Netherlands Institute for Fisheries Research (RIVO)

P.O. Box 68	P.O. Box 77
NL 1970 AB Ymuiden	NL 4400 AB Yerseke
The Netherlands	The Netherlands
Phone: +31 255 564646	Phone: +31 113 672300
Fax: +31 255 564644	Fax: +31 113 573477
Internet:postmaster@rivo.wag-ur.nl	

Base line studies North Sea wind farms: Final report pelagic fish

RIVO report
Report number: C047/04

R.E. Grift, I. Tulp, M.S. Ybema, A.S. Couperus

Commissioned by:	Ministry of Transport, Public Works and Water Management National Institute for Coastal and Marine Management/ RIKZ P.O. Box 20907 2500 EX The Hague The Netherlands
Project number:	3161268002
Contract number:	RKZ-1273
Approved by:	E. Jagtman Head of the Department
Signature:	____________________
Date:	29 June 2004

Number of copies:	50
Number of pages:	77
Number of tables:	8
Number of figures:	18
Number of annexes:	7

Table of Contents:

Summary

The Dutch government has decided to allow the construction of a Near Shore Wind Farm (NSW) demonstration project under the condition that a monitoring programme on - among other things - the ecological impacts is carried out. The Dutch government is responsible for providing a thorough description of the present ecological situation in order to evaluate future effects of planned wind farms. The Netherlands Institute for Fisheries Research has carried out the baseline study on pelagic fish. During this study, the pelagic fish community was sampled twice in April and October 2003: with a high spatial resolution in the planned location of the wind farm and in two reference sites, and with a low spatial resolution in a larger area in the coastal zone. Because of the absence of long-term datasets and to allow investigation of inter-seasonal patterns, we supplemented the data collected in this project with unpublished data from two other projects in which pelagic fish were recently sampled in the same area but in different seasons (June 2002 and November 2003). The combination of these four surveys enabled a year-round description of the pelagic fish community. This report describes the baseline situation for pelagic fish and presents the sampling approach, processing of the acoustic and trawl data and the analysis of all data.

The occurrence, density, spatial variation and population structure of the pelagic fish fauna in the reference situation were assessed by means of echo integration and reference hauls during hydro-acoustic surveys. Before, very little was known of the pelagic fish community off the Dutch coast but this study provided insight into the structure and temporal and spatial patterns of the pelagic fish assemblage. Although the weather and new methods applied caused some unforeseen problems and limited the number of transects that could be carried out, the general pattern in the distribution of pelagic fish was described adequately. For pelagic species of commercial interest for the Netherlands (Herring, Horse Mackerel and Mackerel), a lot of biological information was already available but this was certainly not the case for Anchovy, Pilchard, Raitt's Sandeel, Lesser Sandeel and Greater Sandeel. For these species, new information on biological parameters (sex, maturity, weight and age) was collected.

In general terms, the pelagic fish community in the Dutch coastal zone consists of nine species that show a large temporal variation and of which spatial patterns only occur at larger scales along north-south and near shore-offshore gradients. The number of species observed (nine) is small in comparison to the demersal fish assemblage in the coastal zone (more than 32 species), but far more than the two pelagic species (Herring and Sprat) that are usually encountered in annual pelagic surveys on the North Sea.

Generally, the highest biomass of pelagic fish occurred in the deepest area (>20 m) and the species composition showed a large variation among areas and periods. In biomass terms, Mackerel was the most important species in October and April, while in November Herring and Sprat dominated. Sandeel were the commonest group in June. Of all species, mature individuals were observed and of many species also 0-group fish were present in the Dutch coastal zone. For most species, length-frequency distributions did not vary among the different areas but in general, small species and the smaller individuals of Herring were observed more inshore.

Because in the baseline situation, spatial patterns mainly occurred at larger scales (north-south, near shore-offshore) and were absent from the scale of the wind farm, we think that small-scaled effects of

wind farms on pelagic fish may be detected if they alter spatial patterns to a large enough extent. It remains, however, difficult to predict this. In the baseline situation, there was no pattern in the spatial distribution of pelagic fish in and just around the planned wind farm area. Any non-random pattern detected after the building of the wind farm, may indicate an effect. The reference areas play important roles in such an assessment. They were chosen based on location, depth and sediment characteristics and because we expected that fish assemblages here were comparable to those in the Near Shore Wind farm area. In the baseline situation, no large differences were observed between pelagic fish communities in the reference areas and the NSW area and therefore the sites are suitable reference areas. In future, significant differences between the spatial patterns in the wind farm and in the reference areas may indicate effects of the wind farm.

For future sampling we recommend to extend transects further offshore than those in the baseline study to provide a better insight into the occurrence of fish along a near shore-offshore gradient. To save time, the acoustic sampling intensity in the wind farm and reference areas can be lower than was initially planned. June is probably the best month to sample pelagic fish in the coastal zone because in that period, species were most disaggregated. To actually assess the impact of a wind farm area it is important to combine monitoring programmes like this baseline study with process-oriented studies such as mark-recapture experiments and telemetry in which the behaviour of fish can be studied by using radio or acoustic transmitters.

Intermezzos: Sidetracks in the report.

In the report intermezzos are presented that provide side information or present more details on analyses. The report can be read and understood without reading the intermezzos. The following intermezzos are included:

Intermezzo 1. The first European offshore wind farm: Horns Rev in Denmark;
Intermezzo 2. Annual international surveys for pelagic Herring and Sprat;
Intermezzo 3. Ecology of pelagic fish;
Intermezzo 4. Splitting species groups into species according to the catch composition;
Intermezzo 5. Ordination;
Intermezzo 6. Variograms: tools to illustrate spatial variation;
Intermezzo 7. Preliminary prediction of the effect of a wind farm.

Acknowledgements

The fieldwork described in this report was executed on board of the GO58 and we thank Koos de Visser and his crew for the pleasant and professional co-operation. Kees Bakker and Ronald Bol contributed to the execution of the cruise and André Dijkman Dulkes, Rieneke de Jager and Mario Stoker processed the fish at the lab of the institute. The ages of most pelagic species could not have been determined without the help of our colleagues from abroad. We are grateful to Susanne Hansen, Palle Brogaard, Andres Uriarte, Inaki Rico and Alexandra Silva for their help. We thank Jan Jaap Poos for his assistance with programming the analyses of this project. Adriaan Rijnsdorp and Willem Dekker provided useful scientific input at the stage of data processing and writing up.

1. Introduction

The Dutch government wants renewable energy to meet at least 10% of the overall demand for energy in 2020. After this period, that percentage should increase further. Wind energy is one of the most important options. For 2020 a target has been formulated of at least 7500 MW installed turbine capacity, of which at least 1500 MW on land and 6000 MW at sea. This would cover approximately 20% of the domestic electricity demand. Considering the decrease in the cost price in the last few years, this seems a realistic target[1].

The demonstration project Near Shore Wind Farm (NSW) is intended to gain knowledge and experience with offshore wind energy, which in due time should make it possible to realise large-scale projects at sea. The NSW will be situated off the coastal area near Castricum and Egmond aan Zee at a distance of at least eight kilometres from the shore in the territorial waters. To avoid technical-economic risks as much as possible, it will be built in relatively shallow water and close to the shore (near shore). The wind farm will have a capacity of 100 MW. It is a temporary and one-time project that will be realised for a period of 20 years. Within this period, technical, economic and ecological aspects will be monitored. After 20 years the farm will be removed.

The Dutch Government has decided to allow the construction of the Near Shore Wind Farm (NSW) demonstration project under the condition that a monitoring programme on - among other subjects - the ecological impacts is carried out. The most important objective of monitoring is to acquire knowledge and practical experience in the construction and operation of large offshore wind farms in the North Sea[2]. Both the private party that constructs the wind farm as well as authorities (ministries) need this information for future wind farm projects: for construction as well as for developing policy on this topic. Therefore, the (ecological) knowledge acquired with monitoring programmes for NSW must be made available to all parties involved in the realisation of such large-scale wind farms.

The Dutch government is responsible for providing a thorough description of the present ecological situation as a reference for evaluation of future effects. In October 2002, the National Institute for Coastal and Marine Management (RIKZ), part of the Directorate-General of Public Works and Water Management, procured a base line study on the North Sea situation for 2003. This study is on behalf of the Monitoring and Evaluation Programme Near Shore Wind Farm (MEP-NSW) in the North Sea. The baseline study must provide data on the occurrence and density of benthic fauna, demersal fish, pelagic fish, sea mammals, marine birds and non-marine migratory birds. The Netherlands Institute for Fisheries Research of the Animal Sciences Group of Wageningen UR is responsible for the baseline study on pelagic fish. Since this institute is also involved in the MEP-NSW, the sampling programme for this baseline study is designed such that it could be copied to the impact study. Unity in sampling programmes before and after the creation of the Near Shore Wind farm is essential to assess the impact of a wind farm on the pelagic fish community.

The baseline study for pelagic fish should establish the occurrence, density, population structure and migration patterns of pelagic fish fauna in the reference situation. Also, the spatial variation of pelagic fish fauna in the reference situation has to be described. This has to be done in such a way that later

---

1 This Information was retrieved from www.offshorewind.nl.

2 We define offshore wind farms as wind farms at sea outside the 12 miles zone (22 km offshore).

(in the MEP-NSW outside this assignment) quantitative evaluation of the impact of a wind farm is possible. The design of the monitoring programme is justified to meet these goals:

- The occurrence and density were described by sampling pelagic fish in the coastal zone using a combination of hydro-acoustic equipment and a semi-pelagic trawl;
- The population structure was described by collecting biological information (age, sex, maturity and weight) from the most abundant pelagic species;
- Migration patterns were inferred from the temporal variation in fish community composition;
- The spatial variation was described by sampling pelagic fish with a high spatial resolution in the wind farm area and reference areas and with a lower resolution in a larger area covering the entire Dutch coast.

Intermezzo 1. The first European offshore wind farm: Horns Rev in Denmark.
The only offshore wind farm of comparable size to NSW that was build in the North Sea, is the wind farm in the Horns Rev area, Denmark[3]. An environmental Impact Assessment (EIA) was conducted, by assessing eleven years of bottom trawl surveys that were executed by the Netherlands Institute for Fisheries Research (Sole Net Survey – SNS; Beam Trawl Survey – BTS). This study focused on bottom (demersal) fish (Hoffmann *et al.*, 2000). The numbers of fish caught in three ICES rectangles that are partly covered by the planned location of the wind farm were compared. Conclusions were that fish and marine mammals were likely to be disturbed during the construction period, but that it was to be expected that the species would return quickly. Morphological changes would be minor in terms of area covered (3%). However, the foundations of the turbines may attract fish and may, depending on the building materials used, increase productivity. No long-term effects of noise were expected.

Pelagic fish are important for commercial fisheries and as food for many bird species and are by far the majority of fish landed from the North Sea (Table 1.1). Sandeel, for example, represents about 45% of the total annual landings from the North Sea. They are mainly caught by Denmark (62%) and Norway (34%). For the Netherlands, Herring and Horse mackerel are important species; Dutch fishermen land 17% of the Herring and 13% of the Horse mackerel from the North Sea.

The surveys executed for the baseline study wind farms for pelagic fish are one of the very first surveys for pelagic fish in the Dutch coastal zone. Apart from the general assumption that the Dutch coastal zone is a nursery area for the pelagic North Sea Herring, in particular the part of the population that spawns in the English Channel, very little is known of the pelagic fish community off the Dutch coast. In contrast to the demersal fish community, which has been sampled annually by the Netherlands Institute for Fisheries Research since 1969, no long-term datasets exist. Previous to this study, the pelagic fish community in the Dutch coastal zone was only sampled once: in June 2002, pelagic fish were sampled in the Flyland project that was executed to predict the possible effects of an airport island at sea (Grift *et al.* 2002).

[3] More information at http://www.hornsrev.dk.

Table 1.1. *Total North Sea landings (in 1000 tonnes), total landings of Dutch fisheries and its share in the total North Sea fisheries (Grift et al., 2001).*

Group	Species	North Sea	Netherlands	
		Landings (1000 ton)	Landings (1000 ton)	Share%
Pelagic fish	Sandeel	1022.9	0.0	0.0
	Herring	252.7	41.8	16.5
	Sprat	175.4	0.1	0.0
	Mackerel	160.2	1.4	0.9
	Blue whiting	92.7	0.0	0.0
	Horse mackerel	29.5	3.8	12.9
Sub total		*1733.4*	*47.1*	
Demersal fish	Cod	114.3	14.7	12.8
	Pollack	85.1	0.0	0.0
	Haddock	72.5	0.3	0.4
	Norway pout	72.4	0.0	0.0
	Plaice	70.4	30.5	43.4
	Whiting	23.9	1.9	8.1
	Sole	19.7	15.2	77.0
Other species		98.8	21.6	21.9
Total		**2290.5**	**131.4**	**5.7**

Intermezzo 2. Annual international surveys for pelagic Herring and Sprat.
Since 1984 pelagic fish have been sampled annually in the Herring-acoustic-survey that is designed to estimate the spawning stock biomass of Atlantic Herring. This survey is executed offshore in the entire North Sea since 1969. The International Council for the Exploration of the Sea (ICES) coordinates these surveys and Norway, Germany, Denmark, Scotland and the Netherlands participate. ICES also coordinates an international trawl survey (International Bottom Trawl Survey, IBTS) in which Herring and Sprat are sampled. The fishing gear in this survey, is chosen because of its ability to catch pelagic as well as demersal species. This survey only has a few sampling stations in the coastal zone. Knijn *et al*. (1993) provide the fish distribution patterns according to this survey for the period of 1985-1987 by squares of 30X30 nautical miles (ICES rectangles). The resolution of the sampling grid is too low to show spatial patterns on the scale needed for this study.

Because of the absence of long-term datasets, we supplemented the data collected in this project with data from two other projects in which pelagic fish were sampled in the same area: the Flyland project and the ‘Fish-Birds’ project. The latter project was executed in November 2003, in which fish was sampled and birds were counted simultaneously during a two-week period. This survey focussed on the distribution of Guillemots and Razorbills in relation to the pelagic fish abundance and physical parameters of the seawater. This survey is part of the RIKZ, Bureau Waardenburg and RIVO cooperation project ‘Fish-Birds’. Data from these four recent surveys have now become available that, altogether form a basis to describe the baseline situation of pelagic fish in different periods (Table 1.2). In fact, they provide the only information on pelagic fish off the Dutch coast.

Table 1.2. *Overview of data available on the pelagic fish community in the Dutch coastal zone.*

Period	Project	Observations	Name in report
June 2002	Flyland	fish, birds, zooplankton	Flyland
April 2003	Baseline wind farm	fish	NSW April
Sept./Oct. 2003	Baseline wind farm	fish, birds	NSW October
Nov. 2003	Birds and fish	fish, birds	Fish-Birds

Within the Baseline study, the pelagic fish community was sampled twice: in April and October 2003. It was sampled with a high spatial resolution in the planned location of the wind farm and in two reference sites, and with a low spatial resolution in a larger area to provide representative data of the pelagic fish community in the Dutch coastal zone. The objectives and the sampling design of this study are described in a detailed strategy of approach (Grift *et al.* 2003). Detailed reports of both surveys are presented in the respective fieldwork reports of this project (Couperus *et al.* 2003a, 2003b).

This final report integrates all results, describes the baseline situation of the pelagic fish fauna in the Dutch coastal zone and discusses the opportunities for assessing the impact of the near shore wind farm on pelagic fish. It is written in such a way that it can be read independently from the four reports that were previously delivered. They described the strategy of approach (Grift *et al.* 2003), the fieldwork (Couperus *et al.* 2003a, 2003b) and biological data of the main pelagic species (Grift *et al.* 2004). Chapter 2 of this report describes the sampling approach, processing of the acoustic and trawl data and the analysis of all data. The results are presented in Chapter 3 and discussed and synthesized in Chapter 4 in which guidelines for future sampling are also given.

Intermezzo 3. Ecology of pelagic fish.

Anchovy (*Engraulis encrasicolus*) is a southern species that has its northern distribution limit in the North Sea. In the IBTS, Anchovy was seldom caught in the 1980s (1985-1987 only two specimens were caught; Knijn *et al.* 1993) whereas from 1990 onwards this species occurred irregularly in low numbers in the IBTS catches (Fig. 1.1). Anchovy grows up to 20 cm, but usually lengths vary between 12-15 cm. Individuals in tropical waters are generally smaller than those in northern waters (Whitehead *et al.* 1988). Anchovy live close to the surface and feed on zooplankton. Spawning takes place in summer and the eggs are pelagic. By early October juveniles in the southeastern North Sea have reached a size of 3-4 cm (Aurich, 1953). In the late 1940s, three spawning areas were known: in the Schelde estuary, in the former Zuiderzee and in the German Bight. In the 1930s, Anchovy was found as far north as the western Baltic (Aurich, 1953).

Herring (*Clupea Harengus*) is widely distributed in the North Atlantic. The species can be divided in several (sub) populations. Young Herring off the Dutch coast is part of the Down's Herring, which spawns in November/December in the Channel. The eggs are laid on gravel and the larvae hatch in winter and drift with the current to the south. In early spring the larvae metamorphose at a length of approximately 5 cm. The Wadden Sea area and the German Bight are considered important nursery areas (Corten, 1995). At the end of the summer the Herring (approximately 12 cm) migrates towards deeper water. In the next year the 1.5-year-old Herring is found frequently in large parts of the southeastern North Sea. In the next summer the Herring gradually spread more to the west and north. About two thirds of the Herring matures in the next year (2.5 year). In autumn they move towards the spawning ground. Herring feeds on plankton, mainly on euphausids, copepods, fish larvae, and fish eggs but also on juvenile sandeels.

Pilchard (*Sardina pilchardus*) is a southern species, which is common in the English Channel and the Bay of Biscay. The distribution of Pilchard in the North Sea has been associated with the influx of relatively warm water through the Channel (Sahrhage, 1964). The specimens caught during the IBTS summer surveys are generally large (average length 25 cm, Knijn 1993). Pilchard feed on zooplankton and phytoplankton. Important food items in the Channel are copepods, ostracods, euphausiids, larval and juvenile stages of many other groups of crustaceans, and diatoms. Feeding intensity is highest during spawning and at a low level during winter (Hickling, 1945). Spawning occurs far into the North Sea (van der Land, 1990), but probably only by a small part of the population that has migrated to the North.

Sprat (*Sprattus sprattus*) is distributed in the whole North Sea, the Baltic, Bay of Biscay and the Mediterranean. The distribution during summer is more confined to coastal areas. In the IBTS, Sprat is the most abundant species (Fig. 1.1). Sprat primarily feeds on copepods, but other groups are found in their stomachs too: cladocerans, *Oikopleura dioica*, bivalve larvae, mysids and euphausiids. This clupeid is a multiple batch spawner, which means that each female repeatedly spawns during the spawning season. Spawning takes place at night and, in contrast to Herring, the eggs are pelagic. The main spawning season in the German bight is from May to August (Wahl & Alheit, 1988) and at the south coast of Norway from February to July (Torstensen, 1985). Alshuth (1988) mentions a spawning period up to October, whereas only a proportion of the Sprat born in the German bight metamorphose before their first winter. Some Sprat may spawn all year round (Whitehead *et al.,* 1985).

Greater Sandeel (*Hyperoplus lanceolatus*) is found from northern Spain to Northern Norway, and from Iceland to deep in the Baltic. It is one of the three common sandeel species found off the Dutch coast. This species occurs, however, in much lower numbers in the catches than Raitt's Sandeel (*A. marinus*, Wheeler 1975, Macer 1966, Knijn *et al.* 1993). In the IBTS catches, the length ranged from 10 to 35 cm. Specimens smaller than 15 cm feed on a wide range of planktonic crustaceans, fish eggs and larvae. With increasing size, fish becomes more important as a food item. In the southwestern North Sea other sandeels (Ammodytes species) are an important food item. Macer (1966) suspects that larger specimens migrate to areas where smaller sandeels are abundant. Spawning takes place from April to August. Specimens that hatch in summer, reach a length of 12-15 cm in the next summer (Macer, 1966).

Raitt's Sandeel (*Ammodytes marinus*) is distributed in the northeast Atlantic at depths of less than 30 m (Macer 1966, Wheeler 1969). This species is by far the most abundant of the three common sandeel species in the survey area. Sandeel is an important trophic link between commercial fish species (Cod, Haddock, Whiting, Saithe and Mackerel) and fish eating seabirds (Fulmar, Gannet, Kittiwake, Puffin, Razorbill and Guillemot). Important spawning areas are situated at Shetland, off the Scottish and Danish coast, in the German bight and the southern North Sea (Proctor *et al.,* 1998). Three major spawning areas have been distinguished in the southern North Sea: Dowsing, Southernmost Rough (both Dogger) and Southern Bight (Macer 1966). The eggs are demersal and deposited near or at the bottom where they stick to the sand (Williams *et al.,* 1964 in Reay 1970). The larvae are pelagic. As a result they are more widely distributed than the adults (Macer 1966). There is much variation in the direction of the larval transport, because during the spawning period the North

Sea circulation is determined by wind that is highly variable. In summer variation in distribution patterns is much more caused by the density of seawater (Proctor *et al.,* 1998). In early spring the larvae form large concentrations. At lengths of 30-40 mm the larvae become demersal. From that moment on their distribution depend strongly on sandy substratum and enough current. The juveniles occur in the same areas as the adults and there is no evidence that sandeel uses nursery areas (such as, for example, Herring). Normally Sandeel matures at an age of two years, but larger specimens may mature after one year (Macer 1966, Gauld & Hutcheon 1990). According to Economou (1991) the diet of larvae are “small, slow moving preys”. The prey size increases with the length of sandeels. East of Shetland the larvae (<26mm) consumed mainly zooplankton: nauplii of the copepods *Calanus finmarchicus* and *appendicularia* (*Oikopleura sp.*) (Economou, 1991). In the southern North Sea, juveniles (<10 cm) feed on copepods (*Calanus* and *Temora*). The main food of larger specimens consisted of newly metamorphosed polychaetes, but also of copepods (mainly *Calanus*, Macer 1966). Although sandeel in this study is considered a pelagic species, it has no swim bladder and no large fins that may help to remain higher up in the water column. In order to avoid predation, the species buries itself in the sand (Reay, 1970), hence the name. Sandeel releases itself from the sediment for feeding or spawning (Macer, 1966). During the summer months they actively feed at daytime (Reay, 1970) above the sediment that they are living on (Macer, 1966; Reay, 1970 and Wright *et al.,* 2000). Concentrations of sandeel are encountered on open sea, in shallow areas with currents, such as the edges of sandbanks (Macer, 1966; Reay, 1970 and Wright *et al.,* 2000). The densities decrease strongly with increasing silt concentrations (2-10%). According to Wright *et al.* (2000), sandeel prefer sediment with a fine to middle-sized structure (2-16 mm diameter particle size) to sediment consisting of larger particles. Places with silt concentrations of > 10% are avoided (Wright *et al.*, 2000). This can be explained by the fact that buried sandeel do not maintain holes, which means that they have to filter oxygen from the interstitial water. Because of their specific habitat preference the distribution of sandeels is determined by the distribution of suitable habitats.

In comparison to Raitt’s Sandeel, very little information is available for **Lesser Sandeel** (*Ammodytes tobianus,* also known as Small Sandeel). Small Sandeel has a similar distribution area as Raitt’s Sandeel, but occurs in shallower water. The diet of this species is similar to Raitt’s Sandeel: plankton (Macer, 1966). For Small Sandeel, two spawning periods, spring and autumn, are recognized in the North Sea, suggesting two separate populations (Reay, 1970).

Horse Mackerel (*Trachurus trachurus*) is an important commercial species with a southern distribution. The North Sea Horse Mackerel is considered a separate population (i.e. Eltink, 1992). In the IBTS surveys, Horse Mackerel is one of the most frequently caught species in summer (Fig. 1.1). In winter Horse Mackerel is almost absent from the IBTS catches (Knijn *et al.*, 1993). Horse Mackerel feeds on a wide range of plankton, fish and squid (Wheeler, 1969). The North sea population spawns in summer. The earliest occurrence of pelagic 0-group fish in the English Channel and the Southern North Sea is in Mid August at lengths of 4-5 cm (Macer, 1977).

It is assumed that **Mackerel** (*Scomber scombrus*) caught in the North Sea belongs to two different stocks. The western stock is distributed south, west and north of the British Isles along the continental slope. The North Sea Mackerel spend the winter in deep waters close to the shelf edge near Shetland and migrate south in spring to spawn in the central part of the North Sea (Lockwood, 1988 and Eltink 1987). Western stock Mackerel, predominately smaller specimens, also enter the North Sea through the English Channel (Knijn *et al.,* 1993). The Mackerel off the Dutch coast may therefore be a mixture of North Sea and western Mackerel. Mackerel is a common species in the IBTS survey in summer. In winter the densities are very low (Knijn et al., 1993, Fig. 1.1). Mackerel of all sizes feed on small planktonic prey such as copepods and euphausiids. However, fish, particularly Herring, Sprat, sandeel and Norway Pout constitute more than a third of larger Mackerel. In the southern North Sea, stomach contents were dominated by fish (Mehl & Westgård 1983).

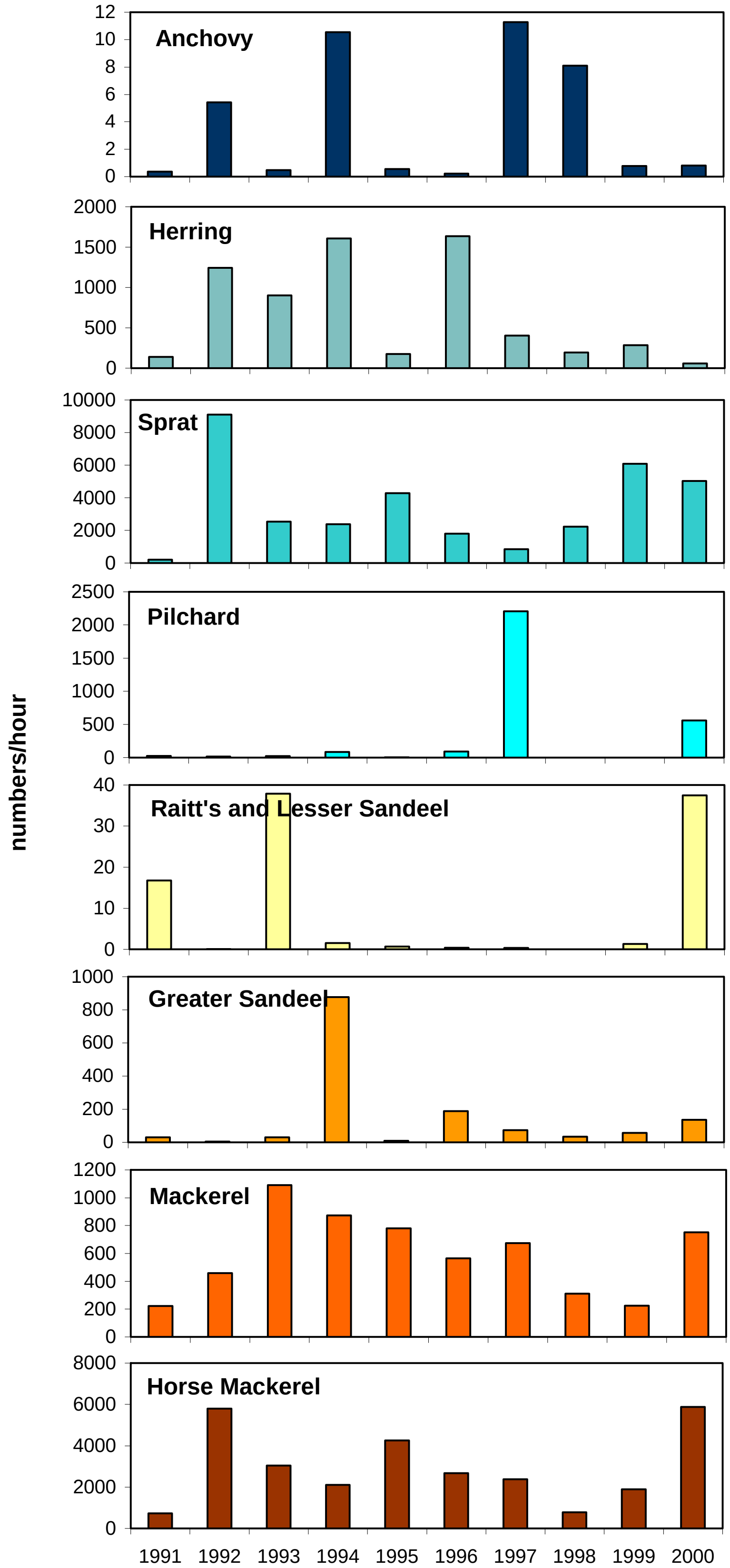


Figure 1.1. *Indices (numbers of fish per hour trawling) for pelagic species derived from the International Bottom Trawl Survey (IBTS). As the IBTS gear is not suitable for catching sandeels, indices for these species probably do not represent abundance well.*

2. Data collection and analysis

2.1 Sampling strategy of the baseline study

In order to assess temporal variation in the pelagic fish community, pelagic fish were sampled twice within the current project, in April and October 2003 (weeks 16/17 and 40/41). The sampling design is discussed in detail in the strategy of approach (Grift *et al.* 2003) and will be summarised here.

The sampling scheme provides a detailed description in the areas of particular interest, but also provides a description of the pelagic fish community in the whole coastal zone. It covers the planned location of the Near Shore Wind Farm, reference sites and provides representative data of the pelagic fish community in the Dutch coastal zone (Fig. 2.1). The reference sites have the same size as the wind farm area, are chosen so that they are similar to the wind farm area regarding species community, water currents, water depth and seabed morphology. Transects with a high resolution are 8-10 km long (the size of the wind farm) and the distance between them is 0.5-1 km. This resolution is required to be able to detect possible effects of the wind farm on the occurrence of fish in the impact study. If these effects occur, they are small-scaled and a high-resolution sampling scheme is needed.

Additional sampling with a lower resolution in a larger area is required to get an overview of the position of the NSW and reference sites in a larger coastal system and to judge the collected data in the perspective of the observed patchiness over a larger area. The sampling transects for the larger area are based on the sampling scheme for the Flyland project, carried out in June 2002, which provided good insight in the pelagic fish community in the entire coastal zone.

Evaluation of the first baseline survey in April 2003 lead to an adapted sampling programme for the second survey in October 2003. Not all transects could be sampled in the planned two weeks in April and as a result, the sampling intensity of the planned location of the wind farm and in the reference sites was reduced by half. Because of adverse weather conditions both surveys for this project could not be completely executed as planned but gave a good description of the pelagic fish community.

Both other surveys for pelagic fish of which data are used in this report had different sampling designs. The largest area was sampled in the Flyland project and transects were positioned further offshore than in the baseline study (Fig. 2.1). The combined Fish-Bird survey extended to 100 km offshore and extended further North than both the Flyland and the baseline surveys. Acoustic and catching methodologies used in these surveys were identical to those used in the baseline study as was the assessment of length-frequency distributions.

The four different surveys will be further referred to as: baseline April (2003), baseline October (2003), Flyland (June 2002) and Fish-Birds (November 2003).

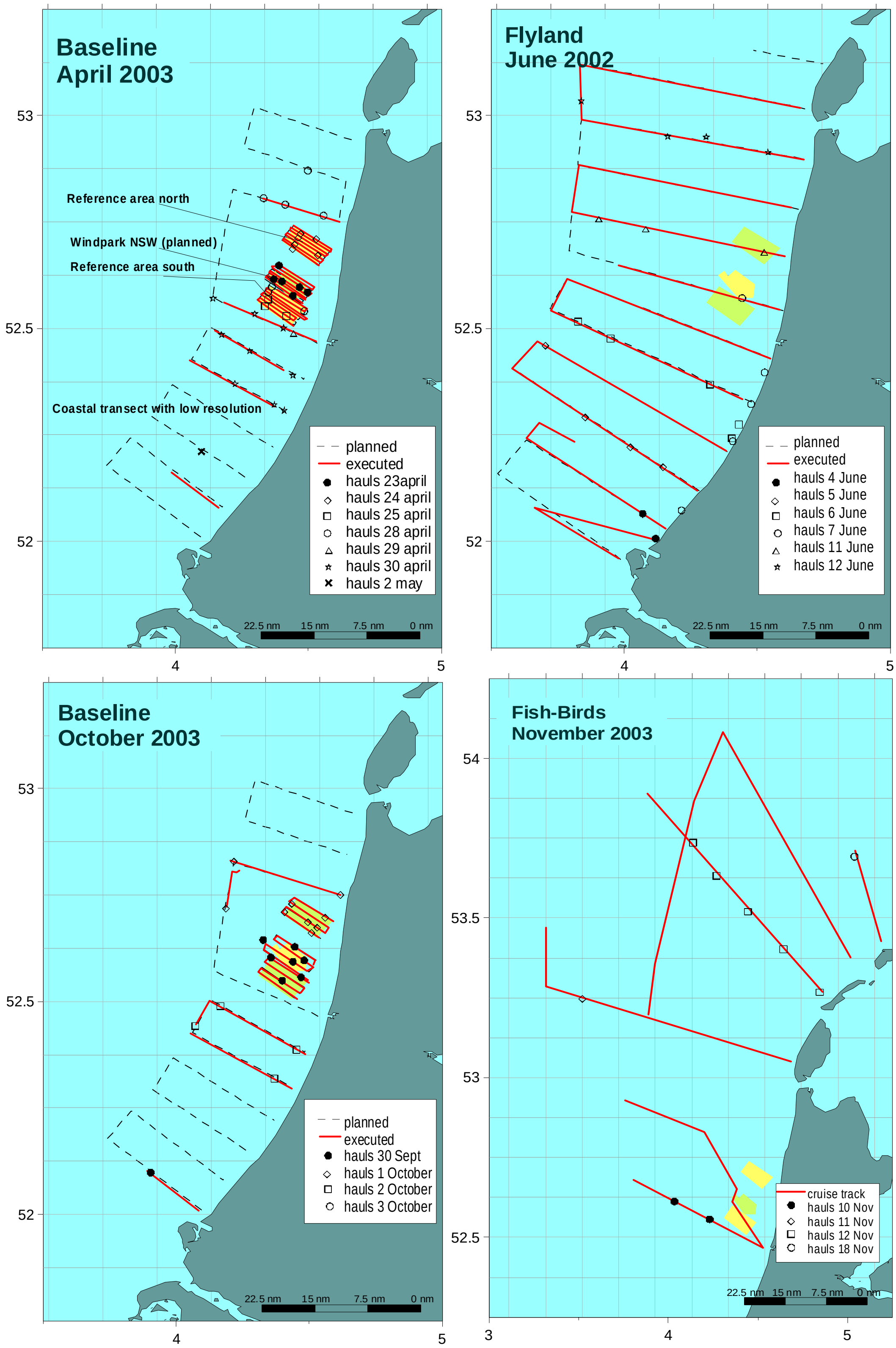


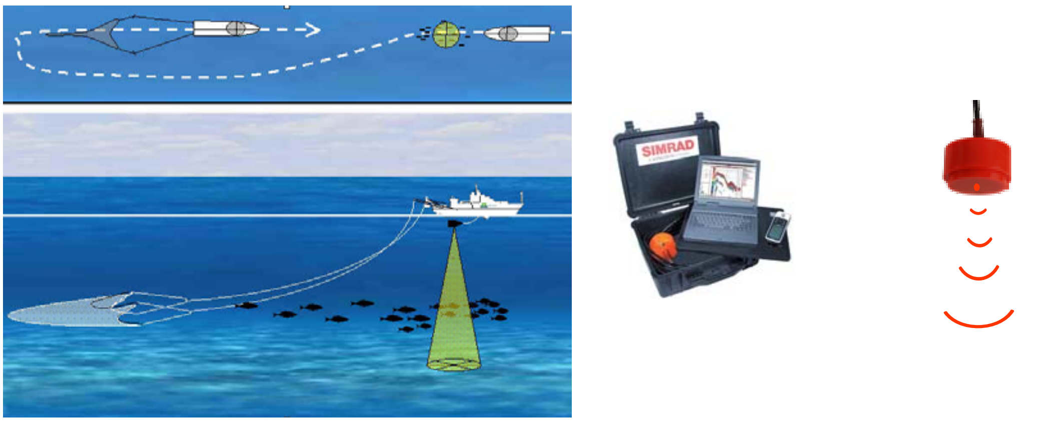
Figure 2.1. *Planned and executed transects of the acoustic surveys in the Baseline study in April (upper left panel) and October 2003 (lower left panel), the Flyland survey in June 2002 (upper right panel) and the Fish-Bird survey in November 2003 (lower right panel). Planned transects are plotted with a black dotted line, executed transects are red. Symbols indicate trawl stations and the dates on which they were sampled.*

2.2 Details of the acoustic surveys

The occurrence, density, spatial variation and population structure of the pelagic fish fauna in the reference situation were assessed by means of echo integration and reference trawl hauls during hydro-acoustic surveys. Hydro-acoustic surveys are an efficient tool in describing spatial distribution and biomass estimates of pelagic fish over large areas. However, additional trawl hauls are required to validate the acoustic observations on fish density and distribution. In addition, catching fish enables collecting biological data (length, age, sex and maturity). When an undefined school of fish is detected by means of echolocation, a haul is made to investigate species composition and length distribution. The net is shot within 15 to 20 minutes after detection of the school. Hauls for species identification can therefore never be planned in advance and are not randomly spread.

Acoustic equipment

Acoustic data were collected using a Simrad EK60 echo sounder with a 38 kHz- and 200 kHz-split beam transducer fixed to a towed body, which was towed from the bow of the trawler (Fig. 2.2 and Photo 1). Two frequencies were used to distinguish species better. To ensure a continuous vertical position of the acoustic beam, a heel and pitch sensor was connected to the towed body.



A) Survey method B) Simrad EK60 echo sounder C) Simrad transducer

Figure 2.2. *Scheme of the sampling method for pelagic fish. When an undefined school of fish is detected on he echo-sounder (B), the vessel turns and shoots a pelagic trawl within 15 to 20 minutes. During this manoeuvre the transducer (C) will be used to track the school.*

Photo 1. *The towed body with the 200 kHz (left, orange) and the 38 kHz (right, yellow) transducers.*

Acoustic theory

The echo sounder transmits and receives acoustic signals (pings) that are reflected by objects in the water column such as fish, plankton and the bottom. This detection method is called *Echo location* (Fig. 2.3).

Figure 2.3. *Method of echo location. An acoustic signal is sent by the transducer and will reflect on structures in the water such as fish, plankton and the bottom.*

The strength of the reflection of the signal is a measure for the structure of the object and in fish, the size of the swim bladder. The presence of a swim bladder is the primary biological factor influencing the amount and variability of backscattered signal from a fish. Swim bladder size and its location in the fish body will determine the amount of acoustic signal reflected back to a transducer. The relationship between the strength of the signal and relative swim bladder size is thus species specific. A 'typical' fish anatomy is pictured below (Photo 2) in the radiograph of Atlantic cod (*Gadus morhua*).

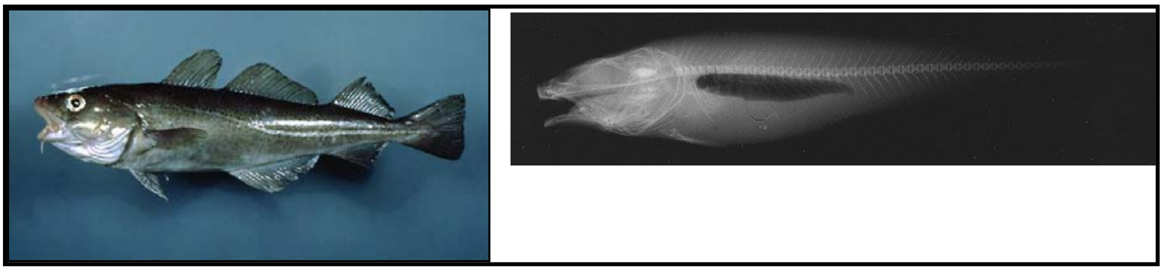


Photo 2. *Radiograph of Atlantic Cod (right picture) showing the swim bladder. Source: http://www.acoustics.washington.edu.*

The time between the transmitted and incoming signal is a measure for the distance between the transducer and the fish. To identify species, assess length distributions and collect biological data, a sample of the fish is taken with a pelagic trawl.

Calibration of equipment

The 38 kHz and 200 kHz split beam transducers were calibrated at the beginning of each sampling period. The depth of the towed body was approximately 2.5 - 3 meter below the water surface. Data were logged per 0.3-second ping intervals with Echoview software. During both surveys for the baseline study, the 200 kHz transducer was calibrated with poor results. One of the electrical cables proved to be partly broken. As a consequence, only the 38 kHz transducer could be used to estimate biomass and the 200 kHz transducer was additionally used to better separate species. For the Fish-birds project, executed immediately after the baseline study wind farms, we hired a 200kHz transducer from the manufacturer that was calibrated reasonably successfully in the basin of the Netherlands Institute for Fisheries Research. To estimate fish numbers and biomass, we only used the data collected with the 38 kHz transducer, because this transducer was employed successfully in all four surveys.

All surveys were planned and carried out during daytime, apart from one transect in the Fish-Bird survey (the transect in North-South direction (Fig. 2.1). The surveys were executed during daytime for two reasons; 1) during daytime pelagic fish generally occur in schools that makes it possible to distinguish between species by means of specific characteristics. During the night they are dispersed over the entire water column. 2): during daytime fish are available as prey for birds, which were an important study object in the June – and the November survey.

By each haul, the total weight per species was measured and for each species, length-frequency distributions were assessed with a precision of 0.5 cm for Sprat, Herring, Anchovy and Pilchard and of 1 cm for other species. If more than 100 individuals per haul were caught, representative sub-samples were taken to assess length-frequency distributions. Individuals of species, for which biological data were collected, were stored on ice for later processing at the institute.

For all surveys the same vessel was used that used a specially designed trawl for small pelagic fish in coastal water (Table 2.1).

In the baseline study, environmental conditions at sampling locations were measured using a CTD measuring device and a Secchi disk. The CTD device continuously recorded its depth, water temperature, conductivity, oxygen saturation and turbidity. During the April survey, turbidity was not measured correctly. It was assumed that this was due to the fact that the probe was towed at insufficient depth. Therefore in October, the CTD probe was attached to the net. Hence hydrographical data from that month were only collected during trawling. In April, in addition to the CTD, at all trawl stations visibility was measured with a Secchi-disk.

Table. 2.1. *Characteristics of the half pelagic trawl used in all surveys.*

Characteristic	Value	Unit
Upper rope	23.5	Meter
Bottom rope	29.7	Meter
Standing rope	19.4	Meter
Mesh width at cod end	6.0	Millimetre
Vertical net opening	5 - 8	Meter

2.3 Selection of the study area

To be able to compare data from different surveys, we divided the sampling area in six sub areas (geographical strata) and for each survey we pooled data from within these areas (Table 2.2; Fig. 2.4). Because of differences in targets among surveys, not all areas were sampled in each survey (Table 2.2).

Table 2.2. *Overview of areas and the surveys in which they were covered. The areas are depicted in Figure 2.4.*

Area	Geographical strata	Covered in survey
1	Near Shore Wind farm area	Baseline
2	Reference Area North	Baseline
3	Reference Area South	Baseline
4	Near shore south	Baseline, Flyland, Fish-Birds
5	Offshore south	Baseline, Flyland, Fish-Birds
6	Northern area	Flyland, Fish-Birds

The areas, *wind farm NSW*, *reference area North* and *reference area South* were taken into account separately because of their special status in the project. The coastal zone was divided in two areas: *South offshore* and *South near shore*. The near shore area was defined as an area shallower than 20 meters and is generally situated in the coastal river. We used a grid compatible with the ICES grid to define these areas. As a result the border between offshore and near shore is not smooth. During the Fish-Birds survey the emphasis was put on a more northern part of the Dutch North Sea, but it also comprised a part of the coastal zone. Since the northern area was only sampled once it cannot be used for inter-seasonal comparisons.

In all analyses in which the four surveys were compared, the data were confined to the study area of the baseline study (Fig. 2.4). In these comparisons, data from outside this area were thus omitted.

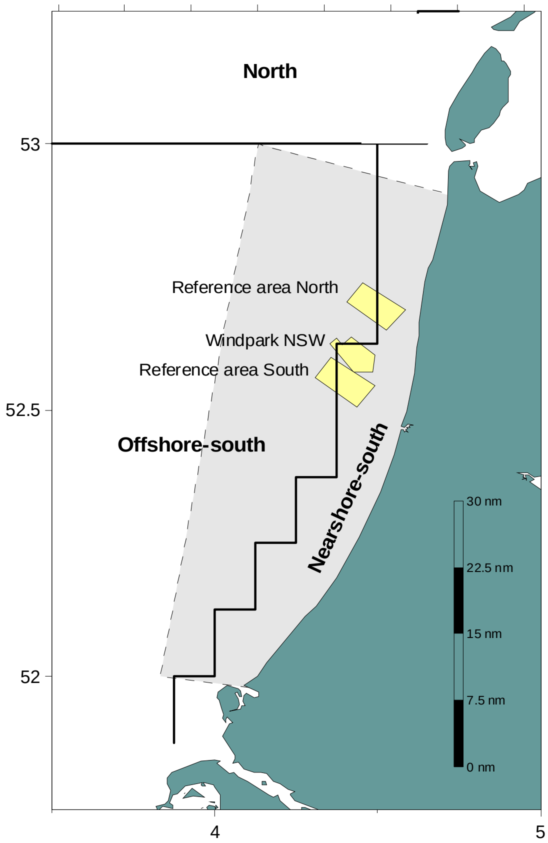


Figure 2.4. *Used areas within the data analysis. The grey area indicates the study area of the baseline study.*

2.4 Acoustic data processing

Raw acoustic data were transformed into estimates of numbers and biomass per fish species following two basic steps: 1) assign acoustic signals to species or groups of species based on the appearance of signals on the screen (scrutinizing) and 2) derive densities and biomass from acoustic signals using relations on target strength (species-specific reflection), length, age and weight information from trawl catches and literature.

2.4.1 Scrutinizing acoustic data

Acoustic data were displayed in so called 'echograms' and live-viewed along the cruise track by the echo sounder. After the survey, in the lab, echograms were scrutinized, partly with Sonardata 'Echoview' software (Fig. 2.5) and with the Simrad BI500 post processing software. Scrutinizing is the translation of acoustic signals into densities per species. It is mostly based on species-specific acoustic characteristics shown in the echograms (Fig. 2.6) and this manual process requires many years of experience.

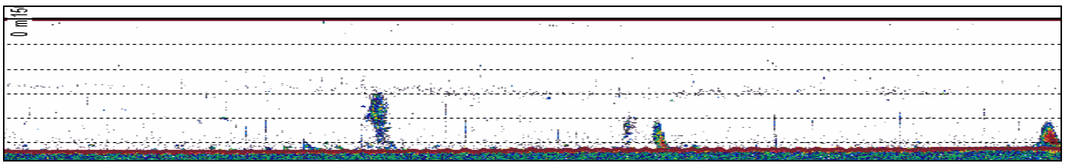


Figure 2.5. *Raw acoustic signals from the echo sounder presented as a vertical slice through the water column (echogram). In the scrutinizing process these signals are assigned to species or groups of species (Table 2.3).*

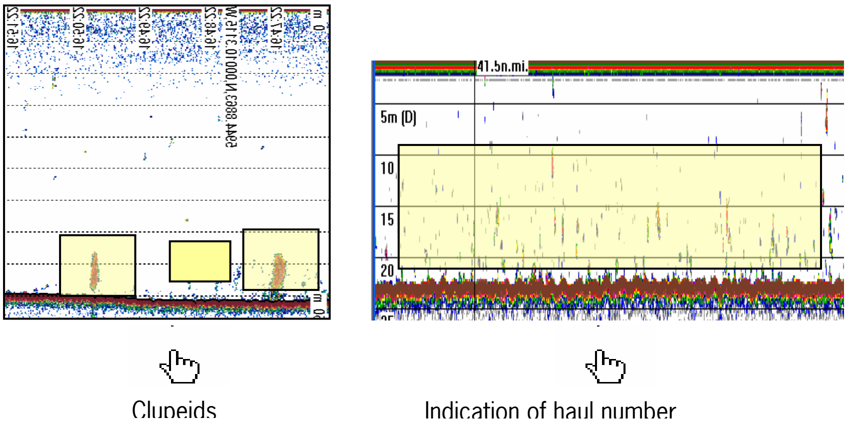


Figure 2.6. *Scrutinizing according to school characteristics or species composition in the trawl.*

Based on these species-specific characteristics, we assigned acoustic output to species and several groups of species that were acoustically similar in that specific period (Table 2.3). Output of the scrutinizing process are acoustic signals called *Nautical Acoustic Scattering Coefficients* (NASC's*)* for each species or species group per square nautical mile (Fig. 2.7). The data were then stored by 0.5 nautical miles intervals (Fig. 2.8).

Table 2.3*. Assignment of species to groups in the case acoustic signals of individual species could not be assigned to species level.*

Species	Survey			
	Flyland	Baseline	Baseline	Fish-Birds
	June	April	October	November
Herring	-	clupeids	clupeids	clupeids
Sprat	-	clupeids	clupeids	clupeids
Pilchard	-	clupeids	clupeids	clupeids
Anchovy[4]	-	clupeids	clupeids	clupeids
Mackerel	-	Mackerel/sandeels	-	-
Horse Mackerel	-	clupeids	-	-
Lesser Sandeel	-	Mackerel/sandeels	sandeels	-
Raitt's Sandeel	-	Mackerel/sandeels	sandeels	-
Greater Sandeel	-	Mackerel/sandeels	sandeels	-

4 Anchovy does not belong to the family of clupeids, it is an engraulid, but in the data processing it was treated as a clupeid because it has the same acoustic characteristics.

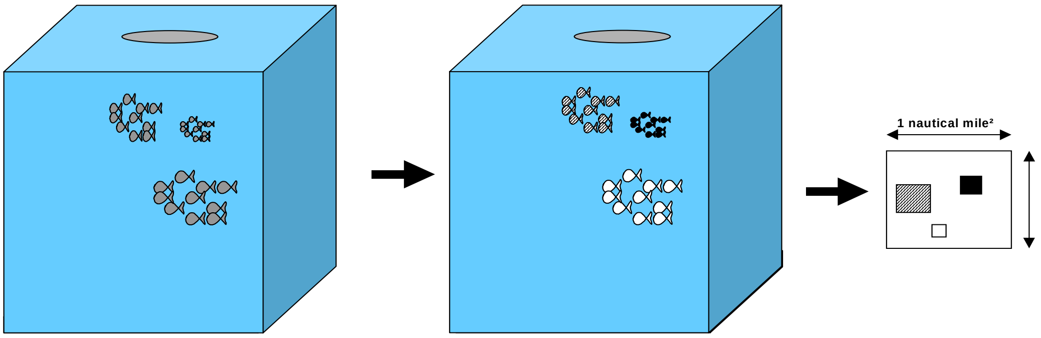


Figure 2.7. *Transformation of raw acoustic signals into acoustic back-scattered area per square nautical mile.*

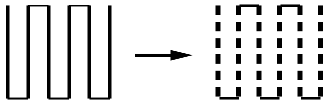


Figure 2.8. *Acoustic back-scattered area (in m²/nm²) along the cruise track is integrated per 0.5 nautical miles.*

2.4.2 Analysing acoustic data

Densities and biomass per species were estimated by translating the scrutinized data (NASC's per group of species) with the SAS software package following four steps:

1. Assignment of geographical strata;
2. Combine acoustic data with trawl data and divide acoustic signals per group over species;
3. Translate acoustic signals to density and biomass per species;
4. Split numbers and biomass per species into length and year class per species.

Intermezzo 4: Splitting species groups into species according to the catch composition

In occasions when acoustic signals could not be assigned to species due to lack of specific acoustic characteristics in the echogram, the assignment to species level was done, using the catch composition in the vicinity of the recorded fish concentrations.

This causes no problems if the species specific Target Strength (TS) were similar for all species. However, the TS of fishes of the same length differ among some species. Whiting, for example, has a high TS. Herring, Sprat, Pilchard, Anchovy and Horse mackerel have TS values of 2.4 times as low. Mackerel en sandeel have even much lower TS values due to the absence of swim bladders: the TS of Mackerel is more than 50 times lower than that of whiting and the TS of sandeel is more then 400 times lower. For example: a Sprat of 15 cm has the same TS as approximately 200 sandeels of that size. In order to compensate for this, 'NASC correction factors' were used to correct for different NASC's of species in the catch (Table A), using known TS – Length relationships (Anonymous, 2004).
An example: when a mixed school of Whiting **(50%)** and Mackerel **(50%)** is detected, the acoustic ratio of Whiting/Mackerel in this school will respectively be 28.1 / 0.5. Raising this ratio back to 100% gives 0.5/(28.1+0.5)=**98.25%** for Whiting and 0.5/(28.1+0.5)=**1.75%** for Mackerel. This means that most of the acoustic signals in the echogram will be related to Whiting.

The NASC factors were retrieved from literature and originate from experiments in which the acoustic reflection of these species was measured in tanks under laboratory conditions. These factors are thus rather accurate.

Table A. *NASC correction factors per species (Anonymous, 2004).*

Species	Correction factor
Whiting	1.0
Horse Mackerel	2.4
Herring	2.4
Sprat	2.4
Anchovy	2.4
Pilchard	2.4
Mackerel	56.2
Sandeel	426.6
Raitt's Sandeel	426.6
Lesser Sandeel	426.6
Greater Sandeel	426.6

1. Assignment of geographical strata

To account for spatial variation in length frequency distributions we assigned geographical strata to combine trawl data and acoustic signals. Based on the patterns in length frequency distribution strata were assigned according to the division in areas. As explained in paragraph 2.2, the information from the trawl catches is required to translate the acoustic signals into densities per species and size class. Here, we pooled trawl data from each stratum to the acoustic data in that stratum.

2. From species group to species

Acoustic signals from groups of fish were divided into separate species according to the weight composition in the nearest catch, correcting for species-specific acoustic responses (see intermezzo 4).

3. From acoustic signal to density and biomass

Acoustic signals per species were translated into densities using the mean length of the fish by stratum. When trawl information within a stratum was lacking, the mean length over all the hauls in the entire survey was taken instead. For an average fish within a species group, the *acoustic cross section* (sigma, □) was calculated, using a target strength-length relationship of $TS = 20\log L - \beta$ (Table 2.4). (Where TS is the target strength of a single fish, L is the mean length of the fish in the school observed and β is a known, species-specific constant). For this study, the TS-length relationships as used in the North sea hydro acoustic survey for Herring were used (Anonymous, 2004).

Subsequently, the total back-scattered acoustic area of that species within the 0.5 nautical miles was divided by the *acoustic cross section* of one fish. In this way, the numbers of fish were estimated (Fig. 2.9).

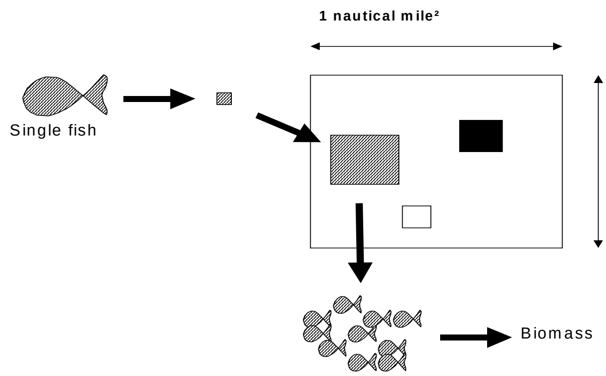


Figure 2.9. *Deriving numbers and biomass per nautical mile by dividing total acoustic area by the calculated acoustic area of 1 fish.*

Table 2.4*. Equations used to estimate densities from acoustic signals (NASC's):*

Sigma (mean length) = $4*pi*10^{((20*\log10((\text{mean length})+0.25)+(-B))/10)}$

density(mean length)=(NASC*(1/(1.85^2)) interval distance)/sigma.

Where:	
Sigma	=acoustic back scattering of a single fish (m^2)
B	=species specific constant.
Density	in numbers/km^2
NASC	=Nautical Area Backscattering Coefficient (m^2/nautical mile^2)
Interval distance	=acoustic survey resolution (0.5 nautical mile)

Densities were translated into biomass according to standard length-weight relationships for each species. In this project data on length and weight of pelagic fish was also collected but the number of observations was too low to predict biomass from these relationships accurately (Grift *et al.* 2004). Therefore we used the standard length-weight relationships that gave precise estimates.

4. Splitting numbers of fish and biomass into length and year classes.
Finally, densities of fish and biomass were split up to year- and length classes according to length-frequency distributions and length-age keys per species (Grift *et al.* 2004).

2.5 Analysing the relationship between abiotic factors and catch: ordination

The analyses of the relationship between abiotic factors and the catch composition were limited to the trawl hauls from the baseline studies in April and October, because only for these surveys complete sets of CTD measurements were available for the majority of the hauls. Analysis of these relationships is useful to explain variation in the abundance of species and can contribute to assessing the effect of a wind farm on the spatial distribution of pelagic fish. In addition, we are interested whether some species aggregate or not to assess if changes in aggregations in a future wind farm are natural or caused by the wind farm. We employed multivariate ordination methods using the Canoco software package (ter Braak and Šmilauer, 2002). Analyses were carried out for April and October separately, for the total numbers and numbers of small and large specimens respectively. This method is explained in more detail in Intermezzo 5.

Intermezzo 5. Ordination.

In contrast to traditional regression methods, in which usually the effect of (several) explanatory variable(s) on one response variable is investigated, multivariate methods can deal with more than one response variable. Instead of the abundance of *one* species at a time, the effect of several a-biotic variables on a species *community* can be analysed simultaneously.

Because environmental variables were only available for the surveys carried out in the baseline study, the ordination analyses are limited to the April and October survey. Data on environmental variables (pH, oxygen, temperature, salinity, turbidity) were obtained from CTD measurements. For the April survey data on visibility (Secchi) were also available. As Canoco interprets missing values as zeros, missing values were inter- or extrapolated based on the nearest haul. As a latitudinal (north-south) gradient was expected in some of the fish species, in addition to environmental data, latitude was also included in the analysis.

Ordination was carried out based on the trawl data using Canoco 4.5 (ter Braak and Šmilauer, 2002). We chose not to analyse the acoustic data in this way because the link with CTD data was more complicated. To explore the relationship between species and environmental variables we used a direct gradient analysis, Redundancy Analysis (RDA, Jongman *et al.* 1995) on the fish abundance (n/hour fishing) and environmental data. In this method environmental variables are used to explain the variation in species composition. Data for each period (April, October) were analysed separately. Because a different distribution was expected for small and large fish, we also carried out separate analyses for these groups. For Anchovy, Pilchard and Sprat the fish were separated at 12 cm, the other species at 15 cm.

RDA assumes that a linear response model best describes the abundance of each species (for example a linear relationship between fish abundance and depth). If the length of the axis only covers a small fraction of the response curve, or if the response curve is not unimodal, multivariate analyses assuming a linear response curve can be used. The choice between methods based on unimodal or linear response curves can be based on the length of gradients. As these were smaller than four times the standard deviation, we used RDA (Jongman *et al.,* 1995). Fish abundance data were log-transformed. Analyses were limited to pelagic species only. Rare species (occurring only in less than three hauls) were excluded from the analysis.

2.6 Collection of biological data

In total, biological data were collected from 647 fish within the baseline study and biological data were retrieved from 1496 fish from other programmes that were executed by the Netherlands Institute for Fisheries Research (Table 2.5). No biological data were collected in the Fish-Birds survey.

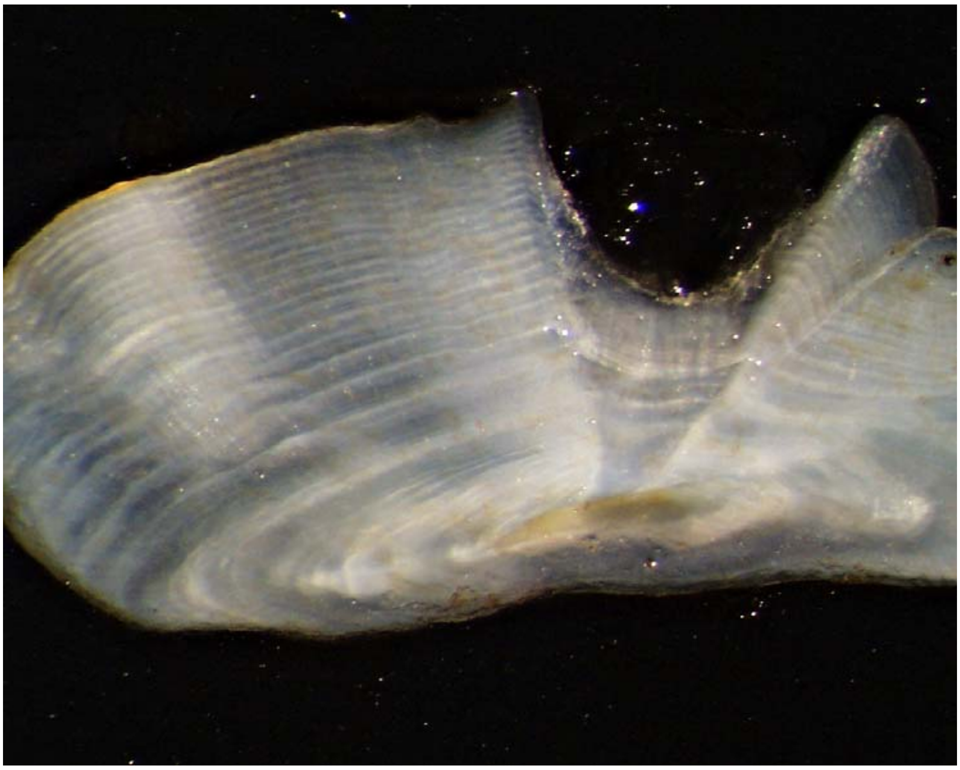


Photo 3*. Cross-section of an otolith of a Horse Mackerel of 21 years old (From Bolle et al. 2003).*

Table 2.5. *Numbers of fish for which biological data were collected (length, weight, sex, maturity and otoliths). Numbers printed in bold represent fish for which data were retrieved from the Baseline study, without bold/italics from programmes in the Dutch coastal zone and in italic from programmes in the entire North Sea. A table with all English, Dutch and scientific names is presented in Annex I. Quarter 2: April-June; Quarter 3:July-September; Quarter 4: October-December.*

Species	Dutch name	Quarter			Total
		2	3	4	
Anchovy	Ansjovis	**104**	-	**39**	39
Greater Sandeel	Smelt	**36**	-	**9**	9
Herring	Haring	**129**	-	175	175
Horse Mackerel	Horsmakreel	*525*	-	250	250
Lesser Sandeel	Kleine zandspiering	**58**	-	-	58
Mackerel	Makreel	*875*	-	50	50
Pilchard	Pelser	**53**	-	**28**	28
Raitt's Sandeel	Noorse zandspiering	**93**	-	-	93
Sprat	Sprot	**39**	*151*	-	190
Total		1914	151	78	2143

As described in the strategy of approach, we did not collect data for pelagic species that are sampled in other, routine programmes of the institute. Therefore, we did not collect biological data from Mackerel and Horse Mackerel. Instead, for the fourth quarter (period of the second baseline survey) data collected by other surveys in the coastal waters of the Netherlands were used. For the second quarter (first survey), no data were available for Mackerel and Horse Mackerel for the coastal areas, and survey data from the entire North Sea had to be used. For Herring and Sprat, we only collected new data during the first survey of the baseline study. For Herring in the fourth quarter data from the coastal waters could be used. For Sprat, no data in the fourth quarter were available and data from the third quarter and the entire North Sea had to be used. The additional data from other programmes resulted in a total of 2143 fish for which biological data were collected.

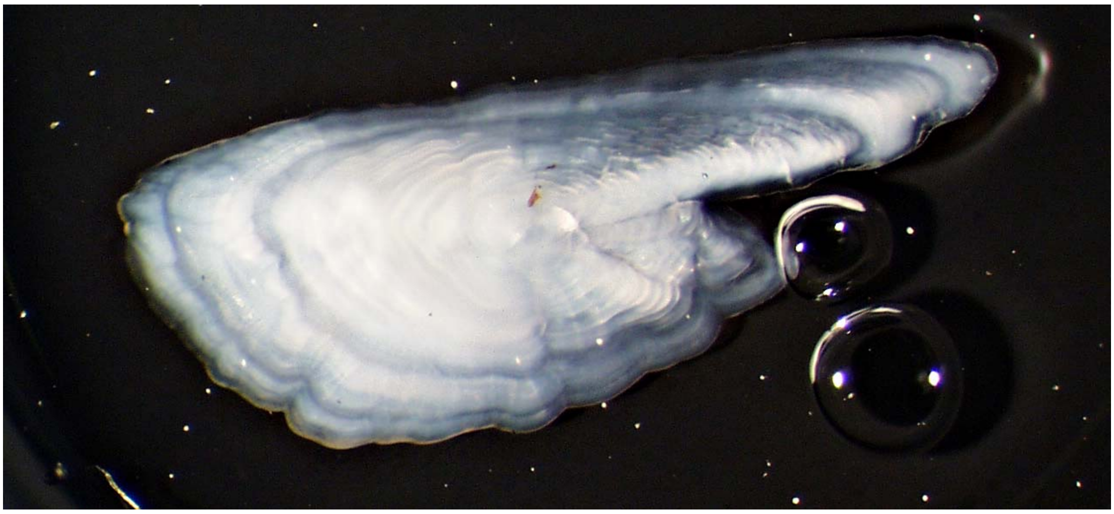


Photo 4. *Cross-section of an otolith of a Mackerel of 3 years old (From Bolle et al., 2003).*

Of all these fish length, weight, sex, maturity stage and age were determined in the laboratory. Length was measured to the nearest mm and weight to the nearest gram and sometimes decigram. Sex and maturity stage were determined by visual observation of the gonads. Ages were determined from reading the otoliths.

Because the Netherlands Institute for Fisheries Research had no experience with reading otoliths of Anchovy, Greater Sandeel, Lesser Sandeel, Pilchard and Raitt's Sandeel, otoliths of these species were sent to colleagues in Spain, Portugal and Denmark. In addition, the reading of otoliths by other institutes was also an independent test for the identification of species.

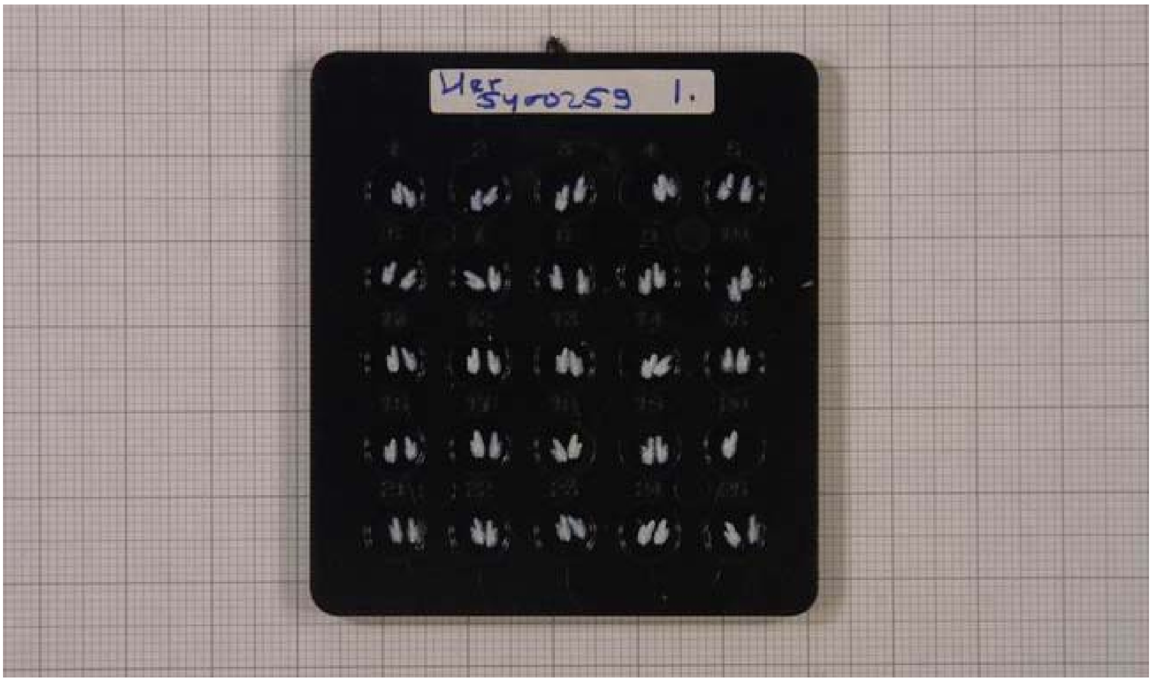


Photo 5. *Storage of Herring otoliths before they are read.*

Otoliths of Herring, Sprat, Mackerel and Horse Mackerel are read in routine programmes of the Netherlands Institute for Fisheries Research executed since the 1960s (Photos 3, 4 and 5). The ages were read following standard procedures of the Netherlands Institute for Fisheries Research (Bolle *et al.*, 2003). Age-length keys, sex-maturity keys and weight-length keys were constructed.

3. Results

In this chapter, the occurrence, density, population structure, spatial variation and migration patterns of pelagic fish fauna in the reference situation will be described. This will be done for the nine pelagic species that were observed in the coastal zone (Table 3.1). First, the size structure of the pelagic fish assemblages will be described by presenting length-frequency distributions per age group. Next, we will describe temporal and spatial distribution patterns of these species. These are all based on the acoustic surveys and serve to derive information on migration patterns and the ecological function of different areas. The emphasis will be on the description of the fish community in the whole coastal zone, rather than focusing on the Near Shore Wind farm area.

Table 3.1. *Total catch (numbers in trawl catches) of pelagic species in the four surveys*[5]*.*

Survey	Period	Species	North	NSW	Ref N	Ref S	South near shore	South offshore	Total
Baseline	April 2003	Anchovy	–	24	25	80	366	78	573
		Pilchard	–			33	759	679	1471
		Herring	–	3882	13076	1573	1574	159	20264
		Sprat	–	4546	19669	7773	5991	22470	60449
		Greater Sandeel	–	27	7	11	14	13	72
		Lesser Sandeel	–	210	283	140	86	18	737
		Raitt's Sandeel	–	10280	7227	2832	106	53752	74197
		Horse Mackerel	–	18	138	639	118	7709	8622
		Mackerel	–	216	1568	2966	36	118	4904
Flyland	June 2002	Anchovy	–	–	–	–	27943	0	27943
		Pilchard	–	–	–	–	132	180	312
		Herring	–	–	–	–	220516	58	220574
		Sprat	–	–	–	–	1559061	8	1559069
		Sandeel spec[6]	–	–	–	–	9	341	350
		Horse Mackerel	–	–	–	–	2106	3052	5158
		Mackerel	–	–	–	–	1774	832	2606
Baseline	Oct. 2003	Anchovy	–	96	1146	24	412	3927	5605
		Pilchard	–	11	468	13	1791	1007	3290
		Herring	–	14630	5370	16212	5516	7967	49695
		Sprat	–	12	16636	9586	76080	3653	105967
		Greater Sandeel	–	33	2	0	6	3	44
		Lesser Sandeel	–	0	0	0	0	0	0
		Raitt's Sandeel	–	0	0	0	0	0	0
		Horse Mackerel	–	155	426	66	157	10738	11542
		Mackerel	–	459	214	131	3	636	1443
Fish-Birds	Nov. 2003	Anchovy	908	–	–	–	0	2	910
		Herring	15669	–	–	–	4320	12776	32765
		Greater Sandeel	15	–	–	–	0	0	15
		Lesser Sandeel	0	–	–	–	0	0	0
		Horse Mackerel	15	–	–	–	0	44	59
		Mackerel	0	–	–	–	0	13	13
		Pilchard	0	–	–	–	0	1229	1229
		Raitt's Sandeel	0	–	–	–	0	0	0
		Sprat	147871	–	–	–	4000	55559	207430

[5] Numbers are not corrected for fishing effort and can therefore not be compared among surveys directly. We did this deliberately because the fishing during acoustic surveys is not random. The total catch data including non-pelagic species are presented in Annex II.

[6] During the Flyland survey sandeel species were not identified to the species level.

3.1 Spatial-temporal patterns

Generally, the highest biomass of pelagic fish occurred in the South-offshore area and the species composition showed a large variation among areas and periods (Fig. 3.1). Total biomass was highest in the near shore area only in April. At the same time the pelagic species assemblage was largely dominated by sandeels in the NSW and the South-offshore area but by Mackerel in the other areas. The proportion of Anchovy and clupeids was comparable in all areas. In June, Anchovy and clupeids were practically absent and the pelagic fish community mainly consisted of sandeels and Mackerel. However, clupeids dominated in a few trawl catches very close to the shore in water that was too shallow for echo integration (<7m). It is therefore likely that the shallow coastal zone is dominated by clupeids at that time of the year. In October, Mackerel predominated in the NSW, Ref S and offshore areas, while Horse Mackerel was the most common species in Ref N and Pilchard in the near shore area. In November only clupeids occurred in the coastal zone.

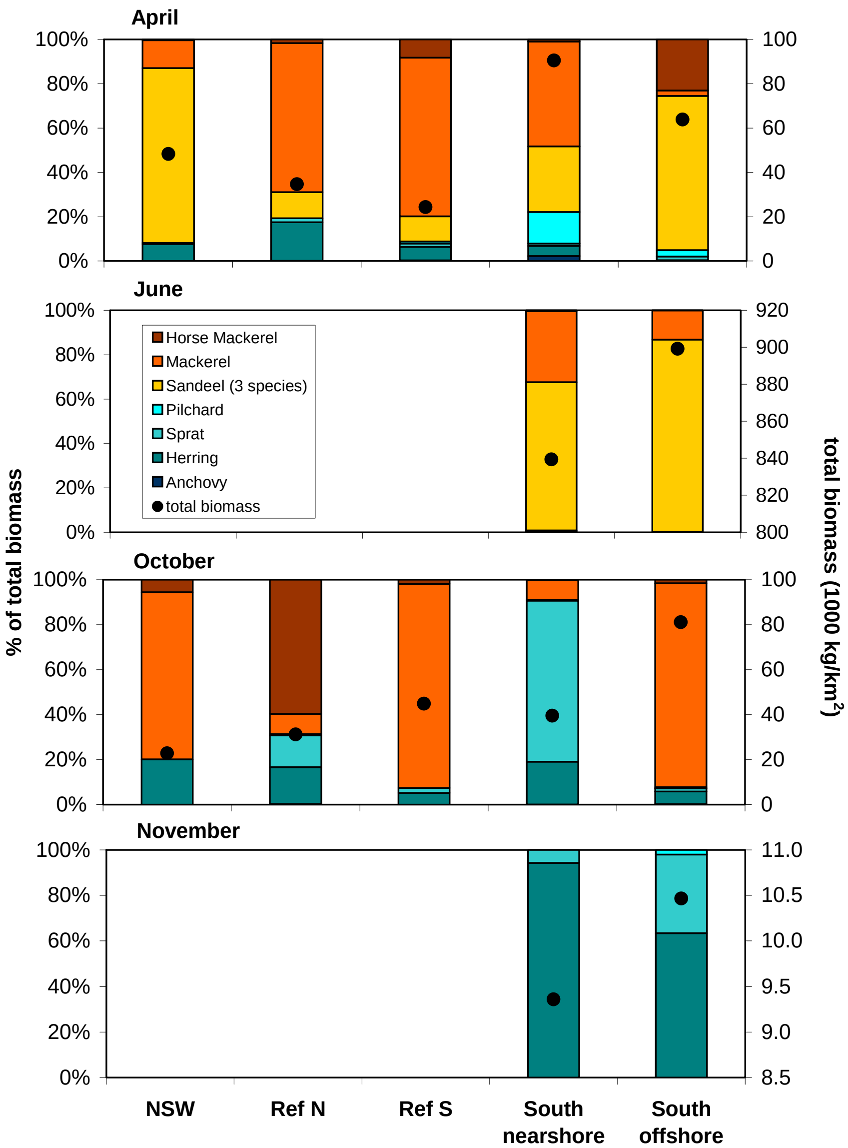


Figure 3.1. *Contribution of the nine pelagic species to the total biomass of pelagic fish (percentage, left y-axis) in the four surveys in the five areas (based on acoustic data). The dots represent the total biomass of these nine species (x 1000 kg km^{2}, right y-axis) averaged for all intervals within each survey and area. In November only the southern near shore and offshore areas were sampled.*

Biomass length distributions of the near shore and offshore areas (Fig. 3.2) and the wind farm area and both reference areas (Fig. 3.3) clearly illustrate the large spatial-temporal variation in species composition and size structure of the pelagic fish community.

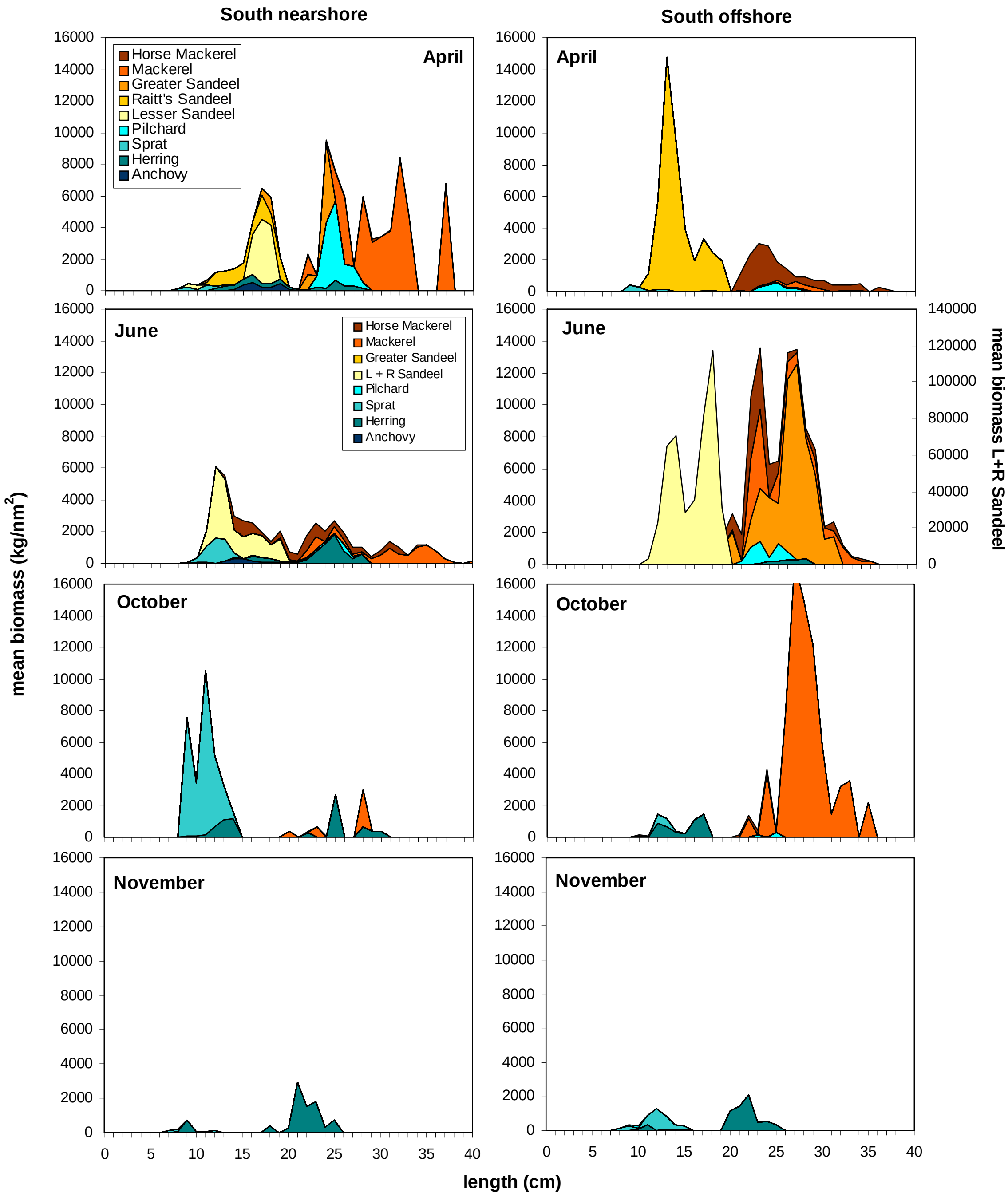


Figure 3.2. *Biomass length distributions of the pelagic species based on the acoustic data in the four periods in the south near shore and offshore area. For October and November see the legend of April.*

The largest differences between the biomass size distributions in the South near shore and offshore areas occurred in April and June (Fig. 3.2). In the near shore area sandeels and large Mackerel dominated whereas Mackerel was absent from the offshore area and sandeels and large Horse Mackerel predominated. In June, the pattern in Mackerel was reversed: relatively few large Mackerel were observed near shore, but many offshore. The size distributions of Lesser sandeel and Raitt's sandeel were similar in both areas and all periods. In April Greater Sandeel occurred in two size classes near shore but not offshore. In June however, large Greater Sandeel was more abundant offshore.

The biomass size distributions in both reference areas and in the near shore wind farm area were comparable (Figure 3.3). Exceptions were the extreme high abundances of Raitt's Sandeel in the NSW area in April and of Horse Mackerel in Ref N in October.

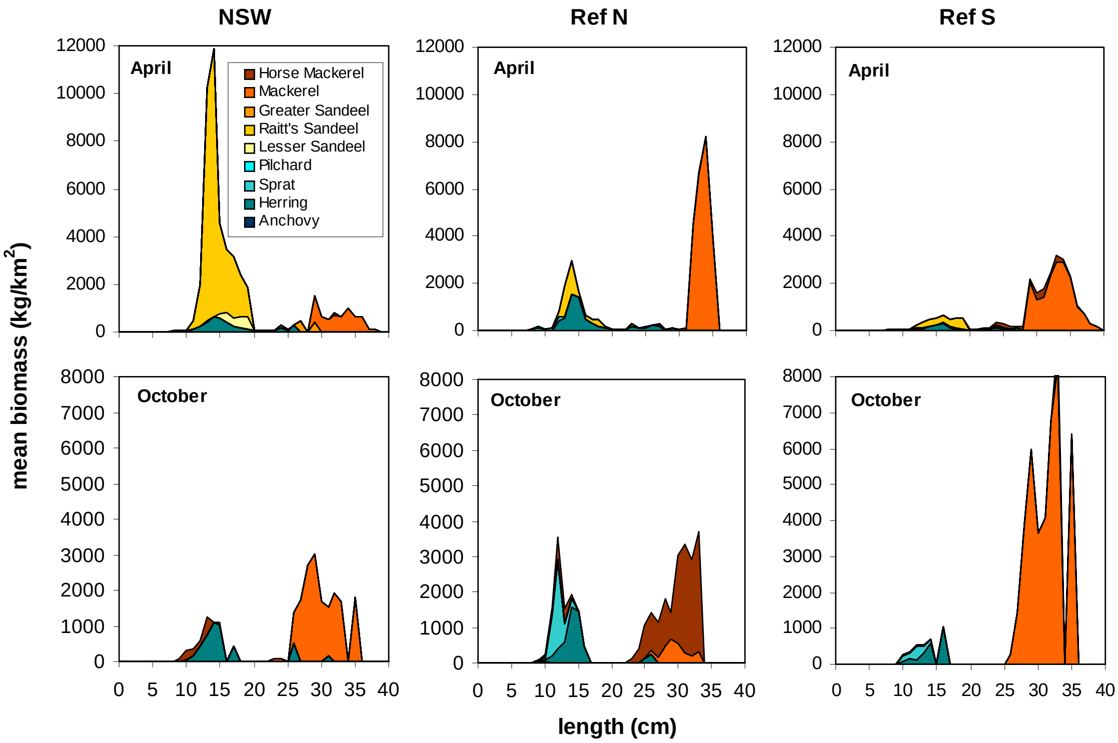


Figure 3.3. *Biomass size distributions of the pelagic species based on the acoustic data in the NSW and reference areas*

Intermezzo 5. Variograms: tools to illustrate spatial variation.
To quantify spatial variation in the abundance of pelagic fish we employed variograms that describe for all observations the relationship between the distance of a pair of observations and the difference in the abundance of pelagic fish between these locations. Absence of such a relationship shows that there is no consistent pattern in the spatial distribution. Variograms were constructed for the acoustic signals for each of the nine pelagic species and for the total acoustic signal of all fish together.

In variograms, the difference in the abundance between two sections is plotted against the distance between these sections (Fig. A). The sections were the half nautical miles for which abundance was estimated. The difference in abundance was estimated by the difference in the log-transformed values. Sections where a species was not observed ('zero catches') were omitted.

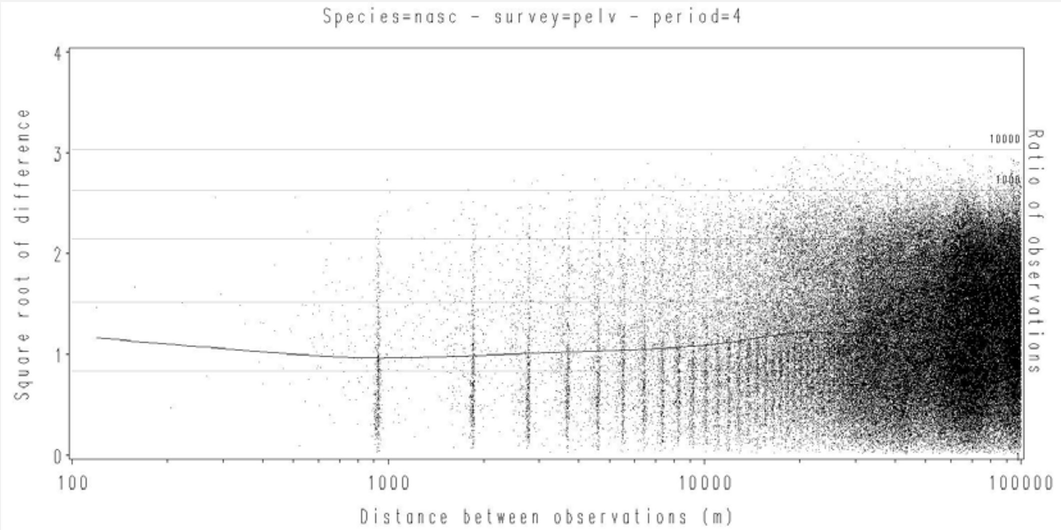


Figure A. *Variogram of the total acoustic signal (NASC) in the baseline study for pelagic fish in October 2003. The x-axis presents the distance between acoustic observations (sections of 0.5 nm), the left y-axis presents the difference between the log-transformed acoustic signals; the right y-axis presents the ratio between the acoustic signals. Each dot is the combination of two sections whereas the line presents the regression line through the dots. Because there is no relationship between the distance between two sections, and the difference in acoustic signal, there is no consistent spatial pattern.*

Of all species of which variograms were constructed, only Anchovy and Greater sandeel showed a relationship between distance and differences in abundance, but the relationship was not strong (Figure B and C).

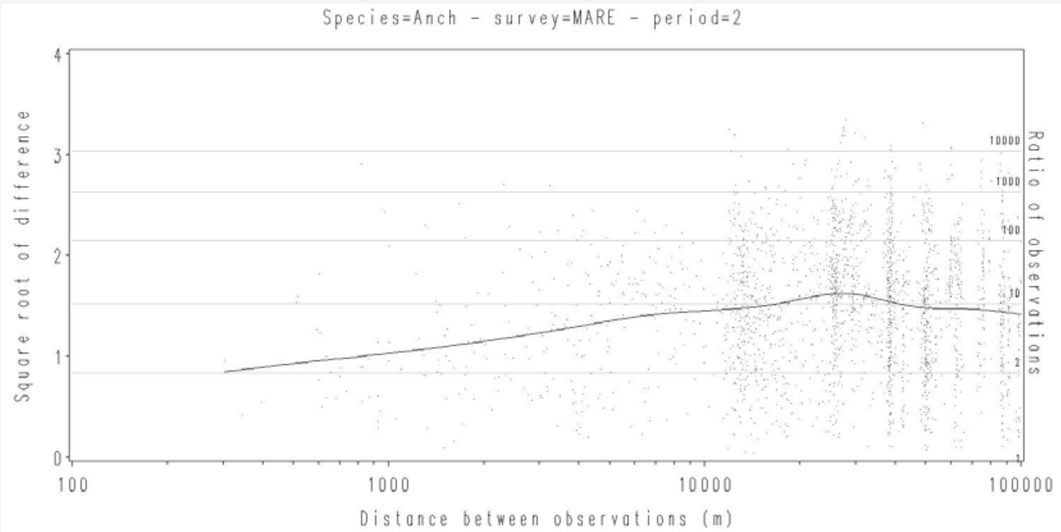


Figure B. *Variogram of Anchovy for observations from the Flyland survey. From a distance of 200 m to a distance of 30000 m between sections, the difference in acoustic signals increases from a factor 2 to 10. This means that, on average, the abundance of Anchovy in two sections that are 200 m separated varies a factor 2 (twice as much or twice as less) whereas at a distance of 30 km this difference is a factor 10.*

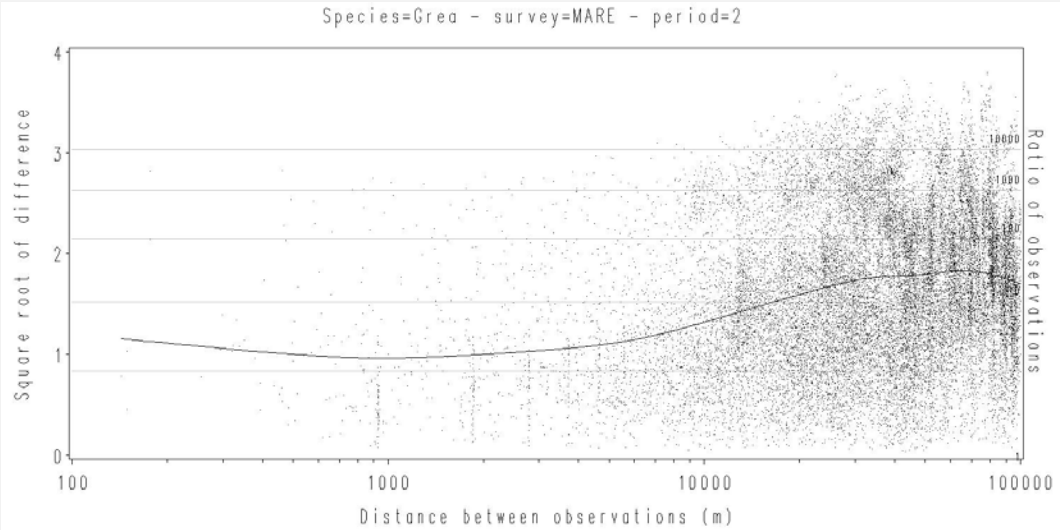


Figure C. *Variogram of Greater sandeel for observations from the Flyland survey.*

The variograms thus show that there are in general no consistent patterns in the spatial distribution of pelagic fish. Because the variograms are based on sections where fish were detected, they give no information on the presence-absence of species but only on their abundance.

3.2 Age and size distributions per species

Of all species, mature individuals were observed and of many species also 0-group fish were present in the Dutch coastal zone. For most species, LF distributions did not vary among the different areas but in general, small species and the smaller individuals of Herring were observed more inshore (Annex III). Exceptions were Herring of which larger and older age classes mainly occurred South-offshore, both in April and October. In contrast, younger and smaller individuals of Mackerel and Horse Mackerel were more abundant offshore than in the other areas. This pattern was most clear in April.

In April and June, the catches of **Anchovy** consisted of 1 and 2 year old (mature) individuals whereas in autumn these age groups had entirely disappeared and only 0-group individuals were observed (Fig. 3.4). These patterns were consistent both near shore and offshore and in the NSW and reference areas (Annex III, Fig. III.1). In April, Anchovy occurred in highest densities close to the coast (Annex V, Fig. V.1)[7]. The variation in densities was large and densities were higher in Ref South than in the NSW and Ref North. In June the distribution differed and Anchovy was concentrated even closer to the coast than in April; further than 20 km offshore, Anchovy was not observed. In November the coastal area was devoid of Anchovy and was only found along the northern transects.

In spring and summer all individuals of **Pilchard** were age 3 and older and were mostly ripe or spawning. In October and November, 0-group fish were observed (Fig. 3.4 and Annex III Fig. III.2). The occurrence of 0-group Pilchards in the North Sea is rare and may be related to the exceptional warm summer of 2003. The adult fishes were not observed in the catches in October, which indicates that

[7] In the interpretation of these maps, the size of the different areas sampled must be taken into account. During the June survey a much larger area (stretching further offshore) was sampled than during any of the other surveys. Bear in mind that there is an important difference between sites that were not sampled and sites sampled but at which no fish was present.

they had been migrating southward to the Channel. The distribution of Pilchard was very patchy in all periods (Annex V, Fig. V.2). In April and June Pilchard was absent from the NSW and Ref N areas, and in October from NSW and Ref S. The distribution seems highly unpredictable due to the variation in the probability of encountering schools. This effect is clearer in Pilchard than in Anchovy or any of the other clupeids.

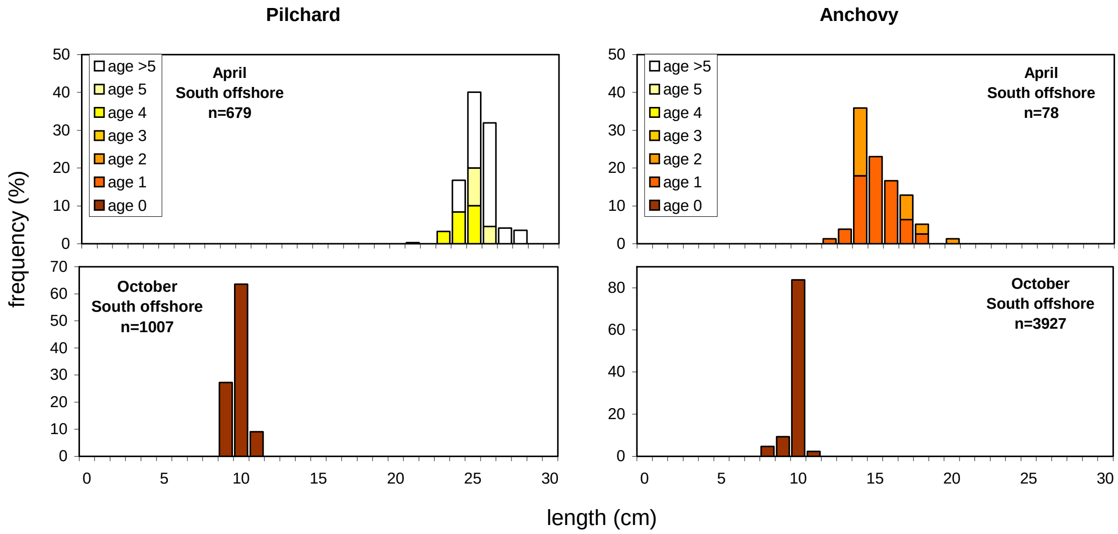


Figure 3.4. *Length frequency distribution per age group of Anchovy and Pilchard in the two baseline surveys in April and October. Because distributions were similar for all areas, only the distributions for South offshore are presented as an example. Because the relationship between length and age was the same in all areas, no graphs for the NSW area separately are displayed. For the complete figures for all species and areas see Annex III and IV.*

Near shore and offshore, the age distribution of **Herring** was similar in spring and autumn. Older year classes (3+) were present in all areas and periods but absent in October. The majority of the individuals from the second quarter had maturity stage 8. This means that they were probably late spawners and belonged to the part of the stock that spawns in the Channel in December. Of all clupeids Herring was most evenly distributed in all periods apart from June (Annex V, Fig. V.3). In that period Herring was most abundant close to the shore. There was a tendency for the smallest individuals to concentrate close to the coast. Mature Herring in June were most abundant and congregate in the feeding grounds relatively close to the shore. Younger individuals were present in all other periods, but because of the large number of older Herring the presence in June seems reduced.

The length distribution of **Sprat** did not show large differences between near shore and offshore areas and was very similar in the four periods (Annex IV, Fig. IV.4). Age classes 1, 2 and 3 were most abundant. In June age class 3 suddenly appeared in the near shore areas. This may be explained by the fact that during the June survey several hauls were made very close to the coast, closer than during any of the other surveys. In November the majority of Sprat consisted of Age class 1 in the near shore area. All Sprat in the second quarter were ripe (stage 6). In the third quarter no ripe individuals were found. Spawning takes place in different periods at different locations (see Intermezzo 1). Therefore, no clear patterns on age and size distributions and fecundity at different times of years can be expected. In April and November, Sprat was abundant throughout the coastal zone whereas in June and October Sprat was most abundant in near shore areas (Annex V, Fig. V.4).

In April, the age length distribution in **Raitt's** and **Lesser Sandeel** was quite uniform (Annex III). All age classes were represented similarly in the different areas. The majority of *Greater Sandeel* consisted of age classes >0. Age classes of >2 were caught both offshore and near shore (Annex III). Sandeel were only observed in April and June and their absence in October and November can be explained because they only occur free swimming in spring and summer and are buried in the sand in other seasons (see intermezzo 3). In April high densities were observed in the whole study area (Annex V, Fig V.5). In June the distribution was much patchier with high concentrations in a few areas.

Horse Mackerel was the most abundant species in June, both near shore and offshore. In spring mainly large individuals (3+) were present, while in autumn these age classes had disappeared and were replaced by younger (age 0 and 1) individuals. Also Horse Mackerel was very scarce in November but abundant at other periods (Annex V, Fig. V.6). In April the highest densities were found in the area south of the NSW. Densities were higher in both reference areas compared to the NSW itself. In June Horse Mackerel showed a much patchier distribution than in April, although this image might be disturbed by the larger survey area in June. In June the highest densities occurred further offshore.

Mackerel migrates into the North Sea to spawn in early summer and moves towards the northern edge of the North Sea in autumn. Larger fish swim faster and arrive therefore earlier. Smaller fish may stay behind which may explain the fact that in October only small sized Mackerel (1 and 2 year old) occurred in the catches. Mackerel were hardly encountered during the November survey (Annex V, Fig. V.7). In April Mackerel was evenly distributed in the NSW and the two reference areas. Also in the surrounding area the distribution was quite even. In June Mackerel occurred in low densities, apart from one small area off the Texel coast.

The distribution of pelagic fish in the northern area in November (only sampled in the Fish-Bird survey) was characterized by a relatively even occurrence of Anchovy, Herring and Sprat whereas Pilchard only occurred in the southern transects. (Annex VI, Fig. VI.1).

3.3 Spatial distribution in relation to environmental variables

In none of the pelagic species a trend in catch composition parallel to the coastline could be detected because latitude did not explain a significant part of the variation. This means that the composition of the trawl catches did not vary along this gradient.

April

In the RDA, the species were grouped as follows: (1) Pilchard and Horse Mackerel, (2) Sandeel and Raitts' Sandeel, Anchovy and Herring (3) Lesser Sandeel, Mackerel and Sprat (Fig. 3.5). Variables explaining a significant proportion of the variation included depth en Secchi disk depth (Annex VII, Table VII.1). Pilchard and Horse Mackerel occurred at deeper areas, while Anchovy, Herring and Raitt's Sandeel were mainly caught in the shallower parts. The negative effect of depth was clearest in Herring. Lesser Sandeel, Mackerel and Sprat occurred in higher densities in the clearest water.

The analyses for the large individuals separately gave a similar picture: both depth and Secchi disk depth were significant (Fig. 3.6). Small species occurring in April were limited to Lesser Sandeel, Raitt's Sandeel, Sprat and Herring. Apart from depth and Secchi disk depth also oxygen concentration was significant. While both sandeel species and Sprat occurred at highest Secchi disk depths, oxygen concentration had a significant positive effect on the Herring density.

October

The grouping of the species turned out slightly different from that in April: (1) Herring, Anchovy, Pilchard and Sprat, (2) Sandeel and Lesser Sandeel and Mackerel and (3) Horse Mackerel (Fig. 3.7). Depth, pH and oxygen concentration explained a significant part of the variation (Annex VII, Table VII.2). Herring, Anchovy, Pilchard and Sprat occurred in higher densities at the shallower areas while density of Horse Mackerel was positively correlated with depth. Mackerel and Lesser Sandeel occurred in higher densities at sites with relatively high pH values. The vector indicating the effect of oxygen concentration was not clearly correlated with any of the fish species.

In October the species of which small specimens were caught were limited to: Horse Mackerel, Herring, Pilchard, Anchovy and Sprat. Variables explaining a significant part of the variation were salinity, pH and oxygen concentration (Fig. 3.8). Horse Mackerel densities were highest at relatively high pH values. The other species responded on salinity with highest densities found at the lowest salinity. Large specimens of all species were caught in October. The only significant environmental variable was pH, with the strongest positive correlation to Mackerel (Fig. 3.7).

In conclusion the clupeids tended to congregate, especially in October. The three sandeel species did not seem to congregate. Environmental variables explained a considerable part of the variation in October but less so in April. The influence of variation in environmental variables was considerable and should be taken into account when assessing the impact of the wind farm. Although temperature and latitude were included in the analysis, they were not significant (and therefore, they are not shown in the RDA plots).

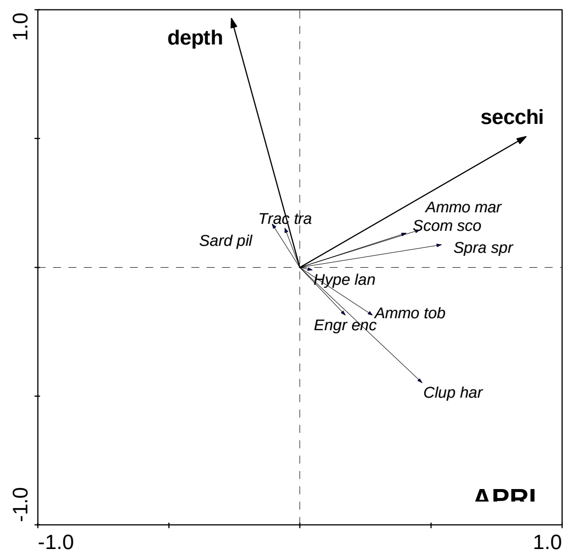
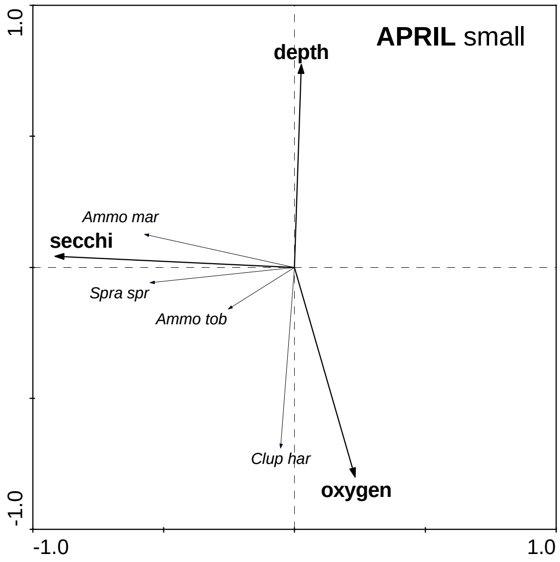


Figure 3.5. *Redundancy analysis ordination biplots of species and variables for April. Only variables that were correlated with one of the two axes are shown. Every arrow (extended in both directions) represents a factor and determines a direction in the diagram. The projections of the species on the arrows show their correlations with environmental variables. The closer the projection of a species or year to the arrow of the vector, the stronger the relationship.*



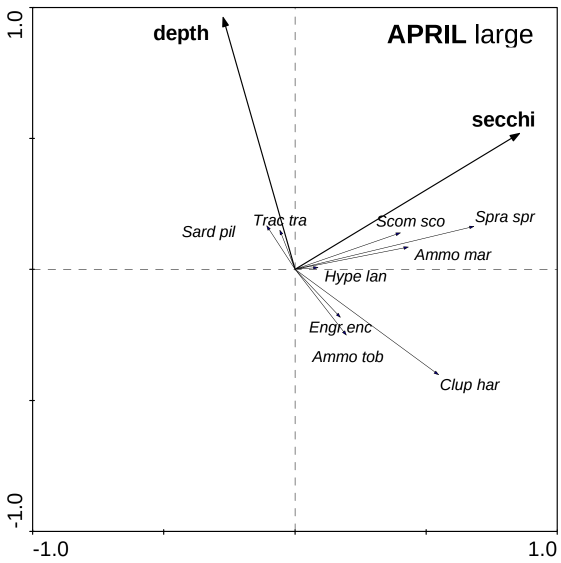


Figure 3.6. *Redundancy analysis ordination biplots of species and variables for small (left) and large (right) specimens in April. Only environmental variables that were correlated with one of the two axes are shown. See for explanation of the biplot Figure 3.5.*

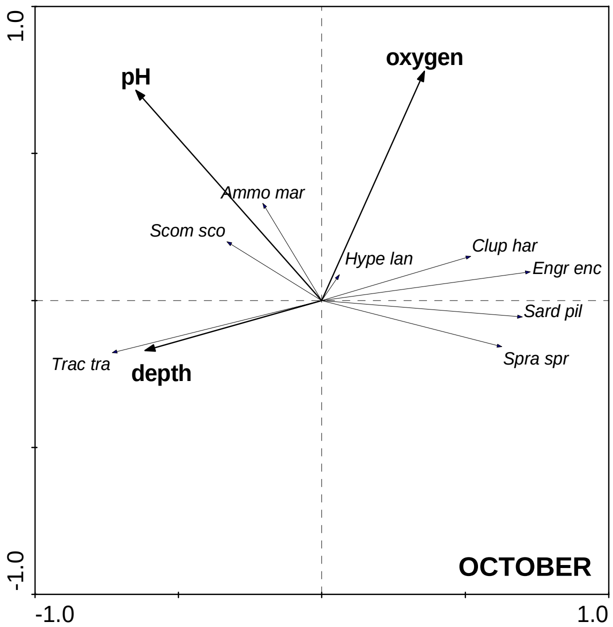
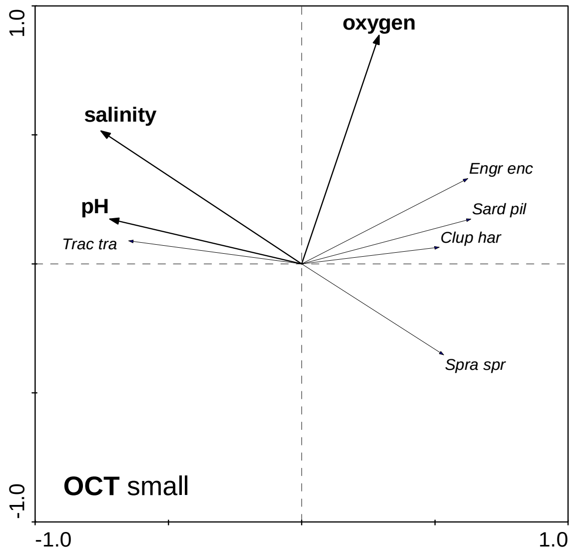


Figure 3.7. *Redundancy analysis ordination biplots of species and variables for October. Only variables that were correlated with one of the two axes are shown. See for explanation of the biplot Figure 3.5.*



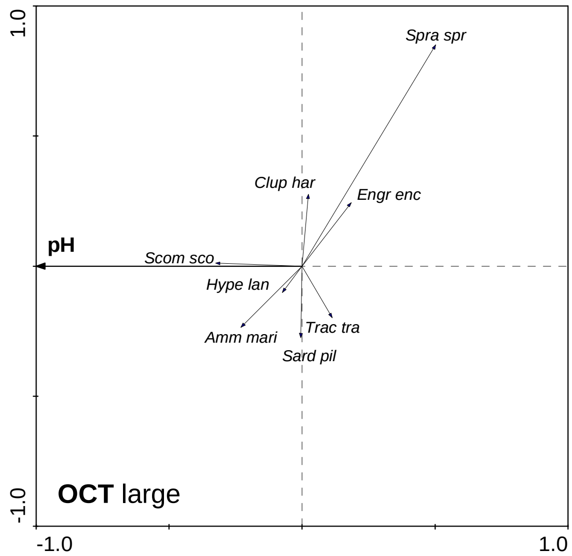


Figure 3.8. *Redundancy analysis ordination biplots of species and variables for small (left) and large (right) specimens in October. Only environmental variables that were correlated with one of the two axes are shown. See for explanation of the biplot Figure 3.5.*

4. Discussion

The surveys executed for the baseline study wind farms for pelagic fish were some of the very first surveys for pelagic fish in the Dutch coastal zone and yielded new information about the distribution, biology and seasonal movements of pelagic fish. Although the weather and new methods applied caused unforeseen problems and limited the number of transects that could be sampled, the general pattern in the distribution of pelagic fish was described adequately. The incorporation of data from two other surveys that were carried out at different times of year resulted in a year round description of the pelagic fish community. For pelagic species of commercial interest for the Netherlands, such as Mackerel, Horse Mackerel, Sprat and Herring a lot of biological information was already available but this was certainly not the case for Anchovy, Pilchard, Raitt's Sandeel, Lesser Sandeel and Greater Sandeel. For these species, new biological information (sex, maturity, weight and age) was collected in this project.

The aim of baseline study for pelagic fish was to establish the occurrence, density, population structure and migration patterns of pelagic fish fauna in the reference situation. In general terms, the baseline situation for pelagic fish in the Dutch coastal zone can be described by a community of nine species that show a large temporal variation and of which spatial patterns only occur at larger scales along North-South and near shore-offshore gradients.

In this chapter, we will synthesize the results and give a general description of the baseline situation of the pelagic fish community. Next, we will discuss the methods and techniques employed. We will conclude this chapter by discussing the applicability of acoustic surveys for this type of research and will give advice for future sampling of pelagic fish in the Dutch coastal zone.

4.1 The baseline situation of the pelagic fish community

The pelagic fish community in the Dutch coastal zone comprised nine species of which three sandeels (Raitt's Sandeel, Lesser Sandeel, Greater Sandeel), three clupeids (Herring, Pilchard, Sprat) and three species representing other families (Mackerel, Horse Mackerel and Anchovy). The pelagic fish community shows a large temporal and spatial variation.

The number of species observed is limited in comparison to the demersal fish assemblage in the coastal zone, but far more than the two pelagic species (Herring and Sprat) that are usually encountered in annual pelagic surveys on the North Sea. In the baseline study wind farms for demersal fish, 32 fish species were observed in the same area in June 2003 (Tiën *et al.*, 2003). Normally acoustic surveys target one or two species in an area and period when the species is (are) expected to concentrate in (pre)spawning or wintering area's. The present survey targeted a defined area instead of a single species.

The large temporal variation indicates that pelagic fish species only utilize the coastal zone in specific periods of the year and reflects migration to and from the coastal zone. The temporal variation was large regarding species composition and the age and size structure. Not all species were observed at all times and the contribution of the nine species to the total biomass varied over time. In the Southern near shore area, for example, Herring and Sprat contributed only a minor proportion to the total biomass in June whereas they dominated the assemblage in October and November. Mackerel and

Horse Mackerel were abundant in April and June but were not observed in November. The temporal variation in age groups was largest for Pilchard and Anchovy of which 0-group individuals were abundant in October whereas they were not observed in April. Not surprisingly, juveniles were observed of most species, which confirms the expectation that these species use the coastal zone temporarily as a nursery area. For some species, temporal variation in their abundance can be explained by known migration patterns. Mackerel for example, was abundant at all times except in November when it was virtually absent. Mackerel does not winter in the North Sea and moves towards the northern limits of the North Sea by November.

On a large scale, there were clear patterns in the spatial distribution of pelagic fish but on a smaller scale, patterns were absent. If patterns occurred, they were more pronounced in the presence or absence than in the abundance of species. Patterns in the occurrence of pelagic species were observed along a North-South and along a near shore-offshore gradient. That patterns were more prominent in the presence or absence of species than in the abundance was clearly illustrated by Pilchard; in November, Pilchard was only observed in the southern half of the study area but in this half, it was homogeneously distributed. Thus, on the scale of the whole study area, a clear pattern occurred whereas this pattern was absent on a smaller scale. Consequently, in the baseline situation no spatial patterns occur at the scale of the planned wind farm.

The abundance of Anchovy and Pilchard is surprising because both were only observed occasionally in previous sampling programmes. Pilchard is known to migrate from the Channel into the North Sea in summer (Knijn et al., 1993), but the occurrence of newly hatched Pilchards in autumn has not been described before. Anchovy, another southern species, is known to occur along the Dutch coast. This species used to spawn in the former Zuiderzee and still small numbers are known to spawn in the eastern Oosterschelde. However, Anchovy was observed only in very small numbers in the IBTS catches in the 1980s (Knijn et al., 1993). Boddeke and Vingerhoed (1996) found Anchovy eggs during a dedicated egg survey in the western Wadden Sea in 1993 and 1994. They estimated the stock at approximately 100 tons. Knowing that in this area the commercial landings during the 1950's and the 1960's were more than 500 tons in good years, this stock estimate is not large, but enough for Boddeke and Vingerhoed (1996) to speak of the return of Anchovy to the Wadden Sea. In the present survey, we found mature and ripe Anchovy in spring and summer, followed by newly hatched Anchovy in October. The biomass estimates off the Dutch coast – here only used as relative indexes - in April and June of approximately 2000 and 1000 tons are indeed in the order of what one could expect of a population which was thought to recover halfway during the nineties. In addition Anchovy was distributed very much near shore, certainly partly out of reach of a hydro acoustic survey. The bulk of the Anchovy caught during the June survey was from four trawl hauls very close to the shore in water too shallow for echo integration. Therefore, we may have underestimated the abundance of Anchovy. Whether the ripe specimens from the June survey were about to spawn in the western Wadden Sea or somewhere else along the Dutch coast remains unanswered. The occurrence of Anchovy and Pilchard are in accordance with the observed trend of more southern species in the North Sea (i.e. Red Mullet and the cephalopod *Sepia officinalis*: data RIVO database). In addition, the year 2003 was an exceptionally warm year. The metamorphosed Pilchard in autumn may origin from larvae hatched in the Channel and carried to the Dutch coast by the current. One may speculate that normally these larvae do not survive at the comparatively low temperatures along the Dutch coast, but metamorphosed in 2003 because of the warm coastal water.

Intermezzo 7. Preliminary prediction of the effect of a wind farm.
From this first description, some effects of a wind farm on the pelagic fish community off the Dutch coast may be predicted, although predictions at this stage must be regarded as preliminary.

Because of the limited size of the wind farm relative to the spatial distribution of pelagic fish, and the high mobility of schools, we think that the Near Shore Wind Farm has no detectable effects on population sizes of pelagic fish. In relation to that, we think that the wind farm will have no detectable effect on the population structure and migration patterns of the pelagic fish community off the Dutch coast. If there are any effects, effects on the local occurrence or spatial distribution may be detectable. On a small scale, the wind farm may have a positive effect such that pelagic fish aggregate close to the turbines. There, they are probably safe from predation by birds. The effect of the wind farm on the abundance of predatory birds determines the distance from turbines to which such an effect extends. There is, however, only sparse knowledge on the interaction between birds and fish and on the effect of birds on the distribution and behaviour of fish.

Obviously, it depends on how strong these effects are whether they can be measured or not. The monitoring programme that was executed for this baseline study will probable be suitable to detect changes in the occurrence of pelagic fish in and around the wind farm area. This will only be possible if other (reference) areas are sampled in comparable ways. A programme like this is, however, not suitable to detect changes in the direct vicinity (<2 m) of the turbines and is not suitable to investigate the processes that can explain changes. Such processes are, for example, the effect of birds on the spatial distribution of pelagic fish, and the effect of turbidity on the behaviour of fish. Research into these processes will improve the environmental impact assessment. The most effective way to assess a possible impact is through a combination of monitoring the abundance and spatial distribution of fish with research into ecological processes that determine changes in abundance and distribution.

4.2 Power of the sampling programme

On a temporal scale, the pelagic fish assemblage showed a large variation both among and within years, which makes it difficult to assess an impact of the wind farm on the abundance of pelagic fish in the entire coastal zone, let alone on the scale of the population. The indices from the annual IBTS survey show that stocks are highly variable from year to year which is probably caused by natural variation in year class strength. In addition, water temperature in a specific year may play an important role in the spatial distribution of pelagic species and hence in their abundance in the Dutch coastal zone. Although water temperature was not significant in the multivariate analyses, temperature may have an effect at larger temporal (inter-annual) and spatial scales. Some southern species such as Pilchard and Anchovy, have their northern distribution limit in the North Sea and may be abundant in the Dutch coastal zone in warm years and almost absent in colder years. The year 2003, in which the baseline study was executed, was an exceptionally warm year. This has probably had an effect on the abundance of juvenile Anchovy and Pilchard in October. Normally, these species are only caught occasionally during the IBTS survey. However in February 2004 small Pilchards were still abundant in the central North Sea. Because of the large variation among seasons, the timing of sampling will largely determine the result. Given the ongoing changes in water temperature and nutrient concentrations (van Raaphorst & de Jonge, 2004), the probability of autonomic changes in species composition and influxes of southern species is high.

Because in the baseline situation, spatial patterns mainly occurred at larger scales and were absent from scales of the wind farm, we think that small-scaled effects of wind farms on pelagic fish may be detected. It remains, however, difficult to predict this. In the baseline situation, there was no pattern in the spatial distribution of pelagic fish in and just around the planned wind farm area. Any pattern detected after the building of the wind farm, may indicate an effect. The reference areas play important roles in such an assessment. They were chosen based on location, depth and sediment characteristics and because we expected that fish assemblages here were comparable to those in the Near Shore Wind farm area. In the baseline situation, no large differences were observed between pelagic fish communities in the reference areas and the NSW area and therefore the sites are suitable reference areas. In future, significant differences between the spatial patterns in the wind farm and in the reference areas may indicate effects of the wind farm.

4.3 Acoustic surveys as a tool to describe pelagic fish community

An alternative approach to acoustic surveys could have been a pelagic trawl survey sampling a dense grid of positions. An important drawback of this method is the observed patchiness of the fish which makes it difficult to catch them when trawl positions are planned in advance. The advantages of an acoustic survey over a pelagic trawl survey are that:

- A large area can be sampled over a short time period;
- Sampling is possible at a very high spatial resolution (0.5 nm intervals);
- The distribution of fish can be determined in a relatively undisturbed situation;
- A standard swept area can be sampled as with a beam trawl;
- It is less harmful to the fish community because less hauls are made;
- The option of live viewing gives the researcher a continuous impression of the underwater situation.

Despite its advantages, the acoustic method has several drawbacks as well. A general problem when sampling pelagic fish distributions by means of the trawl is that pelagic species tend to school. Schools of pelagic fish move fast through the area. Schools consisting of larger specimens can easily out swim a trawl. A trawl catch may consist of a single school and this school may not be representative at all for the species composition of the area. Because of the time lapse between the detection of the school and the actual trawling, the school may have moved and another school than the one detected might be sampled. When this happens and schools of different species co-occur in the same area, a school identified on the echogram might be labelled wrongly. Therefore, we marked the last known position of the school and we always use an echo sounder to re-locate the school. During fishing, fish schools tend to dive but the shallow coastal water make the schools easier to catch than in deep offshore waters.

Biomass estimates for sandeels and Mackerel are less precise than those for other species because of some methodological drawbacks. The density and estimated biomasses of the non-swim bladdered species (the three sandeel species and Mackerel) might be polluted (in an acoustic sense) by the other species (see Intermezzo 4). Considering that the acoustic Target Strength of a clupeid is about 200 times as high as a sandeel of the same length, the impact of an erratic assignment of an echo to sandeel instead of a clupeid is large. While the biomass estimates of clupeids and Whiting are relatively precise, the estimates of sandeels – and to a lesser extent, mackerel – are probably overestimated to a high degree. Unfortunately this has also an impact on the relative species composition. The strong domination of sandeel in June 2002 for example, may be due to this "acoustic pollution". Accurate estimates of sandeel biomass are also hampered by another phenomenon. They are known to bury themselves in the sand under poor light conditions (winter and night). This means that these species occur in the water column only part of the time and are invisible for the echo sounder during long periods. Sandeel abundance is therefore often studied by means of a dredge (i.e. Jensen *et al.*, 2003). For this group echo sounding is only useful in spring and summer. In these periods sandeels are important prey to seabirds and marine mammals. As a consequence, the biomass estimates of sandeels and mackerel presented here should not be seen as absolute values. This means that these estimates cannot be used to compare densities of these species with other species. They do, however, give a good impression of relative values and the spatial and temporal variation in the abundance of the sandeel species.

4.4 Recommendations for future sampling

Before the four surveys were executed there was little experience with this type of sampling under these conditions. The experience with the surveys and the results of the study facilitate further optimisation of the sampling design. Our recommendations are:

- The use of hydro acoustics is a better way to sample the pelagic fish community in this area than trawling. In the near future pelagic fish can probably be sampled with multi-beam technology which makes it easier to distinguish species better;
- More trawl hauls should be made to assign species more accurately to acoustic signals. The local variation in species structure of the pelagic community proved to be large;
- The study area should extend further offshore. The transects of the Flyland programme extended further offshore than those in the baseline study and provided clearer near shore-offshore gradients;
- To save time, the planned sampling intensity in the wind farm and reference areas can be lowered to that of the second baseline survey. Because there was no pattern in the spatial distribution of pelagic fish at this scale, sampling with this spatial resolution will be sufficient;
- June is probably the best month to sample pelagic fish in the coastal zone because in that period, species were disaggregated most and did not mix. Schools of individual species could be detected better;
- The difference between surveys during day and night should be explored. Since fish tend to disaggregate during the night, trawling might be easier and could give a different impression of the fish community. Furthermore, some species can better be detected at night while other species rely on daylight for feeding and will only be visible during daytime;
- More knowledge is needed on coastal physical processes to have a better understanding of the distribution of the fish. Local effects such as the influence of daylight, tides, currents and wind are believed to have a strong local effect on the distribution and behaviour of the pelagic fish;
- Assessing the effect of a wind farm based on monitoring programmes alone will remain problematic because the effect needs to be quite large before detection through this approach is possible. Therefore they should be combined with process studies that actually show individual behavioural responses of fish to the wind farm. To this aim fish could be supplied with transmitters that allow investigation of the movements of fish inside and in the vicinity of the farm. Also, the stationary use of acoustic equipment around wind turbines, to continuously monitor fish abundance and behaviour in the vicinity of the turbines, may be

useful. In addition, images can be placed live on the Internet providing useful information to the public.

Photo 6. *Hauling the pelagic trawl.*

References

Alshuth, S. 1988. Daily growth increments on otoliths of laboratory-reared sprat, *Sprattus sprattus*, larvae. Meeresforschung-Reports On Marine Research. 32 (1): 23-29.

Anonymous, 2004. Manual for herring acoustic surveys in ICES divisions III, IV AND Via. Annex IV: 150-190. In: Anonymous, 2004. Report of the Planning Group for Herring Surveys. ICES CM 2004/G:05 Ref. D: 1-14.

Aurich, H.J. 1953. Verbreitung und Laichverhältnisse van Sardelle und Sardine in der südöstlichen Nordsee und ihre Veränderungen als Folge der Klimaänderung. Helgoländer Meeresuntersuchungen4(3):175-204

Boddeke, R. and Vingerhoed, B. 1996. The Anchovy returns to the Wadden Sea. ICES Journal of Marine Science, 53: 1003-1007.

Bolle, L., Eltink, G., Schaap, L., Vries, M. d., Bakker, K., Groot, P., Rink, G., Beintema, J., Groeneveld, K., Bol, R., Stoker, M., Jongejans, Y. and Rijs, S. 2003. Handboek Leeftijdsbepalingen. Netherlands Institute for Fisheries Research. IJmuiden. Report Nr. CVO 03.010. 73 pp.

Corten, A. 1995. Ecoprofiel Haring. RIVO rapport C059/95.

Couperus, A. S., Ybema, M. S. and Grift, R. 2003a. Base line studies North Sea wind farms: pelagic fish field work report 1. RIVO. IJmuiden. Report Nr. C039/03. 32 pp.

Couperus, A. S., Ybema, M. S. and Grift, R. 2003b. Base line studies North Sea wind farms: pelagic fish field work report 2. RIVO. IJmuiden. Report Nr. C075/03. 39 pp.

Economou, A.N., 1991, Food and feeding ecology of five gadoid larvae in the northern North Sea., Journal du Conseil International pour l'Exploration de la Mer. 47: 339-351.

Eltink, A.T.W.G. 1987. Changes in age-size distribution and sex ratio during spawning and migration of Western mackerel (Scomber scombrus L.). Journal du Conseil International pour l' Exploration de la mMer 44: 10-22

Eltink, A. 1992. Horse mackerel egg production and spawning stock size in the North Sea in 1991. C.M. 1992/H:21.

Gauld, J.A. & Hutcheon, J.R., 1990, Spawning and fecundity in the lesser sandeel, Ammodytes marinus Raitt, in the north-western North Sea., Journal of Fish Biology 36: 611-613.

Grift, R., Couperus, A. S. and Ybema, M. S. 2003. Base line studies North Sea wind farms: strategy of approach for pelagic fish. RIVO. IJmuiden. Report Nr. C013/03. 20 pp.

Grift, R. E., Couperus, A. S., Craeymeersch, J. C., Van Damme, C. and Tulp, I. 2002. Effectketen Noordzee: Schelpdieren-garnalen-demersale vis- pelagische vis, Voortgangsrapportage december 2002. RIVO. IJmuiden. Report Nr. RIVO C062/02. 56 pp.

Grift, R.. Couperus, A.S., Ybema, M.S. & Tiën N.S.H. 2004. Base line studies North Sea wind farms: biological data pelagic fish. Report Nr. C031/04

Grift, R. E., Welleman, H. C., Rijnsdorp, A. D. and Van der Veer, H. W. 2001. De visgemeenschap en de visserij in het Nederlandse kustgebied en de Westelijke Waddenzee. RIVO. IJmuiden. Report Nr. C047/01. 90 pp.

Hickling, C.F. 1945. The seasonal cycle in the Cornish pilchard, Sardina pilchardus Walbaum. Journal of the marine Biological Association of the United Kingdom 26: 115-138.

Hoffmann, E., Astrup, J., Larsen, F. and Munch-Petersen, S. 2000. Effects of marine wind farms on the distribution of fish, shellfish and marine mammals in the Horns Rev area. Danish Institute for Fisheries Research. Charlottenlund. Report Nr. Baggrundsrapport nr. 24. 42 pp.

Jensen, H., Kristensen, P. S. and Hoffmann, E. 2003. Sandeels and clams (Spisula sp.) in the wind turbine park at Horns Reef. Danish Institute for Fisheries Research. Charlottenlund. Report Nr. 45 pp.

Jongman, R.H.G., C.J.F. ter Braak and O.F.R. van Tongeren. 1995. Data analysis in community and landscape ecology. Cambridge University Press.

Knijn, R.J., Boon, T.W., Heessen, H.J.L. and Hislop, J.R.G. 1993. Atlas of North Sea Fishes. ICES cooperative research report No. 194.

Land, van der, M.A. 1990. Distribution and mortality of pelagic eggs of by-catch species in the 1989 egg surveys in the souhern North sea. ICES CM 1990/H:19. 11 pp.

Lockwood, S.J. 1988. The mackerel. Its biology assessment and the management of a fishery. Fishing News books, Farnham, Surrey, England. 181 pp.

Macer, C. T. 1966. Sandeels in the south-western North Sea; their biology and fishery. Fishery Investigations, 2: 1-55.

Macer, C.T. 1977. Some aspects of the biology of the horse mackerel (Trachurus trachurus) in waters around Britain. Journal of Fish Biology 10: 51-62.

Mehl, S. and Westgård, T.1983. The diet and consumption of mackerel in the North sea (a preliminary report). ICES CM 1983/H:34. 28 pp.

Proctor, R., Wright, P.J. & Everitt, A., 1998, Modelling the transport of larval sandeels on the north-west European shelf., Fish. Oceanogr. 7: 347-354.

Van Raaphorst, W. and De Jonge, V.N. 2004. Reconstruction of total N and P inputs from the Ijsselmeer inte the western Wadden Sea between 1935-1998. J. Sea Res. 51: 109-132.

Reay, P.J., 1970, Synopsis of biological data on North Atlantic sandeels of the genus Ammodytes (A. tobianus, A. dubius, A. americanus and A. marinus)., FAO Fisheries Synopsis (82): pag.var.

Sahrhage, D. 1964. Ueber die Verbreitung de Fischarten in der Nordsee. I. Juni-Juli 1959 und Juli 1960. Berichte der Deutschen Wissenschaftlichen Kommission fuer Meeresforschung 18(3): 165-278.

Ter Braak, C.J.F. and P. Šmilauer. 2002. CANOCO Reference manual and user's guide to Canoco for Windows: software for canonical community ordination (version 4.5). Microcomputer Power, Ithaca, NY, USA.

Torstensen, E. 1985. Fecundity of Sprat from the Norwegian coast. ICES CM 1985/H:56.

Tiën, N. S. H., Bol, R. and Grift, R. E. 2003. Baseline studies North Sea wind farms demersal fish survey. Royal Haskoning BV Environment. IJmuiden. Report Nr. 9M9237.01/R004/THIE/Gron. 10 pp.

Wahl, E. and Alheit, J. 1988. Changes in the distribution and abundance of sprat eggs during spawning season. ICES CM 1988/H:45. 4 pp.

Wheeler, A. 1969. The fishes of the British Isles and North-West Europe. MacMillan. London. 613 pp.

Wheeler, A. 1975. Fishes of the world : an illustrated dictionary. New York. 366 pp.

Whitehead, P.J.P., 1985. FAO species catalogue. Vol. 7. Clupeoid fishes of the world. An annotated and illustrated catalogue of the Herrings, sardines, Pilchards, Sprats, shads, anchovies and wolf-Herrings. Part 1 - Chirocentridae, Clupeidae and Pristigasteridae.. FAO Fish. Synop. (125) Vol. 7, Pt. 1:303 p.

Whitehead, P.J.P., G.J. Nelson and T. Wongratana, 1988. FAO species catalogue. Vol. 7. Clupeoid fishes of the world (Suborder Clupeoidei). An annotated and illustrated catalogue of the Herrings, sardines, Pilchards, Sprats, shads, anchovies and wolf-Herrings. Part 2 - Engraulididae.. FAO Fish. Synop. 7(125)Pt. 2:579 p..

Wright, P.J., Jensen, H. & Tuck, I., 2000, The influence of sediment type on the distribution of the lesser sandeel, *Ammodytes marinus*. Journal of Sea Research 44: 243-256.

Annex I. Species names.

Table I.1. *English, Dutch and scientific names of fish species.*

Name	Dutch name	Species	Family
Allis Shad	Elft	Alosa alosa	Clupeidae
Anchovy	Ansjovis	Engraulis encrasicolus	Engraulidae
Bib	Steenbolk	Trisopterus luscus	Gadidae
Bull-rout	Zeedonderpad	*Myoxocephalus scorpius*	Cottidae
Cod	Kabeljauw	*Gadus morhua*	Gadidae
Dab	Schar	*Limanda limanda*	Pleuronectidae
Dragonet	Pitvis	*Callionymus lyra*	Callionymidae
Flounder	Bot	*Platichthys flesus*	Pleuronectidae
Four-bearded Rockling	Vierdradige meun	*Enchelyopus cimbrius*	Gadidae
Greater Sandeel	Smelt	*Hyperoplus lanceolatus*	Ammodytidae
Grey Gurnard	Grauwe poon	*Eutrigla gurnardus*	Triglidae
Herring	Haring	*Clupea harengus*	Clupeidae
Horse Mackerel	Horsmakreel	*Trachurus trachurus*	Carangidae
Lamprey	Rivierprik	*Lampetra fluviatilis*	Petromyzonidae
Lesser Sandeel	Kleine zandspiering	*Ammodytes tobianus*	Ammodytidae
Lesser Weever	Kleine pieterman	*Echiichthys vipera*	Trachinidae
Mackerel	Makreel	*Scomber scombrus*	Scombridae
Pilchard	Pelser	*Sardina Pilchardus*	Clupeidae
Plaice	Schol	*Pleuronectes platessa*	Pleuronectidae
Poor Cod	Dwergbolk	*Trisopterus minutus*	Gadidae
Raitt's Sandeel	Noorse zandspiering	*Ammodytes marinus*	Ammodytidae
Reticulated Dragonet	Rasterpitvis	*Callionymus reticulatus*	Callionymidae
Scaldfish	Schurftvis	*Arnoglossus laterna*	Bothidae
Sole	Tong	*Solea vulgaris*	Soleidae
Solenette	Dwergtong	*Buglossidium luteum*	Soleidae
Sprat	Sprot	*Sprattus Sprattus*	Clupeidae
Transparent Goby	Glasgrondel	*Aphia minuta*	Gobiidae
Tub Gurnard	Rode poon	*Trigla lucerna*	Triglidae
Whiting	Wijting	*Merlangius merlangus*	Gadidae

Annex II. Total catch of all species during the four surveys.

Table II.1. *Baseline survey April and October 2003.*

	april					October				
species	NSW	Ref N	Ref S	South shore	near South offshore	NSW	Ref N	Ref S	South shore	near South offshore
Anchovy	16	20	62	294	57	48	575	14	206	2056
Allis Shad	0	0	0	0	1	0	0	0	0	0
Bull Rout	3	1	1	3	13	0	0	0	0	0
Cod	1	3	0	0	1	0	0	0	0	0
Dab	44	222	12	82	1242	16	86	5	2	30
Dragonet	0	1		1	54	2	16	1	20	16
Flounder	0	0	0	1	2	0	0	0	0	0
Four-bearded Rockling	0	0	0	0	3	0	0	0	0	0
Greater Sandeel	16	8	8	9	8	33	2	0	5	2
Grey Gurnard	1	1	0	0	1	0	1	0	0	1
Herring	3557	12881	1470	1406	101	14627	5354	15999	5501	6468
Horse Mackerel	3	22	108	18	1516	144	246	50	136	9615
Lamprey	0	0	0	2	0	0	0	0	0	0
Lesser Sandeel	115	194	50	26	6	0	0	0	0	0
Lesser weever	2	3	1	2	20	4	6	3	0	104
Mackerel	37	272	559	12	112	425	152	104	3	606
Pilchard	0	0	11	194	200	11	468	13	1791	1006
Plaice	37	20	1	26	185	3	25	4	5	11
Poor Cod	0	4	0	0	1	0	0	0	0	0
Raitt s Sandeel	5271	3706	1153	44	31129	4	1	0	0	1
Reticulated Dragonet	0	0	0	0	1	0	0	0	0	0
Scaldfish	0	0	0	0	4	0	0	0	0	0
Sole	1	1	1	0	1	0	0	0	0	0
Solenette	1	0	0	0	66	0	0	0	0	0
Sprat	2441	12895	5391	4755	11095	5	6499	3797	33240	1553
Striped Red Mullet	0	0	0	0	0	12	17	4	4	78
Transparent Goby	1	0	0	0	0	0	0	0	0	12
Tub Gurnard	0	0	0	2	0	0	0	0	0	0
Whiting	712	622	49	644	383	74	435	50	20	274

Table II.2. *Fish-Bird survey November 2003.*

Species	North	South near shore	South offshore
Anchovy	470	0	1
Cod	1	0	0
Dab	14	2	0
Greater Sandeel	16	0	0
Grey Gurnard	1	0	0
Hagfish	1	1	0
Herring	11868	3500	10336
Horse Mackerel	12	0	37
Lesser Weever	4	1	23
Mackerel	0	0	8
Nilssons Pipefish	0	180	0
Pilchard	0	0	1229
Raitt's Sandeel	0	40	3
Sprat	80142	3280	28138
Striped Red Mullet	6	0	0
Turbot	1	0	0
Whiting	250	5	23

Table II.3. *Flyland survey June 2002.*

species	North	South near shore	South offshore
Anchovy	0	21331	0
Bass	0	20	0
Brill	0	0	2
Bull rout	0	1	0
Cod	0	5	6
Dab	0	5	22
Flounder	0	1	0
Garfish	0	20	0
Greater Sandeel	0	7	236
Grey Gurnard	0	16	10
Herring	0	84589	21
Horse Mackerel	0	1066	947
Lesser Weever	0	6	86
Mackerel	0	550	740
Pilchard	0	34	105
Plaice	0	31	6
Sole	0	3	0
Sprat	0	685539	4
Transparent Goby	0	100	0
Tub Gurnard	0	3	0
Turbot	0	16	0
Twaite Shad	0	20	0
Whiting	40800	1912	863

Annex III. Length frequency distributions.

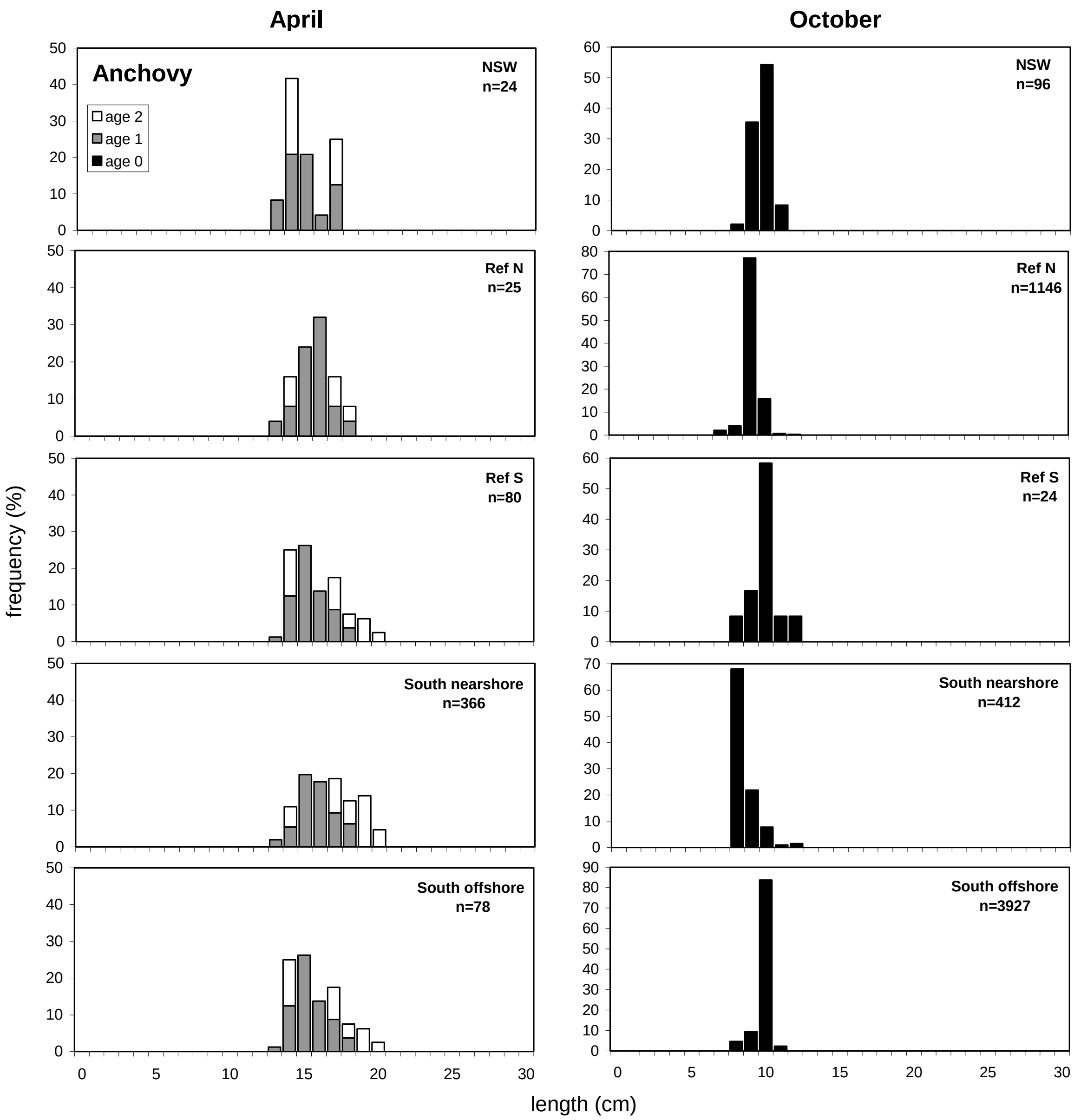


Figure III.1. *LF distributions of Anchovy per age group, area and period for the baseline study. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

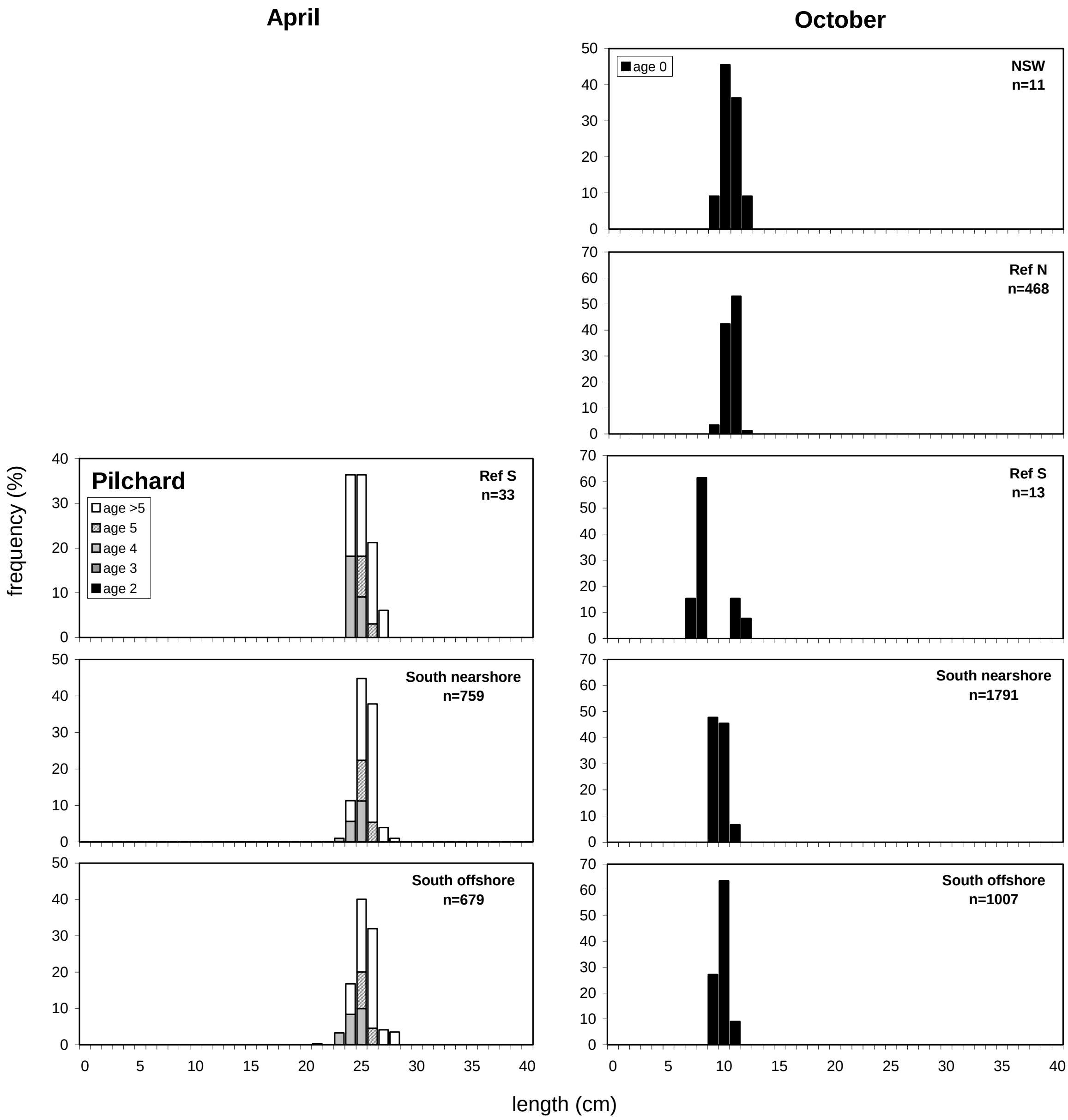


Figure III.2. *LF distributions of Pilchard per age group, area and period for the baseline study. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

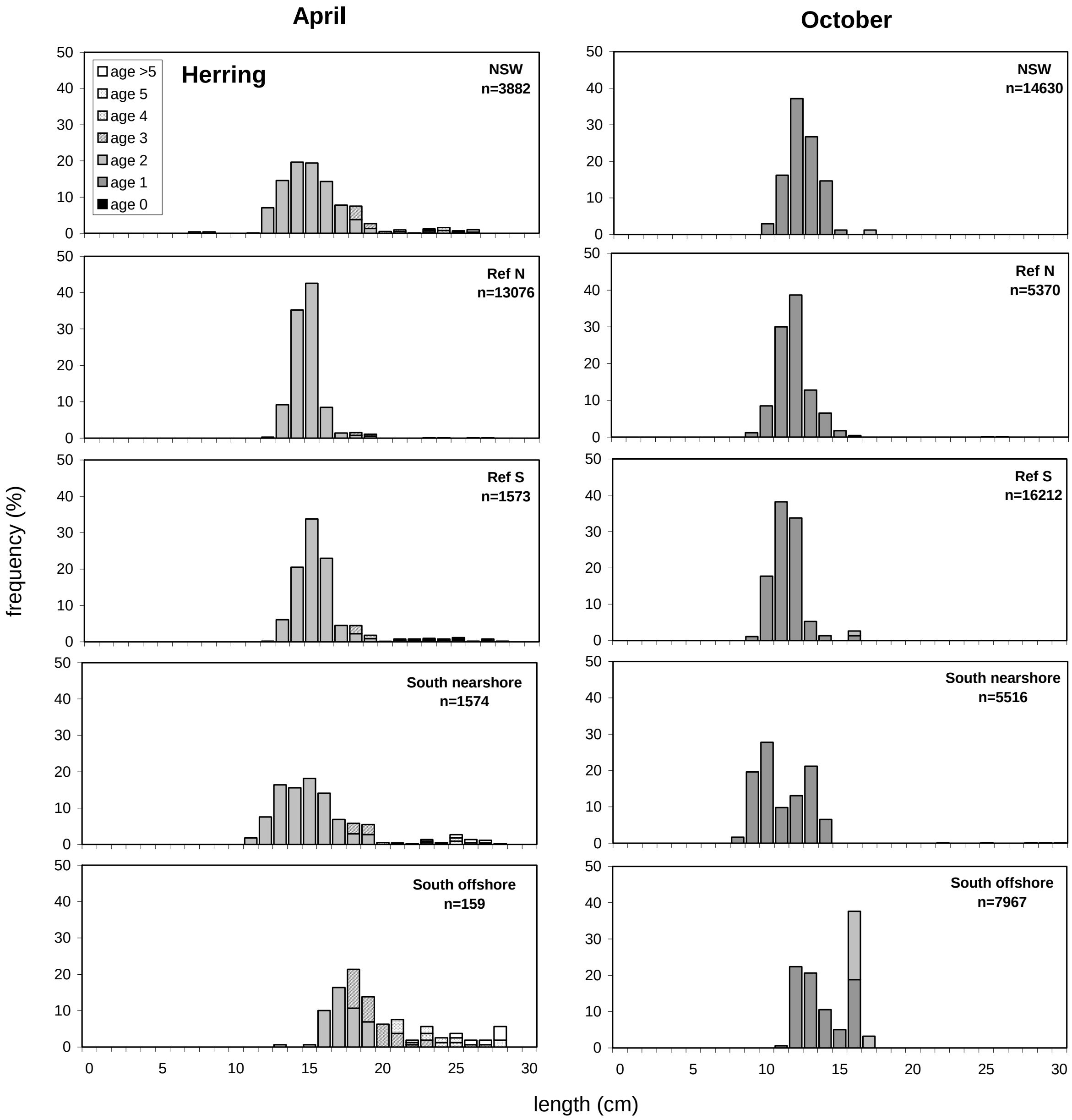


Figure III.3. *LF distributions of Herring per age group, area and period for the baseline study. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

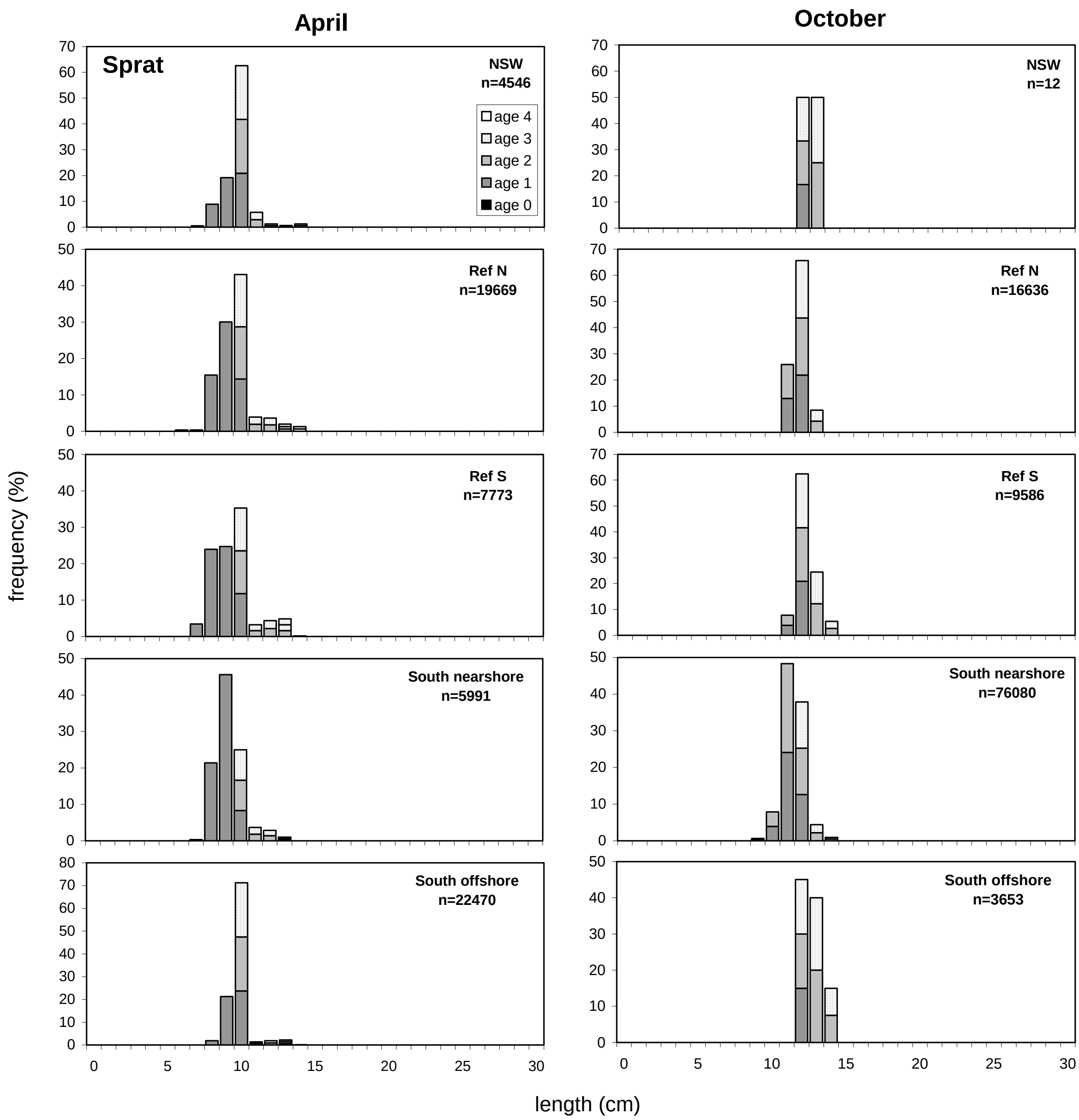


Figure III.4. *LF distributions of Sprat per age group, area and period for the baseline study. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

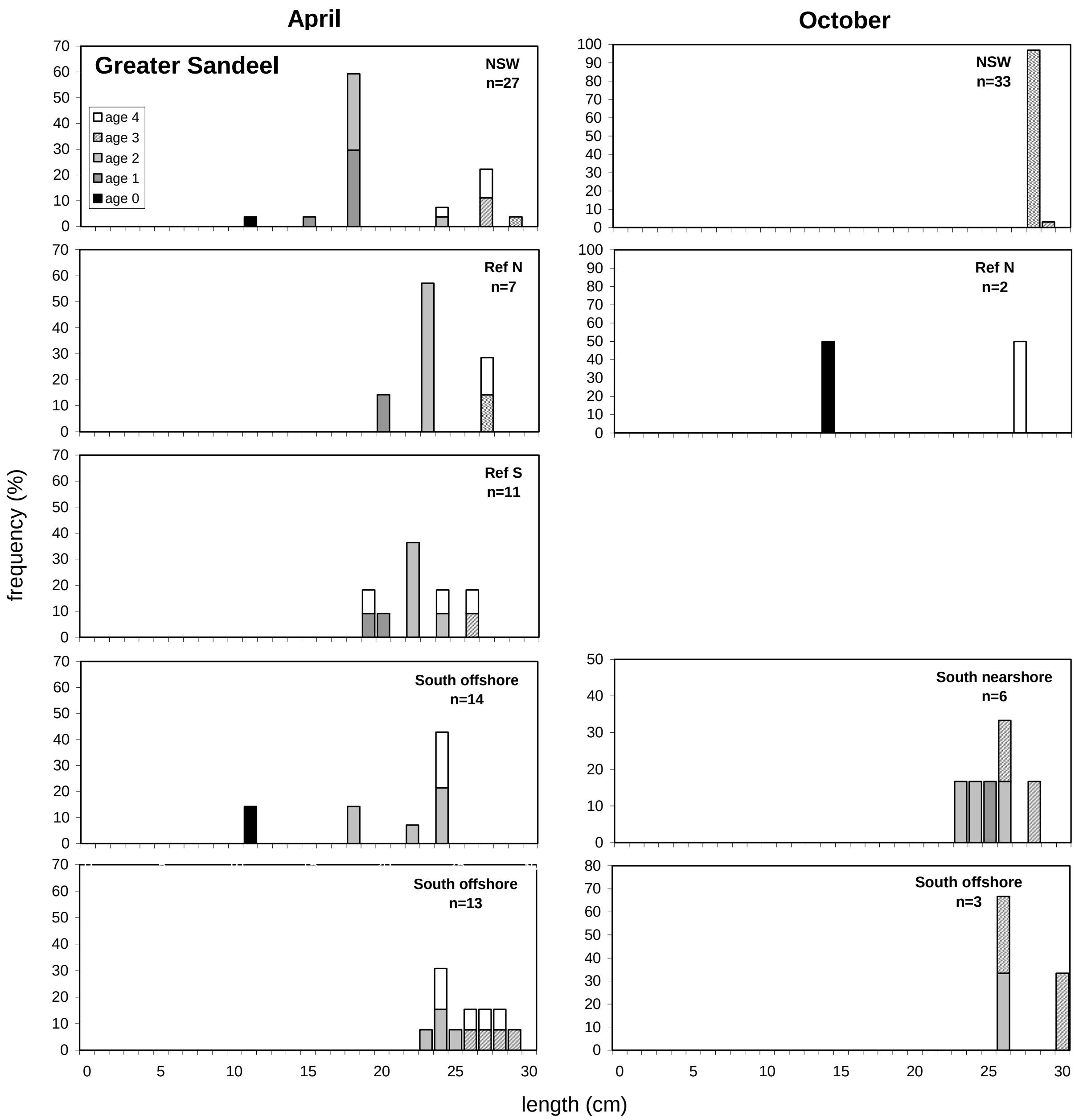


Figure III.5. *LF distributions of Greater sandeel per age group, area and period for the baseline study. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

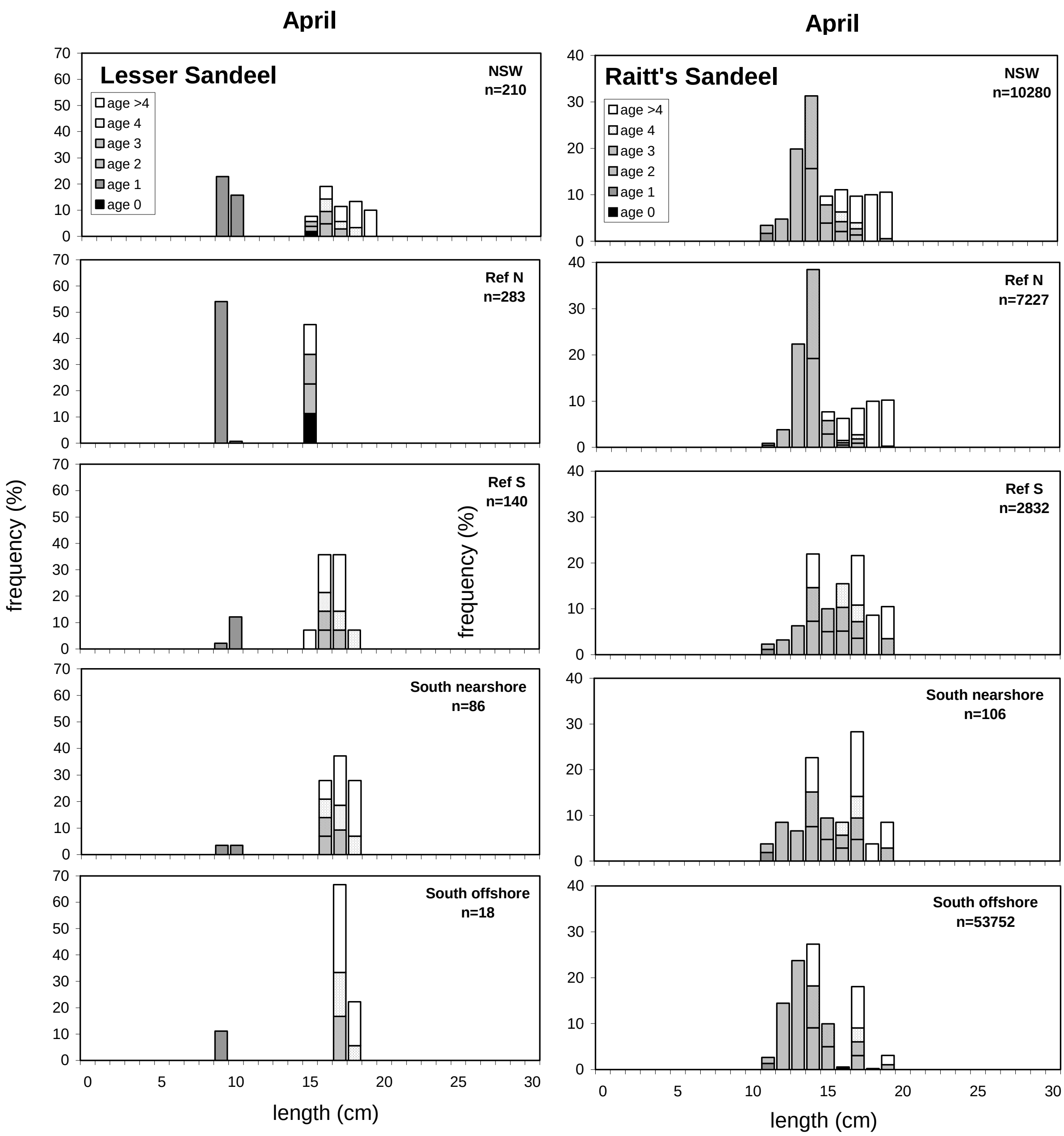


Figure III.6. *LF distributions of Lesser sandeel and Raitt's sandeel per age group and area. Both species were not observed in October. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

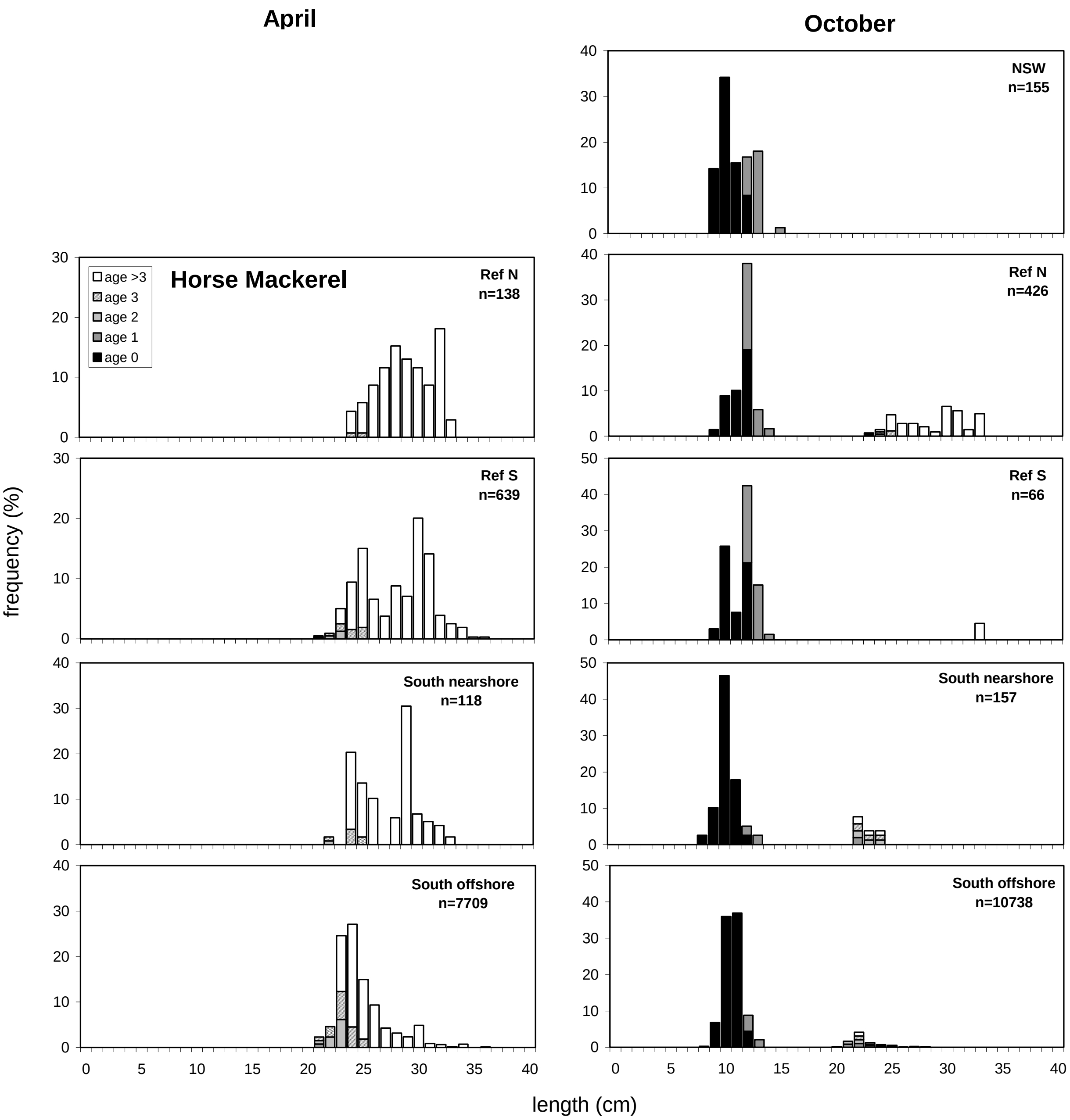


Figure III.7. *LF distributions of Horse mackerel per age group, area and period for the baseline study. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

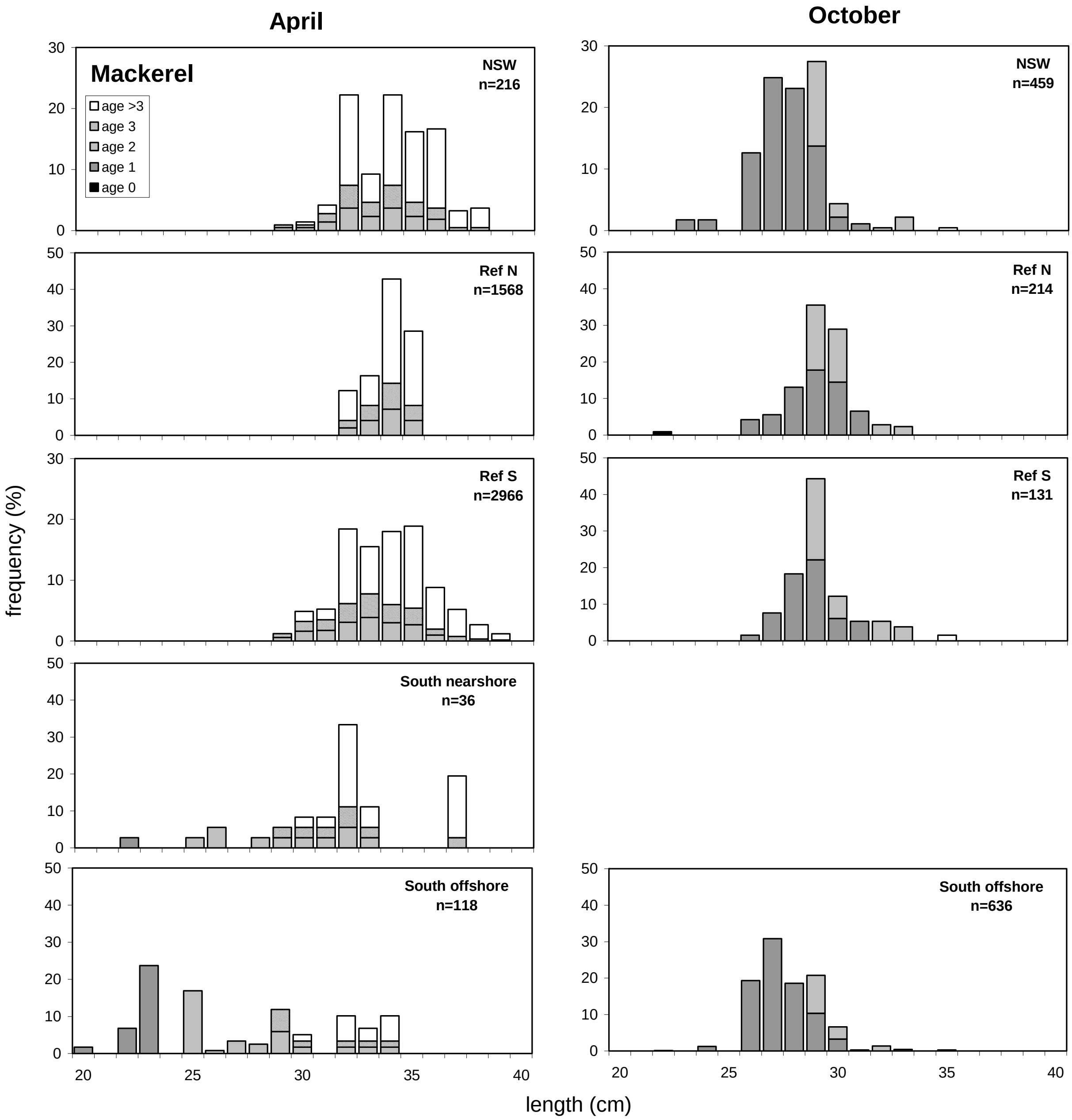


Figure III.8. *LF distributions of Mackerel per age group, area and period for the baseline study. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

Annex IV. Length frequency distributions.

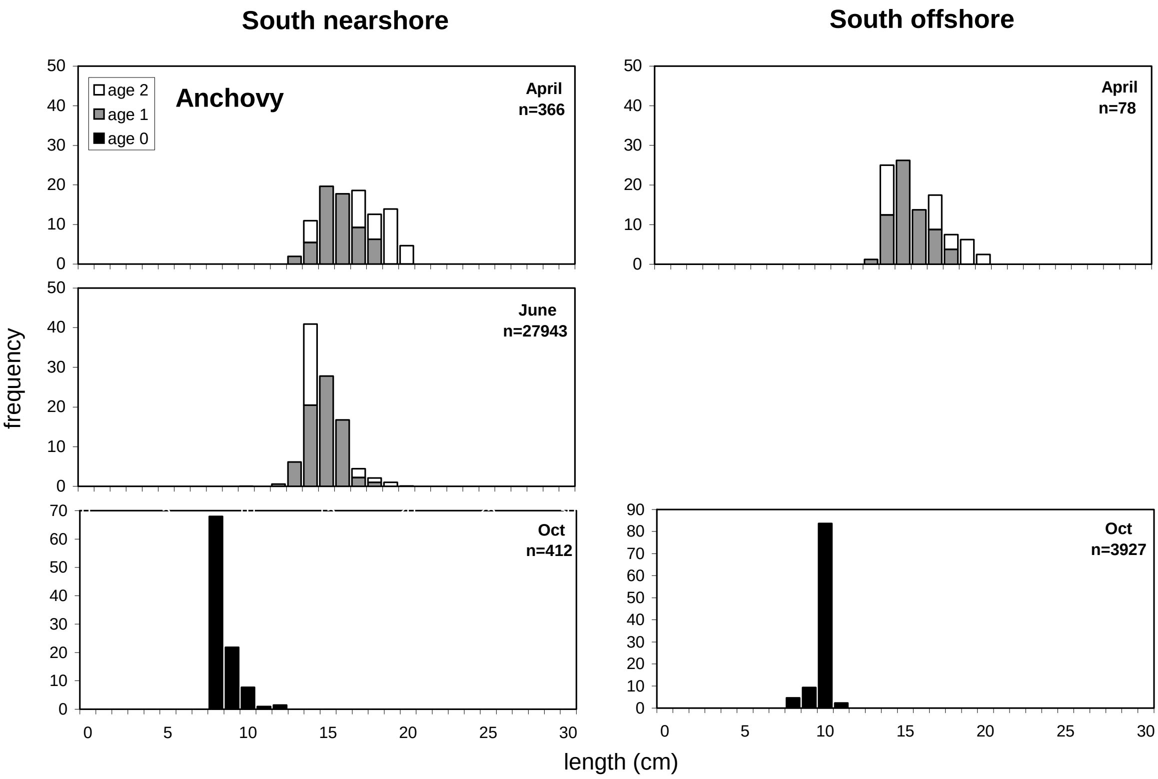


Figure IV.1. *LF distributions of Anchovy per age group and period, offshore and near shore. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated. Anchovy was not caught in November during the Fish-bird survey.*

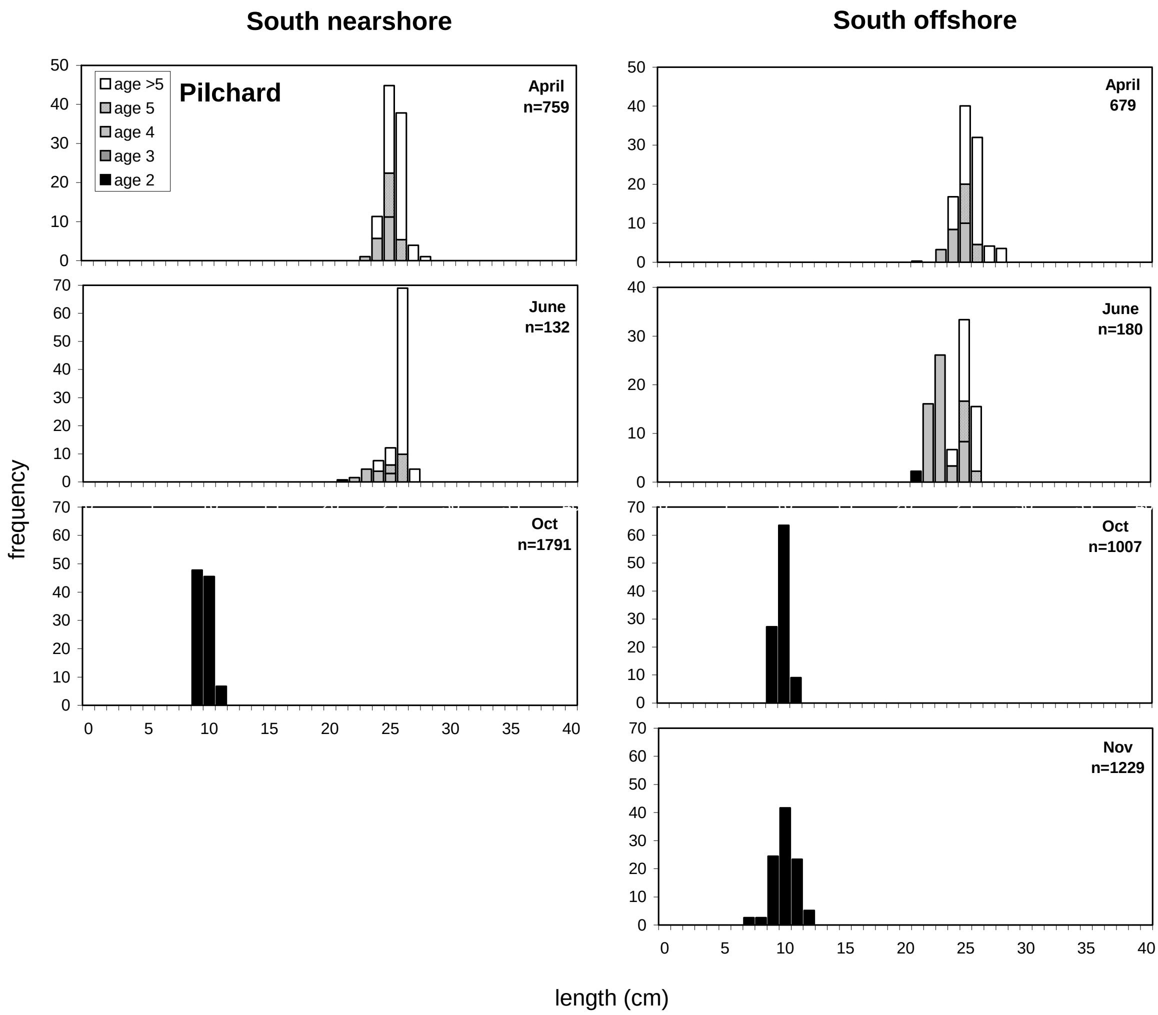


Figure IV.2. *LF distributions of Pilchard per age group and period, offshore and near shore. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated. Anchovy was not caught in November during the Fish-bird survey.*

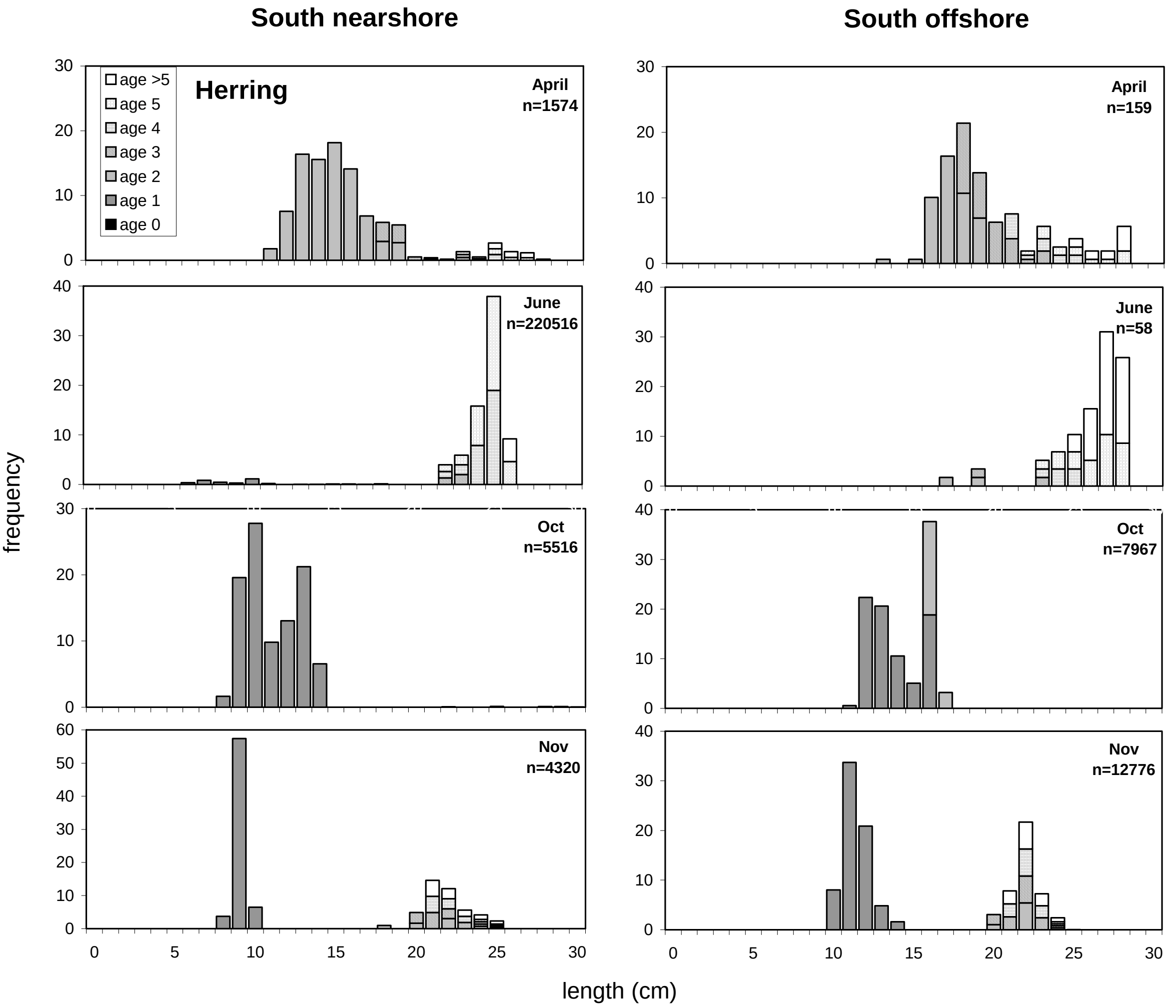


Figure IV.3. *LF distributions of Herring per age group and period, offshore and near shore. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

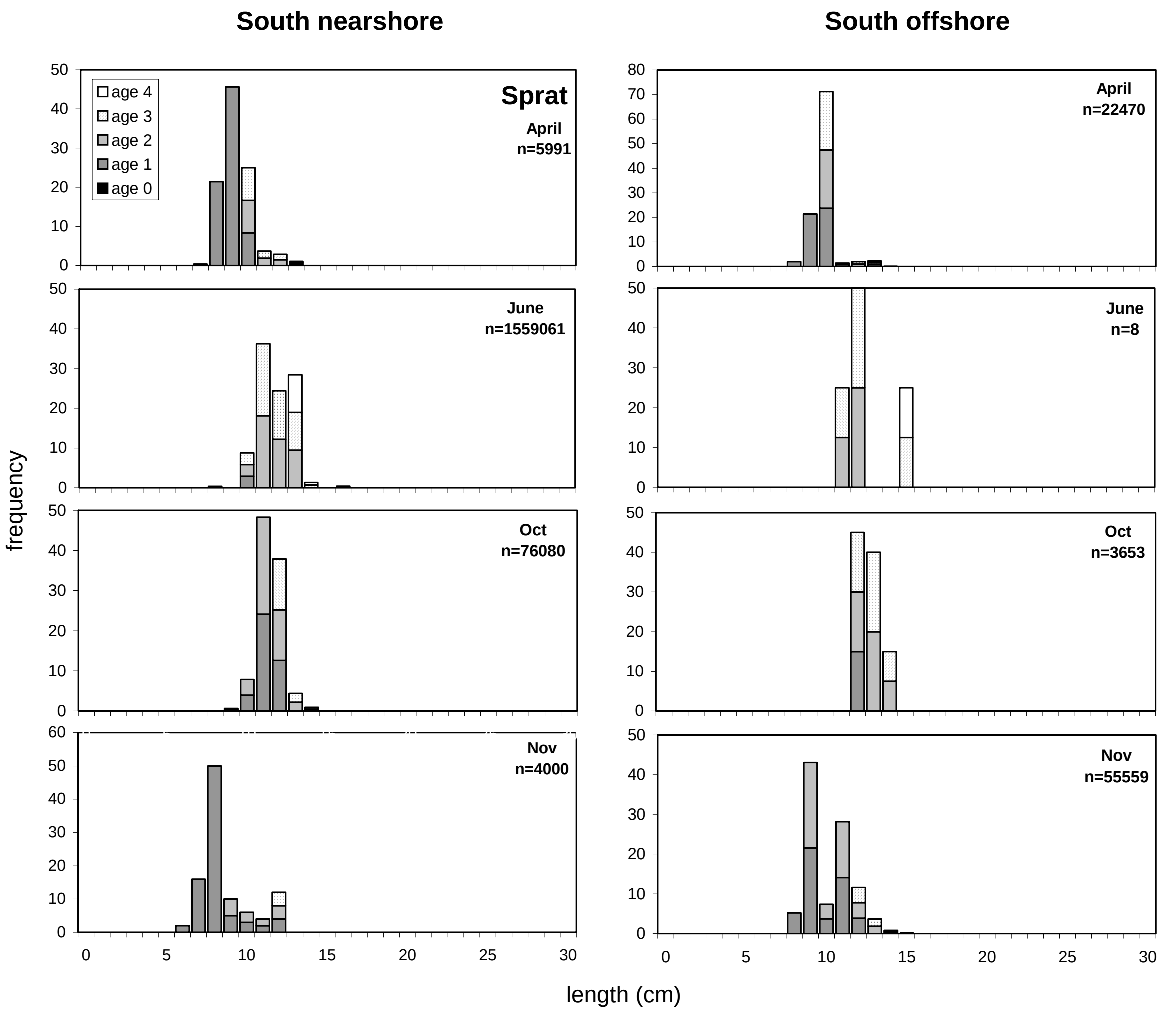


Figure IV.4. *LF distributions of Sprat per age group and period, offshore and near shore. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

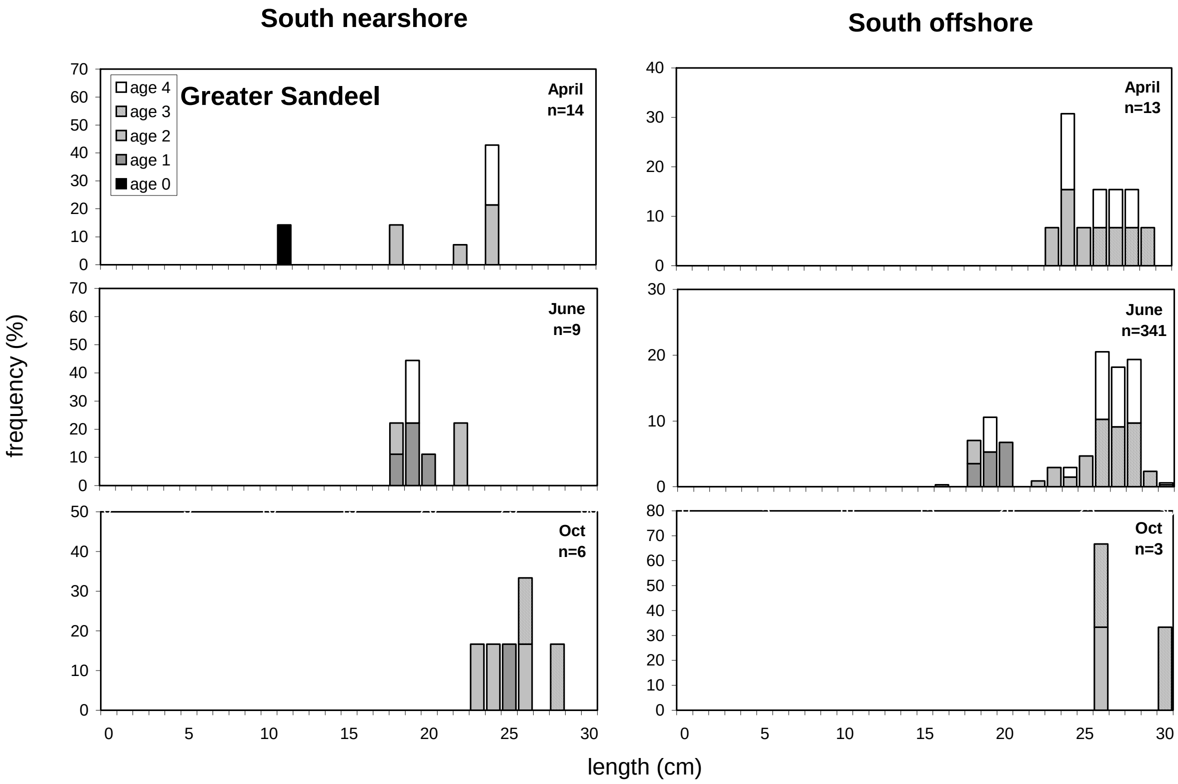


Figure IV.5. *LF distributions of Greater sandeel per age group and period, offshore and near shore. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

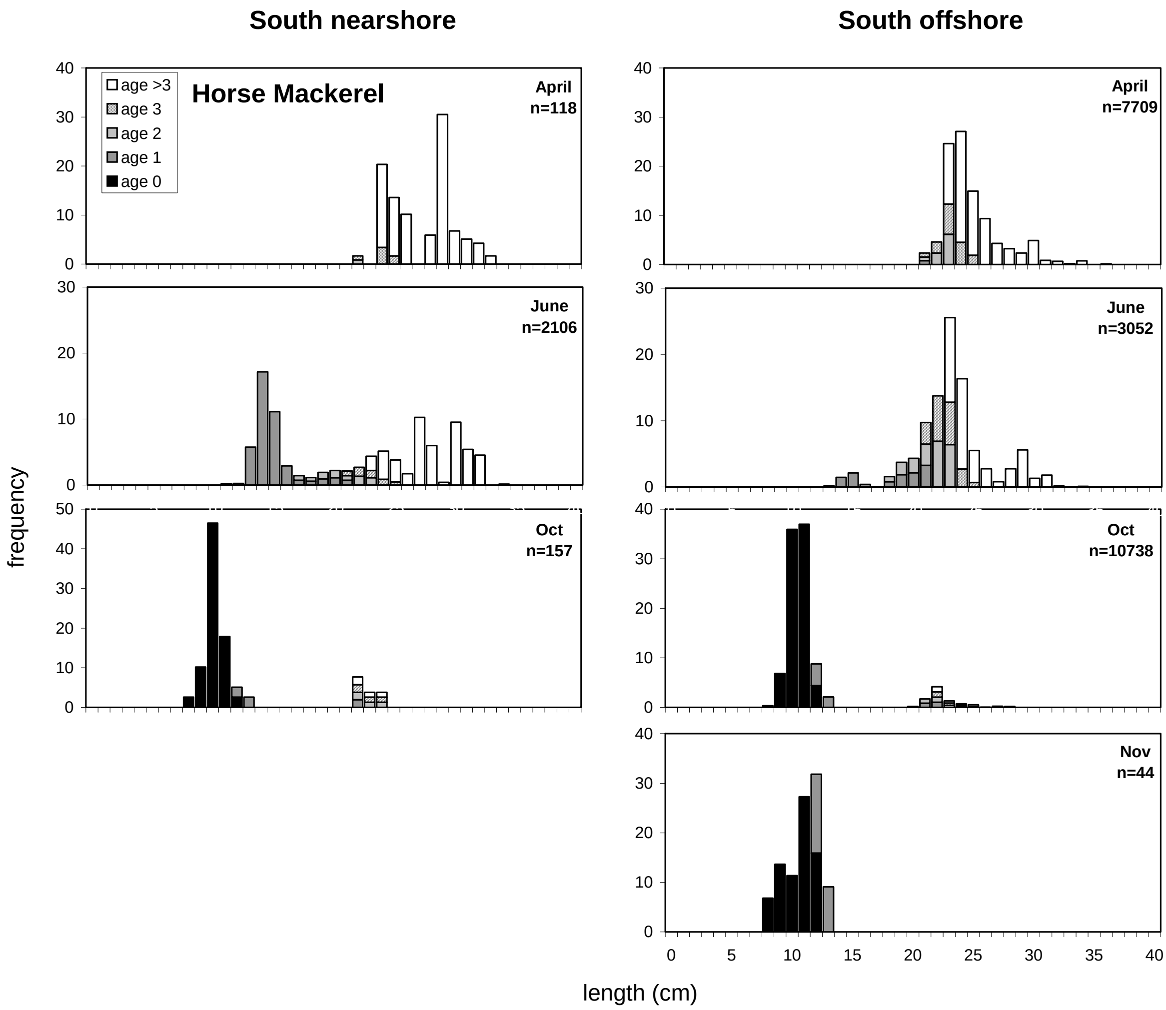


Figure IV.6. *LF distributions of Horse mackerel per age group and period, offshore and near shore. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated.*

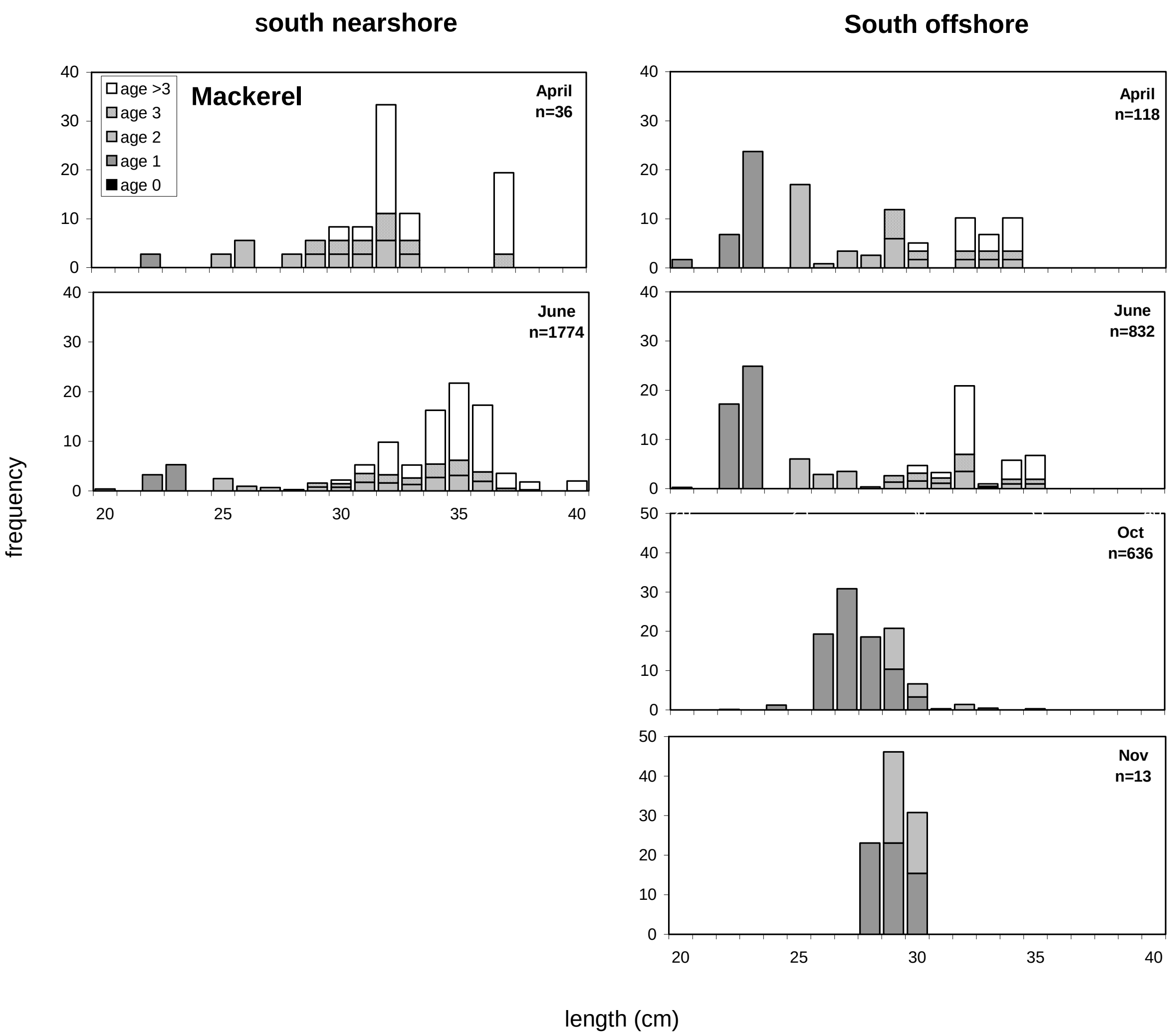


Figure IV.7. *LF distributions of Mackerel per age group and period, offshore and near shore. The percentage in the catch on the y-axis, length on the x-axis. The total number caught (n) is indicated. The total number of mackerel measured that were caught in the trawl is not directly related to the observed densities of mackerel from the acoustic observations. The number of fish that can be measured depends on factors such as the amount of other fish caught, the number of trawl hauls etc.*

Annex V. Spatial distributions of pelagic species.

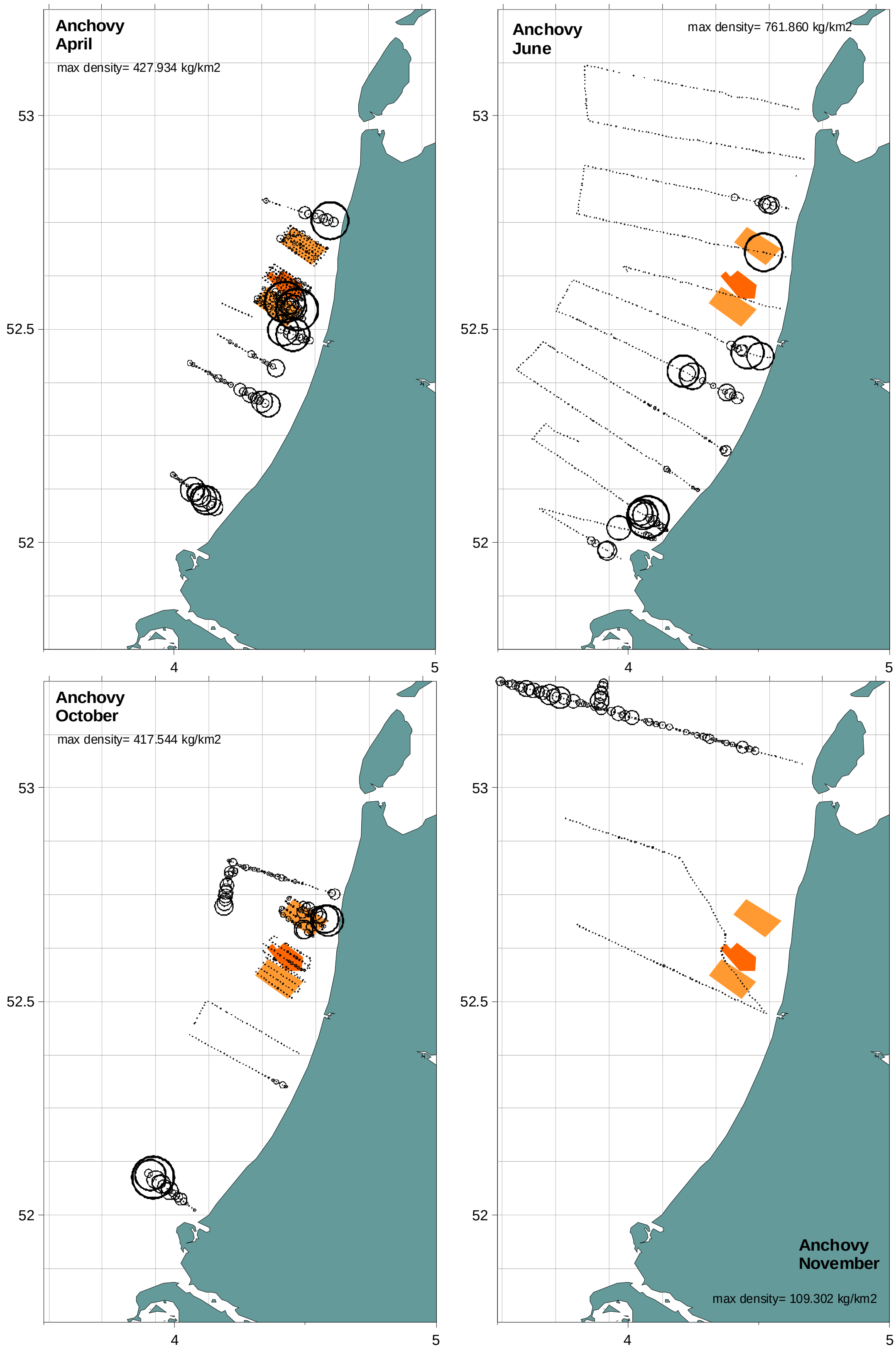


Figure V.1. *Distribution of Anchovy (kg/km²) in the coastal zone during the four surveys (April + October: baseline, June: Flyland, November: Fish-Birds). The size of the largest bubble is indicated by the maximum density and bubble size increases with square root of the densities. The sizes of the other bubbles decrease not linearly. A '+' indicates zero values.*

Figure V.2. *Distribution of Pilchard (kg/km²) in the coastal zone during the four surveys. Legend as in Figure V.1.*

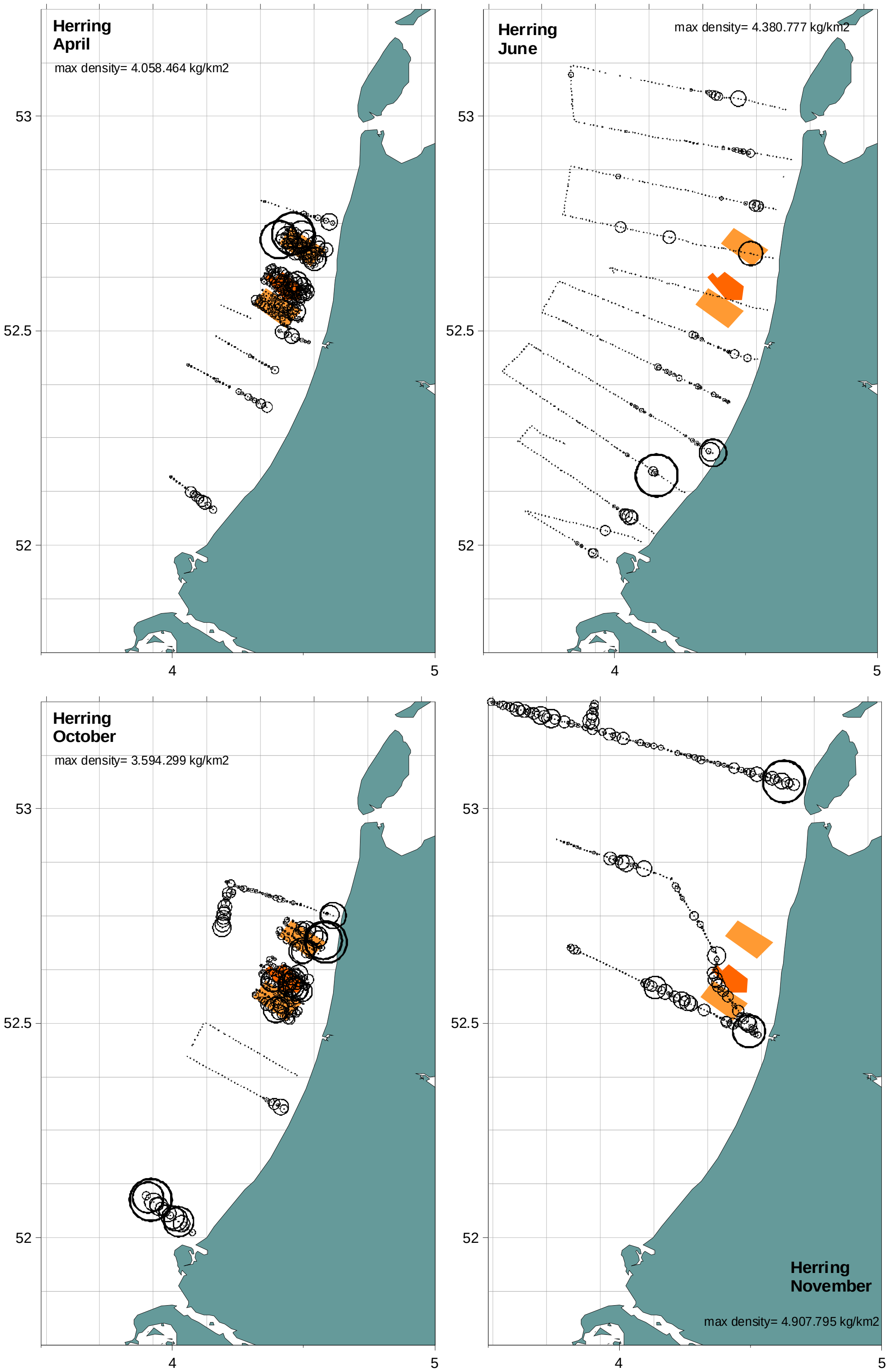


Figure V.3. *Distribution of Herring (kg/km^2) in the coastal zone during the four surveys. Legend as in Figure V.1.*

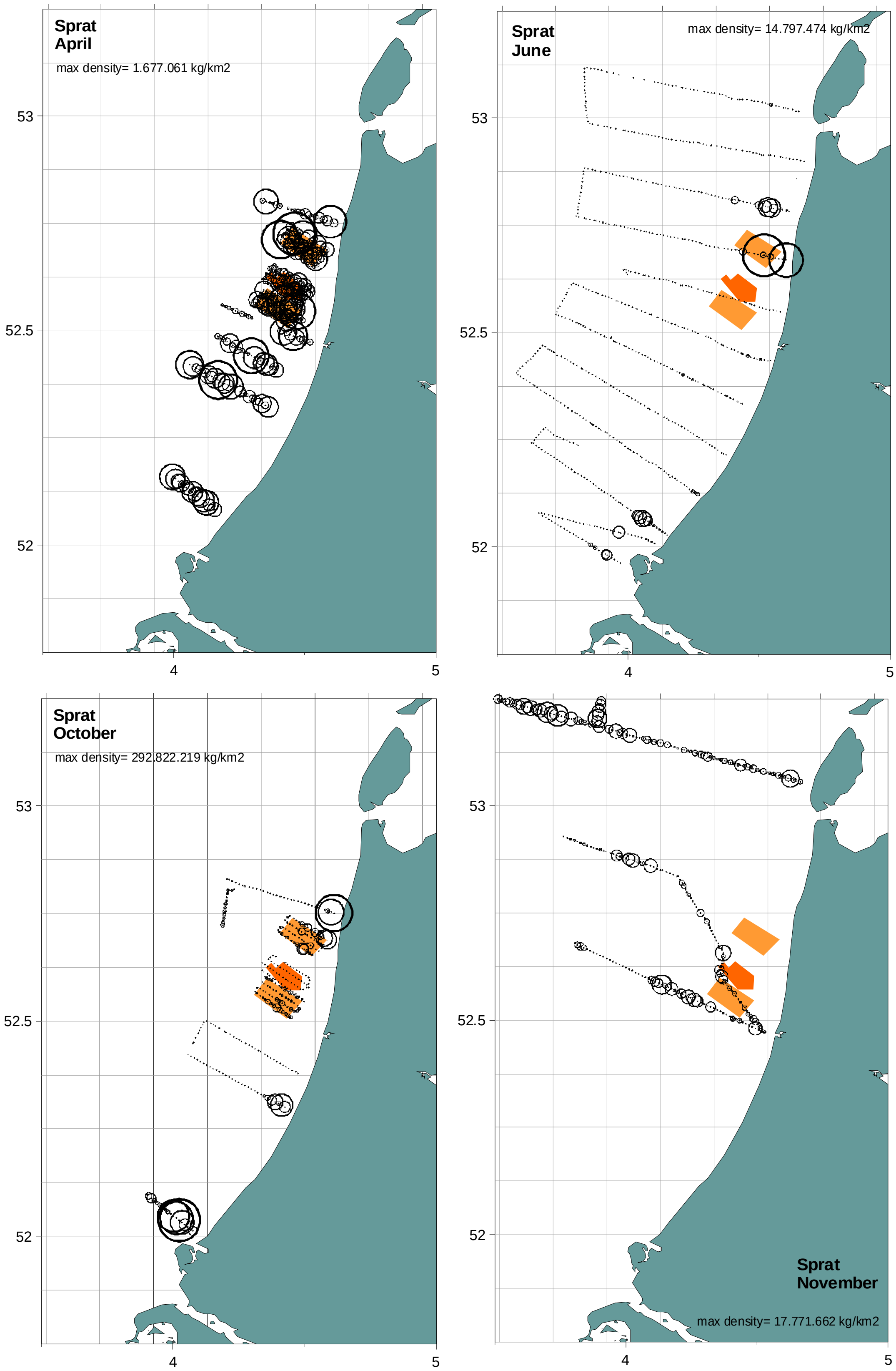


Figure V.4. *Distribution of Sprat (kg/km^2) in the coastal zone during the four surveys. Legend as in Figure V.1.*

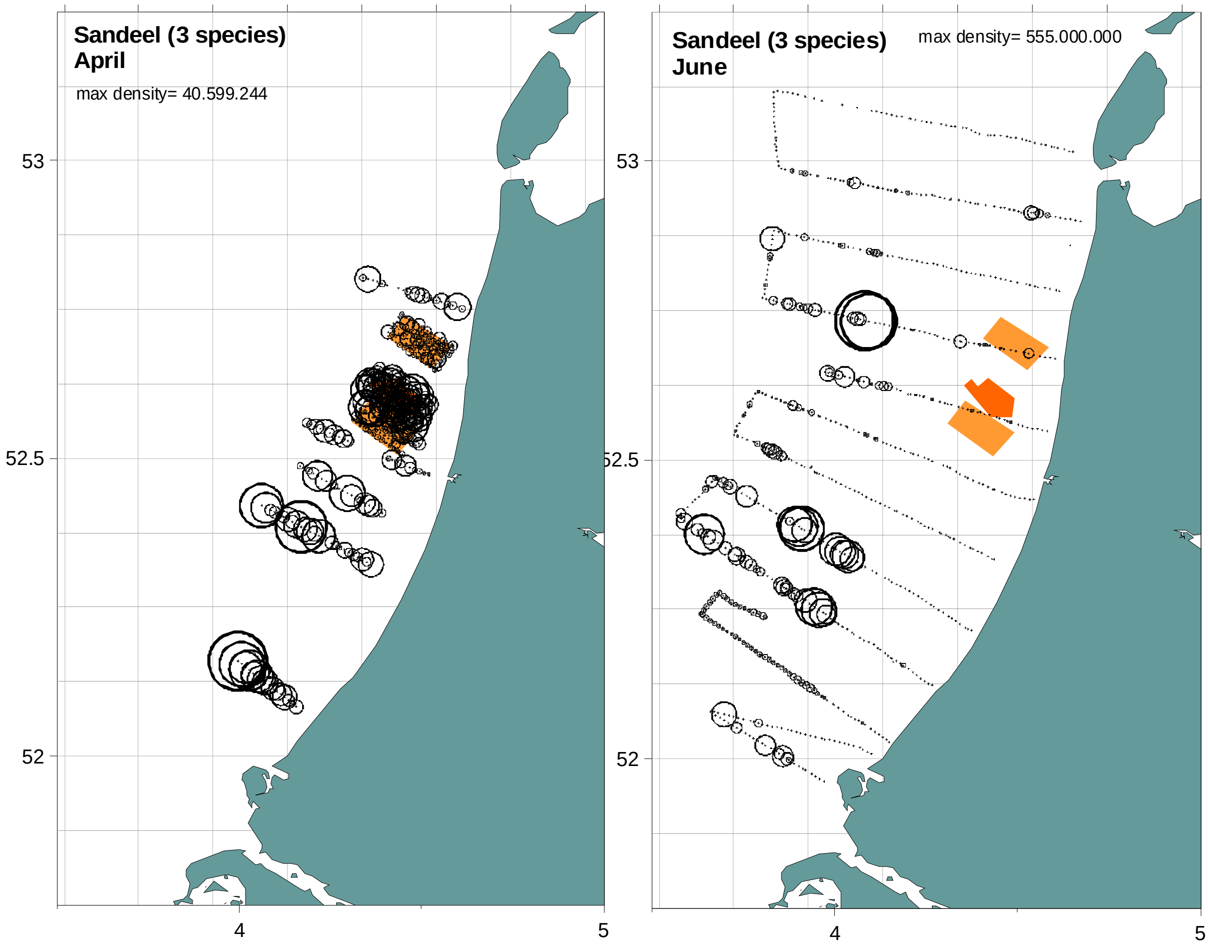


Figure V.5. *Distribution of Sandeel sp. (kg/km²) in the coastal zone during the four surveys. Legend as in Figure V.1. Sandeel species were only caught in very small numbers in autumn and therefore distribution maps of this period are not presented.*

Figure V.6. *Distribution of Horse Mackerel (kg/km^2) in the coastal zone during the four surveys. Legend as in Figure V.1.*

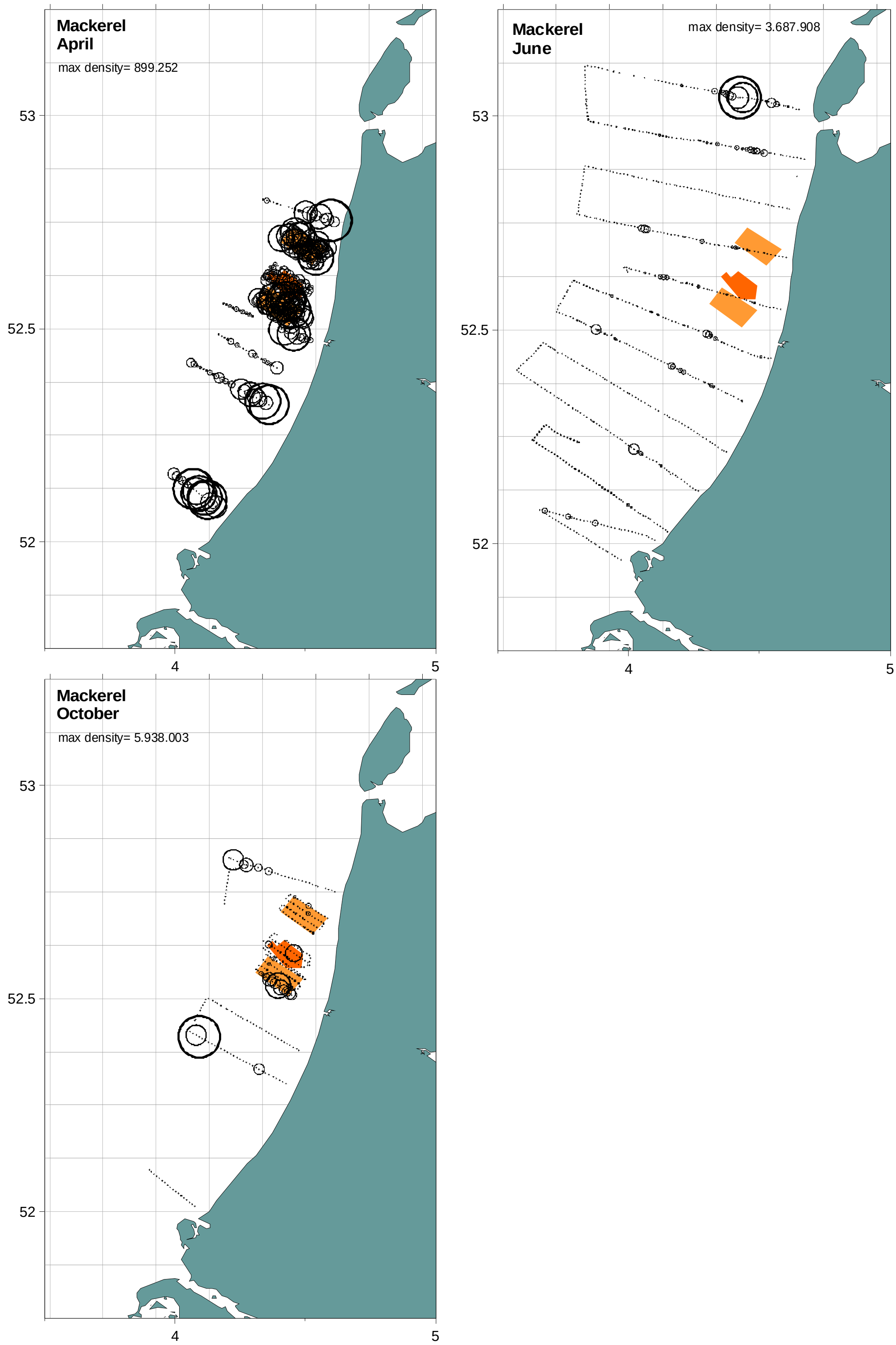
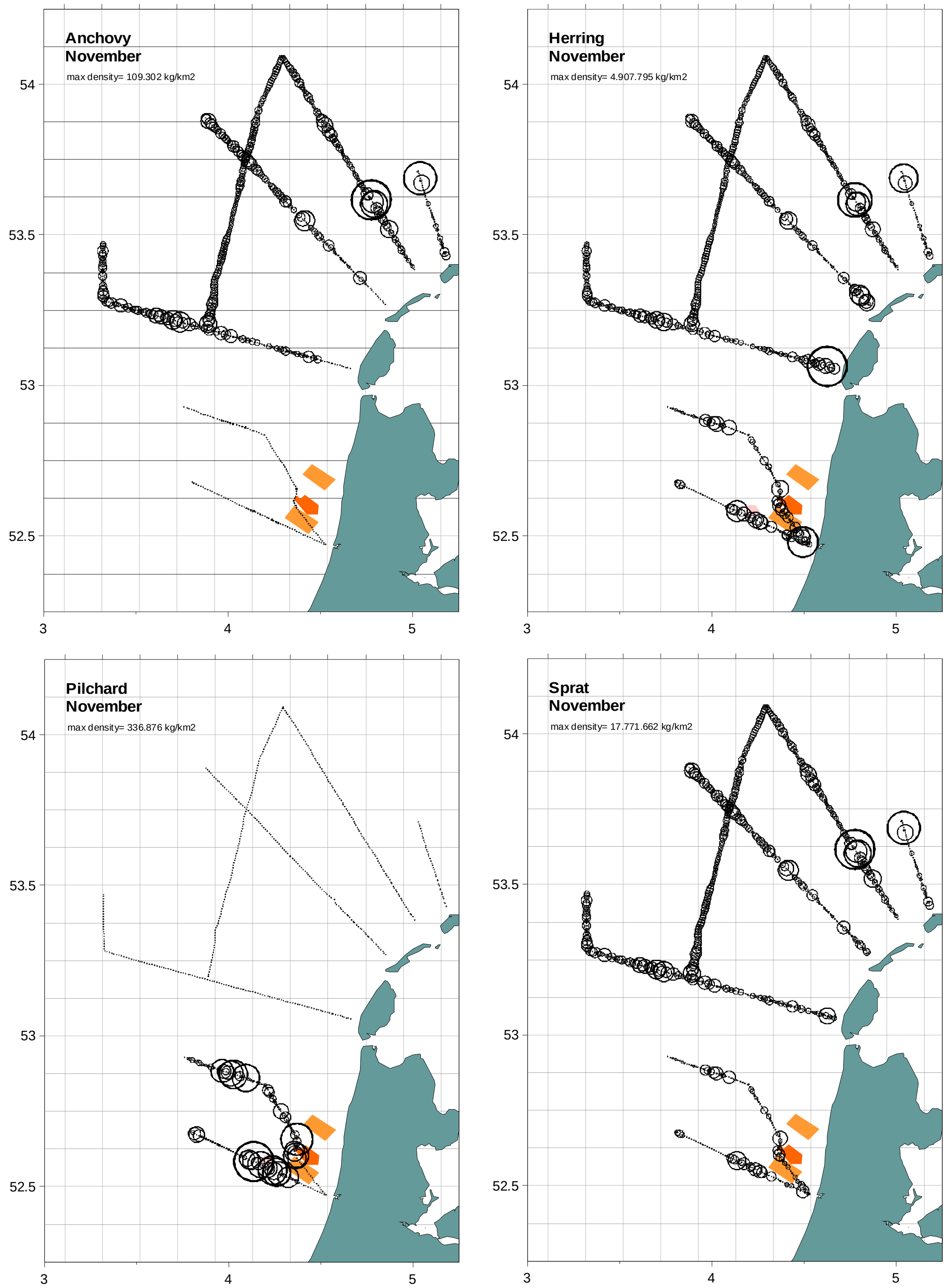


Figure V.7. *Distribution of Mackerel (kg/km^2) in the coastal zone during the four surveys. Legend as in Figure V.1. In November very few Mackerel were observed and showing distribution maps was not relevant.*

Annex VI. Distributions of Anchovy and three clupeid species in the Fish-Bird survey.



Annex VII. Results of the Redundancy analysis.

Table VII.1. *Results of Redundancy Analysis of the April data. Only significant variables are included.*

	axis 1	axis 2
Summary statistics for first two axes		
Eigenvalue	0.148	0.037
Species-environment correlation	0.684	0.527
Percentage of variance explained	14.8	3.7
Correlations with first two axes		
Depth	-0.1785	0.5088
Secchi	0.5899	0.2672

Table VII.2. *Results of Redundancy Analysis of the October data. Only significant variables are included.*

	axis 1	axis 2
Summary statistics for first two axes		
Eigenvalue	0.380	0.021
Species-environment correlation	0.839	0.523
Percentage of variance explained	38.0	2.1
Correlations with first two axes		
Depth	-0.5165	-0.0893
Oxygen	0.3000	0.4074
pH	-0.5439	0.3738