep decline in abundance of sprat was shown at higher temperatures (Figure 8.7, Attrill and Power, 2004).

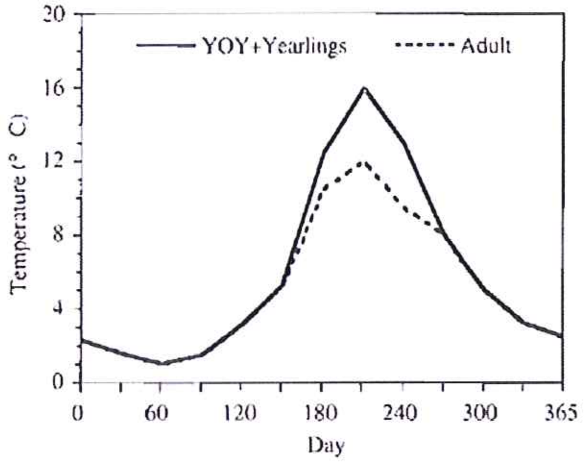


Figure 8.5. Average annual cycles of water temperature assumed to be occupied by various age-groups of herring and sprat in the Baltic Sea (based on measurements from 3 open sea and 1 coastal station given in Arrenhius and Hansson (1993). Sprat are assumed to follow the yearly cycle of older herring (solid line; from Arrenhius and Hansson, 1993).

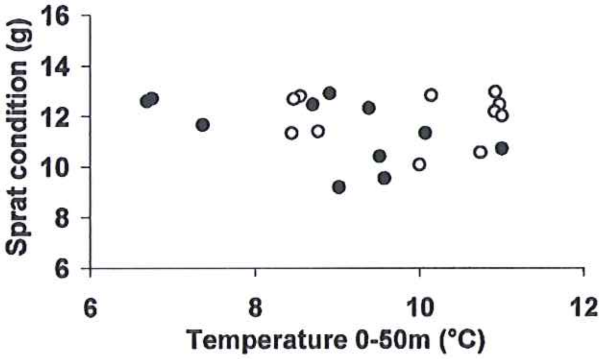


Figure 8.6. Relationship between sprat condition and temperature (from Cardinale *et al.*, 2002).

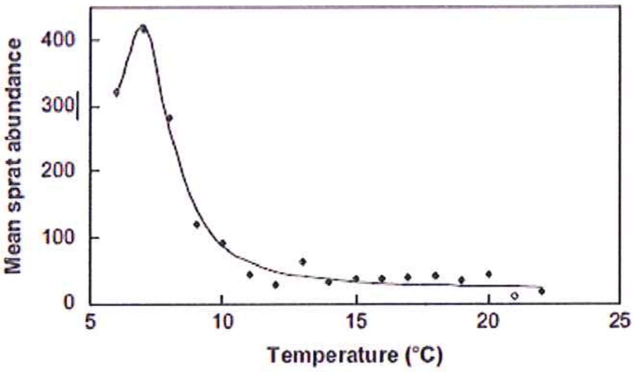


Figure 8.7. Relationship between abundance of sprat and temperature, solid line indicates model fit to the data shown (from Attrill and Power, 2004).

8.5 Sediment

As sprat is a pelagic species, sediment characteristics are unlikely to be of great importance to the habitat requirements of sprat.

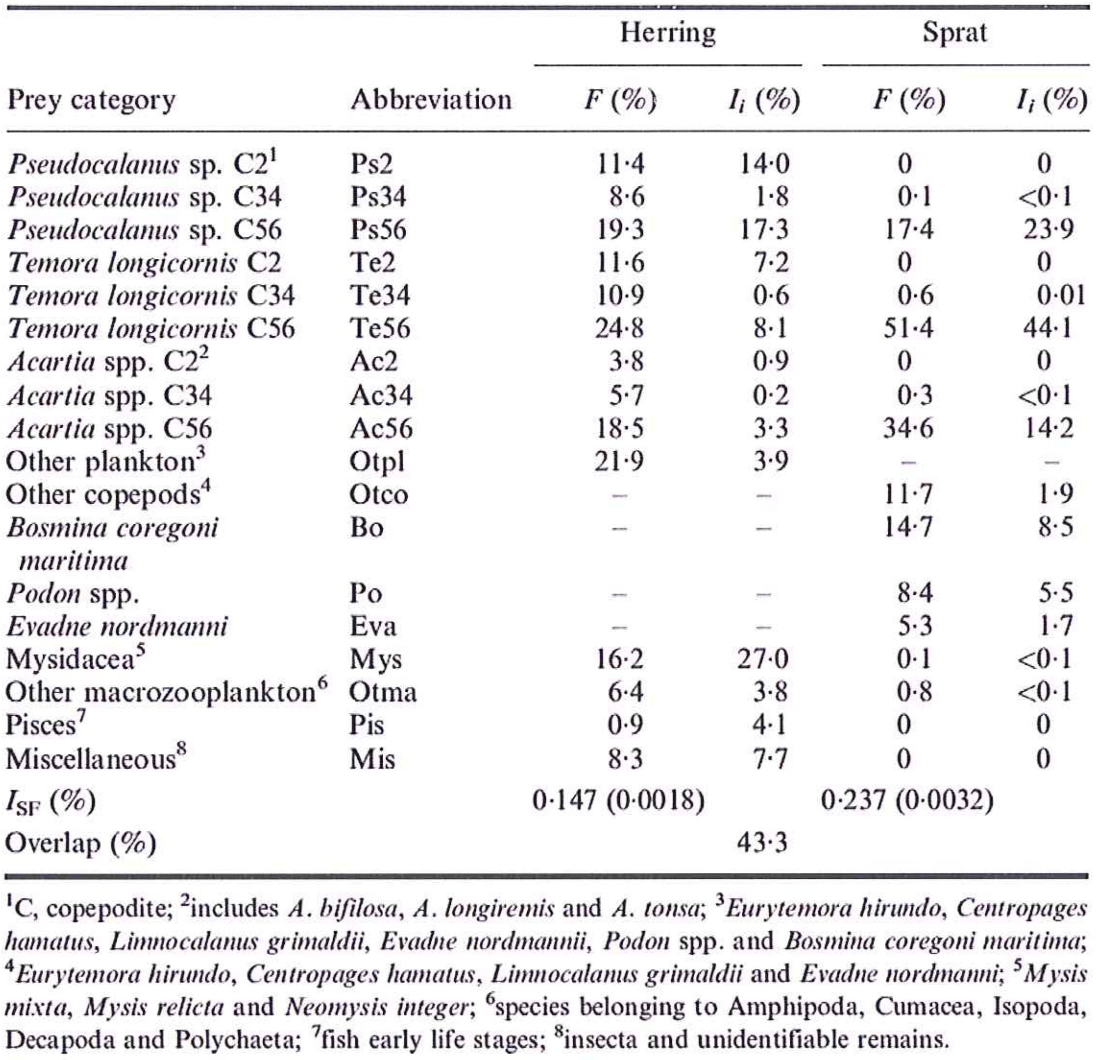
8.6 Other factors

Salinity: Cardinale *et al.* (2002) found that the variation in salinity explained 42% of the variability of the condition factor of sprat in the central Baltic, where salinity levels are lower than in the southern Baltic. This could be explained by the fact that under a certain value, the effect of changes in salinity on sprat growth begins to be significant. In the central Baltic, salinity is the most important factor regulating zooplankton community structure (Dippner *et al.*, 2000; Möllmann *et al.*, 2000) and the decrease of *Pseudocalanus elongatus* has been attributed to a reduced salinity in the Baltic Sea. Thus, variations in salinity may mirror in changes of zooplanktivorous fish growth rates via altering the zooplankton community structure (Möllmann *et al.*, 2000) by a bottom-up process (Flinkman *et al.*, 1998; Möllmann *et al.*, 2000).

Oxygen: Acoustic studies and sampling during 4 winters in a Norwegian fjord showed that sprat inhabited severely hypoxic waters. Their lower tolerable oxygen content was at ~7% O_2 saturation (~0.5 ml O_2 l^{-1} at 7°C), and they occurred as deep as this limit allowed in the 150 m water column (Kaartvedt *et al.*, 2009). Kaartvedt *et al.* (2009) hypothesise that overwintering sprat may take advantage of low oxygen waters due to higher tolerance for hypoxia than their predators (Gadoid predators seemed to avoid waters with oxygen contents below ~15 to 20%).

Food: Sprat are size-selective predators on zooplankton. The prey items making up the majority of their diet in the Baltic Sea are the calanoid copepods *Pseudocalanus* sp., *T. longicornis* and *Acartia* spp. Sprat almost exclusively preyed upon the oldest developmental stages of copepods and, overall, *T. longicornis* was the most important prey item, both in terms of frequency of occurrence on stomachs, as well as per cent relative wet mass of the prey item to the total wet mass of the stomach content (Table 8.2; Möllmann *et al.*, 2004).

Table 8.2. Summary of the feeding data of Baltic Sea herring and sprat (F, per cent frequency of occurrence; I_i, per cent relative wet mass of the prey item to the total wet mass of the stomach content; ISF, total stomach fullness as a per cent of fish wet mass; from Möllmann *et al.*, 2004)



		Herring		Sprat	
Prey category	Abbreviation	*F* (%)	I_i (%)	*F* (%)	I_i (%)
Pseudocalanus sp. C2[1]	Ps2	11·4	14·0	0	0
Pseudocalanus sp. C34	Ps34	8·6	1·8	0·1	<0·1
Pseudocalanus sp. C56	Ps56	19·3	17·3	17·4	23·9
Temora longicornis C2	Te2	11·6	7·2	0	0
Temora longicornis C34	Te34	10·9	0·6	0·6	0·01
Temora longicornis C56	Te56	24·8	8·1	51·4	44·1
Acartia spp. C2[2]	Ac2	3·8	0·9	0	0
Acartia spp. C34	Ac34	5·7	0·2	0·3	<0·1
Acartia spp. C56	Ac56	18·5	3·3	34·6	14·2
Other plankton[3]	Otpl	21·9	3·9	–	–
Other copepods[4]	Otco	–	–	11·7	1·9
Bosmina coregoni maritima	Bo	–	–	14·7	8·5
Podon spp.	Po	–	–	8·4	5·5
Evadne nordmanni	Eva	–	–	5·3	1·7
Mysidacea[5]	Mys	16·2	27·0	0·1	<0·1
Other macrozooplankton[6]	Otma	6·4	3·8	0·8	<0·1
Pisces[7]	Pis	0·9	4·1	0	0
Miscellaneous[8]	Mis	8·3	7·7	0	0
I_{SF} (%)		0·147 (0·0018)		0·237 (0·0032)	
Overlap (%)			43·3		

[1]C, copepodite; [2]includes *A. bifilosa*, *A. longiremis* and *A. tonsa*; [3]*Eurytemora hirundo*, *Centropages hamatus*, *Limnocalanus grimaldii*, *Evadne nordmannii*, *Podon* spp. and *Bosmina coregoni maritima*; [4]*Eurytemora hirundo*, *Centropages hamatus*, *Limnocalanus grimaldii* and *Evadne nordmanni*; [5]*Mysis mixta*, *Mysis relicta* and *Neomysis integer*; [6]species belonging to Amphipoda, Cumacea, Isopoda, Decapoda and Polychaeta; [7]fish early life stages; [8]insecta and unidentifiable remains.

9 Ammodytidae (sandeel)

9.1 Introduction

Picture 8.1. Ammodytidae (*Ammodytidae sp.)*

Ammodytidae (sandeel) are benthopelagic boreal species (Yang, 1982; Ellis *et al.*, 2002; Ellis *et al.*, 2008) and the geographical distribution ranges from the North Atlantic Ocean to the North Sea and the Baltic sea. There are five sandeel species present in the North Sea (Macer, 1966; Wright *et al.*, 2000), the most common are (Small sandeel (*Ammodytes tobianus*), Lesser Sandeel (*Ammodytes marinus*), Greater sandeel (*Hyperoplus lanceolatus*). Sandeel species are found in inshore waters, especially sandy bays and beaches and also occurs in the inter-tidal zone and estuaries. Adult lesser sandeel live closely to well oxygenated bottoms at water depth between 20 and 200 meters (Van Deurs *et al.*, 2009). The maximum length depends per species and can be 20 cm to 40 cm. Ammoditydae reach maturity at age 1-2. Depending on the species they spawn up to 25,000 eggs in multiple batches (Munk and Nielsen, 2005) during different periods of the year. The demersal eggs stick to the substrate until they hatch (Wright and Bailey, 1996), after which larvae are found in most of the water column. After metamorphosis the juveniles settle into the aggregations of adults. Comparisons of growth data from the North Sea by Bergstad *et al.* (2002) showed that both spatial and temporal variation in growth of sandeel could be substantial. They hypothesised that temporal and spatial variation in food availability within the North Sea is important for modulating the growth of sandeel. Sandeels are the principal prey of many of the most abundant seabird species that feed in the North Sea, they are an important part of the diet of commercial fish species and several marine mammals feed intensively on sandeels during spring and early summer (Pedersen *et al.*, 1999; Greenstreet, 2006). Recent recruitment failure of lesser sandeel in recent years was argued by van Deurs *et al.* (2009) to be caused by climate-generated shifts in *Calanus* species (food for sandeels) composition, leading to a mismatch in timing between food availability and the early life history of lesser sandeels.

9.2 Temporal patterns

Sandeels spend most of their time buried in the sediments during September-March (Winslade, 1974a, b, c), emerging briefly to spawn in mid-winter (Bergstad *et al.*, 2001), and to feed in large schools during part of the day over a more prolonged period in late spring and early summer. Emergence in the spring corresponds closely with the increasing abundance of zooplankton and is triggered by temperature, photoperiod and food availability (Mackinson, 2005). During peak occurrence in May-July, sandeels exhibit strong diel behaviour. At night they bury in the sandy sediment, while during day-light hours they form shoals in the water column and forage (Winslade, 1974b; Mackinson *et al.*, 2005).

9.3 Spatial patterns

The proportion of the sandeel population active in the water column varies considerably in response to several circumstances, such as variation in water temperature, light level, and zooplankton abundance, and the risk from predation (Winslade, 1974a, b, c). The observations of vertical distribution patterns of sandeel larvae across a range of different environmental conditions was suggested by Jensen *et al.* (2003) to have a strong influence of light conditions, hydrography and prey distribution. Different components of the population may also spend different fractions of the available time feeding in the water column and buried in the sediment (Bergstad *et al.*, 2002, Greenstreet *et al.*, 2006). The more homogeneous distribution of sandeel observed during night may be related to a reduced swimming activity (Jensen *et al.*, 2003).

Depth appears to be an important explanatory variable influencing both sandeel occurrence and density. The optimal depth range of 30-70 m determined from a model by Wright *et al.* (2000) is consistent with the recorded sandeel distribution in other regions of the North Sea, and with the North Sea sandeel fisheries locations.

9.4 Temperature

Winslade (1974b) investigated the behaviour of sandeel at temperatures of 5, 10 and 15°C, using a photographic method of recording activity. The activity patterns at 10 and 15°C were very similar, there being a high level of swimming activity during the light period, which fell to a low level at 5°C. Swimming activity at 10°C decreased towards the end of the experiment. It is suggested that this might have been due to an increase in the fat contents of the fish. It is concluded that after spawning in the December-January period the fish remain buried in the sand until April, because of the limiting effect of the environmental factors on swimming and feeding activity in the intervening period. The higher activity of sandeel in April is related mainly to temperature, but food (as measured by numbers of copepods), light intensity and photoperiod are factors that can have effect on sandeel activity.

9.5 Sediment

Holland *et al.* (2005) and Temming *et al.* (2004) reported that sandeel prefer very specific sediments with medium to coarse sands with median grain sizes between 0.25 and 2 mm and likewise avoid sediments with gravel or higher silt, clay and very fine sand fractions. Holland *et al.* (2005) studied sandeel abundance and sediment particle size data from 2886 grab samples collected during 14 surveys undertaken in the Wee Bankie/Marr Bank region of the north-western North Sea between 1998 and 2003. At a higher proportion of coarse gravel (≥8 mm) and fine gravel (≥2 to <8 mm) or fine sand (≥63 to <250 µm) and silt (<63 µm) in the seabed habitat, sandeels show reduced selection for and increased avoidance of the habitat (Figure 9.1). Conversely, at a higher proportion of coarse sand (≥710 to <2 mm) and medium sand (≥250 to <710 µm) in the sediment, sandeels show reduced avoidance of and increased selection for the habitat. Variation in sandeel density across these 8 habitat types is primarily influenced by the silt content in the sediment. Variation in the size of sandeels occupying each habitat type is mainly dictated by the coarseness of the sediment.

Analysis of Wright *et al.* (2000) found that sandeel was absent from sediments with a silt/clay content of >10% and densities declined between silt/clay fractions from 2 to 10%. Size-related differences in sediment preference were found from a comparison between sandeels <65 and >65 mm Ttotal length in sediment mix 1. The smaller sandeels did not prefer the coarsest sand over medium sand suggesting that the preference for

coarse sands may increase with fish size. A higher proportion of the sandeels buried in sediment A, coarse sand/fine gravel, than in the other sediment compositions.
Two factors may explain the absence of sandeel from silt-rich sediments. First, sandeels do not maintain permanent burrow openings so they have to ventilate their gills with interstitial water. This means that fine particles could clog their gills. Consequently, oxygen tension and the rate of exchange of interstitial water could be important factors influencing sediment choice. The ease of penetration is generally regarded as a key determinant of sediment choice in sandeels (Pinto *et al.*, 1984).

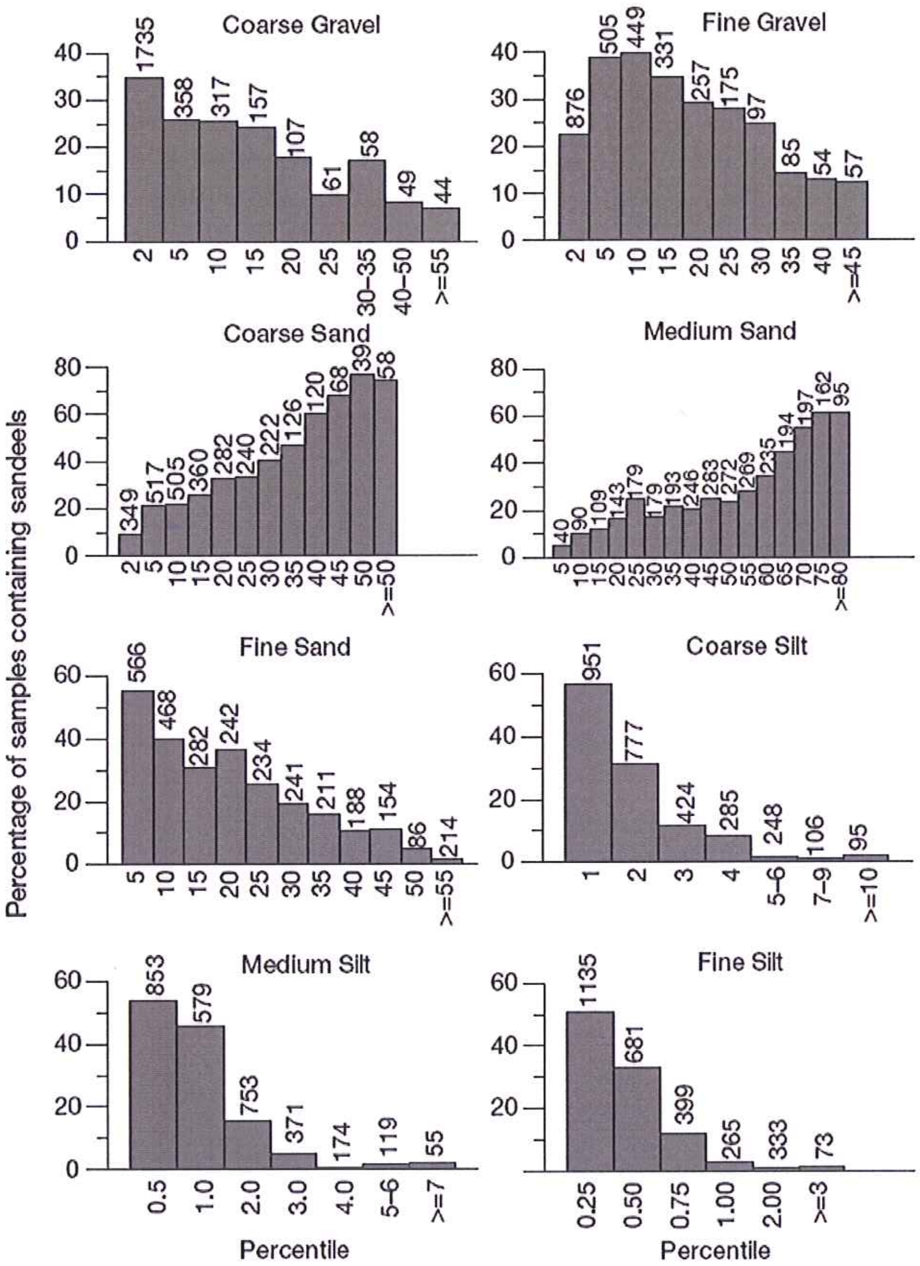


Figure 9.1. Variation in the percentage of sediment samples containing sandeels with varying proportions of each of the sediment categories. Histogram bar labels indicate the number of samples (from Holland *et al.*, 2005).

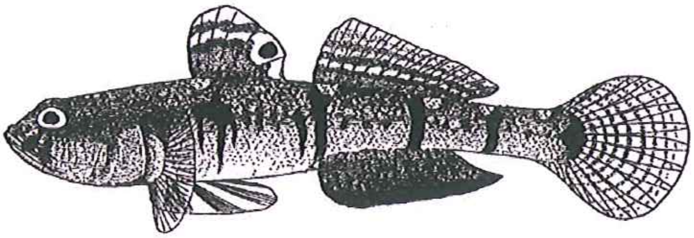
9.6 Other factors

Oxygen: Sandeels appear to have a metabolic compensatory mechanism that enables them to cope with oxygen tensions as low as 16 μmol.dm^{-3} during their hibernating phase, they have been observed to move out of substrates when exposed to low oxygen tensions (Wright *et al.*, 2000).

Light intensity: The behaviour of sandeel has been investigated by Winslade (1974c) at light intensities of 1, 10, 100 and 1000 lux, using a photographic method of recording activity. The level of swimming activity was high at 1000 and 100 lux, declining to a very low level at 1 lux. It was concluded that this was due to the limiting effect of light on feeding. The threshold light intensity for swimming activity in the tank was estimated as being approximately 20 lux but it was considered that at the sandeel fishing grounds the threshold might be higher than this, up to about 100 lux. The number of hours light per day above 20 and 100 lux at a depth of 15 m in the area of the Outer Dowsing sandbank (53°30'N, 01°00'E) was estimated for the various months of the year. It was shown that during the winter the light intensity normally does not reach 100 lux and only exceeds 20 lux during a few hours a day. It is suggested that this could limit swimming activity at this time of year. Measurements were made of the penetration of light into sand and it was concluded that fish which are buried might be able to detect light, possibly via the pineal gland.

10 Sand goby

10.1 Introduction



Picture 10.1. Sand goby (*Pomatoschistus minutus*). Picture from Fonds and Veldhuis (1973).

The Gobiidae are a large group of fish and up to 13 species are found in the North Sea, of which 5 along the Dutch coast. The sand goby, one of these 13 species, is common in the north-eastern Atlantic from Norway to the south of Spain, in some sectors of the western Mediterranean (Gulfs of Lions and Genoa), in the Adriatic (Venice Gulf) and along western Black Sea coasts (Bouchereau and Gueloret, 1997). It can reach a size of 5 to 7cm in the first year and 7 to 9 cm in the second year. Maximum age is 2 years (Fonds, 1973), although 3 year olds have been reported for the Tagus estuary, Portugal (Moreira *et al.*, 1991) as have gobies with a maximum length of 11cm (Muus and Dahlström, 1978). Both sexes have a black spot in the first dorsal fin. In spring the males exhibit a green anal fin with black border and 5 to 6 rather broad dark transverse stripes on the body. The species is classified as Lusitanian (Yang, 1982; Ellis *et al.*, 2008) and lives especially in estuaries and on shallow sandy shores. The sand goby is common in the Dutch estuaries and the North Sea coastal area from about 1 to 25 meters depth (Fonds, 1973; Fonds and Veldhuis, 1973). Sand gobies are semelparous batch spawners (Hamerlynck and Cattrijsse, 1994) that lay demersal eggs in empty shells (Russell, 1976). The territorial males fan and guard these eggs, which can be spawned by multiple females (Hamerlynck and Cattrijsse, 1994). After the spawning season only few adults survive (Fonds, 1973). The eggs hatch within 7 to 14 days depending on the temperature (Russel, 1976), followed by a pelagic larval phase. At a length of 17-18 mm juveniles start their demersal life (Fonds, 1973; Hamerlynck and Cattrijsse, 1994). The distribution of shells with sand goby eggs in the North Sea and the Wadden Sea shows that the species spawns in the North Sea at a depth of 10 to 25 m and water temperatures from 8 to 14°C. Sand gobies may spawn in estuarine lagoons, and eggs were also found occasionally in the Wadden Sea, but there is no evidence that sand gobies preferably reproduce in shallow parts of estuaries (Fonds, 1973). They generally disappear from the inshore areas at the onset of the reproductive season. Spawning may be restricted to areas covered with numerous lamellibranch shells located outside the estuary (Fonds, 1973).

10.2 Temporal patterns

Sand gobies migrate for spawning, and additionally, outside the breeding season to avoid low salinity or low temperatures (Bouchereau and Gueloret, 1997). In the Baltic Sea, sand goby shows seasonal migrations, spawns in very shallow waters in spring, and is fairly abundant down to 40 m depth during August–November (Ehrenberg and Edjung, 2008).

Ehrenberg and Edjung (2008) studied behaviour of sand gobies kept in a laboratory. They concluded that sand gobies had a similar activity pattern in low light intensity in the aquarium as described for low light intensities found in shallow water. The fish swim significantly more in darkness than in light, and bury in the sediment mainly at day (Figure 10.1). This behaviour, recorded in the absence of predators, are suggested to be adaptations to avoid predators. On average, a fish was fully visible at about 71% of the light and 97% of the dark period. There was a large individual variation in burying during light, with roughly half of the fish being hidden half of the time, the rest visible most of the time.

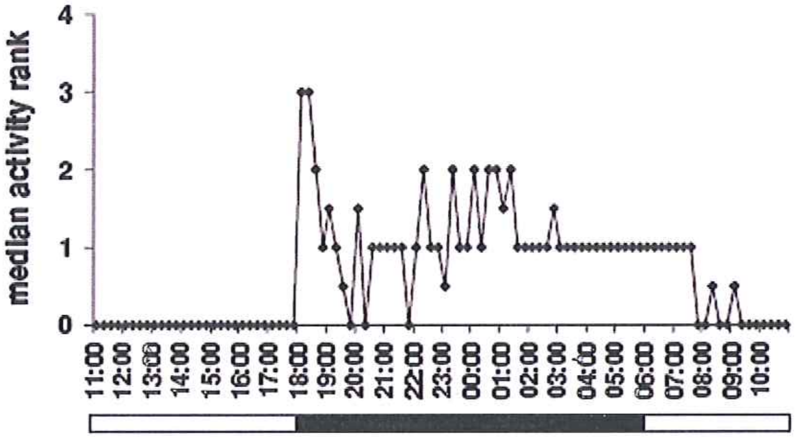


Figure 10.1. Median activity rating for all sand gobies (n = 18) for every 5 min observed. Time is shown on the x-axis, and the bar beneath indicates light or darkness (from Ehrenberg and Edjung, 2008).

Thetmeyer (1997) also investigated behaviour of sand gobies in a laboratory. Between 22.00 and 04.00 h, the mean fraction of swimming sand gobies was above 50% (Figure 10.2). When the illuminance rose to 5–10 lux at dawn, swimming activity decreased. During the day, the average fraction of fish swimming was 35%. At dusk, sand goby became more active again, but the increase in swimming activity at dusk was smoother than the decrease at dawn. During the day sand goby consumed 6.2 mmol 02 g-1 h-1 on average. The highest respiration rates (7.6 mmol 02 g^{-1}.h^{-1}) were measured after midnight.

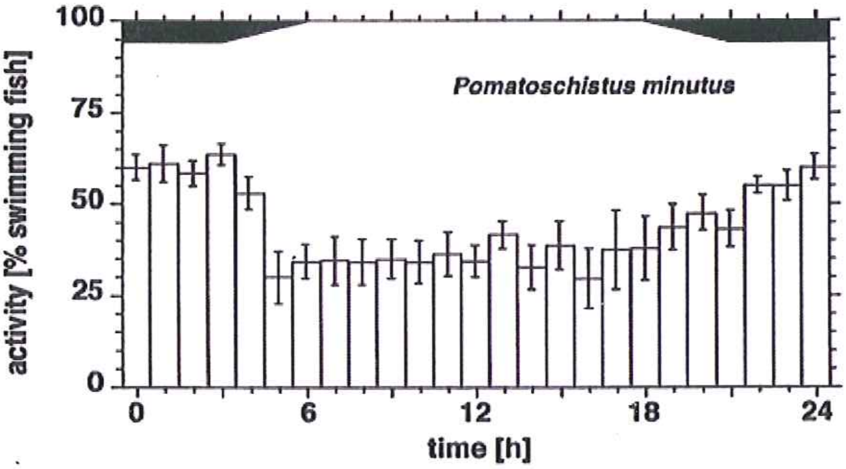


Figure 10.2. Diel rhythm in swimming activity of sand goby. The mean percentage of fish swimming for each of the 24 h of the day is plotted with its standard error (from Thetmeyer, 1997).

10.3 Spatial patterns

Fonds (1973) investigated seasonal variation of sand goby along the Dutch coast. Sand goby showed a marked seasonal variation in numbers in the Dutch Wadden Sea, with high densities in autumn and spring and low densities in winter and early summer. In autumn large numbers of sand gobies were found in the Wadden Sea and North Sea. They appeared to be more abundant in the outer half of the Wadden Sea and the adjacent North Sea coastal area, as compared to the inner half of the Wadden Sea along the Ijsselmeer and the mainland. In winter the numbers decreased rapidly in the Wadden Sea, especially during the second half of November and December, when the water temperature declined from about 6 to 1°C. During January and February very few sand gobies were found in the Wadden Sea. Their distribution shows that they disappeared from areas with a water temperature below 2°C, but remained in the North Sea coastal area at temperatures of 2.5 to 3.5°C. With rising water temperatures in March, the sand gobies returned in the Wadden Sea. They remained, however, more abundant in the adjacent North Sea coastal area.

10.4 Temperature

During winter the sand goby disappeared from the Wadden Sea when temperatures dropped below 2.5 °C and returned in March as the temperature had increased again to 3°C to 4°C (Fonds 1973). This is in agreement with the observations made in Gullmarsfjord, Sweden, and Penpoul, France (Fonds 1973). In more temperate areas, where water temperatures do not fall below 3°C, sand gobies do not migrate offshore in winter. Hesthagen (1979) reported that in the field sand gobies are not found at temperatures above 20°C.

10.5 Sediment

Magnhagen and Wiederholm (1982) studied habitat preference of sand goby and common goby (*Pomatoschistus microps*). These species live sympatrically on some shallow bottoms along the Swedish coast. Field samples showed that sand goby was found in both the open and vegetated habitat while common goby occurred mostly in open areas. In two kinds of laboratory experiments, in which the fish were offered a choice of habitat only and a choice of a combination of habitat and food, they examined if and how these species segregate. They found that sand goby chose the two habitat types in equal proportions and was not influenced by the presence of common goby. It ate of both prey items but seemed to prefer chironomid larvae to amphipods. On the other hand, common goby preferred the vegetated habitat and always took most of its food in that habitat. A certain amount of segregation thus occurs in sympatry because one of the species retreats into a subset of its entire niche, but there is nothing like complete segregation. The results from field samples and laboratory experiments suggest that sand goby is a generalist in its habitat selection.

Wiederholm (1987) studied coexistence and habitat distribution of black goby, (*Gobius niger*), common goby and sand goby in a wave-sheltered hallow bay on the Swedish west coast in September 1983. The fish were collected from two different habitats, viz. open mud-sand and vegetation (primarily eelgrass). The sand goby was found in both habitats. In laboratory experiments sand goby exhibited the same habitat distributions as in the field.

Wilkins and Myers (1992) studied the microhabitat utilisation by five temperate Gobiidae. The sand goby was characterised by its preference for a high percentage cover of mud in relative deeper water compared to the other goby species, with absence of hard substrata, algae and current.

10.6 Other factors

Oxygen: Petersen and Petersen (1990) studied behaviour and oxygen consumption in the sand goby, exposed to hypoxia. At 15°C and 20‰ mortality was 50% at 15.2% oxygen saturation. Avoidance and oxygen saturation showed a linear inverse relationship. At levels lower than 60% saturation increased activity occurred; avoidance was significant at 30% saturation. Sand goby reacts to acute, moderate hypoxia by increasing its activity. At sufficiently low oxygen saturation the goby tries to escape the hypoxic area or attempts aquatic surface respiration. The level at which active escape movements/swimming are induced seems to be at 30-40% saturation and may be this low because of the hazards of escape (e.g. increased risk of predation, changed food availability) and/or may be seen as a consequence of the costs of active swimming. At normoxia, active oxygen consumption is substantially higher than routine oxygen consumption. At lower temperatures where the metabolic scope is smaller, the response to acute hypoxia is somewhat different. At prolonged hypoxia the stress element will diminish through acclimation and metabolic activity will be channeled into adaptations like haemoglobin synthesis or other ways of increasing the carrying capacity of the blood.

11 Syngnathidae (pipefish)

11.1 Introduction

Picture 11.1. *Syngnathidae*; Left snake pipefish (*Entelurus aequoreus*), right Greater pipefish (*Syngnathus acus*).

Pipefishes have been normally found in the northeastern Atlantic from the Azores in the south to Norway and eastwards to the Baltic (Wheeler, 1969). The Atlantic snake pipefish (*Entelurus aequoreus*) can also be found near Iceland (Wheeler, 1969; Fleischer *et al.*, 2007). While most *Syngnathidae* species are small and live among marine vegetation close to the coast, the Atlantic snake pipefish is much larger, reaching up to 60 cm in length and lives in the open sea (Fleischer *et al.*, 2007). Pipefishes share the habit of the males incubation the eggs. In the male *Entelurus* the abdomen is round. In *Syngnathus* the males have a developed pouch under the tail and the eggs and developing young are enclosed within it by the soft skin of its walls. The pouch has a ventral slit in the centre along its length. *Entelurus* males receive eggs from one female while males of the genus *Syngnathus* receive partial clutches from several females (Vincent *et al.*, 1995). Incubation time is species dependent and takes 3-5 weeks. After release the juveniles can immediately assume a bottom living existence (great pipefish) or assume a pelagic mode life for a short while, then live on the bottom (snake pipefish and lesser pipefish, *Syngnathus rostellatus*) (Wheeler, 1969; Silva *et al.*, 2006). In general pipefishes are feeble swimmers, propelling themselves mainly with their dorsal fins. Because of their small mouth opening, their food consists of planktonic animals.

11.2 Temporal patterns

Breeding of pipefish is mostly between June-August. Spawning/breeding time for the Atlantic snake pipefish time starts much earlier in March and April in the oceanic form (Kloppman and Uleweit 2007).

11.3 Spatial patterns

The great pipefish is found mostly in shallow coastal waters down to a depth of 15 m, rarely much deeper (Dawson, 1986). Lesser pipefish is mostly found in shallow water, immediately below low tide level, usually over sand and also amongst floating or attached seaweed. Pipefish tolerates water with low salinity and can be found in estuaries.

In 2004, a sudden mass occurrence of snake pipefish took place in the Northeastern Atlantic and the abundance has been increasing since (Lindley *et al.*, 2006; Harris *et al.*, 2007; Van Damme and Couperus, 2008). Before 2004, snake pipefish were mainly found in coastal areas and have been reported only occasionally in oceanic waters. The oceanic form lives free in the water column while the coastal form is found among sea weeds or in sea grass beds. Abundance indices (numbers per hour fishing) from inshore surveys have remained at the same level, while those from offshore surveys show a very strong increase since 2004. The length distributions differ significantly between surveys, with coastal snake pipefishes being larger. Although the outward appearance of the coastal pipefishes seems different from the pelagic specimens, no differences were found when comparing taxonomic features. Apart from appearance the habitat is different for the two types of snake pipefish (Van Damme and Couperus, 2008). The oceanic specimens of snake pipefish are much leaner than the coastal specimens. Stomach contents of the oceanic snake pipefishes revealed remains of relatively small calanoids (mean length 2.4 mm). The calanoid population has recently changed and is nowadays dominated by the smaller *Calanus helgolandicus*. Van Damme and Couperus (2008) put forward the hypothesis that the sudden appearance of the snake pipefish in the deeper waters is a result of the change in the average lengths of calanoids which in turn is caused by changes in the hydroclimatic environment.

Vincent *et al.* (2005) studied the reproductive ecology of five pipefish species in one eelgrass meadow in Sweden. Pipefish species varied somewhat in their habitat occupancy of the meadow (Figure 11.1), but overlapped a great deal. Lesser pipefish were found primarily in the shallower water with its sparser, shorter eelgrass but most pipefish (snake pipefish and all *Syngnathus* species) preferred the 6 m wide strip at the top of the slope, where eelgrass was dense and tall. Of these, only snake pipefish were also found on the slope, with its anemone-laden eelgrass.

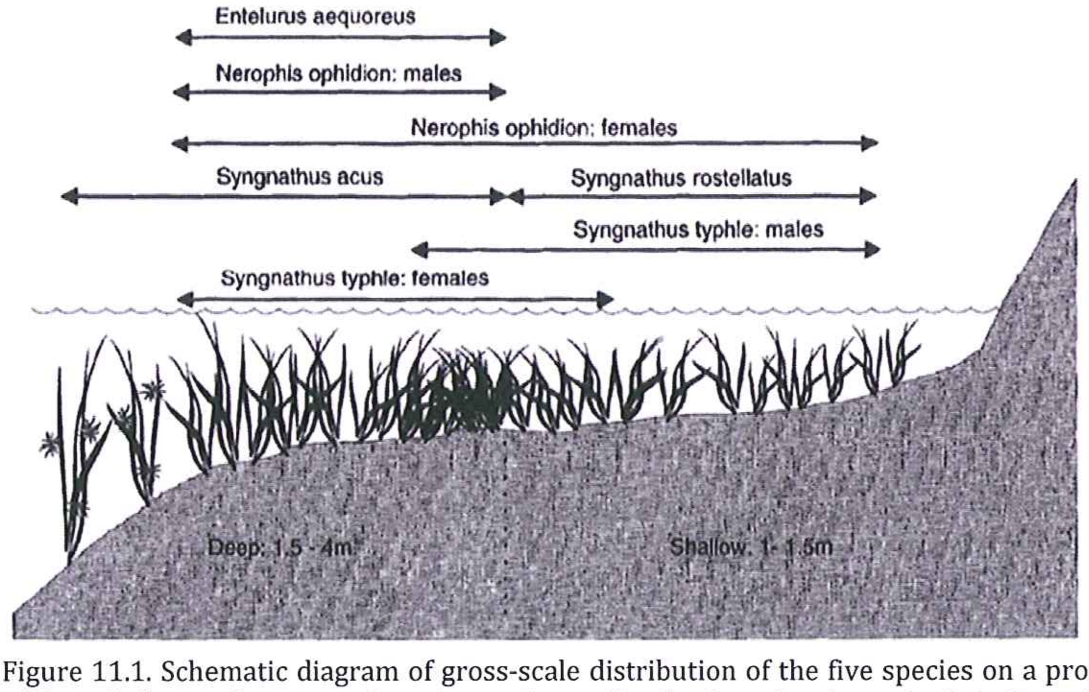


Figure 11.1. Schematic diagram of gross-scale distribution of the five species on a profile of Kvarnbukten eelgrass meadow. Approximate distribution of each species is indicated by a line. The eelgrass was sparser and shorter in the inshore 10 m, denser and longer in the next 6 m and sparse, long and anemone-laden on the 4 m wide outer slope. We compared the number of times pipefishes were found in the shallower and deeper halves of the meadow, using only first sightings for each individual. No species were found equally over both parts (from Vincent *et al.*, 2005).

11.4 Temperature

The increase of snake pipefish in the Northeastern Atlantic was reported to be a result of increased sea surface temperatures in the Northern Hemisphere, linked to global warming (Kirby, 2006). The extension of the Atlantic snake pipefish's northernmost distribution range may result from the expansion of their habitat in more southern regions of the Northeastern Atlantic. The high numbers of juvenile pipefish described by Kirby (2006) related to an earlier onset and a longer period of reproduction induced by higher sea surface temperature and a possible expansion of adult distribution in those regions might result in a propagation into areas influenced by the North Atlantic current. Thus, a northward transport of juvenile and adult stages of snake pipefish along the northwestern European coasts towards artic regions is possible (Fleischer *et al.*, 2007).

Harris *et al.*, (2007) concluded however that the population explosion of snake pipefish in the northeast Atlantic appears unprecedented in recent times. Although the underlying cause is currently uncertain, the increased abundance is likely to have an effect on the food web dynamics in the region.

11.5 Sediment

After the major loss of eelgrass habitats in the 1930s the snake pipefish was considered to be rare in the Wadden Sea (Polte and Buschbaum, 2008). They hypothesize that a sudden increase in pipefish abundance observed in the area since 2004 is related to new habitats provided by the introduced Japanese seaweed *Sargassum muticum*. SCUBA observations conducted near the Island of Sylt during July 2006 showed that approximately every second Japanse Seaweed thallus was inhabited by snake pipefish, whereas no pipefish could be found on sedimentary areas dominating the Wadden Sea. In a field experiment, we removed thalli from a Japanese seaweed bed and transplanted them to an unvegetated site and to the donor seaweed bed, respectively. Nine days after the transplantation, abundances of pipefish per thallus were almost equally high within all transplanted units at vegetated and originally unvegetated sites. Abundances pipefish in transplanted thalli did not significantly differ from those found in unaffected control thalli located in the donor seaweed bed. Zooplankton densities were significantly higher inside the seaweed beds. Harpacticoid copepods were the dominant group associated with Japanese seaweed and also represented the major prey of pipefish. They concluded that stocks of pipefish are promoted by seaweed beds since they benefit from higher food supply during the spawning season, probably in addition to increased shelter by habitat complexity.

11.6 Other factors

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12 Brown shrimp

12.1 Introduction

Picture 12.1. Brown shrimp (*Crangon crangon).*

The brown shrimp (Picture 12.1), is distributed along north-eastern Atlantic coasts from the White Sea and Iceland down to Morocco, in the Baltic Sea and the Mediterranean Sea as well as the Black Sea (Holthuis, 1980). It can reach a maximum total length of 89mm and is considered an important species both ecologically and commercially.

Brown shrimp mature at a size of at least 30-40 mm, depending on temperature conditions, and at an age of one year (Tiews, 1970). Sexual reproduction consists of internal insemination of the females, who store sperm and carry their fertilized eggs until they hatch (Boddeke *et al.*, 1991). Reproduction occurs a number of times a year until the brown shrimp reach their maximum age of three to five years (Tiews, 1970). The majority however will not get older than two years (Hufnagl et al. 2010). As a highly abundant prey for several fish, crustacean and bird species (e.g., Nehls and Tiedemann, 1993; Hampel *et al.*, 2005) as well as predator of fish and shellfish larvae and juveniles (e.g., Norkko, 1998; Hiddink *et al.*, 2002; Wennhage, 2002), *C. crangon* plays a key role in near-shore ecosystems (Pihl and Rosenberg, 1984; van der Veer *et al.*, 1998; Philippart *et al.*, 2003; Beukema and Dekker, 2005).

The species is commercially exploited throughout most of its distribution range, with a total harvest for the North Sea reported between 27-39 thousand tons over the last 15 years (ICES, 2010). The Netherlands and Germany are responsible for the main part of catches (87% in 2004) (Garibaldi, 2002). Total catches of the brown shrimp have shown a pattern of decrease from the 1950s and 1960s (40,000–70,000 tons per year) until 1990 (less than 16,000 tons in that year), after which catches have been increasing again (Garibaldi, 2002). Although concerns have been raised over the status of the target species itself (e.g., Revill and Holst, 2004; Polet *et al.*, 2005a,b), it is thought that the species cannot easily be overfished (Welleman and Daan, 2001). However, other effects can be expected on population dynamics of species that suffer mortality as discarded bycatch or by being harmed during bottom trawling (e.g., (Polet 2003) Berghahn and Purps, 1998; Vorberg, 2000) and indirect effects of shifts in brown shrimp abundance on other taxa in the food web (e.g., Philippart *et al.*, 2003; Beukema and Dekker, 2005).

12.2 Temporal patterns

Egg development varies between 10 and 12 weeks at 6°C and about 3 weeks at 18°C (Tiews, 1970; Wear, 1974). After hatching, development of the pelagic larvae lasts about 3–7 weeks, again depending on temperature (Criales and Anger, 1986). The post-larvae settle in shallow waters with sandy or muddy substrata. Because there is no fixed reproductive season, settlement can be expected to occur throughout the year, however two important waves can occur from spring/summer and from autumn eggs (Welleman, 2001; Campos, 2009).

Size dependent migration patterns occur. The young (and smaller) shrimps and berried females are the first to invade shallow areas in spring/summer, while the bigger ones are the first to leave these areas in the winter (Campos, 2009). During their growth, brown shrimp gradually move to deeper waters (Kuipers and Dapper, 1984). In autumn, decreasing temperatures initiate a migration of both juveniles and adults to more offshore waters, to return in early spring in Atlantic populations (Lloyd and Yonge, 1947; Kuipers and Dapper, 1981, 1984; Henderson and Holmes, 1987; Beukema, 1992).

Seasonal catch data of *Crangon crangon* are available in a long term fyke dataset collected by NIOZ on the island of Texel (the Netherlands) near the southeastern point of the island. Despite a large daily variation in catches of brown shrimp, Spaargaren (2000) found a distinct seasonal pattern with a large peak between October and December (Figure 12.1). During autumn, the abundance of the brown shrimp was on average five times greater, and interannual fluctuations were more pronounced as compared to spring. Time lag effects of up to one year were found, which are consistent with the species longevity and life cycle. The population seemed to respond rapidly to changes in environmental conditions: abrupt declines after exposure to adverse conditions, as in spring 1999, were followed by steep recoveries, already in the autumn of the same year. A reverse pattern to the pattern shown by Spaargaren (2000) was shown by Beukema (1992) for juvenile *Crangon crangon* on the nearby tidal flats in the westernmost part of the Wadden Sea: a single peak in summer, and from September to January the catches decrease to very low numbers (Figure 12.2). This is in fact the reverse pattern as found for the adult *Crangon crangon* near 't Horntje. Such differences in the seasonal patterns suggest the possibility that the presence of the animals near 't Horntje may be partly determined by seasonal changes in passive transport processes, which in winter accumulate the animals in this region, while in summer the (smaller) animals settle in shallow, quiet water.

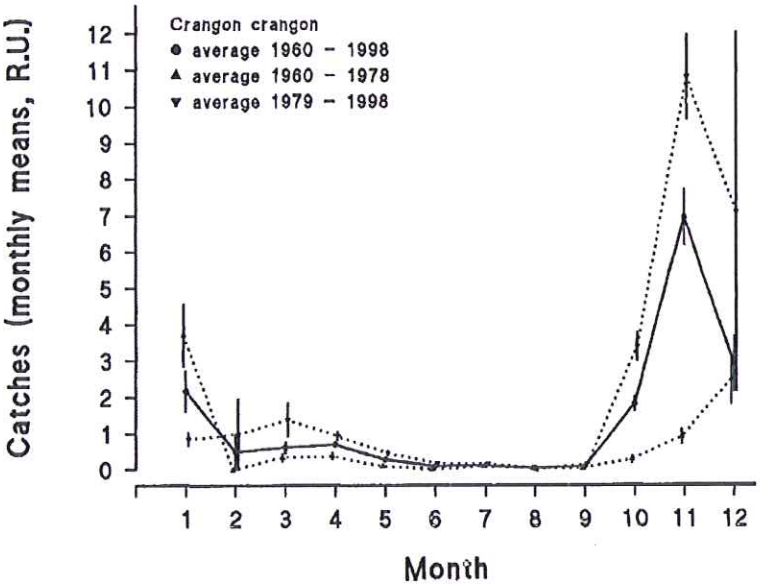

Figure 12.1. Seasonal variation in the catches of *Crangon crangon* (L., 1758) near 't Horntje (Texel). Illustrated are the average monthly catches over the period 1960-1998, and the averages over the sub-periods 1960-1968 and 1969-1998. The symbols represent the

average values (in relative units, R.U.: actual value divided by the long-term average); the vertical lines give the standard error of the means (from Spaargaren, 2000).

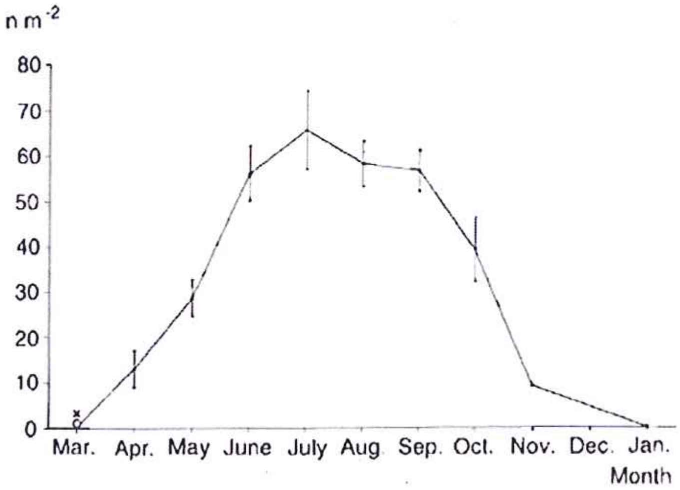

Figure 12.2. Seasonal course of densities (monthly means, no m-2) of brown brown shrimp sampled at low tide on tidal flats in the westernmost part of the Wadden Sea: 9 yr averages of 3 (small points) or 2 (circle) stations ± 1 SE and 20 year average of 15 stations (×) (from Beukema, 1992).

12.3 Spatial patterns

Crangon crangon is widely distributed in the southern and central North Sea (Figure 12.3). It is an epibenthic species inhabiting soft sediment estuarine and coastal habitats, including coastal lagoons, at depths of 0–20 m, although records of up to 130 m exist (Holthuis, 1980). Brown shrimp prefer productive estuaries with strong tidal movements of brackish water masses (Kuipers and Dappers, 1984)

Shallow parts of estuaries and coastal bays, including tidal zones, serve as important nursery areas for juvenile brown shrimps (Boddeke, 1978; Berghahn, 1983; Kuipers and Dapper, 1984; Henderson and Holmes, 1987).

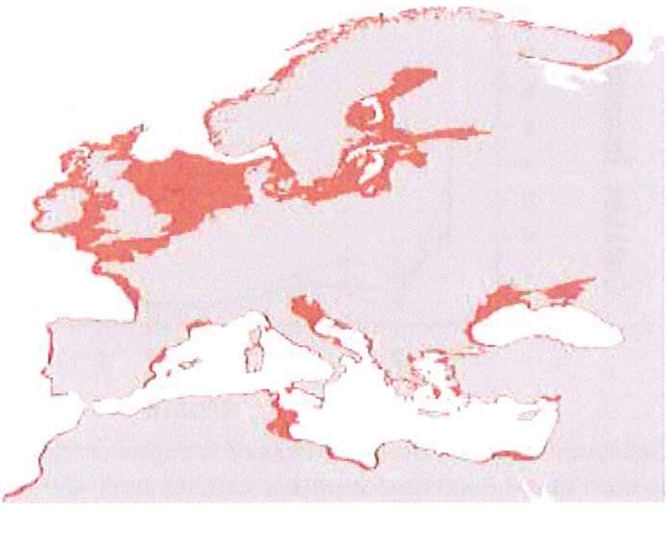

Figure 12.3. Distribution of the common brown shrimp, *Crangon crangon* (from www.fao.org)

12.4 Temperature

Spaargaren (2000) caught *Crangon crangon* in a broad range of temperatures (between 2 and 14°C; Figure 12.4). Below 2°C and above 14°C, *Crangon crangon* is not present in the samples, which can indicate either that the brown shrimp is not present or, due to the method of fishing using a fixed net (not trawling), the brown shrimp is not active in the area in which the net was located. Campos (2009) reported that *Crangon crangon* can survive at temperatures between 6°C and 30 ºC.

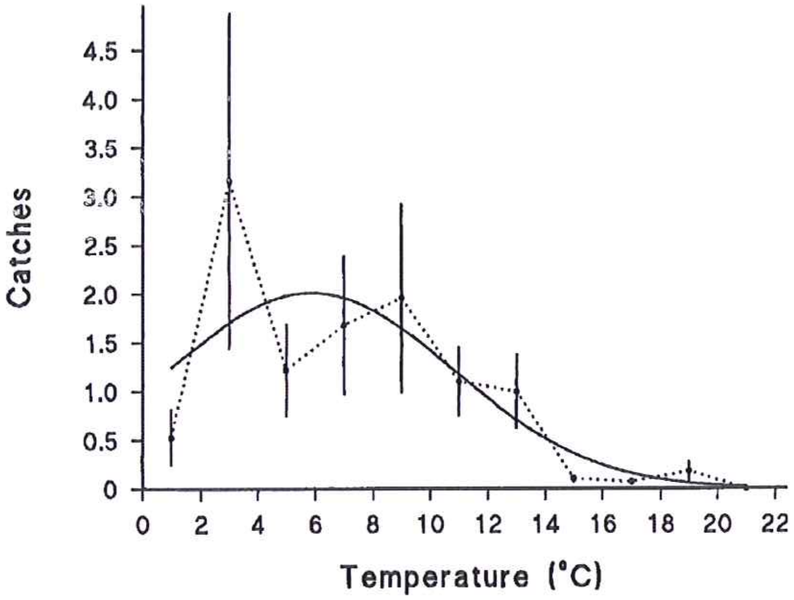

Figure 12.4. Relation between catches of *Crangon crangon* (L., 1758) near 't Horntje (Texel) (all data between 1960 and 1998) and temperature. The symbols represent the average values; the vertical lines through the symbols give the standard error of the means (Spaargaren, 2000).

12.5 Sediment

As a benthic species that hides from predation by burying in the ground, *Crangon crangon* mainly inhabits soft bottom substrates but can also be dominant on sandy shores (Kuipers and Dapper, 1984; Hufnagl, 2009). The preferred grain size is between 125 and 710 µm (Pinn & Ansell, 1993).

12.6 Other factors

Salinity: Spaargaren (2000) report large catches of *Crangon crangon* off Texel during periods of lowest salinities (Figure 12.5). The lower salinity limit is to be set to about 5 psu (Hufnagl, 2009). At this salinity zoeal stages and decapodids suffer high mortality. Evidently, the (adult) animals are capable of avoiding waters of higher salinity. By this behaviour the animals stay in water with salinities close to their isosmotic point (around 23 ppt; e.g., Flügel, 1960; Spaargaren, 1971).

Food: The diet of the common brown shrimp was studied in Port Erin Bay (Isle of Man, Irish Sea) by analysis of stomach contents and showed that mysids and amphipods together constituted the dominant prey, accounting for > 60% of the diet in both percent occurrence and percent abundance. Mysids were most important irrespective of season or size class (Oh *et al.* 2001).

In western Sweden, the main food item of small brown shrimp was found to be meiofauna, mainly ostracods and harpacticoids. Mid-sized and large brown shrimp preferred macrofauna such as *Mya arenaria*, *Cardium edule*, *Nereis* spp. And *Corphium volutator.* In contrast to the Irish Sea study, mysids were only eaten in some years (Pihl and Rosenberg 1984). Pihl and Rosenberg (1984) concluded that food was selected according to size, but apart from that food items were taken approximately in relation to their relative occurrence, which may explain differences in diets between regions.

The diet of brown shrimp was also studied by Campos (2009). The diet includes both meiofauna and endobenthic macrofauna and consists of three predominantly bottom-dwelling categories: infaunal organisms (bivalves, cumaceans, foraminifereans, harpacticoids, nematodes, oligochaetes), epifaunal organisms (amphipods, isopods, gastropods) and demersal organisms (mysids, shrimps and fishes). Potential prey items change with increasing shrimp size and shift from juvenile shrimps eating mainly meiofauna towards a diet on macrofauna-sized items when they reach a total length over 20 mm.

13 Conclusions

The coastal zones of the Dutch part of the North Sea form important habitats for a number of species and are particularly important as nursery habitat for some commercial species (plaice, sole), which settle in the area before migrating further offshore as they grow. Others (e.g. sprat, brown shrimp) inhabit the area all year round. The key habitat requirements of the fish species studies are summarised in Table 13.1.

Because all species encountered in this area are used to the seasonality of a temperate environment, they are generally adapted to a range of temperatures and are only likely to be affected when these exhibit extreme peaks (e.g. during a particularly hot summer or cold winter when shallow seas warm or cool more than normal). Many species have migration patterns which are adapted to optimising their experienced temperature.

In terms of substrate, all species show a particular preference for a specific range of grain sizes, ranging from fine sand (e.g. turbot, plaice, sole) to medium/coarse sand (sandeel) and floating seaweed (pipefish). Substrate is often a key factor in determining the settlement of larvae in a particular area.

In terms of planning a survey to understand the distribution and habitat use of the Dutch coastal zone by the named species, a number of potential limitations must be taken into account:

- Seasonal patterns: as the species exhibit different seasonal use of the area (see Table 13.2), the time of sampling will determine to some extent which species dominate the catches, whilst other species may be underrepresented in terms of their use of the area during other months

- Daily migrations: some species exhibit differences in habitat use between the day and night (e.g. burial, diel migrations), so the time of day at which sampling takes place can affect the catchability of different species, e.g. lesser weever bury during the day, sandeel bury at night.

- Sediment preference: different species prefer different sediment characteristics, so a wide scale of sediment types should be sampled.

- Depth: due to the tidal nature of the areas in question, the survey needs to be extended over a depth range, taking into account underwater sanddunes.

- Water visibility: water visibility can influence both fish abundance, as well as the opportunity for fish to notice a fishing gear, and react to it by fleeing.

Table 13.1: Summary of habitat preferences of the nine species. ± indicate positive/negative relationships, NA indicates where no information is available. Information printed in *italics* is not published but based on expert judgement.

Species	Depth	Temperature	Substrate	Salinity	Food	Other	Seasonal pattern
Plaice	all	< 22°C	Fine sand (< 0.5mm)	32 - 34 ‰	Large variety	-	All year round, but particularly important as nursery area: April-September
Sole	+	*< ~25°C*	Mud - Sand (<0.2mm)	NA	Polychaetes, amphipods, small bivalves	-	All year round, but particularly important as nursery area: May-September
Turbot	-	< 17-20°C	Fine sand (62–125 µm)	10 - 35 ‰	Benthic prey, switch to fish when > 20cm	Preference for sheltered over exposed sites	Settlement in coastal areas: June - September
Brill	shallow	*< ~17-20°C*	*Fine sand*	NA	Prey on fish, adults rely on sandeel	-	Settlement in coastal areas: July/August
Sprat	all	2 - 16°C optimal: 6.4°C	NA	NA	Zooplankton (calanoid copepods)	Can tolerate low oxygen (~0.5ml O_2 l^{-1})	Coastal areas/estuaries important for juveniles and adults all year round, highest catches in winter
Lesser Weever	0 - 50 m	> 5°C	Sand (250-300µm)	NA	Large variety, preference for gobies	Bury during day, activity higher in flood	Lower catches in winter (either due to migration or increased burial during winter)
Sand Goby	1 – 25 m	2°C - 20°C	Mud	NA	Chironomid larvae, amphipods	Bury during day, prefers vegetated habitat	High densities in autumn/spring, low winter/early summer
Sandeel	20 – 200m	> 5°C	Medium to coarse sand (0.25-2mm)	NA	Zooplankton (Calanoid copepods)	Bury at night. Tolerate > 16 µmol O_2 dm^{-3}	Buried in sediments: September – March (spawn mid-winter), emerge May-July
Pipefish	< 15 m	NA	Sand, floating seaweed, eelgrass	Tolerant of low salinity	Small calanoids (~2.4mm)	Differences in habitats between species	Breeding between June - August
Brown shrimp	0 – 20 m	6°C - 30°C	Mud – Sand (125-710µm)	~ 23 ‰	Meiofauna and endobenthic macrofauna	-	All year round, lower in winter

Table 13.2. Summary of probability of occurrence of the nine species throughout the year within the surf zone. Probabilities are given as: L = Low probability of occurrence, H = High probability of occurrence. Low probabilities were assigned to species where they are

expected to show their main area of distribution outside of the surf zone, e.g. offshore migration may occur decreasing numbers inshore, or where a species may be present but catch rates low due to species behaviour (e.g. burial during certain times of the year). High probabilities are assigned for species expected to inhabit the area and be readily caught (i.e. not buried), but also where species are expected to be undergoing settlement following spawning and metamorphosis and using the surf zone as nursery habitat.

Month:												
Plaice												
Sole												
Turbot												
Brill												
Sprat												
Lesser Weever												
Ammodytidae												
Sand goby												
Syngnathidae												
Brown shrimp												

14 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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5 Justification

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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Ingeborg de Boois

Signature:

Date: 22 april 2011

Approved: Ingrid Tulp

Signature: Ingrid Tulp.

Date: 22 april 2011

Approved: Jakob Asjes

Signature:

Date: 22 april 2011

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