Monitoring- and Evaluation Program Near Shore Wind farm (MEP-NSW)

Fish community

Ralf van Hal, Bram Couperus, Sascha Fassler, Sven Gastauer, Ben Griffioen, Niels Hintzen, Lorna Teal, Olvin van Keeken, Erwin Winter

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IMARES Wageningen UR
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Client:	NoordzeeWind 2e havenstraat 5b 1976 CE IJmuiden, the Netherlands

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P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

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

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

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Summary

In 2006, the first Dutch offshore wind farm was built 10-18 km from the shore of Egmond aan Zee by a joint venture of Nuon and Shell Windenergy. A Monitoring and Evaluation Program accompanied the plans for the construction and exploitation of this farm. The program contained plans for the monitoring and evaluation of potential ecological consequences in the Dutch coastal zone related to the wind farm and was divided in six topics, of which the topics on fish are presented in this report.

Potential ecological consequences for fish were hypothesized to be linked to the introduction of new habitat, i.e. the monopiles and the scour protection surrounding them, disturbance by the operation of the wind farm (e.g. noise) and the exclusion of fisheries in the wind farm and its surrounding safety zone. To monitor and evaluate these hypothesized effects, five sub-projects performed focussing on different parts of the fish community, their spatial and temporal distribution and their behavioural aspects.

To study the demersal part of the fish community a BACI-approach was used, which means that monitoring was executed prior to the construction of the farm, i.e. the baseline (T0), and after the impact during the operational phase. As baseline (2003/2004) and in one year after (T1 2007/ 2008) and five years after (T5 2011) the construction of the wind farm, surveys with beam trawls were performed in the winter and summer. Fishing with the beam trawls took place in the wind farm and in three reference areas that were considered similar in respect to distance to shore, water depth and seabed morphology.
The pelagic part of the fish community was studied using a similar approach. Here, monitoring was done acoustically and for reference purposes fishing was done with a pelagic net. The survey was performed in the wind farm, two reference areas and in transects along the Dutch coast in April (T0, T1, and T5) and October (T0 and T5).

On a smaller scale the species composition and abundance of fish in the vicinity of the monopiles compared to the sandy habitats in the middle of the wind farm were studied using gillnets and the DIDSON (acoustic high frequency camera using sonar). Multi-mesh gillnets were used, which were placed on the scour protection as close as possible to the monopiles and in the middle between monopiles on the sandy bottom, in order to identify species and to estimate fish abundance in the lower part of the water column. The DIDSON surveys yielded abundance estimates for the entire water column, however without information on species. Both the gillnets and DIDSON were executed in three seasons during the T5.

Behaviour of individual fish in and around the wind farm was studied by a tagging and telemetry study for which sole (*Solea solea*) and cod (*Gadus morhua*) were selected to represent both sand and hard substrate dwelling species. Tagging of sole was executed in 2007 and 2008. The transmitters for the telemetry study were implanted in a number of sole and cod in 2008 and January 2009, while the detection stations were retrieved in June-July 2009.

The surveys monitoring the species on a larger scale in the Dutch coastal zone did not show significant effects of the wind farm on the abundance of fish in the farm compared to the reference areas. This means that the construction of the farm and the exclusion of fisheries in the area did not lead to detectable changes in abundance of the monitored species. The length compositions of fish caught in the surveys showed only a slight increase in the length of two pelagic species, sprat (*Sprattus sprattus*) and anchovy (*Engraulis encrasicolus*). This was hypothesized to be related to a reduction in predation pressure due to the protection by the wind farm.

On the smaller scale of the wind farm clear differences were observed between the new artificial hard-substrate habitat and the sandy bottom. Large aggregations of fish were observed near the monopiles mainly in summer, which can most likely be attributed to the presence of horse mackerel (*Trachurus trachurus*). Furthermore, a significant higher abundance of cod, edible crab (*Cancer pagurus*), bib (*Trisopterus luscus*), bullrout (*Myoxocephalus scorpius*), sea scorpion (*Taurulus bubalis*) and common dragonet (*Callionymus lyra*) was observed on the scour protection near the monopiles. In contrast, a lower abundance was observed for the flatfish species, sole, dab *(Limanda limanda*) and plaice (*Pleuronectes platessa*) and also for whiting (*Merlangius merlangus*). For these last four species the construction of the wind farm might have led to a nearly negligible reduction in habitat. However, for the other species the higher abundance near the monopiles may lead to a protection from fisheries with a potential effect on their populations. This is especially the case for cod, for which the telemetry study showed that part of the cod spends long periods within the wind farm and for which other research suggests that they can also spawn and settle in the wind farm. Overall the presence of the wind farm seems to have limited, if any effect, on the fish community of the Dutch coastal zone. For some species local benefits due to a combination of the creation of new hard substrate habitats and exclusion of fisheries might have occurred.

The Offshore Wind Farm Egmond aan Zee has a subsidy of the Ministry of Economic Affairs under the CO2 reduction scheme of The Netherlands.

Contents

1 Introduction

This document presents the fish part of the Monitoring and Evaluation Program-Near Shore Wind farm (MEP-NSW) during the operational phase. The program is commissioned by NoordzeeWind (NZW), a joint venture of Nuon and Shell Windenergy.

The Dutch Offshore wind farm Egmond aan Zee (OWEZ), built in 2006, lies off the coast between Castricum and Egmond aan Zee (Figure 3-1). It is situated between 10 and 18 km of the coast and consists of 36 Vestas V90 wind turbines, which are placed in four rows at a distance of approximately 1 km, and a distance of 650 m between the turbines in a row. Each turbine has a capacity of 3 MW and together they will supply yearly enough renewable electricity for more than 100,000 households. The foundation of each turbine consists of a steel monopile hammered into the sea floor to a penetration depth of about 30 m. To prevent scouring, a layer of stones, with a diameter of approximately 25 m, consisting of a filter layer of small sized rock and a top layer of heavier rocks, has been installed around each pile.
The total surface area of the wind farm is 27 km^2. The farm and its 500 m safety exclusion perimeter are closed to all shipping. This resulted in an area closed for fisheries in the Dutch coastal zone in which trawling occurred regularly during the last decades (Rijnsdorp et al. 1998).

The main goal of the Monitoring and Evaluation program was to gain experience and stimulate exchange of knowledge on the impact of a large offshore wind farm on its marine environment. The program was divided into six main topics: the effects on 1) migratory and 2) local birds, on 3) benthic organisms, on 4) pelagic and 5) demersal fish and on 6) marine mammals. This report focusses on the potential ecological consequences of the wind farm for the fish community, 4) pelagic and 5) demersal, in the first years of the wind farm operational phase.
The fish program in the operational phase incorporated two main study periods, T1 in 2007/2008 being the first year after the construction and T5 in 2011 being the fifth year after the construction. The periods are compared with a baseline study (T0) executed in 2003/2004 prior to the construction of the wind farm (Grift et al. 2004, Tien et al. 2004).

Monitoring was performed to study the potential effects on demersal fish, the part of the fish community that lives close to or on the bottom such as flatfish and cod (*Gadus morhua*), and pelagic fish, the part of the fish community that freely swims in the water column such as herring (*Clupea harengus*), mackerel (*Scomber scombrus*) and anchovy (*Engraulis encrasicolus*). These main monitoring tasks were accompagnied by a separate study on the residence time and behaviour of sole (*Solea solea*) and cod (Winter et al. 2010) and studies using gillnets and a DIDSON to provide additional information on the fish community near the monopiles.

In this report, each study is treated as a sub-project:

- Effects on the demersal fish community using demersal fish surveys;
- Effects on the pelagic fish community using acoustic surveys;
- Effects on fish near the monopiles using gillnets;
- Effects on fish near the monopiles using the DIDSON;
- Residence time and behaviour of sole and cod.

Each sub-project has its own chapter (chapter 4 to 8) with the details of the fieldwork and the analysis along with the results and a subproject-specific discussion. This is followed by a general discussion (chapter 9) combining the results and discussions of the sub-projects drawing conclusions (chapter 10) based on the combination of chapters 4 to 8. The report is finished with a chapter on the lessons learned during the execution of the project.

2 Assignment

2.1 History

The Dutch Government set the learning objectives for the Monitoring and Evaluation Program. These were similar for the pelagic and demersal fish topics, consequently a similar design was used: a so called Before, After, Control, Impact (BACI)-approach (Green 1979, Smith et al. 1993). The Before aspect means that the abundance and seasonal variation of both fish communities was monitored prior to the construction of the wind farm, the baseline (T0) (Grift et al. 2004, Tien et al. 2004). The Control aspect means that besides monitoring in the planned wind farm area, monitoring is executed in reference (Control) areas in the vicinity. The Impact is the construction and operation of the wind farm and as After monitoring comparable monitoring was executed one year after the construction (T1) and five years after the construction (T5) during the operational phase of the wind farm.

2.2 Learning objectives

The learning objectives of the Monitoring and Evaluation project are to increase understanding of the potential ecological consequences of the impact of constructing offshore wind farms. The construction of an offshore wind farm alters its surrounding in various ways (Broström 2008) which might have impact on the ecosystem.

The vertical monopiles extending from the sea bottom to above the water surface alter the local hydrological and light conditions. The altered hydrological conditions might alter the substrate structure and texture, which is already altered by the introduction of a new hard substrate, the scour protection placed at the base of each monopile. This hard substrate is introduced in a sandy bottom that is inhabited by a species community very different from that of hard substrates. A wind farm in the operational phase introduces noise in the environment by surface seawater noise against the monopiles, and noise from the turbine and rotor. The transmission of electricity through cables of the wind farm generates electric and magnetic fields that might be sensed and affect marine organisms (Petersen & Malm 2006, Öhman et al. 2007). These alterations of the environment are considered to be permanent during operation (Svane & Petersen 2001, Gill 2005, Inger et al. 2009).

Besides the construction of the wind farm itself fisheries were band in the Dutch offshore wind farms.

2.2.1 Introduction of new habitat

Two types of new habitat were introduced by the construction of the wind farm, the monopile as a vertical structure in the water column and the hard substrate of the scour protection surrounding the monopiles.

These solid man-made structures have been shown to attract fish as shown in numerous studies (e.g. (Glasby & Connell 1999, Barros et al. 2001, Wilhelmsson et al. 2006), the so-called artificial reef effect (Bohnsack 1989). Reasons for this are possibly enhanced protection from predators and food availability due to increased production of sessile and fish prey species. Furthermore, artificial reefs may support assemblages of fish and epibiota that are different from natural local communities (Ambrose & Swarbrick 1989, Connell & Glasby 1999, Rilov & Benayahu 2000, Bouma & Lengkeek 2009, Kerckhof et al. 2010). The artificial solid structures can also change local abiotic conditions, such as currents and light levels, influencing the composition of the potential epibiota prey in the surrounding bottom area (Guichard et al. 2001). A change in the regime of the currents

may also enhance food availability for plankton-feeding pelagic fish (Rilov & Benayahu 1998, Neira 2005).
On a larger scale artificial reefs created by an assembly of wind turbines may influence pelagic fish assemblages inhabiting the area as well as those present at a distance several hundred metres away from the construction (Grove et al. 1991). Such artificial reefs have been shown to contain greater fish densities and biomass, not only when compared with surrounding soft-bottom areas, but also in relation to adjacent natural reefs (Bohnsack & Sutherland 1985, Ambrose & Swarbrick 1989, Brock & Norris 1989, Bohnsack et al. 1994, Wilhelmsson et al. 1998). Therefore, the extended influence of wind farms on pelagic fish may be connected to synergetic effects on the fish community structure, supported by positive biological interactions between the biota around the turbines.

2.2.2 Exclusion of fisheries

On forehand, it was expected that the largest effect of the deployment of the wind farm, at least on a larger scale, would be the creation of an unfished zone in a heavily fished area (Rijnsdorp et al. 1998). Before its construction, the OWEZ area was intensely fished, mainly by eurocutters (<300 hp) using beam trawls fishing for flatfish (Figure 2-1). It was estimated that every spot in the Dutch coastal zone (12-miles zone) was fished at least once every 1.5 years by a eurocutter with beam trawls (Verver et al. 2003). All fisheries activities, except for monitoring purposes, are excluded in the safety zone of 500 m around the monopiles since the start of the construction of the farm. This is clearly shown by the white area in Figure 2-1. The monitoring area (OWEZ) is larger than the 500 m safety zone, and fisheries still occur in the part of the monitoring area that lies outside the exclusion zone.

Fisheries activity by eurocutters has clearly decreased to nearly zero in the wind farm and safety zone. However reports of "illegal" fishing activities have been made. As the farm and its safety zone are largely unfished it forms a 27 km^2 area that could function as a refugium for fish. As such, it might act as a relatively small scale marine protected area (MPA) in a traditionally fished area.

2.2.3 Disturbance effects

Wind turbines may also influence marine life by for example the increase in sound levels during construction and operation (Wahlberg & Westerberg 2005, Andersson et al. 2007). The noise emitted by offshore wind farms is not very well described up to now. In OWEZ, underwater noise measurements are being carried out, but the work has not been finalised yet. Moreover, very little is known on the behavioural responses of fish to anthropogenic sounds (Slabbekoorn et al. 2010). Therefore, at present it cannot be determined which types of (species-specific) response do occur: i.e. avoiding behaviour by being disturbed or scared away, indifferent behaviour when the fish do not respond or even attraction behaviour e.g. when fish learn to associate these sounds with favourable conditions.

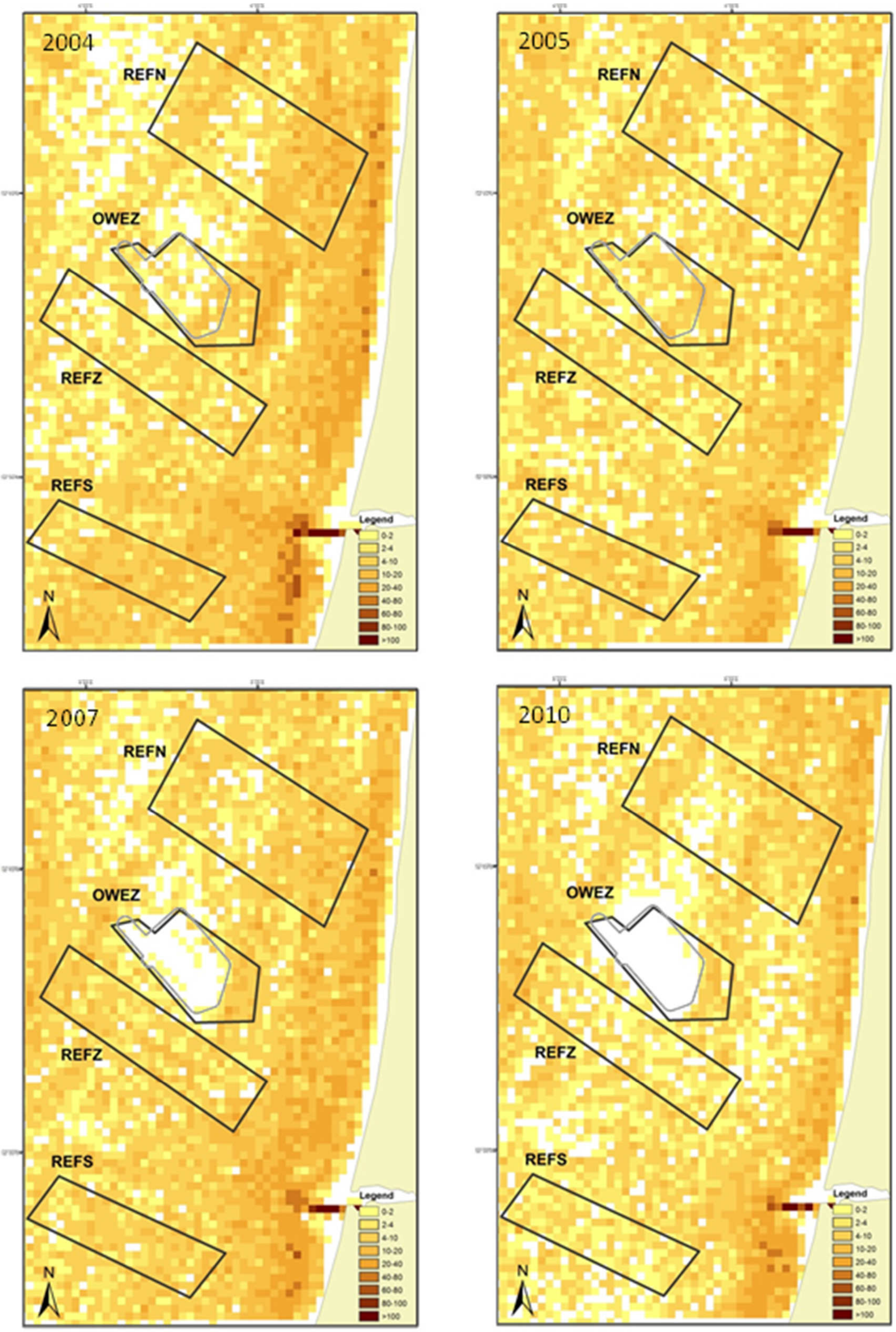


Figure 2-1: Fishing intensity of Dutch eurocutters in hours of VMS registrations (average registration is 2 hours) considered as fishing activity based on the speed of the vessel. Upper panels 2004 and 2005 prior to the construction of the farm (OWEZ); lower panels 2007 and 2010 in the operational phase of the farm (OWEZ). The sampling areas and the 500m exclusion zone are indicated (thin grey line).

2.3 Effects on fish: research questions and hypotheses

The main research question of this Monitoring and Evaluation Program is:

- What are the effects of the offshore wind farm OWEZ on fish during the operational phase?

To study this, the above broad question can be further subdivided into more specific questions. Firstly, it needs to be addressed if there are any effects at all:

- Are there detectable changes in fish related to the operation of the wind farm?
- And if so, for which species or groups of fish?

Within the set-up of the sampling program a distinction was made between studies or surveys targeting 1) demersal or 2) pelagic fish to perform BACI-tests (Before, After, Control, Impact designed studies), where the null-hypothesis to be tested can be stated as:

- There are no detectable effects if the differences between before and after control and impact areas are not statistically significant.

The demersal fish community includes the fish that live close to or on the bottom such as flatfish and cod. More than 50 species (or genera if identification on species level is difficult) that can be considered as demersal (Tien et al. 2004) have been found in IMARES surveys in the Dutch coastal zone between 1969-2004. These species all play their own important role in the ecosystem, for example the abundant gobies (Gobiids) are important prey items for birds and piscivorous fish (Magnhagen 1988) and therefore form a link between secondary production and birds. Some of these demersal species are target species for commercial fisheries (e.g. sole, plaice (*Pleuronectes platessa*) and cod), while others are landed as by-catch species (e.g. dab, brill (*Scophthalmus rhombus*) and tub gurnard (*Trigla lucrna*)). Even though most of the species are not of commercial interest, they are in many cases affected by bottom trawl fisheries.
For many juvenile fish species, including the commercially valuable demersal flatfish species plaice and sole the Dutch coastal zone, and thus the OWEZ area, is considered an essential nursery area. The presence of these species in the area is confirmed by the baseline (T0) study (Grift et al. 2004) and is shown by the data collected by regular IMARES surveys (e.g. (Tulp et al. 2008).

The pelagic fish community includes the fish species that live close to the surface or in the water column and not usually in or near the bottom, such as herring, mackerel, sprat and anchovy. Only limited information was available on the pelagic fish community in the Dutch coastal zone. The available data came from the short programs Flyland (Grift et al. 2002), the baseline of the wind farm program (Grift et al. 2003) and the bycatch of pelagic species in regular bottom trawl surveys. The data showed that the pelagic fish community in the Dutch coastal zone comprises nine species of which three sandeel species Raitt's sandeel (*Ammodytes marinus*), lesser sandeel (*Ammodytes tobianus*) and greater sandeel (*Hyperoplus lanceolatus*), three clupeids herring, pilchard (*Sardina pilchardus*) and sprat and three species of other families mackerel, horse mackerel (*Trachurus trachurus*) and anchovy. In fact one may discuss whether sandeel is a real pelagic species, because it lives in the sediment for a large part of its life. However, the species behaves as a pelagic species as soon as it is out of the sediment, whereas it is missed by bottom touching gear (beam trawl) when it hides in the sediment.

Flyland and the baseline of this wind farm showed a large temporal and spatial variation in the pelagic fish community. The temporal variation indicated that species only utilised the coastal zone in specific periods of time. For example mackerel and horse mackerel were abundant in April and

June but absent in November (Grift et al. 2004). Juveniles were observed of most species, which confirms the expectation that these species use the coastal zone temporarily as a nursery area (Grift et al. 2004). Patterns in spatial variation occurred on a large scale, while on a smaller scale patterns were absent. Consequently, no spatial patterns seemed to occur at the scale of the wind farm (Grift et al. 2004). On this local scale pelagic fish aggregate in schools which show a high mobility and seem to use at least large parts of the coastal zone.

The BACI-study on on the demersal and pelagic fish community might result in effects found for specific fish species or groups. Then there are many mechanisms thinkable underlying them (Gill 2005, Inger et al. 2009). Moreover, some effects might not be detected by BACI-design studies, e.g. because the effects are 1) too small in relation to the variance in occurrence of fish to be detected by the monitoring setup or 2) because not all habitats were covered during T0, T1 and T5 or could be covered during T0 such as the newly created habitats of the monopiles and the scour protection.

To explore these effects and their underlying mechanisms, several process-dedicated studies were performed during the operational phase (T1 and T5): 1) tagging and telemetry experiments to study the behaviour of fish within the wind farm, and 2) gillnets and 3) DIDSON acoustic surveys to study habitat use at smaller scales with special emphasis on the newly created habitats versus ‘open water’ habitats within the wind farm during the operational phase.

The three main mechanisms that might lead to effects of the wind farm on fish are discussed in 2.2: i.e. 1) exclusion of fisheries in the wind farm and its safety zone, 2) creation of new (hard substrate) habitats, 3) disturbance caused by the operation of the wind farm. Below we will discuss research questions and hypotheses related to these three types of mechanisms.

Exclusion of fisheries in the wind farm and its safety zone

Because the main fisheries activity in the coastal area is bottom trawling, it was expected that the effect of exclusion of fisheries in the wind farm area was largest for the demersal fish community. The wind farm and its safety zone could function as a refugium for these species, depending on their spatio-temporal behaviour in relation to the scale of the wind farm, and therefore have a positive effect on the demersal fish community. This leads to the following research question:

- Can the wind farm and its safety zone act as a refugium for fish due to the exclusion of fisheries?

And if so, it can be hypothesised that the BACI-studies yield:

  - A significant higher density of a fish species or groups in the wind farm (impact) than in the reference and control areas before and after the construction of the wind farm.

The fisheries that occurred in the area targeted larger fish; therefore fisheries mortality was higher on larger fish. By excluding fisheries in the farm it can be hypothesised that:

  - Age and size of fish within the wind farm is older and larger than outside or prior to the construction of the wind farm
  - Residence time of individual fish staying within the wind farm area needs to be large to be protected against fisheries.

To address these questions it is important to determine the population structure, the population size and the residence time of these fish species within the wind farm area. To do this, biological information on fish, e.g. length, gender, maturity, weight and age need to be collected along with abundance estimates of the fish species in the wind farm and reference areas outside the farm. To function as a refugium for fish the residence time is an important aspect. In order to be protected from fisheries mortality, fish need to stay within the wind farm area at least for a certain period of time. When the farm is only used randomly and as passage way the protection will be limited. Thus the longer a fish species stays within the farm, the better the refugium function of the farm is for this species. The positive effect of a wind farm on the fish population is a multiplication of the fraction of the population in the farm and the fraction of time this part of the population stays in the farm. As an extension to the BAC-approach, residence time experiments were executed to understand the behaviour of fish in the farm. It is important for understanding the refugium function of the farm to known how fish use the farm. Do they swim in an out, or do they stay in the farm their whole life.

Most of the demersal fish species predate on benthic species that might be affected by the exclusion of fisheries as well (Kaiser et al. 2006). Therefore in relation to the exclusion of fisheries it can be hypothesised that:

- Bottom fauna in the sandy habitats within the wind farm will change due to the absence of fisheries and thus change the food availability and subsequent diet of demersal fish within the wind farm.

Creation of new habitats and artificial reef effect
The second type of effects is related to the creation of new habitats, resulting in the research question:

- Did the creation of new habitats and structures affect local species composition and abundance?

The monopiles and the scour protection offer new hard substrate habitat for both fish and other fauna. Fish might be attracted to these new structures for food or shelter. This is often referred to as the artificial reef effect. The new structures are expected to attract species like the commercial fish species cod, seabass (*Dicentrarchus labrax*) and whiting (*Merlangius merlangus*) or species with specific habitat requirements provided by the newly created habitats that were not met in the situation before the construction of the wind farm. The introduction of new habitat might even attract species formally unknown to or very rare in the area. For example it is expected that the hard substrate will attract fish species as bib *(Trisopterus luscus*) but also a species as edible crab (*Cancer pagurus*) (Langhamer & Wilhelmsson 2009). It can therefore be hypothesised that:

- Local species composition and abundance directly around the monopiles and scour protection is different from the surrounding sandy or 'open water' habitats.

In addition to the altered bottom fauna in the sandy habitats due to the exclusion of fisheries, fish species predating on benthic species might also be affected by the introduction of new habitat due to the potentially altered food availability in these new habitats. Thus it can be hypothesised that:

- New habitats and structures offer additional prey species and food availability and subsequent alter the diet of demersal fish within the wind farm.

The potential impact on benthic fauna is studied in a separate part of the full MEP-NSW program (Bergman et al. 2012 draft). It is expected that changes in the benthic fauna affect the feeding of demersal fish in the wind farm area, therefore information on consumption by the demersal fish community is collected, in order to make a link between the demersal fish community and the benthic organisms in the farm. In this diet study it is challenging to disentangle an 'exclusion of fisheries' effect (see above) from a 'new habitat' effect.

The above effects might not only occur in demersal fish species, but also in pelagic species. Attraction of pelagic fish by the underwater structures of the monopiles through an artificial reef effect was expected (Baine 2001, Charbonnel et al. 2002, Arena et al. 2007). This attraction was shown to occur in a pilot study in the wind farm (Couperus et al. 2010). The monopiles might act as a shelter for predation by birds, reducing mortality. However, an aggregation of fish on a small spatial scale, could also lead to an attraction of birds or predatory fish, increasing mortality. Sheltering around the monopiles for unfavourable currents could also reduce the energy expenditure, which might lead to a better condition of the fish. Also an altered food availabiltiy might play a role in the attraction of pelagic.

Whether the scale of the wind farm and newly created habitats is sufficiently large to benefit pelagic fish populations remains to be seen, but was expected to be too small. Therefore we hypothesise the following for pelagic fish species:

- Based on the limited size of the wind farm relative to the spatial distribution of pelagic fish, and the high mobility of schools, no effects on population size, structure or migrations of pelagic fish are expected, but the underwater structures of the monopiles attract pelagic fish, increasing the local abundance of fish near these structures.

Disturbance caused by the operation of the wind farm

Potentially, fish might be disturbed by the operation of the wind farm, e.g. by the anthropogenic noise associated with the operation of the wind farm, or electric fields around the cables. If these effects occur, it is important to know the spatial scale on which they occur, small scale (e.g. only directly around the monopiles) or large scale (e.g. avoiding the wind farm).

When a large scale disturbance occurs, it can be hypothesised that the BACI-studies yield:

- A significant lower density of a fish species or group in the wind farm (impact) than in the reference and control areas before and after the construction of the wind farm.

Small scale disturbance, e.g. by noise directly around the monopole, is more difficult to measure and disentangle from habitat preference of fish species i.e. preferring sandy habitats over hard substrates of the monopile or scour protection. Within the collected datasets with small scale resolution (gillnets, DIDSON and telemetry experiments), possible links to disturbance will be discussed based on the observed patterns. More details on this will be given in the chapters presenting the sub-projects.

3 Basic information

3.1 Description of the study area

The wind farm is located within the Southern Bight of the North Sea in an area, with predominantly fine sand. The depth of the area varies around 16-20 metres, only the westernmost part is located in slightly deeper water, 21-25 m (Figure 3-1). The seawater originates mainly from the English Channel as the primary current in the North Sea is anti-clockwise. Fresh water flows in from the rivers Rhine and Meuse, which discharge about 90 kilometres to the south, and forms a low salinity plume ('coastal river'), which moves northeast along the Dutch coast into the German Bight. Some salinity stratification may occur in the area during high river discharge events, but was not expected to affect the wind farm. The tidal currents along the Dutch coast are among the strongest in the North Sea (up to 1.4 m sec^{-1}) (Jarvis et al. 2004). The high current speed affects the bottom characteristics by winnowing out fine-grained sedimentary and organic particles. Sediments therefore consist of fine to medium sands with low organic carbon content. Benthic species richness and abundance of infaunal and epifaunal animal communities are usually low here in comparison to other North Sea areas (Jarvis et al. 2004).

The main monitoring area was the wind farm (OWEZ). As control, three reference areas were selected in the T0 (Tien et al. 2004), an area north of the wind farm referred to as REFN and two areas south of the wind farm. The area directly south of the wind farm is referred to as REFZ. The most southern area is referred to as REFS, and is located south of the entrance to the Noordzeekanaal (Figure 3-1). These areas were considered similar to the wind farm in respect to distance to shore, water depth and seabed morphology. Due to physical similarity of the areas and their vicinity, it was assumed that water currents are similar in all areas.
The demersal survey sampled in all three areas, while the pelagic survey only sampled in the areas directly north and south of the wind farm (REFN and REFZ); the most southern reference area (REFS) and the northern area (REFN) overlap with reference areas of the benthic program (Daan et al. 2009). The research programmes with gillnets, the DIDSON acoustic camera and telemetry and tagging experiments on residence time and behaviour were executed only in the wind farm.

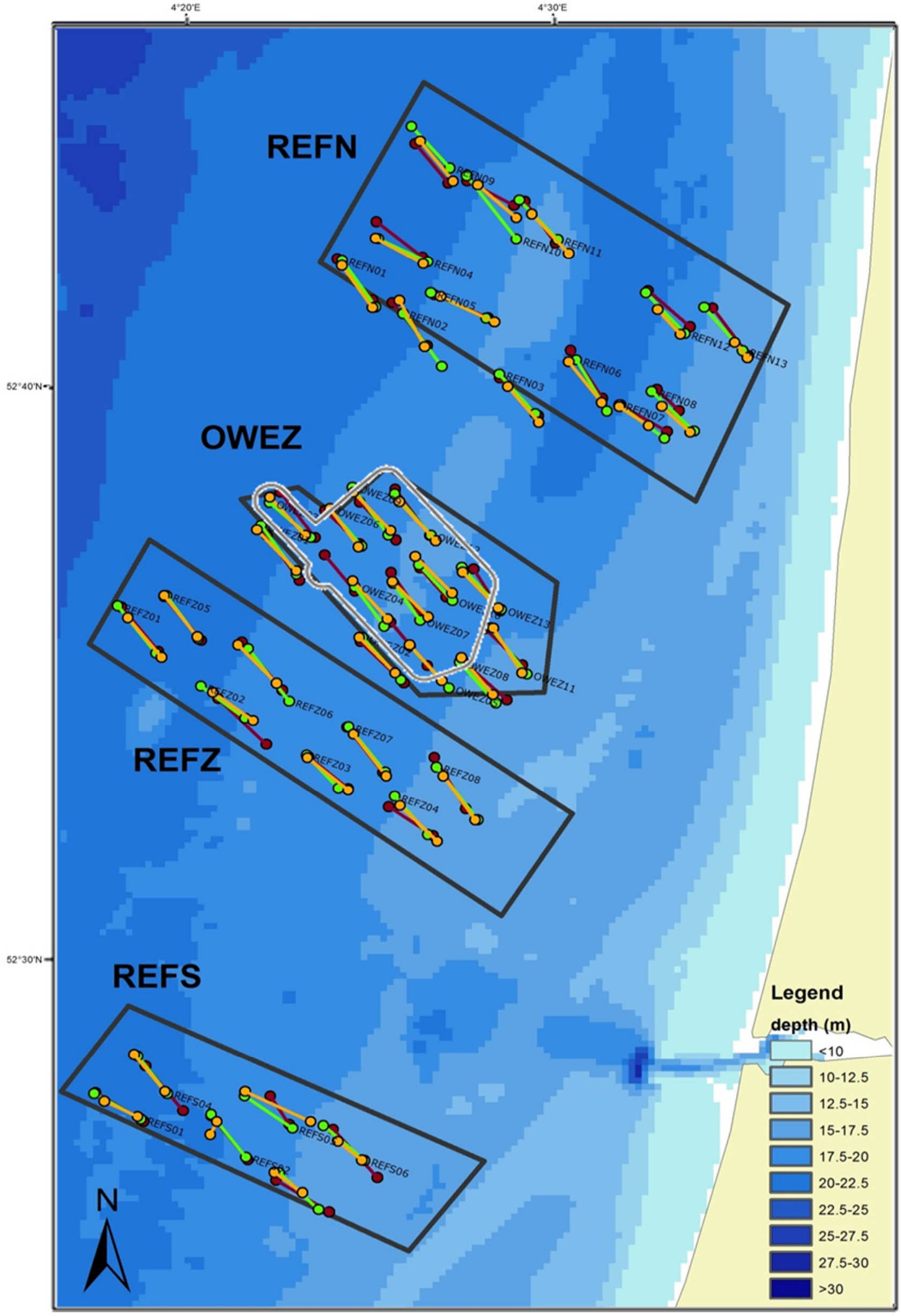


Figure 3-1: Locations of the OWEZ and reference areas (Black lines) and the 500 m exclusion zone (thin grey line), in relation to depth. Included are the trawl positions of the demersal survey in the T5, winter (green) and summer (orange) and the winter survey of the T1 (dark red).The locations of the pelagic survey are presented in Figure 5-2 and Figure 5-3.

3.2 Hydrography

In sub-projects 1 and 2 hydrography data were collected using a CTD device on the beam trawl (bottom) or the towed body (surface), in order to collect information on temperature, conductivity (salinity), depth and turbidity. These parameters are important drivers behind the spatial distribution of fish, besides that they have a direct or indirect impact on the fishery catches. The baseline showed that the influence of visibility and depth was considerable, while temperature and latitude were found to be not significant (Grift et al. 2004, Tien et al. 2004). Although the impact of water temperature was not significant in the T0, temperature may have an effect at larger temporal (inter-annual) and spatial scales. For example, species 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 be absent in colder years (Knijn et al. 1993).

The CTD device mounted on the towed body used in the pelagic survey (sub-project 2), produced continuous large spatial scale measurements of temperature, salinity and turbidity in April 2007 and 2011 (Figure 3-2) and on a smaller spatial scale in October 2011 (Figure 3-3; Appendix figure A-1; Appendix figure A-2). The figures show that the wind farm and the reference areas are on the border of coastal water (low salinity, high turbidity) and offshore North Sea water. Apart from a large scale frontier parallel to the coast, the maps reveal small scale variations in salinity and turbidity. Small scale variations are also found in temperature. These small scale variations are most likely the result of the mixing of coastal and offshore water masses in relation to tidal currents. Blobs of turbid and/or low salinity water may show up amidst clear, high salinity offshore water and vice versa. However, the state of environmental variables is not merely a result of the division of coastal and offshore water and mixtures of these water masses, as the maps do not suggest a high correlation between salinity and turbidity.

Despite the high variability in temperature on a small spatial scale, the main variation was shown on a temporal scale, in particular induced by changes in weather conditions. Water temperature in October 2011 dropped by 1.5 °C in 8 days (Figure 3-3), following a strong wind period.

The relatively large variability in temperature on a short time scale and between years is presented by the average weekly temperatures measured in the T1 and T5 pelagic and demersal surveys (Figure 3-4). The data are the averages of the continuous registrations and thus combine data from the different areas sampled. It shows that the T5 temperature in April was clearly lower than in the T1. This difference between the years had disappeared already in June as shown in the demersal data. The T0 data was collected in a different way and therefore impossible to present on a similar scale. To indicate the differences in temperature between the T0 (2003) and the operational phase larger scale data from the BSH is used (Figure 3-5). This figure shows that temperature in the North Sea in week 15 (April) 2007 was high in comparison to 2003 and 2011, the warming of the water in 2007 started early. Temperature in week 40 (October) 2003 was exceptional high in the North Sea due to a hot summer.

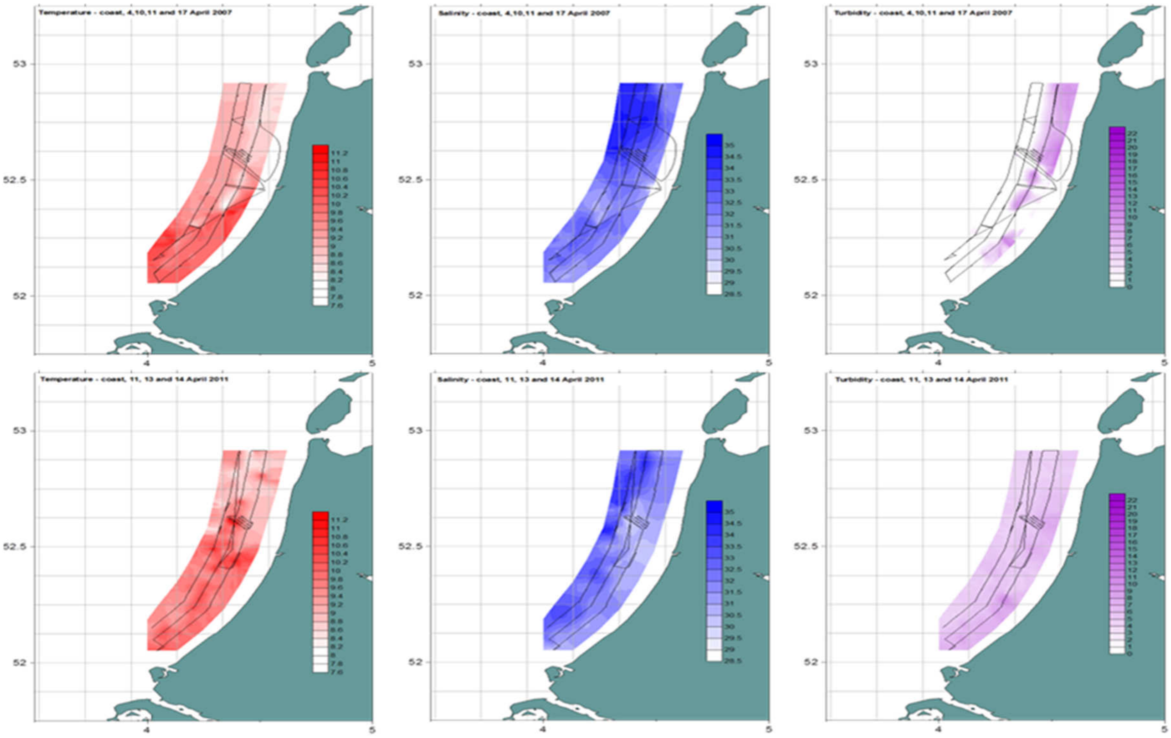


Figure 3-2: Temperature (°C, range 7.6 to 11.2°C), salinity (PPT, 28.5 to 35 PPT) and turbidity (NTU, 0-22) during the cruises in April 2007 and 2011.

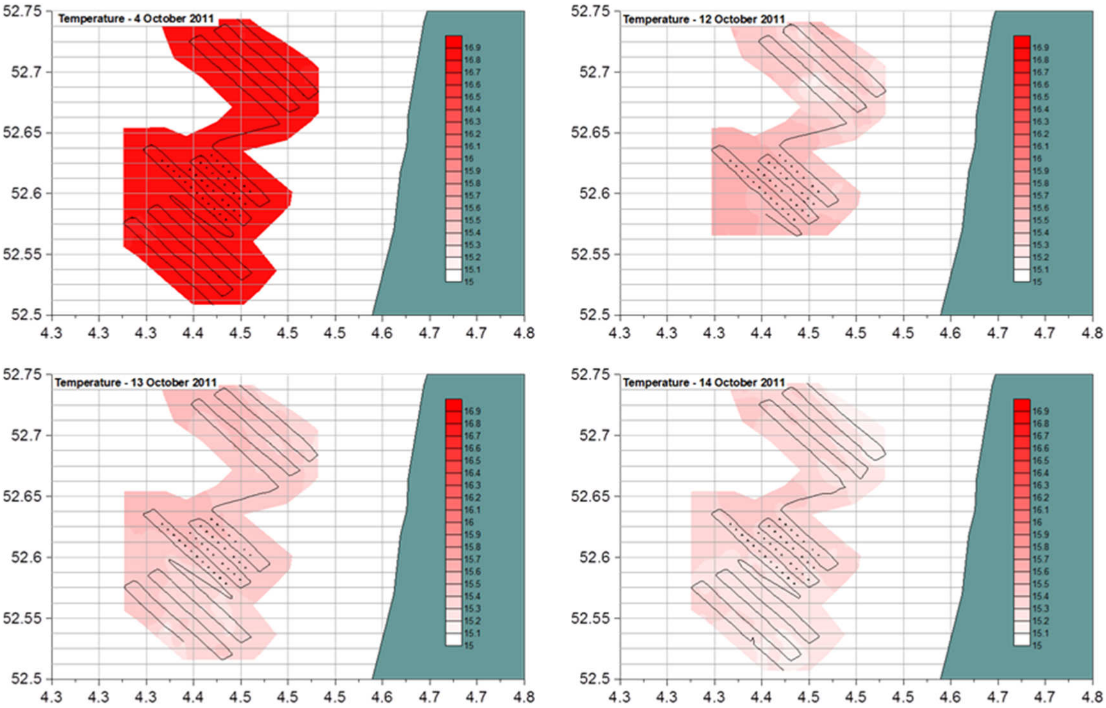
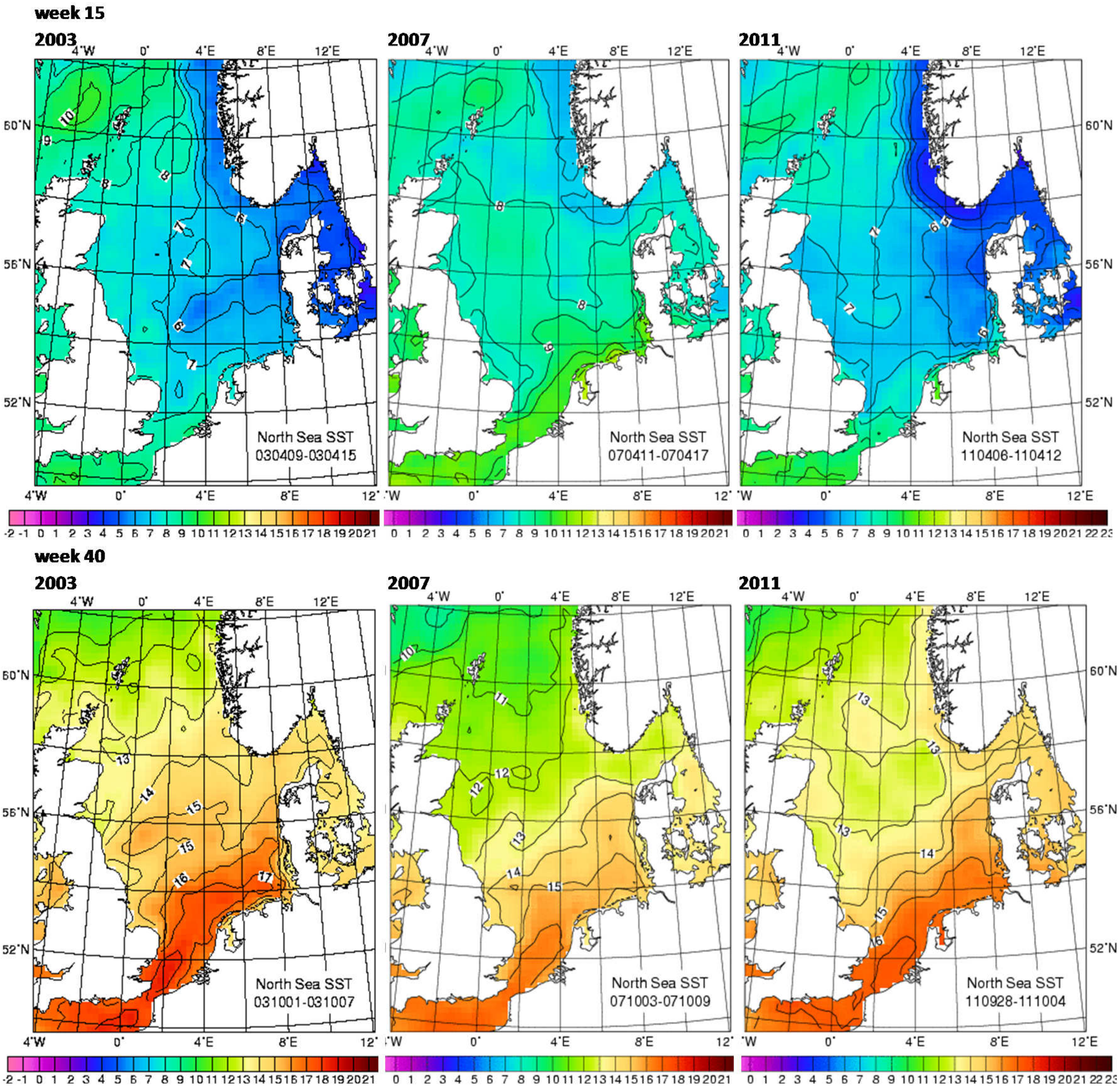


Figure 3-3: Temperature (°C, range 15-16.9) in the wind farm and the reference areas at different days during the survey in October 2011.

Figure 3-4: Average temperature by week for the pelagic survey in April (T1 and T5, above left); the pelagic survey in October (T5, above right); demersal survey in January (T5, below left); demersal survey in June (T1 and T5, below right); dotted lines represent the standard deviation. T1 winter demersal data are not available, no October pelagic survey was executed in the T1.



week 15

2003 **2007** **2011**

week 40

2003 **2007** **2011**

Figure 3-5: North Sea Surface temperature in week 15 and 40 for 2003, 2007 and 2011. Temperature in spring 2007 was comparatively high. Temperature in autumn 2003 was high in 2003.
Data from: Bundesambt für Seeschifffahrt und Hydrography
http://www.bsh.de/en/Marine_data/Observations/Sea_surface_temperatures/SST_d.jsp#0

3.3 Overall catches

Three of the five sub-projects collected fish, a list of the species by sub-project (Table 3-1) and period is presented in Table 3-2. A list of all non-fish species caught is shown in Appendix table A-1. Not all fish has been identified consistently to species level, as for some genera it is difficult to distinguish the different species in the field. These genera are:

- Ammodytes:
    - Raitt's sand-eel (*Ammodytes marinus*);
    - Lesser sand-eel (*Ammodytes tobianus*);
- Pomatoschistus
    - Lozano's goby (*Pomatoschistus lozanoi*);
    - Painted goby (*Pomatoschistus pictus*);
    - Sand goby (*Pomatoschistus minutus*);
- Syngnathus
    - Nilsson's pipefish (*Syngnathus rostellatus*);
    - Greater pipefish (*Syngnathus acus*);

The individual species of these genera have been identified in some cases, therefore we know all of them were caught, thus 61 fish species were caught within this project. The species described above are however combined on genus level in all analyses, creating the list of 57 fish species or genera shown in Table 3-2.

The list shows that 4 species were caught exclusively in the T0. Of these two were caught twice, while the other two were only caught once.

In the T1, five unique species were caught, while in the T5 six unique fish species were caught, two of these in the static gear only executed in the T5. Most of the unique species were rare or vagrant species found only in a single or very low number of hauls.

The three fish species with an asterisk in Table 3-2 were recorded in the surveys; however doubts arise if these have been identified correctly. For Allis shad it is more likely that this was Twaite shad. Spotted dragonet is a more northern species likely confused with reticulated dragonet or common dragonet. Big-scale sand-smelt is most likely confused with sand-smelt (*Atherina presbyter*).

Table 3-1: Dates of the fieldwork activities.

	T0		**T1**		**T5**
Survey	**2003**	**2004**	**2007**	**2008**	**2011**
Demersal	23 June-4 July	19-30 Jan	25 June-6 July	22-Jan-12-Feb	10-18 Jan & 27 June- 6 July
Pelagic	14-25 April & 29 Sept-10 Oct		2-20 April		4-22 April & 3-15 Oct
Gillnets					9-18 April & 8 June-12 July & 25 Sept-1 Oct
DIDSON					14&18 April & 5 June & 24 & 30 Sept.

*Table 3-2: All fish species caught in the three sub-projects by period and season (W=winter, Sp=spring, S=summer, Au=autumn). NSWDEM=Sub-project 1 demersal survey; NSWPEL= Sub project 2 pelagic survey; NSWGILL= Sub-project 3 gillnets. T0=2003/2004; T1=2007/2008 and T5==2011. The species are order from those caught in all periods and season to those caught only in a single survey. Species in bold are exclusively caught in the T0, underlined species exclusively in the T1, and in grey the species exclusively caught in the T5. Species with * are most likely misidentified.*

				NSWDEM						**NSWPEL**				**NSWGILL**	
				T0		**T1**		**T5**		**T0**		**T1**	**T5**	**T5**	
	Dutch name	**English name**	**Scientific name**	**S**	**W**	**S**	**W**	**W**	**S**	**Sp**	**Au**	**Sp**	**Sp**	**Sp**	**S**
1	Pitvis	Common dragonet	Callionymus lyra	x	x	x	x	x	x	x	x	x	x	x	x
2	Haring	Herring	Clupea harengus	x	x	x	x	x	x	x	x	x	x	x	x
3	Schar	Dab	Limanda limanda	x	x	x	x	x	x	x	x	x	x	x	x
4	Wijting	Whiting	Merlangius merlangus	x	x	x	x	x	x	x	x	x	x	x	x
5	Schol	Plaice	Pleuronectes platessa	x	x	x	x	x	x	x	x	x	x	x	x
6	Ammodytes	Sandeel species	Ammodytes sp.	x	x	x	x	x	x	x	x	x	x	x	
7	Smelt	Greater sandeel	Hyperoplus lanceolatus	x	x	x	x	x	x	x	x	x	x	x	
8	Zeedonderpad	Bull rout	Myoxocephalus scorpius	x	x	x	x	x	x	x		x	x	x	x
9	Sprot	Sprat	Sprattus sprattus	x	x	x	x	x	x	x	x	x	x		x
10	Dwergtong	Solenette	Buglossidium luteum	x	x	x	x	x	x	x			x	x	x
11	Kleine pieterman	Lesser weever	Echiichthys vipera	x	x	x	x	x	x	x	x	x	x		
12	Bot	Flounder	Platichthys flesus	x	x	x	x	x	x	x		x	x	x	
13	Tong	Sole	Solea solea	x	x	x	x	x	x	x		x		x	x
14	Horsmakreel	Horse mackerel	Trachurus trachurus	x	x	x			x	x	x	x	x	x	x
15	Schurftvis	Scaldfish	Arnoglossus laterna	x	x	x	x	x	x	x			x	x	
16	Kabeljauw	Cod	Gadus morhua	x	x	x	x	x		x		x		x	x
17	Grondel	Goby species	Pomatoschistus sp.	x	x	x	x	x	x	x		x	x		
18	Harnasmannetje	Hooknose	Agonus cataphractus	x	x	x	x	x	x				x		x
19	Makreel	Mackerel	Scomber scombrus	x		x			x	x	x		x	x	x
20	Griet	Brill	Scophthalmus rhombus	x	x	x	x	x	x					x	x
21	Steenbolk	Bib	Trisopterus luscus	x	x		x	x		x			x	x	x
22	Grauwe poon	Grey gurnard	Eutrigla gurnardus	x	x				x	x	x		x	x	
23	Tarbot	Turbot	Psetta maxima	x	x	x	x		x					x	x
24	Syngnathus	Pipefish species	Syngnathus sp.		x	x	x	x	x			x	x		
25	Vijfdradige meun	Fivebeard rockling	Ciliata mustela		x		x	x	x				x	x	
26	Mul	Striped red mullet	Mullus surmuletus	x		x			x		x			x	x
27	Rode poon	Tub gurnard	Trigla lucerna	x		x			x	x		x			x
28	Glasgrondel	Transparent goby	Aphia minuta	x						x	x	x	x		
29	Rasterpitvis	Reticulated dragonet	Callionymus reticulatus	x	x		x		x	x					
30	Ansjovis	Anchovy	Engraulis encrasicolus							x	x	x	x	x	
31	Tongschar	Lemon sole	Microstomus kitt			x	x		x					x	x
32	Pelser	Pilchard	Sardina pilchardus							x	x	x	x	x	
33	Dwergbolk	Pour cod	Trisopterus minutus	x		x	x			x				x	
34	Fint	Twaite shad	Alosa fallax		x	x	x								x
35	Snotolf	Lumpsucker	Cyclopterus lumpus				x	x				x	x		
36	Driedoornige stekelbaars	Stickleback	Gasterosteus aculeatus					x	x			x	x		

				NSWDEM						NSWPEL				NSWGILL	
				T0		T1		T5		T0		T1	T5	T5	
	Dutch name	**English name**	**Scientific name**	**S**	**W**	**S**	**W**	**W**	**S**	**Sp**	**Au**	**Sp**	**Sp**	**Sp**	**S**
37	Slakdolf	Sea-snail	Liparis liparis		x	x		x	x						
38	Geep	Garfish	Belone belone	x		x			x						
39	Adderzeenaald	Snake pipefish	Entelurus aequoraeus			x	x					x			
40	Groene zeedonderpad	Sea scorpion	Taurulus bubalis			x			x						x
41	**Elft ***	**Allis shad ***	**Alosa alosa ***		**x**					**x**					
42	Zeebaars	Sea bass	Dicentrarchus labrax				x								x
43	**Vierdradige meun**	**Four-bearded rockling**	**Enchelyopus cimbrius**		**x**					**x**					
44	Rivierprik	Lamprey	Lampetra fluviatilis							x		x			
45	Spiering	Smelt	Osmerus eperlanus		x			x							
46	Botervis	Butterfish	Pholis gunnellus						x						x
47	Stekelrog	Roker	Raja clavata			x									
48	Kleine koornaarvis *	Big-scale sand-smelt *	Atherina boyeri *				x								
49	Trekkervis	Grey triggerfish	Balistes carolinensis												x
50	**Gevlekte pitvis ***	**Spotted dragonet ***	**Callionymus maculatus ***	**x**											
51	Kliplipvis	Goldsinny wrasse	Ctenolabrus rupestris												x
52	Zwarte grondel	Black goby	Gobius niger					x							
53	Heilbot	Halibut	Hippoglossus hippoglossus										x		
54	Lichtend sprotje	Pearl side	Maurolicus muelleri			x									
55	Blauwe wijting	Blue whiting	Micromesistius poutassou					x							
56	**Gevlekte gladde haai**	**Starry smoothhound**	**Mustelus asterias**	**x**											
57	Zalm	Salmon	Salmo salar									x			

4 Sub-project 1: Effects on the demersal fish community

4.1 Survey Design

4.1.1 Area

The demersal survey follows the BACI-approach (Green 1979, Smith et al. 1993), including monitoring before (T0) and after (T1 + T5) the impact (construction and presence of the farm) using three control areas representing how the situation would have been without impact. All areas (Figure 3-1) were sampled in an identical way in the T0, T1 and T5. An adjustment following the T0 is that the direction of the hauls has changed from along the coast (south to north) to perpendicular to the coastline, to avoid risks of damaging the ground cables of the wind farm. Another safety measure is the prohibition of fishing closer to the monopiles than 200m, due to which the samples in the wind farm area were located in the middle between the monopiles.
The survey scheme incorporates the variation in depth, grain size and distance to the shore within the wind farm and this is replicated in the three reference areas. A total of 40 hauls per period were executed of which a third (13) in the wind farm (OWEZ), a third (13) in REFN, and the other third was divided over the two southern areas, REFS (6) and REFZ (8). The haul locations were determined in advance and were fixed as far as possible. In the wind farm in the T5, two hauls were moved owing to a lost anchor of another ship at the location of the original hauls. If possible, the duration of each haul was 15 minutes with a towing speed of 6.5 km hr^{-1} (3.5 knots) over the ground. Varying current speeds result in a different distance travelled causing the distance covered by the hauls to vary between periods (Figure 3-1).

4.1.2 Period

In the T0, T1 and T5 the survey was executed in summer and winter. The summer survey in the T0 and T1 was followed by the winter survey in the next year (2003/2004 and 2007/2008). In the T5, first the winter survey was executed followed by the summer survey in the same year (2011). The winter survey was executed in January, while the summer survey was executed in June/July.

4.1.3 Methods and equipment

In the T0, Fisheries Research Vessel 'Isis' was used and in the T1 and T5 the commercial vessel 'GO58'. Both fished with two 6m beam trawls, that were similar in size and weight to those used in the regular IMARES Sole Net Survey (SNS) (van Damme et al. 2010). The beam trawls were equipped with two different nets. One side was rigged with a mesh size of 0.04m in the cod end, which is similar to the SNS net. The other side was rigged with a finer mesh size of 0.02m in the cod end, which is similar to the net of the regular IMARES Demersal Fish Survey (DFS) (van Damme et al. 2010). The two different mesh sizes are used to catch the full length frequency distribution of the fish community. It was shown that both nets were complementary and when the data are combined will give a good

One of the 6m beam trawls used during the demersal survey. Attached to this beam is the 20 mm net. In the middle of the net, the CTD device is visible (Grift 2004).

description of the community (Grift & Tien 2003).
The used mesh sizes are smaller, the weight of the beam trawl is much lower and the towing speed is also much lower than those currently used in the commercial beam trawl fisheries. One of the effects is that the bottom penetration of this gear is less, but also the catch composition will differ from the commercial catches.

4.1.4 Processing of the trawl catches

The catch is brought on board and all species, fish and benthic fauna, are sorted per net. All fish were measured to the cm-below (5.7 cm is recorded as 5 cm). In case of large catches a subsample of the total catch or of a specific species is measured. The epibenthic fauna is counted per species (the benthic fauna has not been registered during all surveys). Weight is not collected from the whole catch.

Typical demersal catch from a beam trawl in the OWEZ area.

Extra information is collected for some specific species, in the T1 and T5 stomach contents were collected and for these fish gender and maturity stage were recorded. The species for which stomachs were collected were those that were expected to be caught in reasonable numbers in all areas and have a demersal feeding behaviour. For each species a maximum of 3 stomachs was collected per size class (cm), per survey per area. In the T1 survey stomachs were collected in both seasons, in the T5 only in summer as the winter T1 stomachs showed a large number of empty stomachs because many species cease or limit feeding in winter. The stomachs were stored in formaldehyde and the contents were later identified to species level and counted. The total weight of the stomach and the total weight of each prey species were recorded.

4.1.5 Hydrographic data

Environmental conditions at sampling locations were measured using a CTD datasonde. This device, attached to the net, continuously recorded salinity, water temperature (Figure 3-4), depth and turbidity (paragraph 3.2).

4.2 Analysis

4.2.1 Area differences in the T5

The statistical analysis aimed to explore whether the catches of demersal fish (by species) in the wind farm (OWEZ) differed from those in the reference areas. Analyses were carried out for:

1. total catch of fish in numbers
2. unique species with sufficient data (plaice, sole, dab, bullrout, scaldfish, whiting, gobies)
3. the length distribution of the unique species.

Boxplots were made as descriptive statistics to present the data range. The boxplots were made per season and each box contained the data of both gears. Each gear was a separate data point in the box. The boxplots present the median (horizontal dark line), lower and upper quartiles (bottom and top of the box), the whiskers represent 1.5 times the interquartile range of the box and circles represent values falling outside the interquartile range.

A simple statistical approach was taken due to the low numbers of hauls per area using an analysis of variance (ANOVA) to test for evidence of difference in mean catches (numbers per hectare) whilst taking into account the sampling date (due to possible fluctuations in the environment). The analysis was done for each season and gear type separately.

If the ANOVA shows evidence for differences, then a Tukey's multiple comparison test was applied. This test compares the difference between each pair of means with appropriate adjustment for the multiple testing. It assumes that the data from the different groups (areas in this case) comes from populations where the observations have a normal distribution and a similar standard deviation for each group. The catches were therefore log transformed to meet the normality criteria.

To get better estimates of absolute difference between areas a generalised linear model (GLM) of the form:

Log(numbers per ha + 1) ~ Area + Season + Gear type + ε

was performed so that the effect of gear type and season could be tested formally alongside the factor 'area'. Models were validated using visual inspection of residual plots to check for homogeneity of variances, normality and outliers. Except for the total and the plaice data all other models were fitted using a Poisson distribution to fit the shape of the log transformed catches. The same analysis was carried out on mean lengths as an indication of the length distribution within the areas.

Each figure type is presented in the text the first time it is mentioned. The boxplots on abundance used as descriptive statistics are presented for all the T5 data. The other figures are only presented when they indicate a significant difference, in all the other cases the figures are given in appendix B.

4.2.2 Comparison with T0 and T1

To study changes between the T0, T1 and T5 a similar approach as above was taken to test whether a change over time related to the presence of the wind farm occurred or whether these patterns were present before the construction (and therefore not related to the presence of the wind farm).

The winter data of the T1 and some individual hauls in other surveys lacked distance trawled, neither was speed recorded (as this should be more or less the same in each haul). Average speed was calculated using the hauls that had information on haul duration and distance trawled. Based on the average speed multiplied with the duration of the haul and the width of the gear the swept area was calculated and with that numbers per hectare.

In the T1 winter survey a single haul in OWEZ caught a huge amount of whiting and cod (Hille Ris Lambers & ter Hofstede 2009). Over 300 times the average catch compared to all other hauls, which is a clear outlier. Even though it is true that a huge amount of whiting was caught in this haul, the absolute values, especially for the other species, are doubtful owing to handling problems on board. Due to the subsample factor used (as only a subsample of the catch was sampled) for example an unrealistically large amount of large cod was recorded in this haul. Therefore this haul was excluded from the analysis.

4.2.3 Species richness

Species richness is presented as the total number of species caught per survey period per area and as median number of species per survey period per area. These are presented visually as bar-graph and boxplots.

4.2.4 Stomach analysis

In the lab, the content of the collected stomachs was identified to species level. However, on board from the outside of the stomachs, it wasn’t possible to detect if stomachs contain food items. Therefore, before identification the fullness of the stomach is determined. Empty stomachs were not processed further and reduce the number of samples. For some species this reduced the number of samples with more than 50%.

Empty stomach might indicate a reduced feeding, during parts of the day or in winter; it might also indicate a low availability of food in a specific area. To look at this, the ratio of empty stomachs (0) and full stomachs (1) is compared. The zero-one data per species is tested using a Binomial GLM with year (T1+T5) and areas (OWEZ+REFS+REFZ+REFZ) as explanatory variables.

The identification of the stomach content of the full stomachs was done at species level when possible. For each prey species, the number of individuals in the stomach was counted, often this was a minimum estimate as the exact number of individuals to which the remains belong is impossible to determine.

The main interest is if different prey species are consumed in OWEZ compared to the reference areas or if the composition of the diet differed between OWEZ and the reference areas. Possible analysis on the stomach data were however limited due to the large number of prey types that where identified and the low number of full stomachs collected. Only for plaice, whiting and dragonet a reasonable number of full stomachs was collected to give a visual interpretation of the diet composition between the years and the areas. For the visualisation the minimum counts per prey species were summed over all stomachs of the predator species in that year and area. This gives a figure with the percentage of the prey species in minimum counts of all stomachs collected.

4.3 Results

4.3.1 Overall information

Six demersal surveys were executed spread over the three periods (T0, T1, and T5). In each period the survey was executed in two seasons (Winter and Summer). In each season, hauls were made in four areas (OWEZ, REFN, REFS, REFZ) and during each haul two gears were used (Demersal fish Survey (DFS) mesh size 0.02m, Sole Net Survey (SNS) mesh size 0.04m). The total number of hauls in each area by year are given in Table 4-1.

Table 4-1: Total number of hauls performed in each area by year. Each haul consisted of two nets, the DFS and SNS net.

year	season	OWEZ	REFN	REFS	REFZ
2003	Summer	13	12	5	8
2004	Winter	14	12	6	8
2007	Summer	13	13	6	8
2008	Winter	13	13	6	8
2011	Winter	13	13	6	8
2011	Summer	13	13	6	8

4.3.2 Area differences during T5

Overall catches (total numbers of fish per ha) of the T5 surveys were higher in summer than in winter and some differences between areas are evident, particularly during winter. In winter the lowest numbers of fish were caught per ha in OWEZ, especially compared to REFN. During summer the patterns are less obvious with median catches all lying between 500 and 1000 fish per ha (Figure 4-1).

Explanation of the Analysis of Variance (ANOVA) figures (Figure 4-2). Here two areas are compared with each other, the horizontal line represents the difference between the two areas. If the line crosses the dashed vertical line (difference being 0.0), the difference between the two areas is not significant (Figure 4-2a REFZ-REFS). If the horizontal line is completely right of the dashed line that means that the first mentioned area has significantly higher catches that the other area (Figure 4-2a REFN-OWEZ), while when the horizontal line is completely left of the dashed line the opposite is true (Figure 4-2b REFZ-REFN).

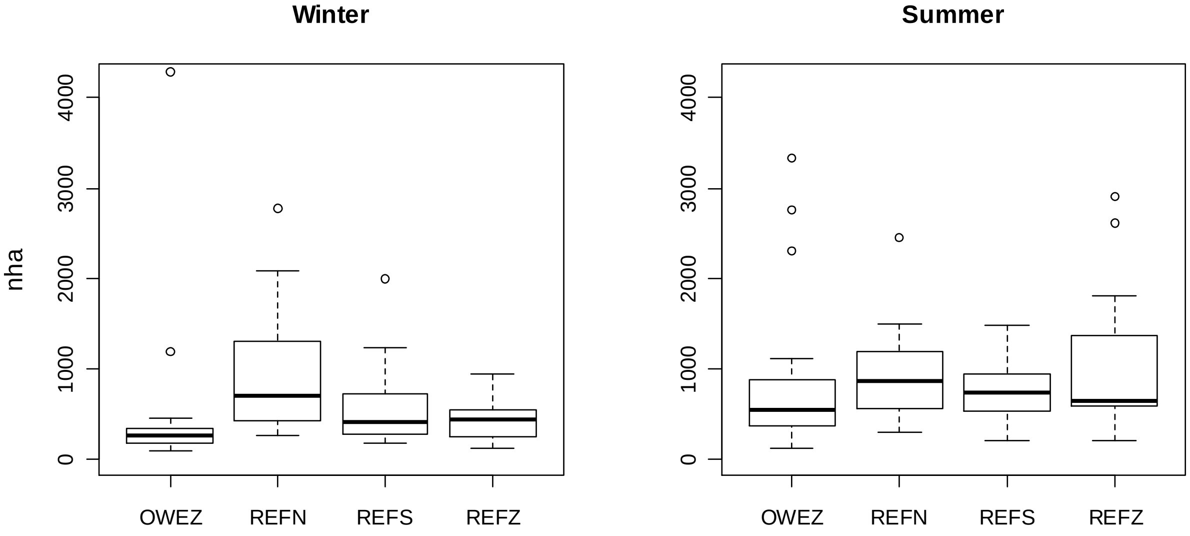


Figure 4-1: The T5 total catches (numbers per ha) per season, both gears presented as individual data points in a single box. The boxplot present the median value (horizontal dark line), lower and upper quartiles (bottom and top of the box), the whiskers represent 1.5 times the interquartile range of the box. The small circles are the data points that fall outside the 1.5 times the interquartile range.

The ANOVA for season and gear separately shows that catches only differ significantly between areas during winter, where REFN shows significantly higher catches than OWEZ ($p < 0.001$) for the gear with the larger mesh size, SNS (Figure 4-2a). In the gear with the smaller mesh size, DFS, REFN again shows significantly higher catches than OWEZ ($p < 0.01$), but also compared to REFZ ($p < 0.05$; Figure 4-2b).

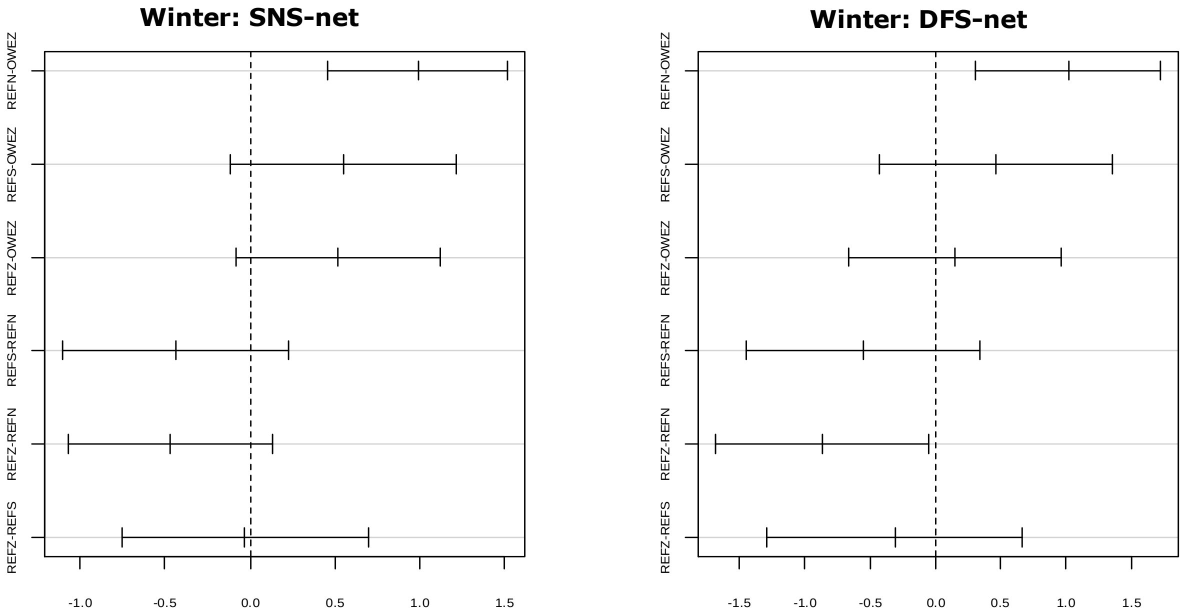


Figure 4-2: Differences in mean levels of total abundance (x-axis) between all combinations of areas during winter for mesh size 0.04m (left panel) and 0.02m (right panel). Range shows the 95% confidence intervals based on the Studentized range statistic, Tukey's method.

In addition, the generalised linear model (GLM) showed that the larger mesh size (0.04m) catches significantly less fish (log scale estimate = -0.3406 ± 0.1048, $p < 0.01$) than the smaller mesh (0.02m) and that catches are significantly higher (log scale estimate = 0.4581 ± 0.1048, $p < 0.001$) in summer compared to winter.

Differences in abundance and length by species between the areas in the T5 are summarised in Table 4-2. The detailed and visualised results are described by species below; a part of the figures is placed in appendix B.

The overall interpretation is that the reference areas were similar compared to OWEZ in abundance and average length of all species. Exceptions to this were: 1) Bullrout in summer had significant higher abundances in two reference areas (REFN and REFS), 2) whiting and sole in winter had significant higher abundances only in one reference area compared to OWEZ, 3) Average length differed significantly for dab and sole in only one reference areas compared to OWEZ.

Table 4-2: Summary of the differences between the three reference areas relative to the OWEZ area during T5. Cells shaded grey show where no significant difference was found between the area indicated and OWEZ. Blue cells show where a significant difference was found in abundance and orange shows the differences in mean length. Plus/minus signs show if the difference was positive or negative in relation to the OWEZ area.

1. Winter

Large mesh	**Plaice**	**Sole**	**Whiting**	**Bullrout**	**Dab**	**Scaldfish**
REFN			🟦 +			
REFS		🟦 +				
REFZ						

Small mesh	**Plaice**	**Sole**	**Whiting**	**Bullrout**	**Dab**	**Scaldfish**
REFN			🟦 +		🟧 -	
REFS						
REFZ						

2. Summer

Large mesh	**Plaice**	**Sole**	**Whiting**	**Bullrout**	**Dab**	**Scaldfish**
REFN		🟧 -		🟦 +		
REFS				🟦 +		
REFZ						

Small mesh	**Plaice**	**Sole**	**Whiting**	**Bullrout**	**Dab**	**Scaldfish**
REFN				🟦 +		
REFS				🟦 +		
REFZ						

Plaice

Catches of plaice (numbers per hectare) are slightly higher in summer than in winter. No strong effect or consistent differences between areas are evident (Figure 4-3).

The ANOVA results and Tukey's comparisons also show no significant differences between areas in either season or gear type. The generalised linear model shows that the large mesh size catches significantly larger numbers of plaice (log scale estimate = 1.923 ± 0.1339, $p < 0.001$) than the smaller mesh size, and that significantly more plaice are caught in summer (log scale estimate = 1.420 ± 0.1339, $p < 0.001$) compared to winter.

Mean lengths were higher in summer than in winter, and no differences were seen between mesh sizes (Figure 4-4). The ANOVA results and Tukey's comparisons show no significant differences in mean lengths between areas in either season or gear type.

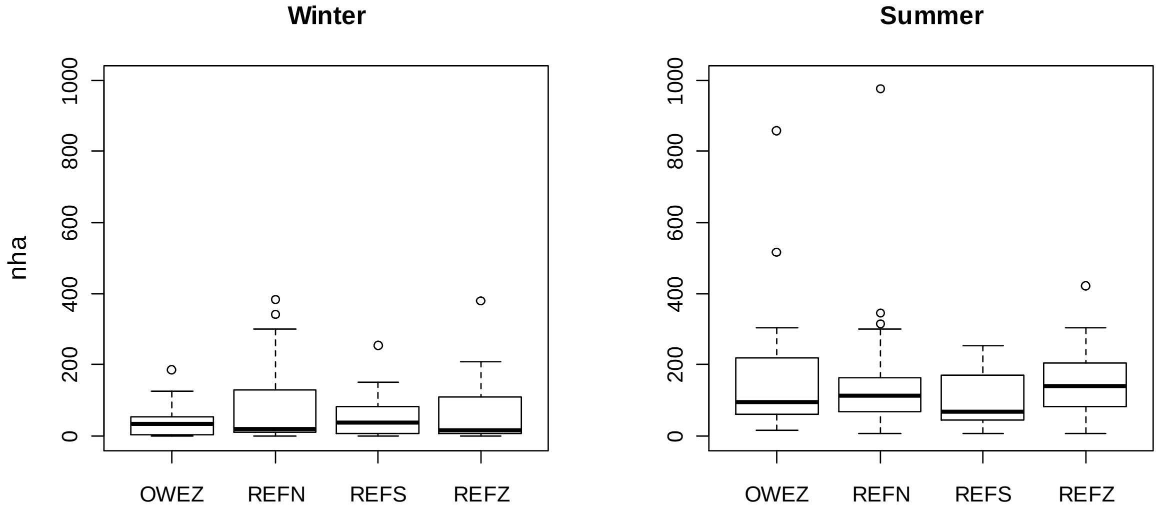


Figure 4-3: T5 catches of plaice (numbers per ha) per season both gears presented as individual data points in a single box.

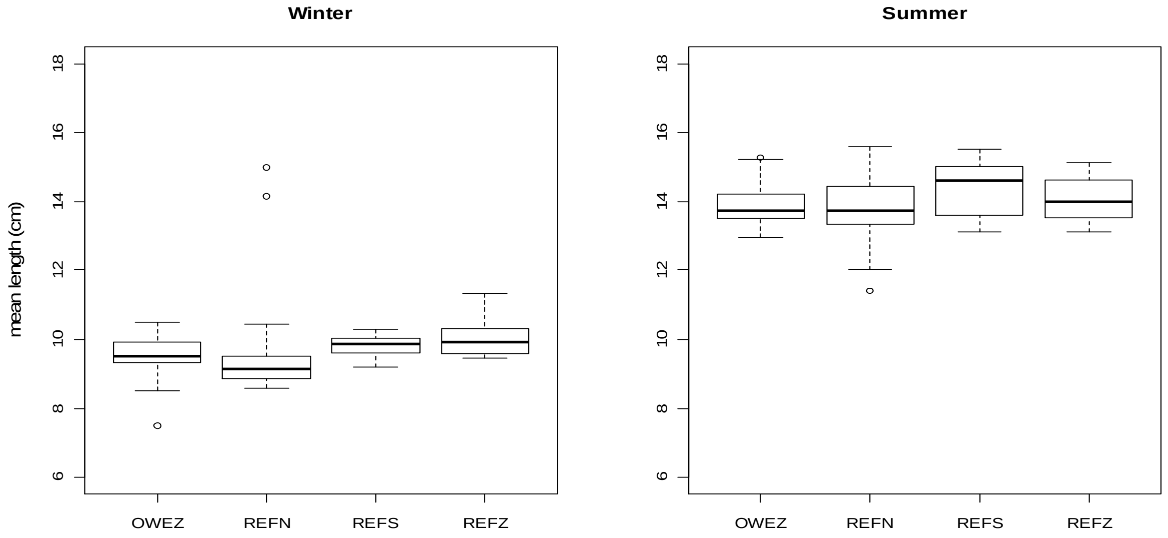


Figure 4-4: Mean lengths of plaice (cm) during T5 in winter and summer both gears presented as individual data points in a single box.

Sole

Catches of sole (numbers per hectare) are considerably higher in summer than winter. Visually in the boxplots there seems to be no difference between the areas (Figure 4-5).

The ANOVA results show that REFS had significant higher catches of sole during winter in the small mesh size compared to OWEZ ($p < 0.01$) and REFN ($p < 0.01$) (Figure 4-6).

The GLM showed that the large mesh size catches significantly larger numbers of sole (estimate = 0.9417 ± 0.1667, $p < 0.001$) than the smaller mesh size, and that significantly more sole were caught in summer (log scale estimate = 1.8590 ± 0.2192, $p < 0.001$) compared to winter.

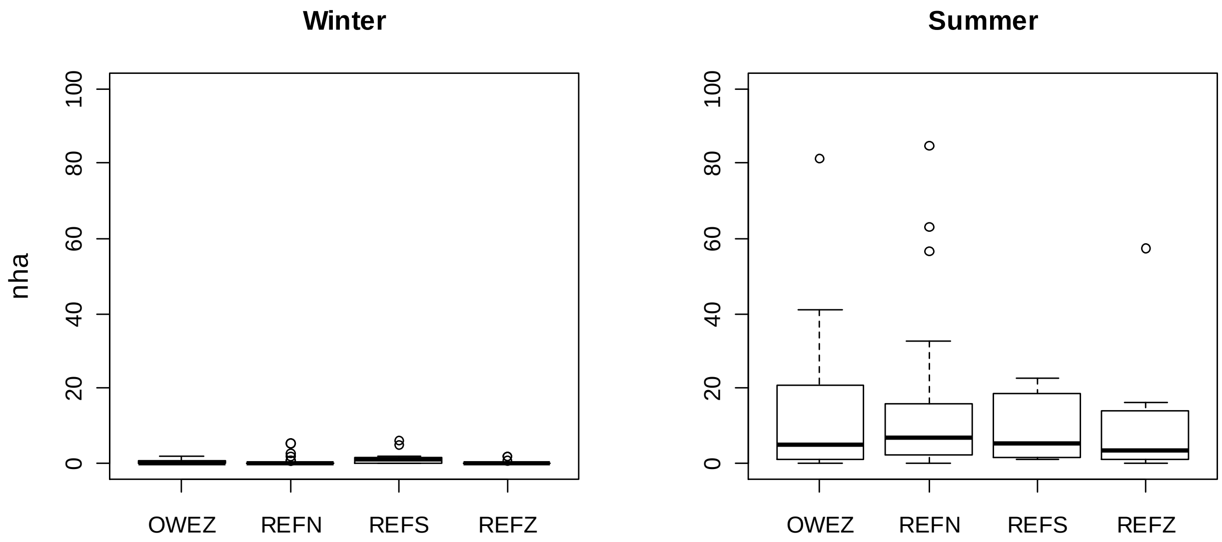


Figure 4-5: T5 catches of sole (numbers per ha) per season both gears presented as individual data points in a single box. (Note: some high outliers in summer catches not shown).

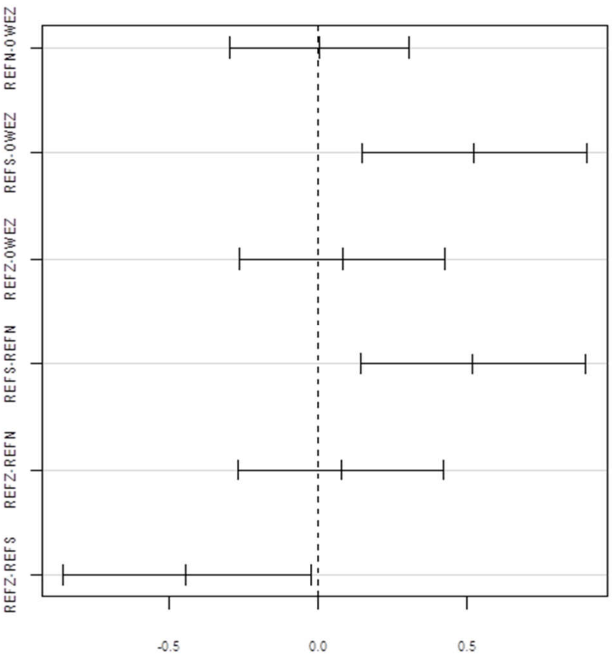


Figure 4-6: Differences in mean levels of sole abundance (x-axis) between all combinations of areas during winter for mesh size 0.02m. Range shows the 95% confidence intervals based on the Studentized range statistic, Tukey's method.

Mean lengths of sole were considerably larger in summer (Figure 4-7) and appear to be lowest in the REFN area. The ANOVA results indicate a significantly lower mean length in the REFN area compared to both OWEZ ($p < 0.01$) and REFZ ($p < 0.001$) in the summer for the larger mesh size (Figure 4-8), but these differences are not seen in the smaller mesh size or during winter.

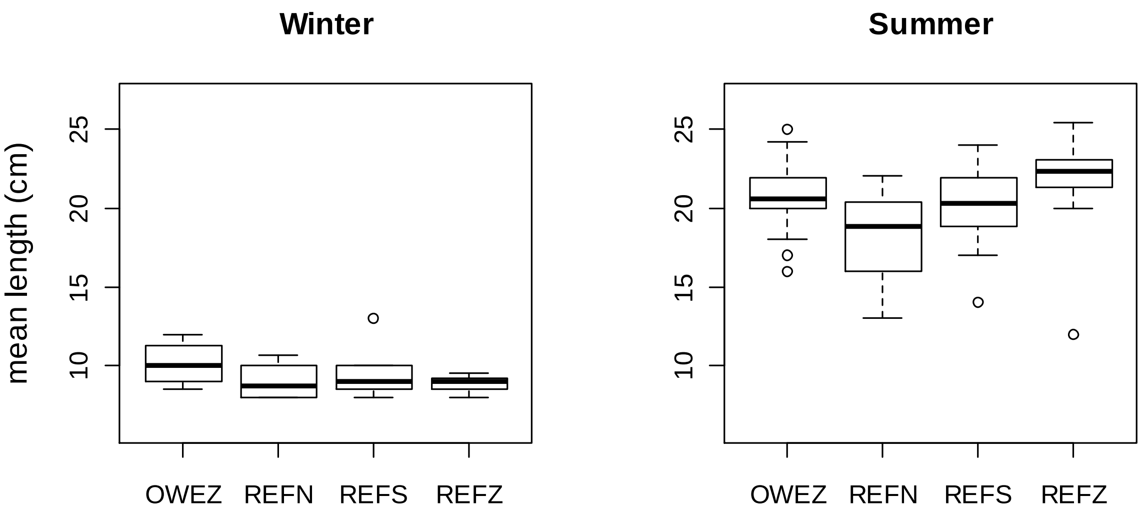


Figure 4-7: Mean lengths of sole (cm) during T5 in winter and summer both gears presented as individual data points in a single box.

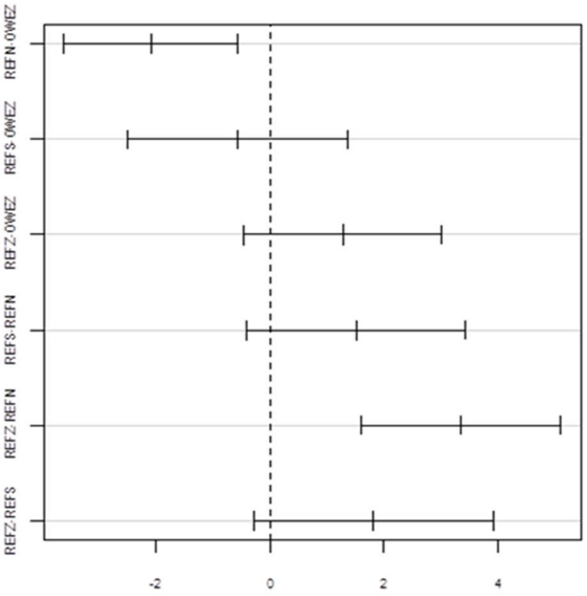


Figure 4-8: Differences in mean levels of length of sole (x-axis) between all combinations of areas during summer for mesh size 0.04m. Range shows the 95% confidence intervals based on the Studentized range statistic, Tukey's method.

Dab

Catches of dab (numbers per hectare) were higher during summer, but show no differences between areas (Figure 4-9). The ANOVA shows no significant differences in means between areas in either season or mesh size.

The GLM shows that the large mesh size catches significantly higher numbers of dab (estimate = 0.23245 ± 0.07632, $p < 0.01$) than the smaller mesh size, and significantly higher catches in summer compared to winter (log scale estimate = 0.24797 ± 0.07639, $p < 0.001$), and no significant differences between seasons. REFN is shown to have marginally higher catch rates than OWEZ (log scale estimate = 0.19304 ± 0.09545, $p < 0.05$) but based on the figures this is not likely to be a consistent feature.

Mean lengths were higher in summer than winter. Differences between areas are not evident in winter but do appear in summer (Appendix figure B-1). The ANOVA results indicate significantly smaller mean lengths in REFN compared to REFZ ($p < 0.01$) and OWEZ ($p = 0.068$), but only for the larger mesh size (Figure 4-10).

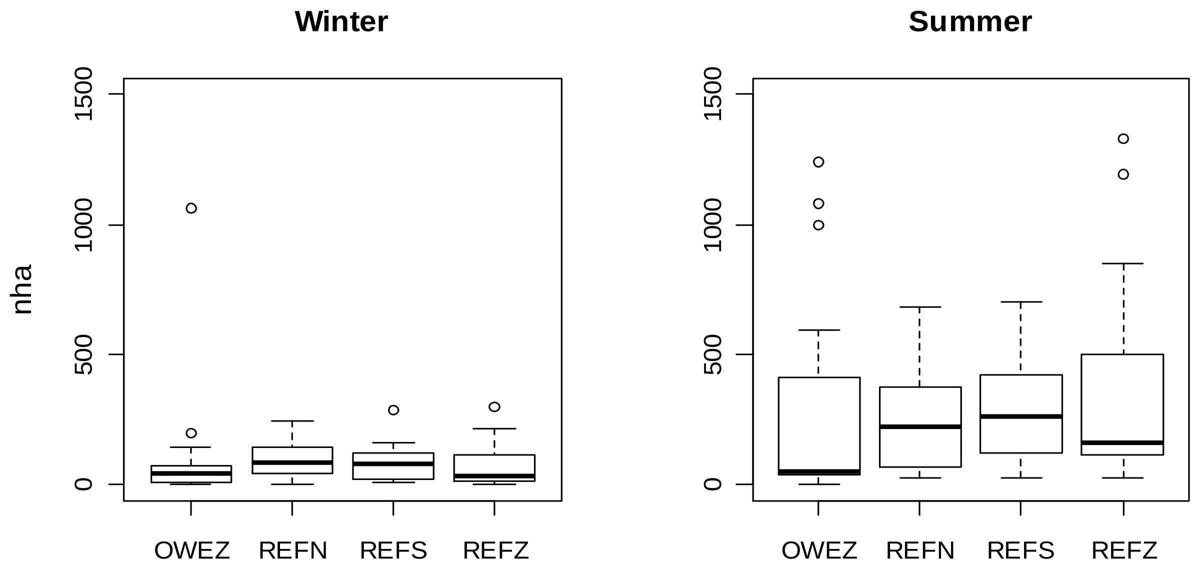


Figure 4-9: T5 Catches of dab (numbers per ha) per season both gears presented as individual data points in a single box.

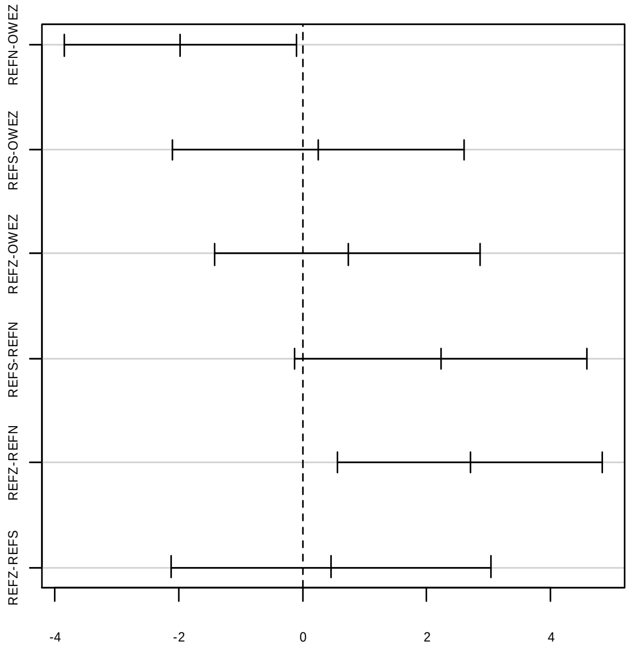


Figure 4-10: Differences in mean levels of dab abundance (x-axis) between all combinations of areas during summer for mesh size 0.04m. Range shows the 95% confidence intervals based on the Studentized range statistic, Tukey's method.

Scaldfish

Catches of scaldfish (numbers per hectare) were rare during winter, yet common during summer. Some variability between areas is evident during the summer although no differences between areas are significant for either mesh size or season (Figure 4-11).

The GLM shows that the large mesh size catches significantly higher numbers of scaldfish (log scale estimate = 0.30395 ± 0.10882, $p < 0.01$) than the smaller mesh size, and not surprisingly significantly higher catches in summer compared to winter (log scale estimate = 3.17472 ± 0.27405, $p < 0.001$).

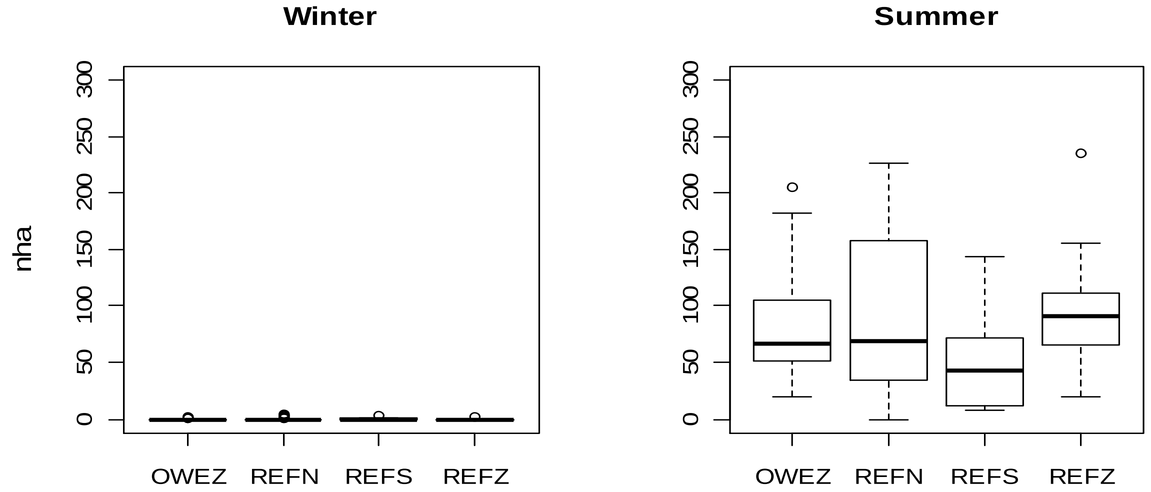


Figure 4-11: T5 catches of scaldfish (numbers per ha) per season both gears presented as individual data points in a single box.

Whiting

Catches of whiting (numbers per hectare) are higher in summer than winter. Differences between areas are evident in winter, but not consistent with summer patterns. During summer large variability is evident within areas (Figure 4-12).

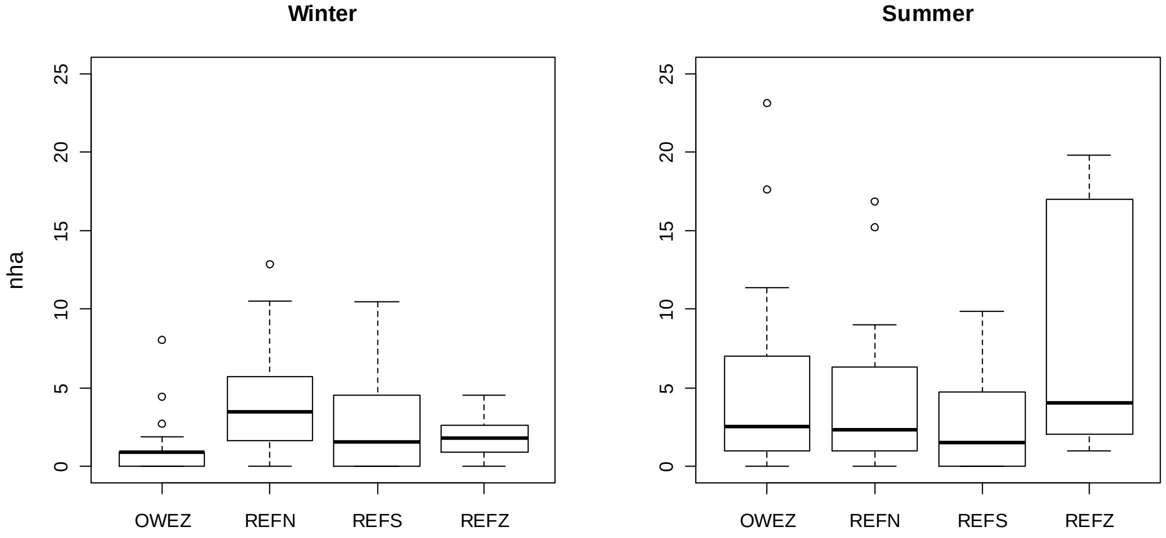


Figure 4-12: T5 catches of whiting (numbers per ha) per season both gears presented as individual data points in a single box. (Note: some high outliers in summer catches not shown).

The ANOVA results show that REFN had significant higher catches of whiting compared to OWEZ during winter in both the small mesh size ($p < 0.05$) and large mesh size ($p < 0.01$) (Figure 4-13).

The GLM showed that the large mesh size catches significantly smaller numbers of whiting (log scale estimate = -0.52659 ± 0.15058, $p < 0.001$) than the smaller mesh size, and that significantly more whiting were caught in summer (log scale estimate = 0.3891 ± 0.14827, $p = 0.01$) compared to winter.

Mean lengths were slightly higher in the summer with more variability present, but between areas the mean lengths were fairly consistent (Appendix figure B-2). The ANOVA shows no significant differences in mean length per area.

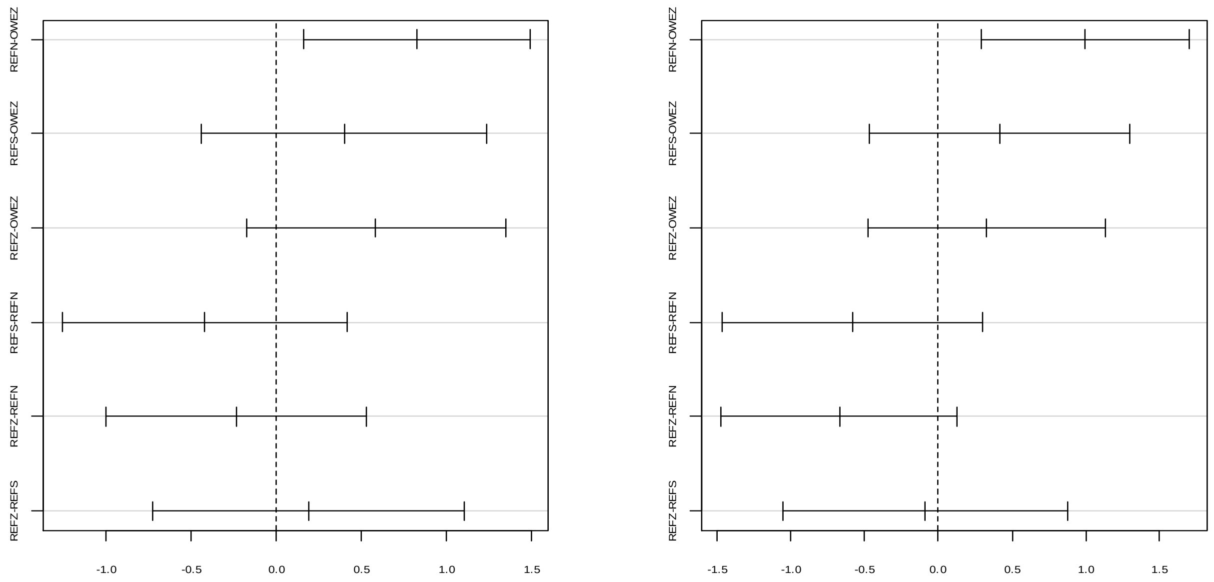


Figure 4-13: Differences in mean levels of whiting abundance (x-axis) between all combinations of areas during winter for mesh size 0.02m (left panel) and mesh size 0.04m (right panel). Range shows the 95% confidence intervals based on the Studentized range statistic, Tukey's method.

Bullrout

Catches of bullrout (numbers per hectare) appear generally higher in summer than winter, although the variation within some areas is large. Differences between areas are particularly evident in the summer. OWEZ shows overall low catches in comparison to other areas, with REFN being the dominant area in winter and REFS showing highest catches in summer (Figure 4-14).

The ANOVA results show no significant differences in means between areas during winter, but REFS shows significantly higher catches in summer than OWEZ (mesh size 0.02m: $p < 0.01$; mesh size 0.04m: $p < 0.001$) and REFZ (mesh size 0.02m: $p = 0.074$; mesh size 0.04m: $p < 0.05$), and REFN shows significantly higher catches in summer than OWEZ (mesh size 0.02m: $p < 0.05$; mesh size 0.04m: $p < 0.05$) (Figure 4-15).

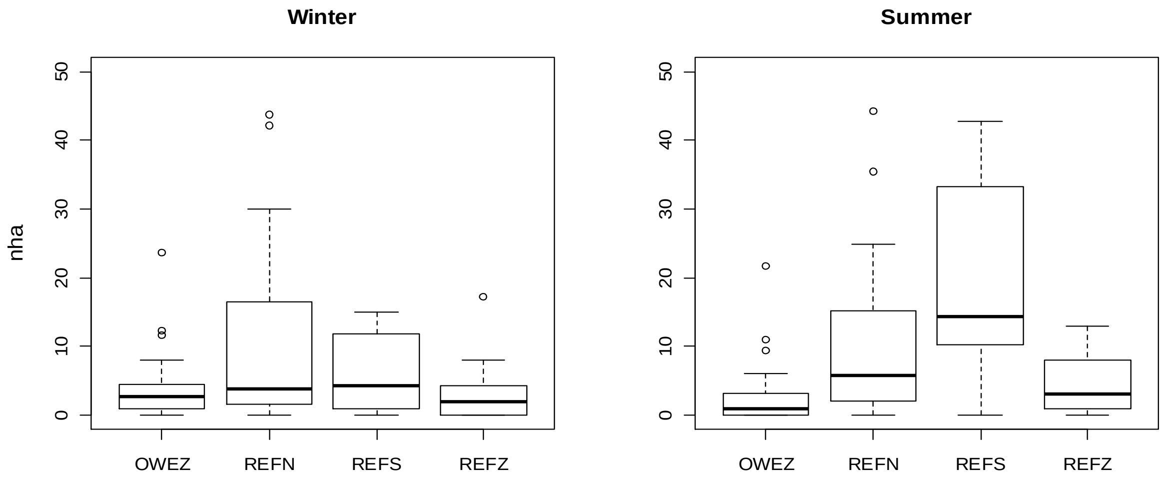


Figure 4-14: T5 Catches of bullrout (numbers per ha) per season both gears presented as individual data points in a single box.

The GLM shows that the large mesh size catches significantly higher numbers of bullrout (log scale estimate = 0.63224 ± 0.13270, $p < 0.001$) than the smaller mesh size, and no significant differences between seasons ($p = 0.648$).

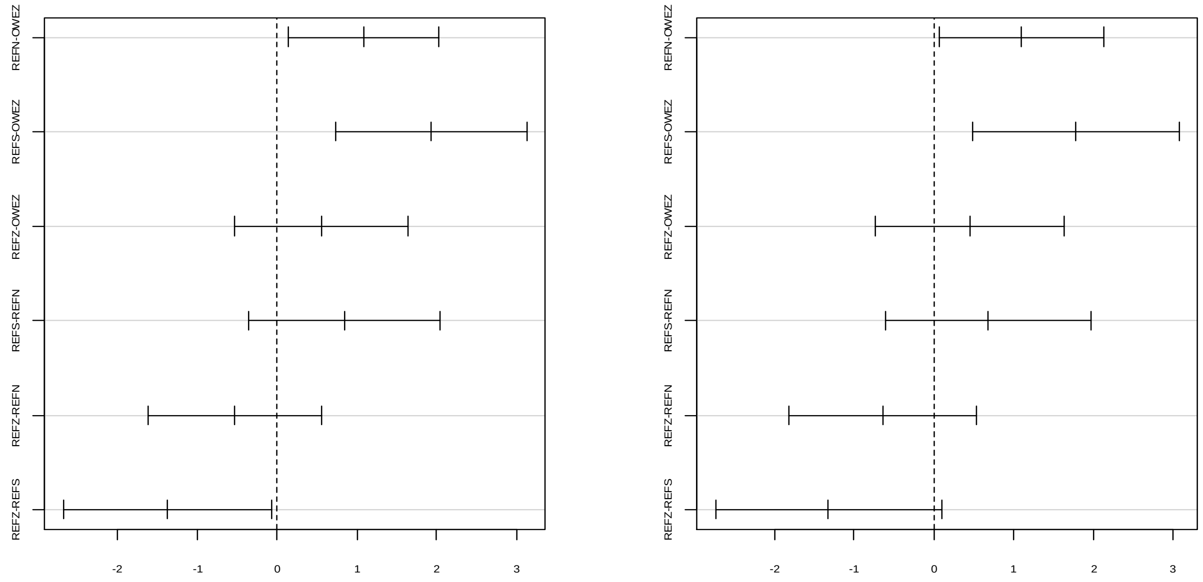


Figure 4-15: Differences in mean levels of bullrout abundance (x-axis) between all combinations of areas during summer for mesh size 0.02m (left panel) and mesh size 0.04m (right panel). Range shows the 95% confidence intervals based on the Studentized range statistic, Tukey's method.

Mean lengths were higher in summer than winter but showed no consistent difference between areas (Appendix figure B-3), which is confirmed by the lack of significant differences found in the ANOVA comparisons.

Gobies

The gobies could consist of three species, which have not been distinguished for this analysis. Catches of gobies (numbers per hectare) appear generally higher in winter than summer (Figure 4-16).

Mean lengths were higher in summer than winter but showed no trends between areas (Appendix figure B-4); however the variation in length is much smaller in summer.

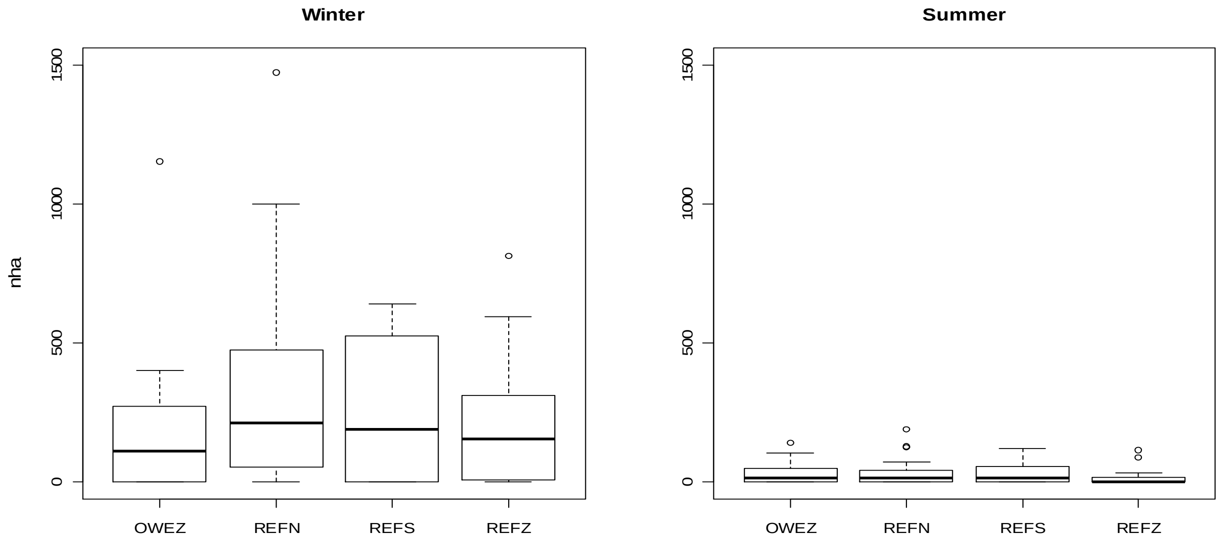


Figure 4-16: T5 catches of gobies (numbers per ha) per season both gears presented as individual data points in a single box.

4.3.3 Comparison with T0 and T1

The comparison of the total catch in numbers per hectare clearly shows that the catches in the T0 were lower than those in the other periods in nearly all areas (Figure 4-17). It cannot be excluded whether this was due to the changes in survey design (changing fishing direction, different vessel), or due to a natural cause. The difference between years is significant; in winter also the area effect is significant (Table 4-3).

However, in these analyses the interaction between year and area is considered as well. The interaction tests whether the trend over years (T0-T1-T5) is significantly different between areas. If for one area the abundance increases from the T0 to the T5 (increasing trend over the years), while for the other the abundance decreases the interaction term is likely to be significant. But also two increasing trends can be significantly different if one is much steeper than the other. If the abundance in OWEZ increase from the T0 to the T5, while the abundance is stable or decreases in the other areas, this is likely to be an effect of the wind farm. Even though, the T5 data indicates no differences in abundance between OWEZ and the reference areas. If trend is mentioned in the following sections and the discussion, this trend over time is meant.

The interaction between period and area for the total catches is not significant, indicating that there is no significant different trend compared to any of the areas. In summer there is even no significant effect between the areas.

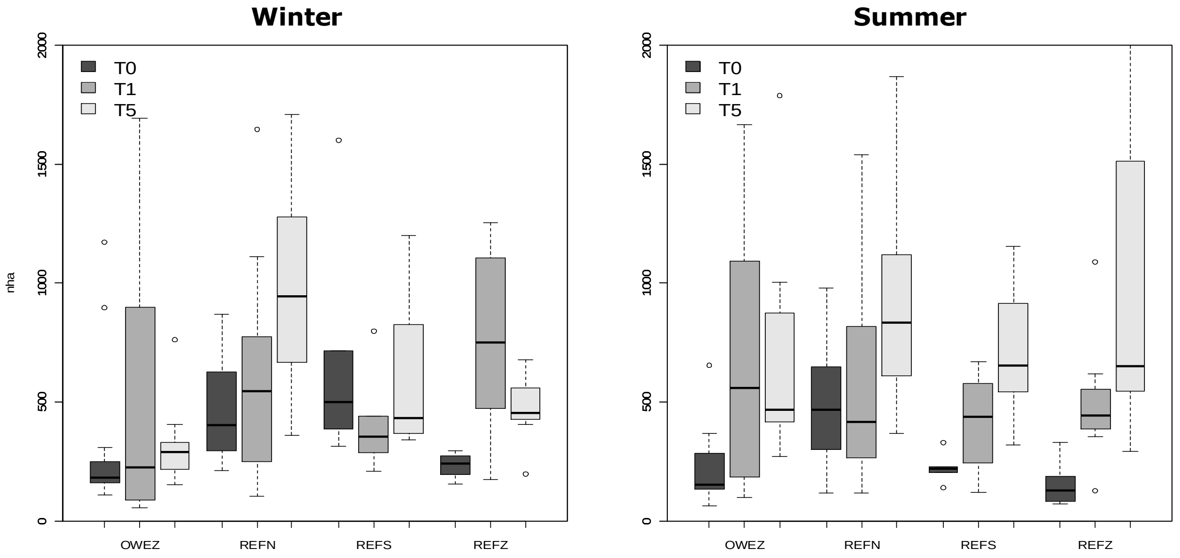


Figure 4-17: Total catches (nha) of both gears (DFS and SNS) presented as individual data points in a single box in the different areas by year (period). Differences between the values here and Figure 4-1 are caused by using average trawled area to calculate the n/ha.

Analysis on the selected species indicates that for many of the species the interaction term and thus the observed trends are significant between areas (Table 4-3). A significant interaction term however only tells that at least one trend is different from any of the trends in the other areas. To interpret significant results in Table 4-3 it is therefore necessary to consider the associated plots (Appendix figure B-5 - Appendix figure B-14).

Table 4-3: Summary of p-values associated with the interaction term used in the generalised linear model. Significant values ($p < 0.05$) indicate that the trend in abundances is different between areas over the years.

Species	Summer: p (Area * Year)	Winter: p (Area * Year)
Total	0.3071	**0.03421**
Plaice	**< 0.0001**	**< 0.0001**
Sole	**< 0.0001**	**0.0018**
Dab	**< 0.0001**	**0.0037**
Scaldfish	0.0509	**0.0244**
Bullrout	**< 0.0001**	**0.0149**
Goby	**0.0007**	**0.0149**

Considering the associated plot for the species that indicated a significant interaction, a consistent increase (i.e. higher numbers in both T1 and T5 compared to T0) in the OWEZ area was observed for:

Plaice - summer: Plots show that the numbers of plaice were higher in the OWEZ area in T1 and T5 compared to T0, but this pattern was also observed in REFS and more gradually in REFZ and is therefore more likely to be due to a general increase in the species rather than an OWEZ effect.

Sole - summer: Although mean numbers show only a small increase from T0 to T1 and T5 in OWEZ, the skew to higher numbers is evidently higher in T1 and T5 compared to T0 (Appendix figure B-7). The same pattern is not seen in the reference areas. Only REFZ shows some increase in T5. However, the patterns are so different between all four areas that causal effects of OWEZ on numbers are difficult to confirm.

Dab - summer: Although mean numbers show only a small increase from T0 to T1 and decrease again slightly in T5, the skew to higher numbers is evidently higher in T1 and T5 compared to T0 (Appendix figure B-9). The same pattern is not seen in the reference areas although both REFS and REFZ show a more steady increase in mean numbers from T0 to T1 and again to T5.

Bullrout – summer and winter: Although means are higher in T1 and T5 compared to T0 in the OWEZ area, a much larger increase is observed in all other areas. This indicates a negative effect of the wind farm.

Some other patterns observed:

Scaldfish summer: This is the only species that does not show a significant difference in trends between areas and this is also very clear from the plots. Scaldfish show a consistent gradual increase in all areas and high numbers in T5.

Gobies – summer and winter: Gobies were present in much larger numbers in T0 than in the other years in all areas.

4.3.4 Species richness

In total 54 different species were recorded in the demersal survey. A number of these 54 species, as mentioned in paragraph 3.3, are aggregated on genus level, resulting in 50 unique species / genera. Of these 39 were caught in winter and 42 in summer (Table 3-2). 40 species were caught in the T0, 39 in the T1 and 38 in the T2. The maximum number of species caught per area and season is only 30 (Figure 4-18).

In all areas and in both seasons the number of species caught in the T0 is lower than in the T1 and T5. As with the total catch this might be an effect of changes in survey design (changing fishing direction, different vessel), or due to a natural cause.

Surprisingly, the number of species caught in REFS and REFZ is not much lower than in the other two areas, while the number of hauls in these areas is lower. The chance to catch rare species is larger with a higher number of hauls. Combining these two areas, to get a similar number of hauls, results in a slightly higher number of species in the southern areas in winter in all years, in summer only the T5 results in higher numbers compared to the other areas.
The total number of species caught in summer is slightly higher than in winter, around 5 species more in the T1 and T5.

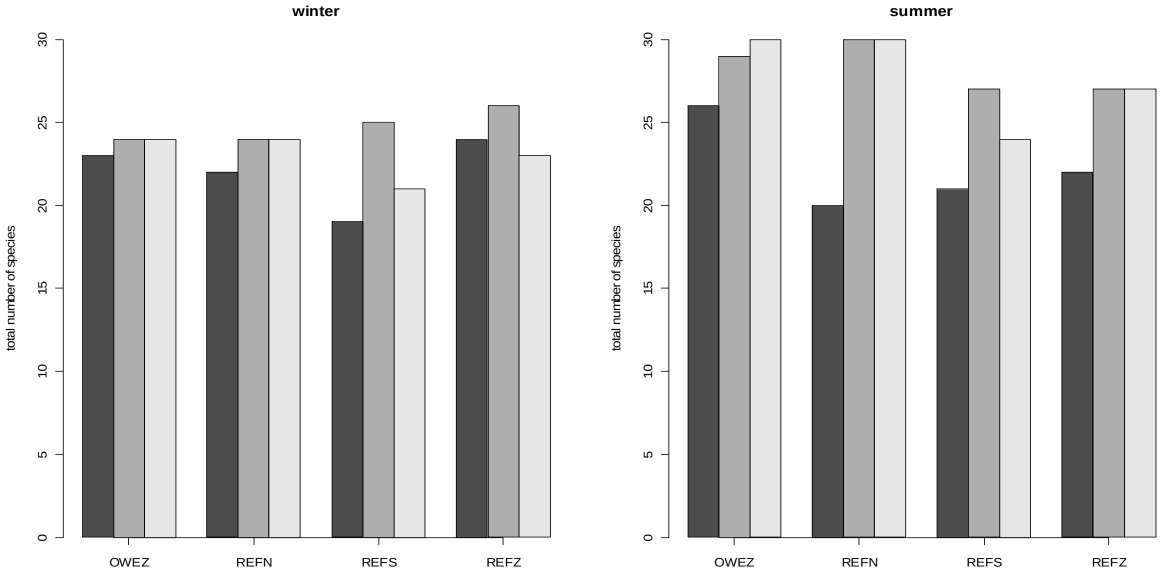


Figure 4-18: Total number of species caught in each area by Period, dark=T0, grey= T1 and light=T5.

When comparing the number of species at a haul level (Figure 4-19), during the summer season the number of species caught per haul has increased in all areas compared to the T0. In winter, the number of species per haul is more variable. In OWEZ a small decrease in the number of species caught per haul is shown, even though a larger total number of species is caught. This indicates that some individual species were more evenly distributed in the T0 or patchier in the T1 and T5. Some of the species were caught in a smaller number of hauls compared to the T0. The observed decrease is not significant, however it has not been observed in the other areas. In the other areas the number of species caught by haul was larger in the T1 and slightly lower again in the T5. But none of the winter changes were significant.

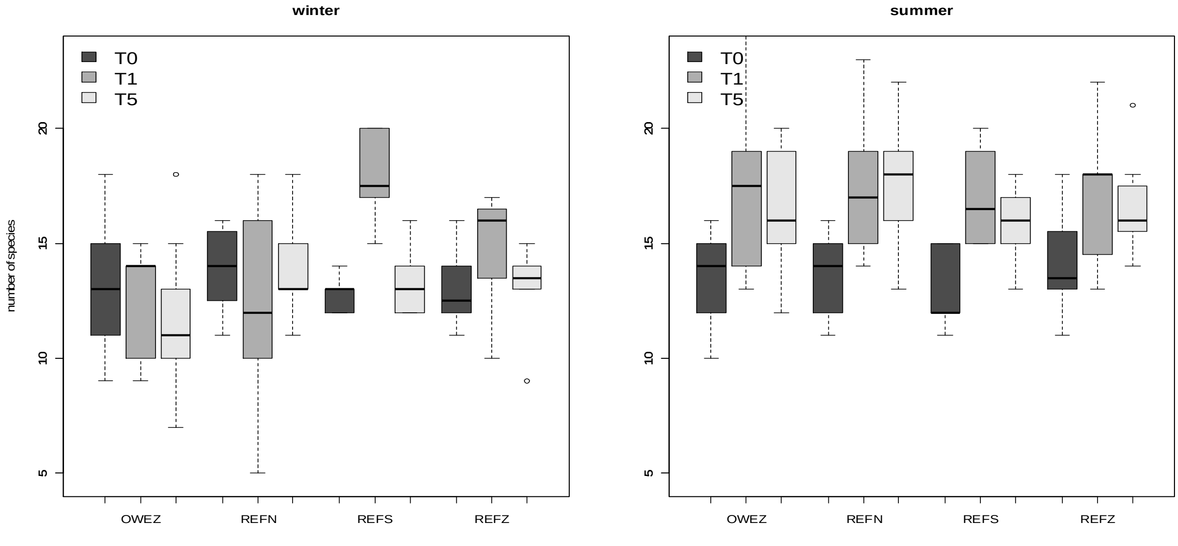


Figure 4-19: Number of species per haul of both gears combined in the different areas by Period.

4.3.5 Stomach analysis

The availability of species and the weather conditions limit the collection of 3 stomachs per length per species and area. Furthermore, a part of the collected stomachs is empty (Table 4-4) limiting the number of samples for the analyses.

During the T1 winter only a limited number of stomachs could be collected, actually only plaice was collected in a reasonable number. Of these plaice stomachs only 30% was full, also a limited number of stomachs of the other species was full. Therefore it was decided to exclude the winter data from the analysis.

The number of empty stomachs was tested for each species in relation to the number of full stomachs. For most of the species there was no significant difference between the number of empty and full stomachs. For dragonet it was shown that the ratio between empty and full differed significantly between the T1 and the T5, with in the T1 more full stomachs while in the T5 more empty stomachs were collected. But no difference was found between the areas. For dab a significant difference was found for the ratios in OWEZ and two of the three reference areas (REFN and REFZ). In OWEZ the ratio indicated more empty stomachs than full, while in the reference areas the opposite was found. However, no dab stomachs were collected in OWEZ in the T1. Also for sole a significant difference was found, however this was not consistent between areas, with REFN having significantly more empty stomachs than OWEZ, while REFS had less empty stomachs. REFS stomachs were only collected in the T5. Furthermore, it is known that sole feed early in the morning and empty stomachs are found only during the first hauls in the morning, thus here the results depend heavily on the time of collection.

Table 4-4: Stomachs collected in each area by year split in empty (0) and full (1) stomachs.

	T1 summer								**T1 winter**								**T5 summer**							
	OWEZ		**REFN**		**REFS**		**REFZ**		**OWEZ**		**REFN**		**REFS**		**REFZ**		**OWEZ**		**REFN**		**REFS**		**REFZ**	
English name	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**1**
Flounder	14	17	11	15	11	9	3	3									1		2		3	3	4	2
Solenette																	10	7	7	3	10	5		
Cod	1	12		9		6		1			1													
Dragonet	15	14	2	26	3	21	6	23	1	2					2	1	18	12	7	3	6	2	15	7
Dab			1	9	3	5	2	2			2	5			4	7	28	14	13	16	23	24	17	34
Plaice	6	28	11	30	10	38	8	36	7	2	15	7	8	5	14	5	17	27	8	8	13	30	6	29
Scaldfish																	5	9	5	7	5	12	1	16
Sole	25	11	10	6			18	5									20	21	33	7	4	12		
Whiting	8	28	1	23	4	20	3	30			2	3			1		1	7	7	12	1	2	7	16
Lesser weever																							7	5

In total 41 prey types were identified in the summer stomachs (Appendix table B-2). The 42nd item is Varia which consists of unidentifiable material. Of the 41 prey types, four were exclusively found in OWEZ in the T1 and two were exclusively found in OWEZ in the T5. All six were only found once. Of the 41 prey types, 12 were exclusively found in stomachs from the reference areas. This number of exclusive groups is most likely related to the higher number of stomachs in the combination of the three reference areas (OWEZ=177 and REF=360 full stomachs). Most of these exclusive groups were found only in a single stomach; only the groups *Eteone* and squat lobsters (*Galatheidae*) were found in five stomachs.

The two most dominant prey groups found in all stomachs were Polychaeta and Crangonidae. In all four areas, polychaeta were found in the highest number of stomachs. In count of individual prey items polychaeta were also dominant in OWEZ, however in the other three areas Crangonidae were highest in number. Of these two prey groups, sole and flounder consumed only Polychaeta, while cod, solenette and lesser weever only consumed Crangonidae. The other species consumed both prey groups.

Most stomachs were collected for plaice, in OWEZ as well as in the reference areas in the T1 and T5. For plaice it is clear that Polychaeta (free living bristle worms) were the main prey items in total numbers in all stomachs in all areas and periods (Figure 4-20). In the T1 Portunidae (swimming crabs) were the second species is the diet, in the T5 this was *Lanice* (a burrowing marine bristle worm) and at that time the contribution of Portunidae was limited. In the T1 Portunidae was also the second dominant prey species in REFN followed by Crangonidea. However, in REFS and REFZ Portunidae were not found in the T1 and there *Lanice* was the second dominant prey species followed by Bivalvia. In the T5, REFS and REFZ showed a similar diet consisting mainly of *Lanice* and Polychaeta, but then also a small part of the data consisted of Portunidae. Most of the other prey species were only found once or twice, many of these other prey groups (e.g. Oligochaeta, Annelida, *Arenicola*, Ascarididae, *Eteone*, Nemertea, Nereididae and Phyllodocidae) are wormlike thus very simalar to polychaeta or *Lanice,* of the 24 prey groups consumed by plaice 10 were worms.

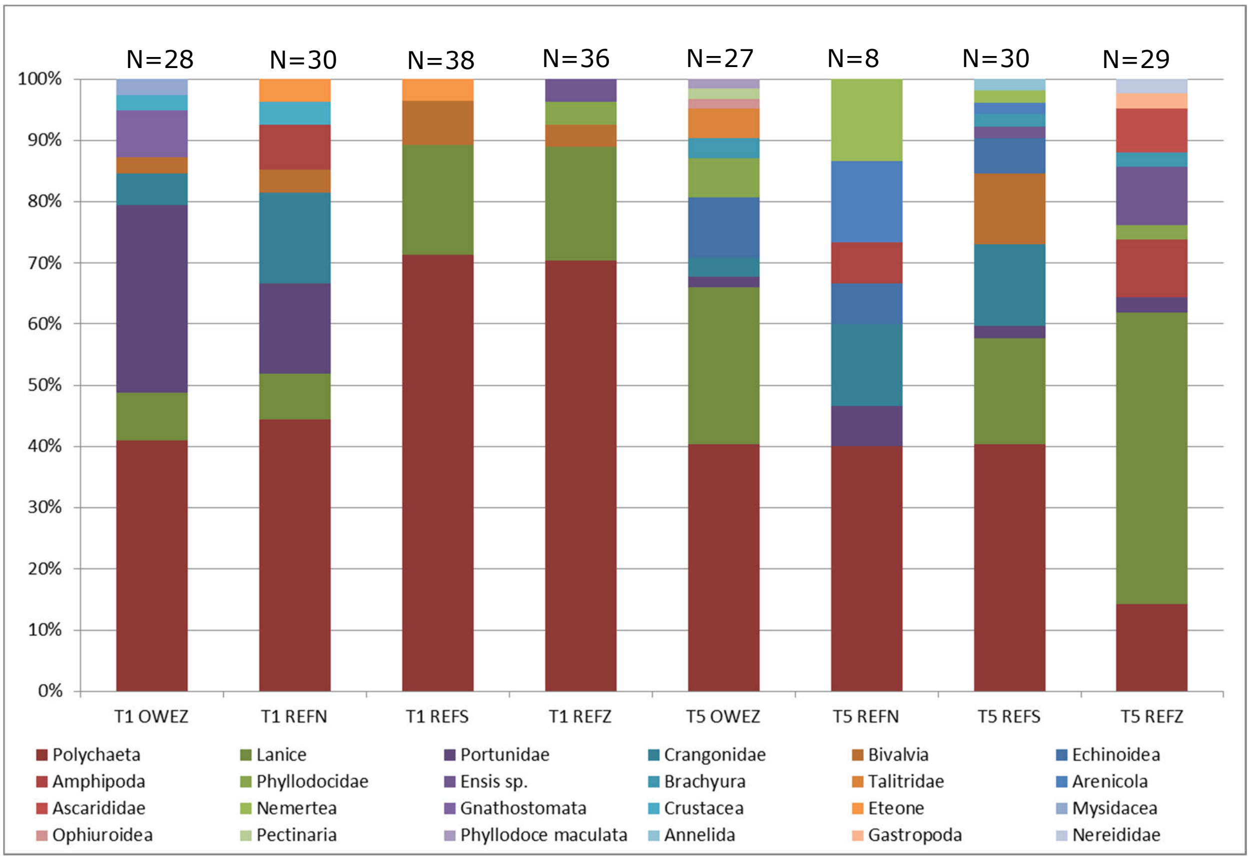


Figure 4-20: Plaice stomach contents in percentage of the number of prey items. N= the number of full stomachs used to calculate these values.

The same graph for whiting (Appendix figure B-15) indicates for the T1 a preference for Crangonidae, decapoda were the second dominant prey followed by Ensis. While in the T5 it were Fish (Gnathostomata) and Brachyura. In OWEZ and REFZ in the T5 Ascarididae (Nematode) was one of the dominant species, however due to the low number of stomachs in the T5, this was caused only by 4 Ascarididae in each area. In the two stomachs collected in REFS, only three items were found, two Crangonidae and one Brachyura.

The graph for dragonet (Appendix figure B-16) indicates that the main prey items were Portunidea especially in the T1. This was followed by Brachyura, Polychaeta and Crangonidae. In the T5, the Portunidea dominated only the diet in REFZ and REFS. In the twelve stomachs from OWEZ, eight prey species were found of which Lanice and Amphipoda were counted five times. In the three stomachs from REFN, three prey species were found, one Brachyura, one Crangonidae and four Amphipoda.

The other species had even less stomachs and were not used to visualise the diet.

4.4 Discussion

As every other fishing gear, beam trawls are developed to catch only part of the fish community. In case of the beam trawl this is the demersal fish community and of this community mainly the flatfish species. The beam trawls used are modified to catch the smaller fish in the community, not only because of the small mesh size but also due to the relatively light beam and the slow speed. This was a well-considered choice, but a choice that has consequences for the interpretation of the data. Even in ideal conditions the used gears have a low catchability for larger fish, and even the catchability for smaller fish is not 100%. Catchability can even be below <15% of the fish present in the path of the trawl (Reiss et al. 2006, Fraser et al. 2007, Piet et al. 2009). This clearly affects the analysis of differences in mean length as due to the gear construction a different ratio of the small fish compared to the larger fish in the community is caught. It also complicates the interpretation of the data for low abundant species; not catching them does not mean they are not present. The catchability is further affected by the local conditions, e.g. visibility, current, temperature etc. Executing the survey in a short period of two weeks helps to keep these conditions somewhat stable within one survey period, but these conditions differ between the different periods and years (Figure 3-4). On top of this, natural variation complicates straightforward interpretation even further. Therefore the analyses are performed only on the more abundant species, which were caught in reasonable numbers, but even then observed differences should be treated with care.

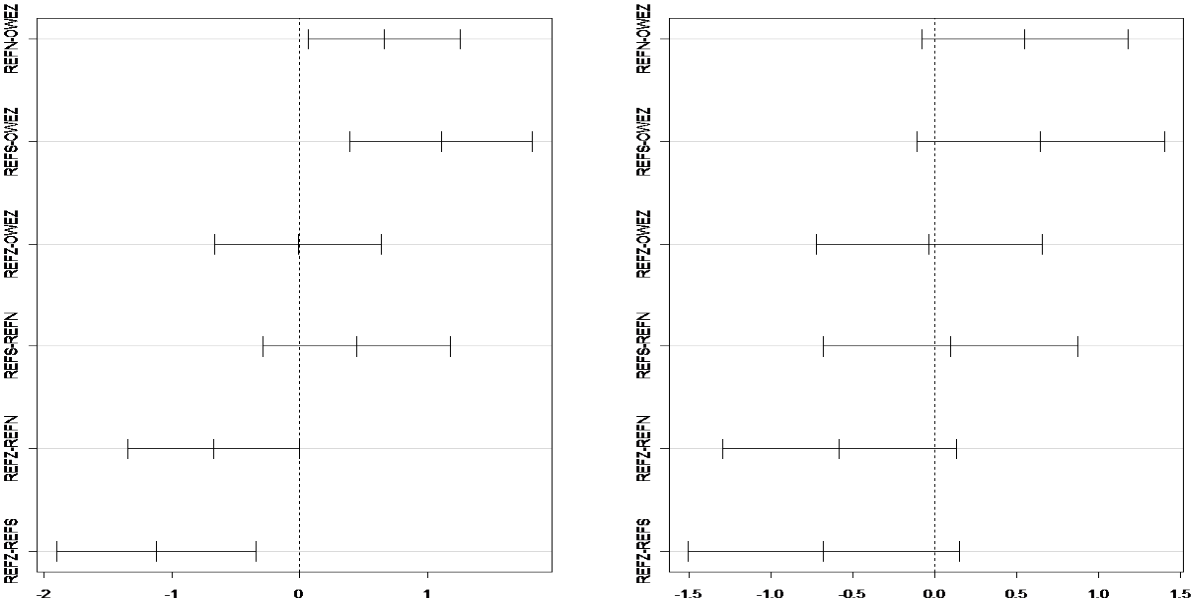


Figure 4-21: Differences in mean levels in the T0 (x-axis) between all combinations of areas during winter for mesh size 0.04m (left panel) and 0.02m (right panel).

Lack of knowledge of natural variability in the area before building makes it difficult to determine causal effects over natural variability. In statistical terms this means that a significant interaction between year and area is needed to show that the development of a trend in one area differs from those in other areas. Even if this was found this still does not mean that there is a causal relationship. The large natural variation also means that a significant difference can be found by chance, and that a significant difference between the wind farm area and a single reference area not directly means an effect of the wind farm. Example of this are the results presented in Figure 4-2, were the total catches in REFN were significantly higher than those in OWEZ. This was however already the case in the T0 and at that time the catches were even significantly higher in REFS (Figure 4-21). There were no consistent results that suggest a significant interaction, thus there is no indication that the development in the OWEZ area differs from the reference areas.

The variation between catches, among others owing to the above, but also due to patchy spatial distribution of species affects the power of the monitoring program as executed. In the T0-report (Tien et al. 2004) a power analysis was presented based on the variation in hauls of the T0. This power analysis showed that the chosen sampling scheme of 13 hauls in the wind farm allows for the detection of a 30% downward or a 40% upward trend in fish biomass (Figure 4-22). Within this range the presented results have to be interpreted. The none significant results as shown in most of the analyses indicate that changes are not outside this range. Considering the power of the monitoring program, the conclusion is that the exclusion of fisheries or the introduction of the wind farm did not alter the demersal fish community. This is in agreement with preliminary observations in a Belgian wind farm (Vandendriessche et al. 2011).

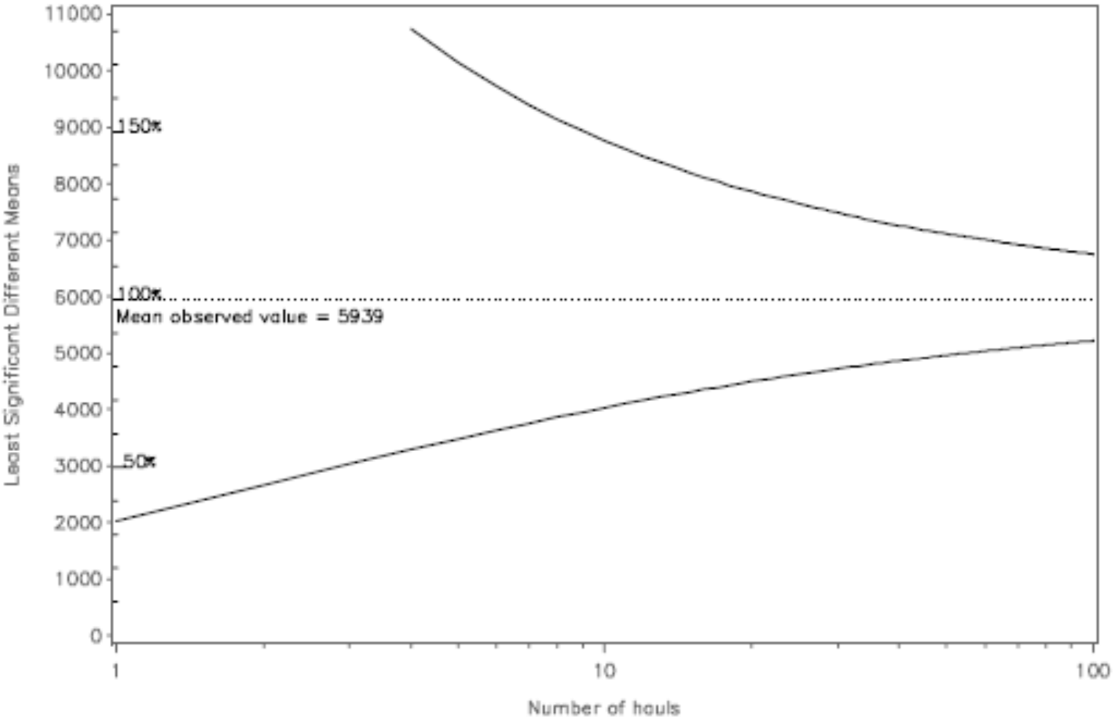


Figure 4-22: The relationship between expected confidence intervals (vertical) and the number of hauls in a monitoring programme (horizontal), here shown for the mean value of all observations. Note the logarithmic nature of the horizontal axis. To detect a significant change in fish biomass, the new level of the fish biomass must be outside the confidence limits i.e.; when 10 hauls are executed, a change in fish biomass can be detected if it changes from 5939 g/ha to less than 4000 g/ha, a reduction by more than 30 % (Tien et al. 2004).

The choice of reference areas was based on the results of the T0 (Tien et al. 2004). The reference areas were considered similar to the wind farm in respect to distance to shore, water depth and seabed morphology. Due to physical similarity of the areas and their vicinity, it was assumed that water currents are similar in all areas. These features were considered the main drivers for the fish community and therefore the choice for the reference areas as acceptable. However, the presented results differ between the OWEZ and reference areas as well as between the reference areas. Rather than questioning the choice of the references areas, this indicates large spatial and natural variation in the occurrence of fish species. As shown in the power analysis this affects the detection of changes which was taken as granted in the T0.

A positive effect on the demersal fish was also expected to occur through changes in food availability, or by the introduction of hard substrate which may provide habitat for different types of species.
Regarding the food availability no clear conclusion can be drawn from the collected stomachs. The large number of empty stomachs reduced the informative sample size. Based on the stomachs of the three species for which a reasonable amount of full stomachs was collected, the variation in prey choice between years was larger than the differences between the farm and the references area. A few months after the construction of the farm, the local benthos community in the sandy area between the monopiles showed no major differences, in composition, densities, overall biomass and diversity compared to the reference areas (Lindeboom et al. 2011). Similar results were found in the T5 benthos measurements (Bergman et al. 2012 draft). Some of the prey species exclusively found in stomachs from OWEZ, were also identified in the study by Bergman et al. (2012). Leucothoe, Paguridae (most likely *Pagurus bernhardus*) and Hydrozoa were found by

Bergman et al. in OWEZ and some of the reference areas. *Eumida bahusiensis* was not found in OWEZ by Bergman et al. but was found in some reference areas. In OWEZ Bergman et al. found *Eumida sanguinea*.

The largest changes in benthic species were expected on the monopiles and/or the scour bed as indicated by Bouma & Lengkeek (2009). The attraction by hard substrate could not be established using trawl gear fishing on the soft bottom between the monopiles. The catches did contain prey species in OWEZ that were not caught in the other areas, but these could not be related to the hard substrate. The stomachs were however collected in the middle between the monopiles on the sandy bottom. It is unlikely that the species have been feeding on the monopiles or the scour protection, and even if they had, the stomach content would already have been partly digested, making prey species identification impossible. In case, prey species would have increased significantly, it is likely that this would have be found in the stomachs, but as shown by Bergman et al. no such increase was found in the benthos.
The positive effect of food availability was expected to be an increased growth or improved condition. It was impossible to study this phenomenon using the present survey design; options for direct measurements of conditions should have been performed for this, e.g. Fulton K or fatty acids and should be considered in following studies.

5 Sub-project 2: Effects on the pelagic fish community

5.1 Survey Design

5.1.1 Area

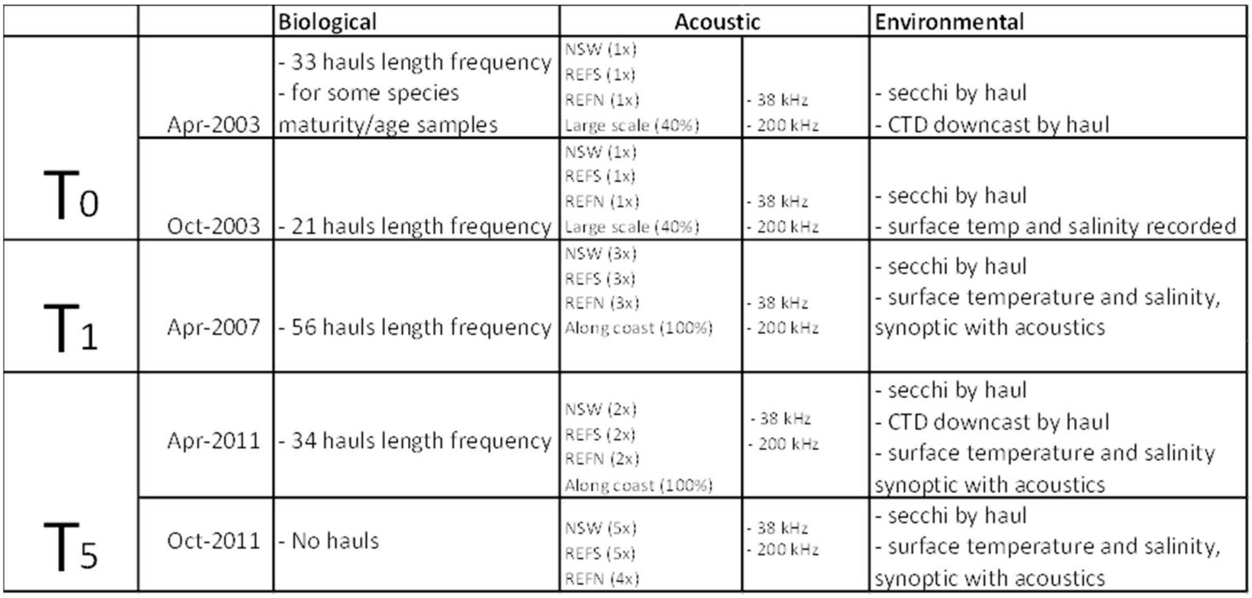
The pelagic survey only sampled the OWEZ, REFN and REFZ areas which were selected already in the T0 (Tien et al. 2004). Within these areas transects with a high resolution were monitored, these transect were 8 to 10 km long and the distance between them was 0.5-1 km (the spatial scale of the wind farm).

Besides these areas, coastal transects were monitored with a lower spatial resolution. In the T0 a total of five U-formed transects with the opening of the U to the coast were monitored. In the T1 and T5 three transects parallel to the coast were monitored. In the T0 the scheme was based on the project Flyland where these lower resolution transects provided a good insight in the pelagic fish community in the coastal zone. Limitations in time prevented monitoring the full scheme in the T0, owing to this the scheme was adjusted in the T1. The new parallel transects were planned such that they followed the depth contours of the coast line (Ybema et al. 2006).

5.1.2 Period

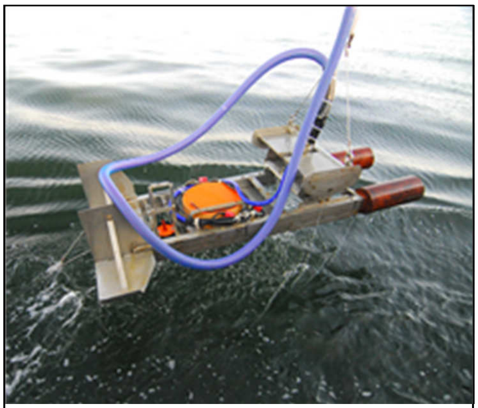
The pelagic survey was executed in the T0, T1 and T5. In the T0, it was performed twice, in April 2003 and October 2003. For both exercises two weeks were available. In the T1, only a single survey that lasted for three weeks was executed in April 2007. An extra week was needed as in the T0 the area coverage was limited, this extra week however it resulted in the loss of the October survey in the T1.
In the T5, a three week survey similar to the T1 was executed in April 2011 and a two week survey focussing only on the small scale resolution was executed in October 2011 (Table 5-1).

Table 5-1: Summary of area coverage by acoustic and biological sampling.



		Biological	Acoustic		Environmental
T0	Apr-2003	- 33 hauls length frequency - for some species maturity/age samples	NSW (1x) REFS (1x) REFN (1x) Large scale (40%)	- 38 kHz - 200 kHz	- secchi by haul - CTD downcast by haul
	Oct-2003	- 21 hauls length frequency	NSW (1x) REFS (1x) REFN (1x) Large scale (40%)	- 38 kHz - 200 kHz	- secchi by haul - surface temp and salinity recorded
T1	Apr-2007	- 56 hauls length frequency	NSW (3x) REFS (3x) REFN (3x) Along coast (100%)	- 38 kHz - 200 kHz	- secchi by haul - surface temperature and salinity, synoptic with acoustics
T5	Apr-2011	- 34 hauls length frequency	NSW (2x) REFS (2x) REFN (2x) Along coast (100%)	- 38 kHz - 200 kHz	- secchi by haul - CTD downcast by haul - surface temperature and salinity synoptic with acoustics
	Oct-2011	- No hauls	NSW (5x) REFS (5x) REFN (4x)	- 38 kHz - 200 kHz	- secchi by haul - surface temperature and salinity, synoptic with acoustics

5.1.3 Methods and equipment



Towed body; the orange object is the 38 kHz transducer.

The occurrence, density and population structure of the pelagic fish fauna were assessed by means of echo integration and reference trawl hauls during a hydro-acoustic survey. Echo surveys are an efficient tool in describing spatial distribution and size distributions of pelagic fish over a large area. Additional trawl hauls are, however, required to validate the acoustic fish density and distribution patterns and to collect length frequency distributions of the fish.

The acoustic equipment is an echosounder, Simrad EK60 with a 38 kHz and a 200 kHz splitbeam transducer. The transducers transmit and receive acoustic pulses in the water that are reflected by objects in the water column (fish, bottom). The strength of the reflection of the signal is a measure for the size of the object (fish). The relationship between the strength of the signal and fish length is species specific. The time between transmitting and receiving the signal is a measure for the distance between the transducer and the fish.

The planned transects were sailed with the commercial vessel "GO58" at a speed of around 8 knots through the water: the speed relative to the bottom may have varied due to tidal currents. During sailing a "towed body" (a stainless steel aerodynamic object of about 250kg and 2m long) containing the transducer, is towed from the side of the vessel. The information is received real-time on the bridge, if an aggregation of fish is detected it can be decided to start fishing on it. The vessel turns around and a semi-pelagic trawl with a vertical net opening varying between 5 and 15 m and mesh size of 10 mm in the codend is shot within 15 to 20 minutes after detection of the aggregation of fish (Figure 5-1). Therefore the number and the location of the hauls could not be planned in advance.

In the second survey in the T5 no hauls were made and only the high resolution scheme (the wind farm and the reference areas) was monitored. During this survey the objective was to sample each area as often as possible, studying the occurrence of aggregations rather than species identification.

Pelagic trawl catch: herring and sandeel

5.1.4 Processing of the trawl catches

All fish caught in each haul were identified to the species level, and then measured by species at half a cm (5.1 cm = 5 cm and 5.6 cm = 5.5 cm). Also shrimps are measured at the mm and benthic species are counted.

5.1.5 Hydrographic data

Environmental conditions were measured using a self-logging CTD measuring device which was towed behind the towed body, measuring salinity and temperature continuously at 1'30" in April 2007 and 0'10" intervals in April and October 2011 (paragraph 3.2). At most stations, visibility was measured with a secchi-disk.

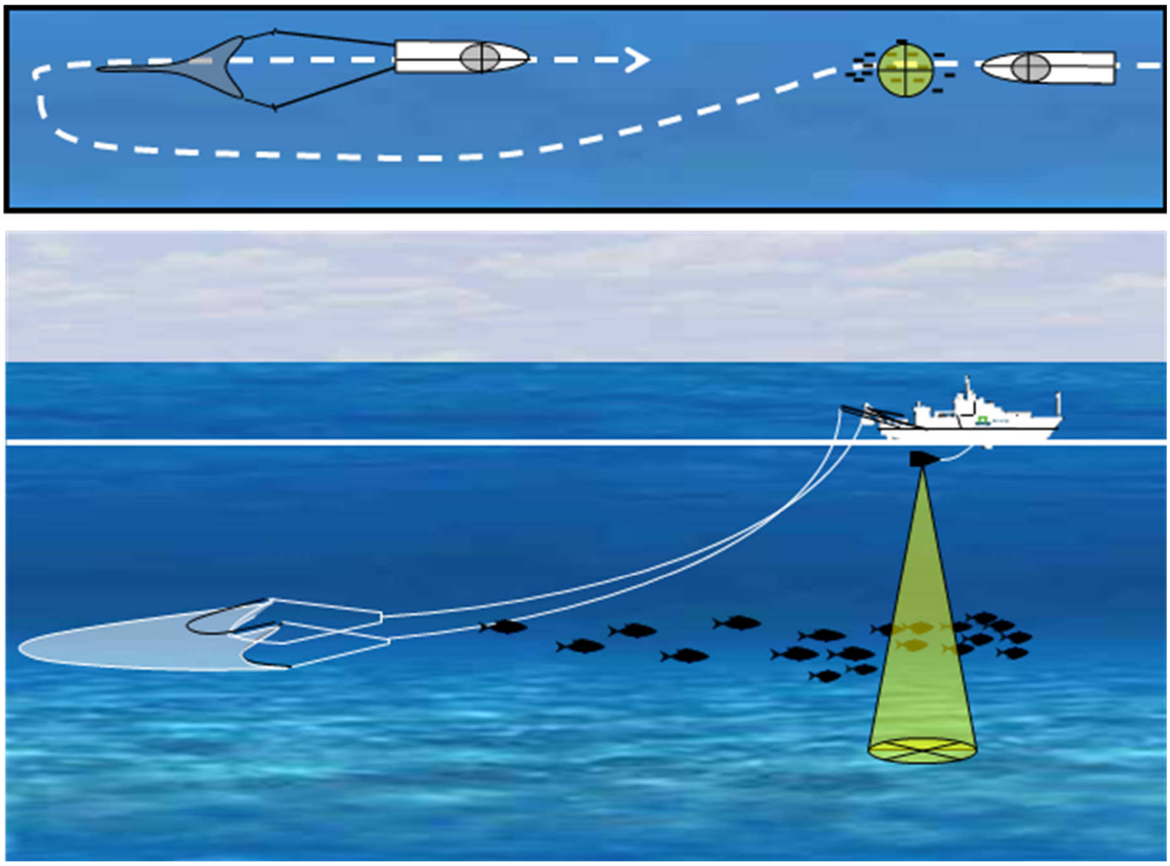


Figure 5-1: Scheme of the sampling methods for pelagic fish. Sailing the transects, observing aggregations of fish, turning around and trying to relocate that same aggregation while fishing.

5.2 Analysis

5.2.1 Acoustic density data

For analyses of pelagic fish communities, acoustic density data (Nautical Area Scattering Coefficient; NASC or s_A, in m^2 nmi^{-2}) from the 38 kHz were extracted for fish with swimbladders. In the survey area, these consisted mostly of small clupeids: herring, sprat, sardine and anchovy. The data were stored with a resolution of 1 nautical mile (nmi) but converted to 3 nmi intervals for subsequent analyses and presentation. Acoustic target strength of clupeids can be assumed similar at the applied frequency. Therefore, s_A data allocated to these fish in the survey area were used directly to approximate fish densities.

s_A data were not normally distributed, therefore, before parametric testing they were log-transformed to verify the assumption of normality. Two-way ANOVA was used to test for the effects of survey date by day and area. As only data collected in April were available for all three years, October data were omitted from the analysis of fish density. Tukey’s HSD test was used to determine significant differences between group means. For analyses of transect lines running parallel to the coast through the wind farm (OWEZ) in April 2007 and 2011, a simple linear regression was used to test for the relation between abundance and distance in nautical mile (nmi) from the wind farm.

5.2.2 Species length-frequency distribution

Species of the Clupeid group that comprised more than 90% of numbers of fish caught were selected for subsequent analyses. Their length-frequency distributions were combined for each of the three different areas (OWEZ, REFN, and REFZ) and the locations outside these areas, by weighting each haul by the number of fish caught. To analyse differences between length-frequency distributions of individual Clupeid species between areas, a Kolmogorov-Smirnov test was used.

5.3 Results

Fish densities of clupeids observed in the 5 different surveys are shown in Figure 5-2 and Figure 5-3. Due to bad weather, coverage in October 2003 was generally poor, which resulted in a reduced coverage compared to the other seasons and years. For all years, the degree of coverage in April was comparable. There were differences in mean acoustic densities (s_A) for all areas combined between years, with the highest in 2003 (95.84 m^2 nmi^{-2}), followed by 2011 (77.07 m^2 nmi^{-2}) and 2007 with the lowest mean density (16.87 m^2 nmi^{-2}). Maximum observed s_A values in the different years showed a similar trend, with the highest overall concentrations seen in 2003 (6123.3 m^2 nmi^{-2}), then in 2011 (4012.7 m^2 nmi^{-2}) and 2007 (1649.6 m^2 nmi^{-2}). The number of 3 nmi intervals was similar in 2007 (1160) and 2011 (1291), whereas in 2003 (only two survey weeks), coverage was about half (471) of that.

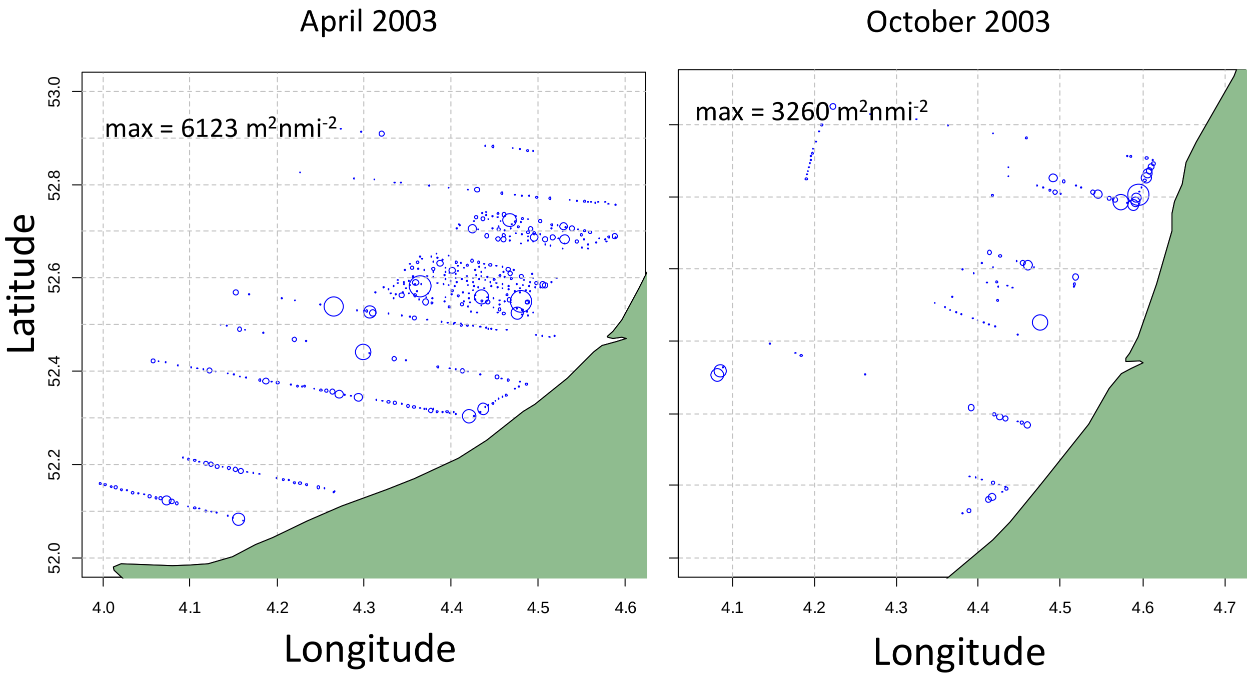


Figure 5-2: Distribution of acoustic density of clupeids within the survey area (on a proportional square root scale relative to the largest value given for each survey) in the T0.

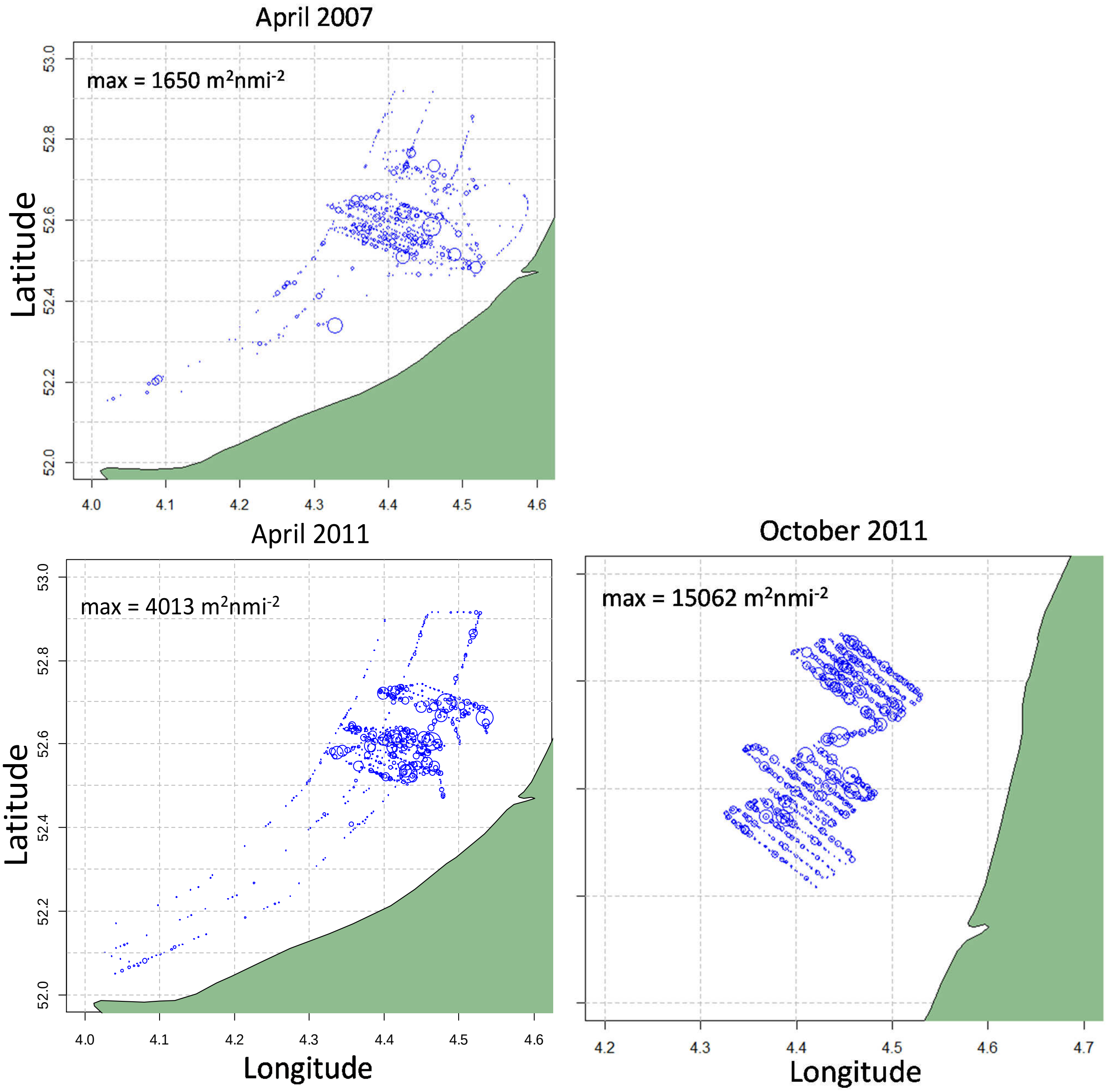


Figure 5-3: Distribution of acoustic density of Clupeids within the survey area (on a proportional square root scale relative to the largest value given for each survey) in the T1 and T5.

5.3.1 *Within-year comparison*

No significant differences in density of clupeids were found between the three areas in April, for all three years analysed (2003: p=0.085; 2007: p=0.200; 2011: p=0.937) (see Figure 5-4 to Figure 5-6 and Table 5-2 to Table 5-4), with the smallest difference observed in 2011. The analysis therefore indicates that fish abundance was independent of the surveyed area, with similar densities in the three areas in each year. In contrast to the non-significant area effect, day effects were significant in 2007 and 2011 (2007: p<0.001; 2011: p=0.011). These can be quite pronounced with, for example, in 2007 the highest mean density registered on 12 April (32.9 m^2nmi^{-2}) and the lowest just 2 days earlier on 10 April (13.9 m^2nmi^{-2}). The analysis of the T5 survey in October 2011 revealed significant area and date effects (Table 5-5). While no differences could be found between OWEZ and REFZ, REFN had significantly higher mean densities of clupeids. However, there were again differences observed between survey days, with one of the days (14 October) yielding significantly higher densities than the other two days (Figure 5-7). Compared to the April survey of the same year, the T5 October survey saw significantly lower mean densities in all areas (OWEZ: 5.4 m^{2}nmi^{-2}, REFZ: 5.1 m^{2}nmi^{-2}, REFN: 6.8 m^{2}nmi^{-2}). With the absence of suitable data, no between-year comparison could be done for the October data.

Table 5-2: Two-way ANOVA results, examining the effects of area and day-date on acoustic density estimates of clupeids in 2003.

Effect	**Sum of Squares**	**d.f.**	**F**	**Significance (p)**
Area	10.1	2	2.478	0.085
Date	0.9	1	0.457	0.500
Residuals	779	381		

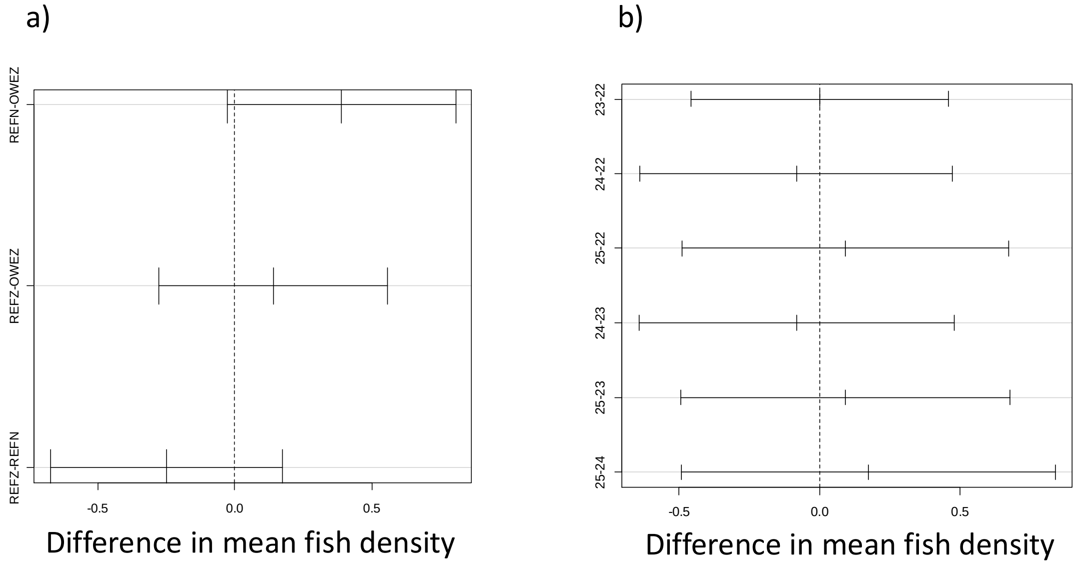


Figure 5-4: Pair-wise comparison of differences in mean log-transformed acoustic density of clupeids between (a) areas (REFN: northern reference, REFZ: southern reference, OWEZ: wind farm) and (b) dates (in days in April 2003).

Table 5-3: Two-way ANOVA results, examining the effects of area and day-date on acoustic density estimates of clupeids in 2007.

Effect	**Sum of Squares**	**d.f.**	**F**	**Significance (p)**
Area	5.3	2	1.617	0.200
Date	114.8	4	17.383	<0.001
Residuals	616	373		

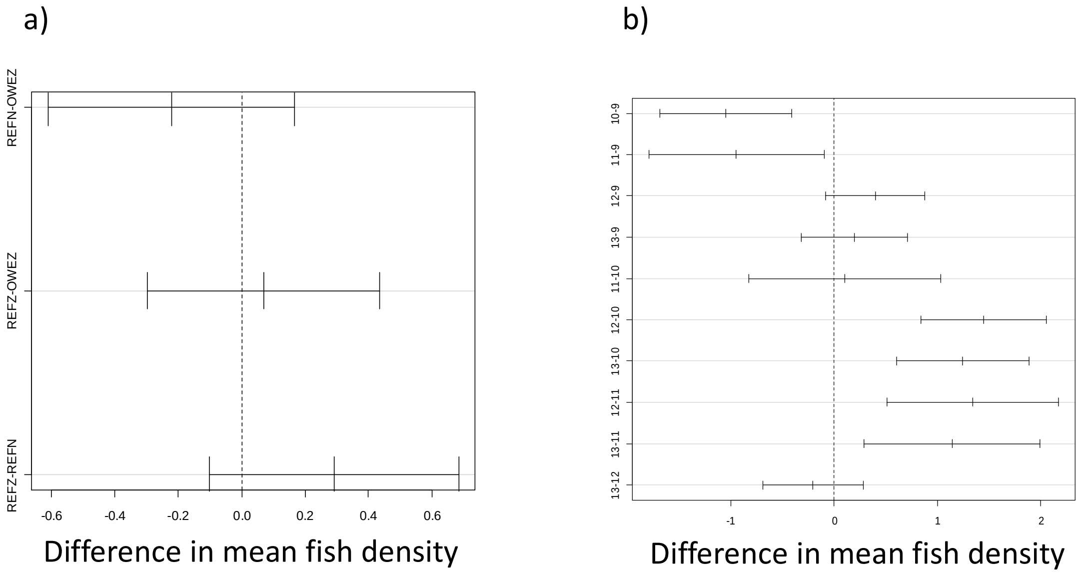


Figure 5-5: Pair-wise comparison of differences in mean log-transformed acoustic density of clupeids between (a) areas (REFN: northern reference, REFZ: southern reference, OWEZ: wind farm) and (b) dates (in days in April 2007).

Table 5-4: Two-way ANOVA results, examining the effects of area and day-date acoustic density estimates of clupeids in 2011.

Effect	**Sum of Squares**	**d.f.**	**F**	**Significance (p)**
Area	0.4	2	0.065	0.937
Date	25.9	2	4.536	0.011
Residuals	1725	605		

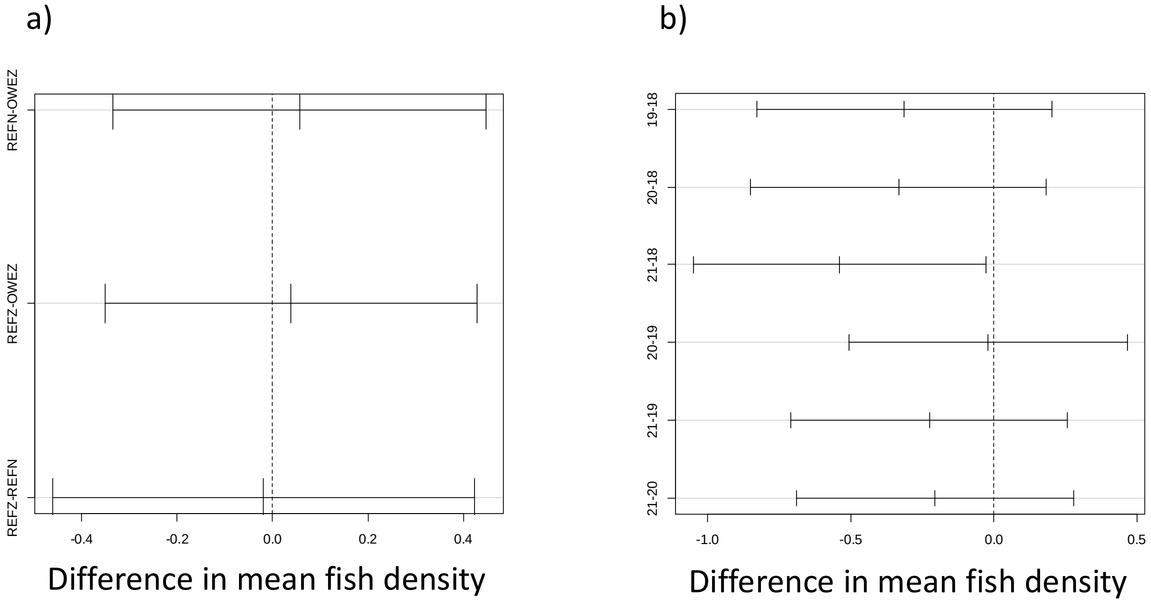


Figure 5-6: Pair-wise comparison of differences in mean log-transformed acoustic density of clupeids between (a) areas (REFN: northern reference, REFZ: southern reference, OWEZ: wind farm) and (b) dates (in days in April 2011).

Table 5-5: Two-way ANOVA results, examining the effects of area and day-date on acoustic density estimates of clupeids in October 2011.

Effect	Sum of Squares	d.f.	F	Significance (p)
Area	104.8	2	22.18	<0.001
Date	24.8	2	5.25	0.006
Residuals	829	351		

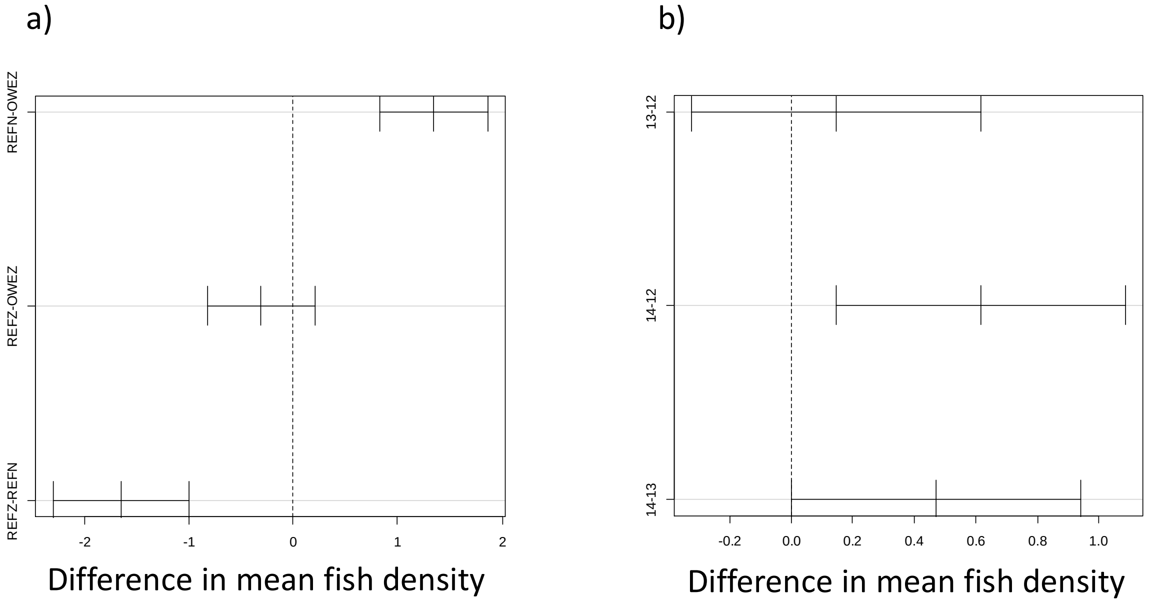


Figure 5-7: Pair-wise comparison of differences in mean log-transformed acoustic density of clupeids between (a) areas (REFN: northern reference, REFZ: southern reference, OWEZ: wind farm) and (b) dates (in days in October 2011), the only three days during which all three areas were covered.

5.3.2 Between-year comparison

There were significant differences in density of clupeids between the years, in all areas (OWEZ: $p<0.001$; REFN: $p<0.001$; REFZ: $p<0.001$) (see Figure 5-8 to Figure 5-10 and Table 5-6 to Table 5-8). The only non-significant pair-wise comparison between years was for the northern reference area (REFN) for years 2011 and 2003 (Figure 5-9). The trend was, however, similar for all areas: highest densities were always seen in the year 2011, followed by 2003, with 2007 showing the lowest densities. Figure 5-10 shows that this trend is true for all areas and years: in any of the surveyed years, there was no difference in mean densities of clupeids between the areas. Over all areas, highest log-transformed densities were seen in 2011 (3.86 m^2 nmi^{-2}), lowest in 2007 (2.68 m^2 nmi^{-2}) and 2003 (3.39 m^2 nmi^{-2}) at an intermediate level (Figure 5-11).

Table 5-6: Two-way ANOVA results, examining the effects of year on acoustic density estimates of clupeids in the wind farm (OWEZ).

Effect	Sum of Squares	d.f.	F	Significance (p)
Year	142.1	2	29.95	<0.001
Residuals	1326	559		

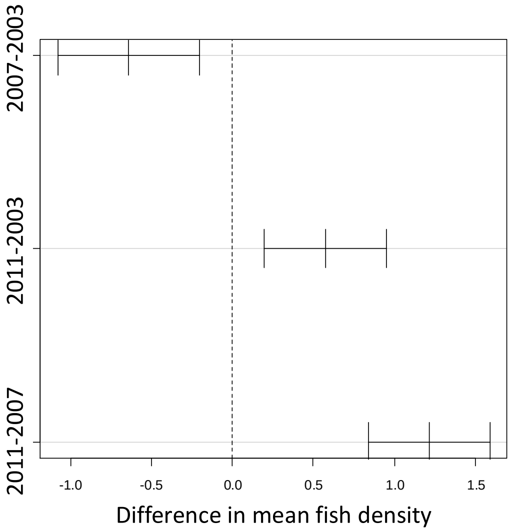


Figure 5-8: Pair-wise comparison of differences in mean acoustic density of clupeids between survey years (2003, 2007 and 2011) in the wind farm (OWEZ).

Table 5-7: Two-way ANOVA results, examining the effects of year on acoustic density estimates of clupeids in the reference area north (REFN).

Effect	**Sum of Squares**	**d.f.**	**F**	**Significance (p)**
Year	154.0	2	31.18	<0.001
Residuals	997	391		

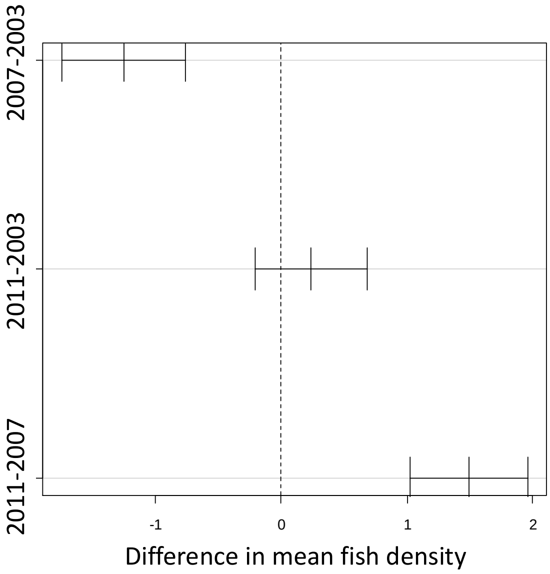


Figure 5-9: Pair-wise comparison of differences in mean log-transformed acoustic density of clupeids between survey years (2003, 2007 and 2011) in the northern reference area (REFN).

Table 5-8: Two-way ANOVA results, examining the effects of year on acoustic density estimates of clupeids in the reference area south (REFZ).

Effect	Sum of Squares	d.f.	F	Significance (p)
Year	102.7	2	22.78	<0.001
Residuals	938	416		

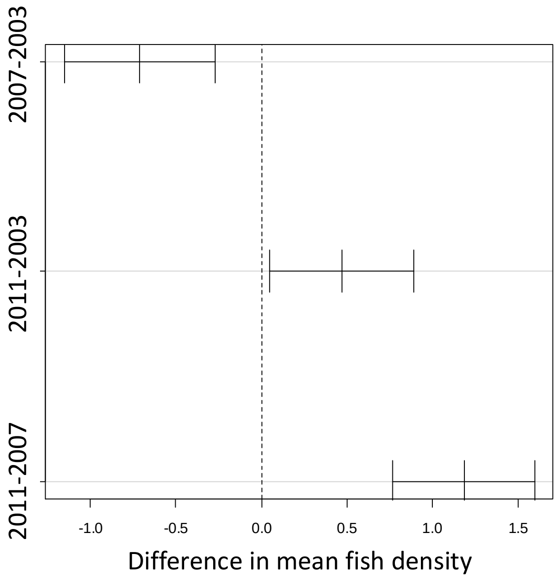


Figure 5-10: Pair-wise comparison of differences in mean log-transformed acoustic density of clupeids between survey years (2003, 2007 and 2011) in the southern reference area (REFZ).

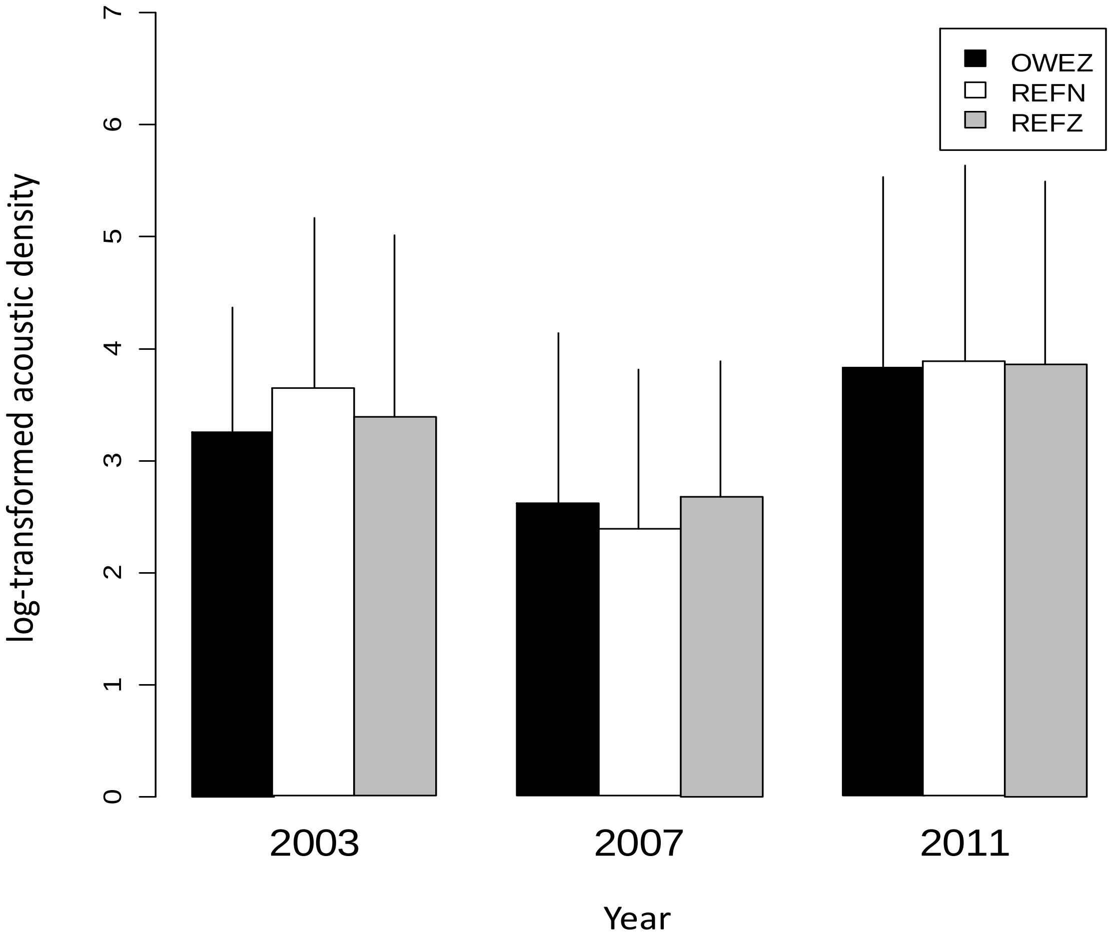


Figure 5-11: Paired bar plots of mean log-transformed acoustic density (+1 S.D.) of clupeids recorded within the three areas surveyed (REFN: northern reference, REFZ: southern reference, OWEZ: wind farm) for each year.

5.3.3 Parallel transects

Clupeid density did not increase or decrease in a linear pattern over a distance of 10 nmi from the middle of the wind farm (OWEZ) both in a northern and southern direction in the April 2007 survey (p>0.050, Figure 5-12). Only one (southernmost) of the parallel transects provided enough data points for an analysis. Data from the other two transects did not extend further than the width of the adjacent reference area (REFZ).

In April 2011, most trends in Clupeid density with distance from the centre of the wind farm did not show a significant linear pattern (Figure 5-12). However, two of the northward transects (the middle and northernmost one) showed a weak significant positive pattern (p<0.05) with distance from the wind farm. The total distance analysed of the southernmost parallel transect in April 2011 was shortest (12 nmi), followed by the middle (20 nmi) and the northernmost one (34 nmi).

5.3.4 Length-distribution analysis of the most commonly encountered species

There were 56 pelagic hauls analysed in T1 and 33 in T5 (see Figure 5-13). There were 12, 8, 12 and 24 hauls taken in the different areas (OWEZ, REFN, REFZ, and outside the areas) in T1. The respective number of hauls per area for T5 was 10, 7, 8, and 8. In T1, the species that contributed >90% in numbers to the total species caught, were: Raitt's sandeel (*Ammodytes marinus*), lesser sandeel (*Ammodytes tobianus*), herring (*Clupea harengus*), anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), and sprat (*Sprattus sprattus*). The respective species and number in T5 were: lesser sandeel (*Ammodytes tobianus*), herring (*Clupea harengus*), anchovy (*Engraulis encrasicolus*), and sprat (*Sprattus sprattus*).

Raitt's sandeel

In T1, Raitt's sandeel showed a bi-modal length-distribution with one mode peaking at about 10 cm and another one showing a peak at 14-15 cm (Appendix figure C-1). The Kolmogorov-Smirnov test showed strong differences in length-frequency distributions between the northern reference area (REFN) and the wind farm (D=0.33, p<0.001) and the outside area (D=0.36, p<0.001). The difference can be attributed to slightly higher numbers of smaller fish observed in the outside area and in the wind farm. In T5, catches of Raitt's sandeel were small.

Lesser sandeel

The haul data in T1 for lesser sandeel showed a length range from 10-17 cm (Appendix figure C-2). There was a slight tendency towards larger fish in the southern reference area (REFZ), however no significant differences in length-frequency distribution could be seen between the wind farm (OWEZ) and either the northern reference area (REFN) or outside any of the areas (D=0.15, p=0.23; D=0.11, p=0.53). In T5, lesser sandeel observed in pelagic trawl hauls covered the length range 8-16 cm (Figure 5-14). Length-frequency distributions did not differ significantly between areas.

Herring

The Kolmogorov-Smirnov test identified significant differences between herring length-frequency distributions in T1 between the southern reference area (REFZ) and both the northern reference area (REFN) and the wind farm (OWEZ). Herring were slightly larger in REFN and OWEZ with mean lengths of 14.5 and 14.3 cm, respectively, compared to REFZ (12.8 cm) and outside the areas (12.7 cm) (Appendix figure C-3). In T5, herring length-frequency distributions differed significantly between all areas. Compared to T1, lengths of herring caught in T5 were smaller at an overall mean of 11.8 cm (Figure 5-15).

Anchovy

The length range of anchovy caught in T1 was from 9-17 cm (Appendix figure C-4). Distributions were generally uni-modal in all areas with the exception of the northern reference area (REFN), where a distinct second mode of small fish at 9.5 cm could be observed. Length-frequency distributions of anchovy were significantly different in all areas analysed, with the exception of OWEZ and REFZ (D=0.12, p=0.51). In T5, length of anchovy ranged from 12.5-16.5 cm (Figure 5-16). Anchovy from REFN had significantly different length-frequency distributions compared to REFZ (D=0.66, p<0.001), OWEZ (D=0.30, p<0.001), but not to those caught outside the areas (D=0.16, p=0.17). Distributions of anchovy in OWEZ and REFZ were also significantly different from each other (D=0.41, p<0.001).

Sardine

In T1, sardine catches for all areas exhibited an approximately normal length-distribution with a mean of 24-25 cm (Appendix figure C-5). None of the length-frequency distributions in any of the areas were significantly different from each other. In T5, sardine did not contribute significantly to the total catches in pelagic hauls.

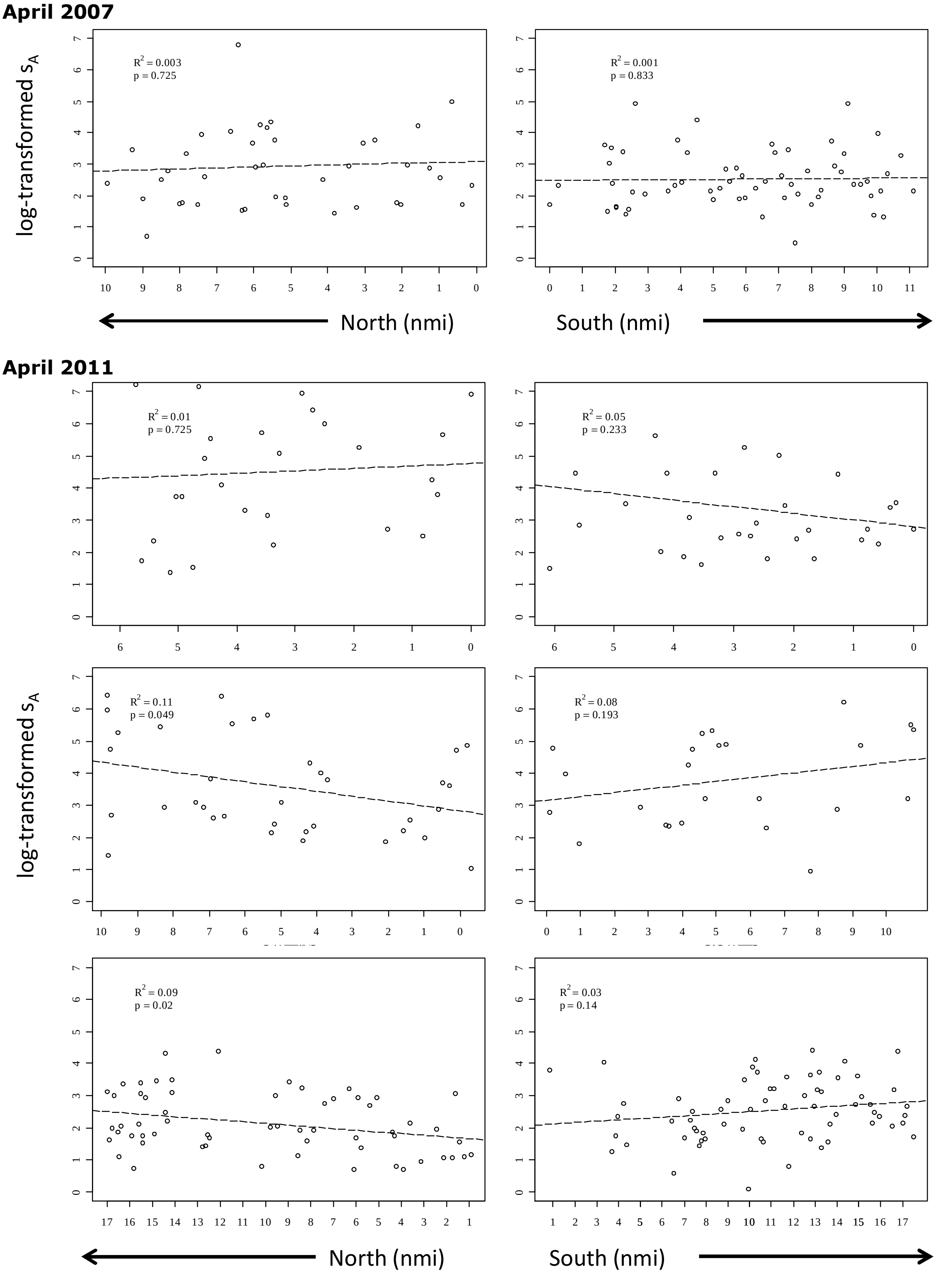


Figure 5-12: Relationship between acoustic density of clupeids and distance to the north and south from the middle of the wind farm (OWEZ). Correlation coefficients and probabilities are given.

Sprat

Sprat catches in T1 revealed length ranges between 7.5-13 cm (Appendix figure C-6). The distribution outside the analysed areas was bi-modal with a peak around 8.5 cm and another one around 11 cm. In OWEZ and REFN, distributions were slightly skewed to the right, and in REFZ, the mode was around 13 cm. The Kolmogorov-Smirnov test showed significant differences between length-frequency distribution of sprat in REFZ and all the other areas: OWEZ ($D=0.22$, $p<0.01$), REFN ($D=0.39$, $p<0.001$), and outside the areas ($D=0.28$, $p<0.001$). Sprat lengths in T5 ranged from 5-10 cm (Figure 5-17). In all areas, length-frequencies were approximately normally distributed with means between 7 cm (REFN) and 8 cm (REFZ). Length-frequencies of sprat in OWEZ were significantly different, slightly larger, from REFN ($D=0.27$, $p<0.01$) and outside the areas ($D=0.21$, $p<0.05$), but not the REFZ ($D=0.10$, $p=0.710$).

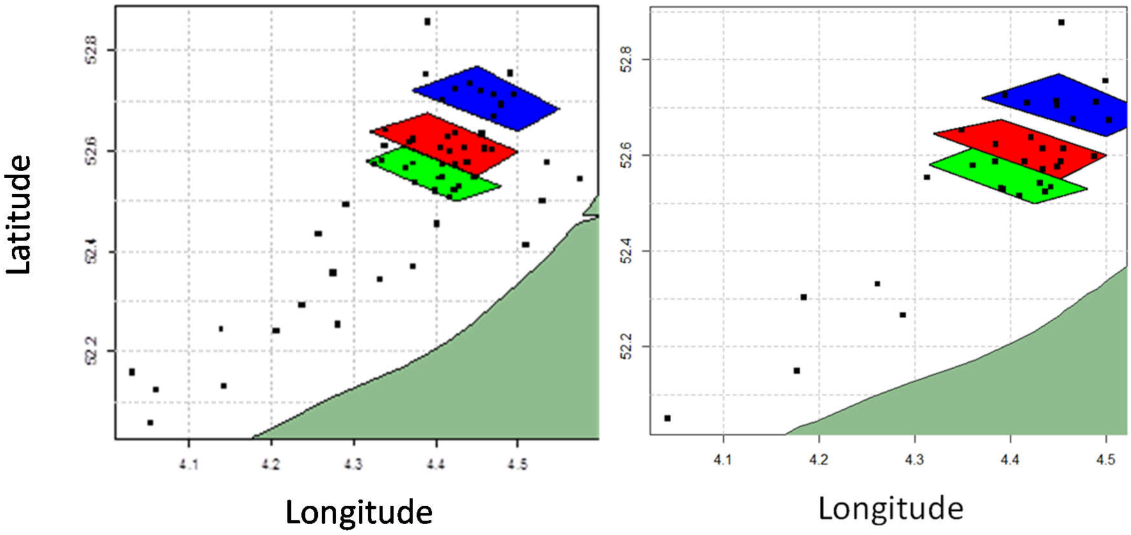


Figure 5-13: Location of pelagic trawl hauls taken during the April 2007 (left) and the April 2011 survey (right). Coloured polygons correspond to the different areas: blue - northern reference area, red - wind farm, green - southern reference area.

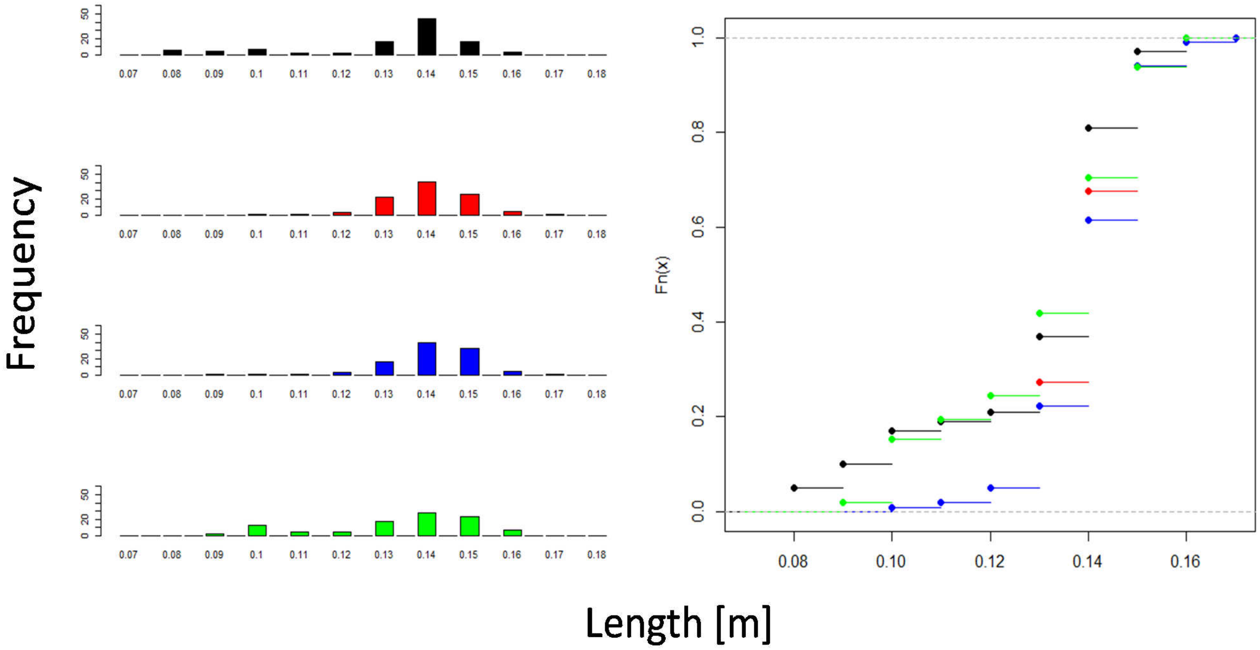


Figure 5-14: (a) density and (b) cumulative length-frequency distribution of ***lesser sandeel (Ammodytes tobianus)*** *in trawl catches taken in April 2011 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*

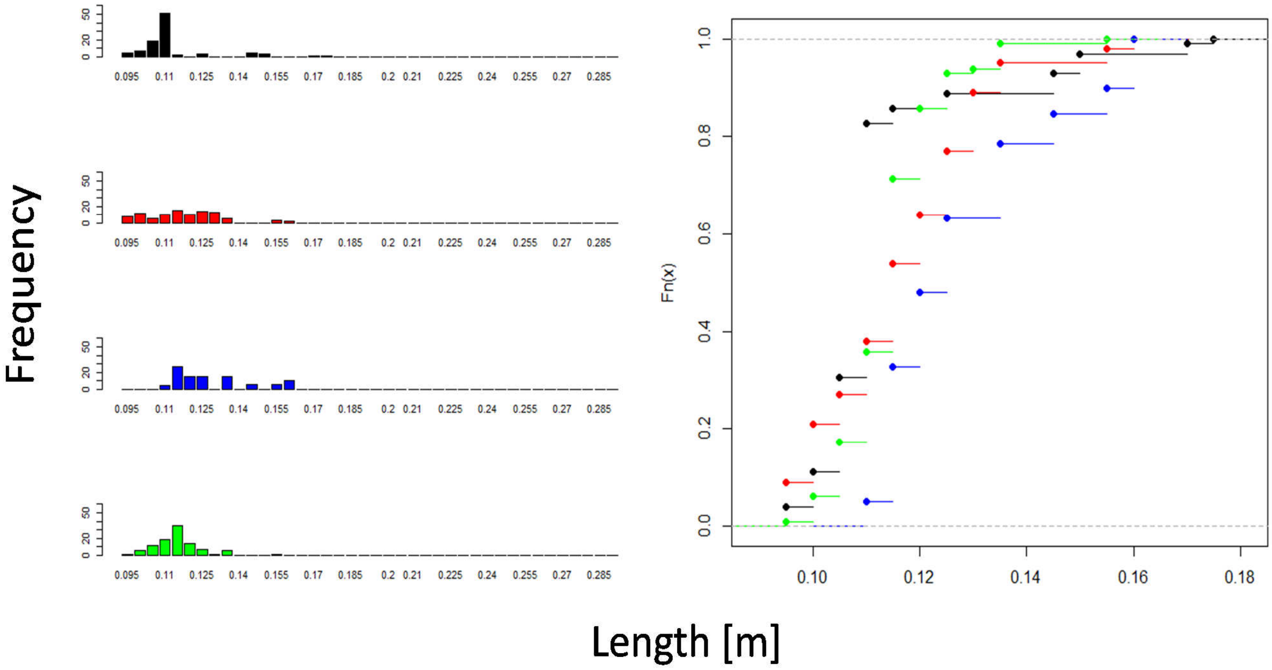


Figure 5-15: (a) density and (b) cumulative length-frequency distribution of ***herring (Clupea harengus)*** *in trawl catches taken in April 2011 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*

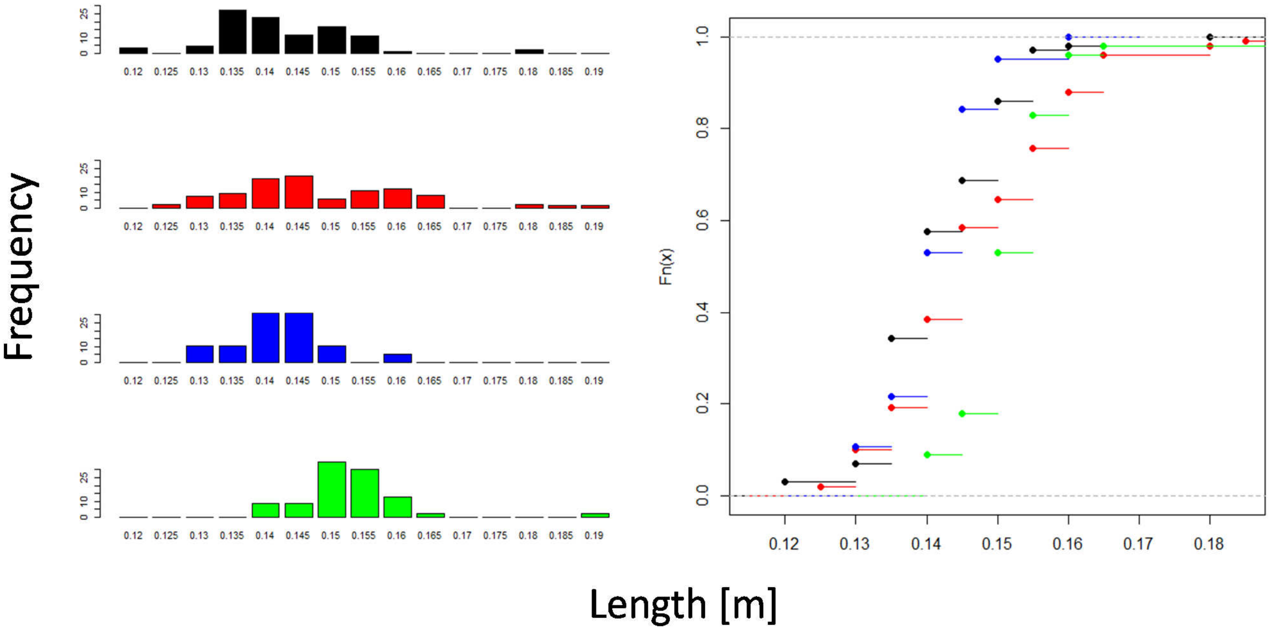


*Figure 5-16: (a) density and (b) cumulative length-frequency distribution of **anchovy (Engraulis encrasicolus)** in trawl catches taken in April 2011 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*

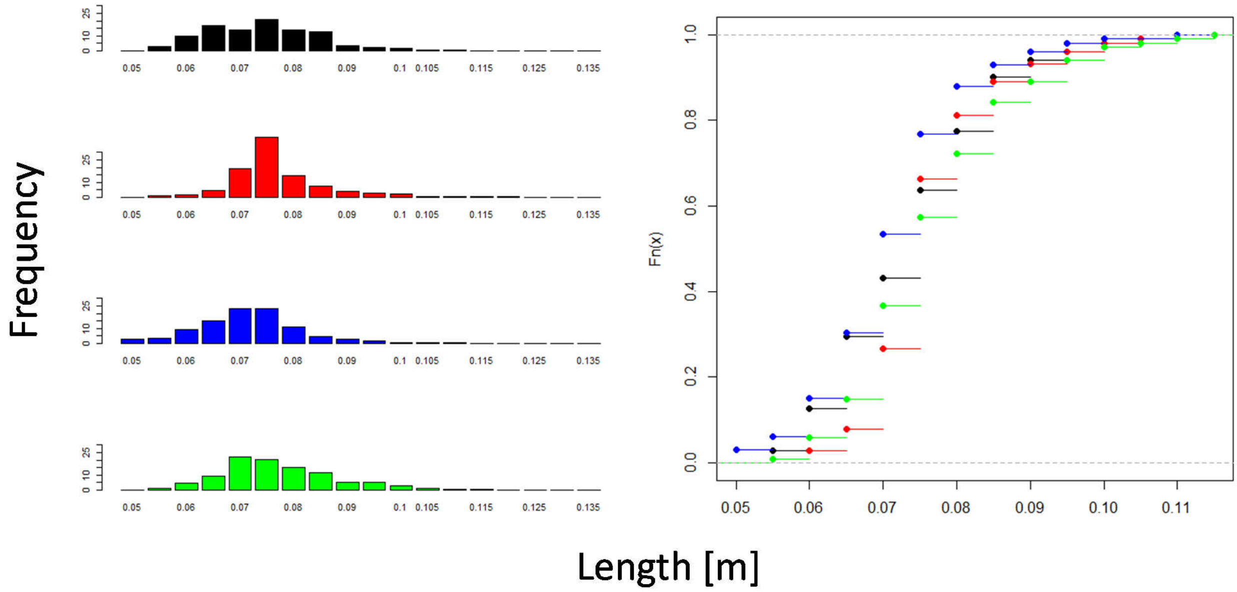


*Figure 5-17: (a) density and (b) cumulative length-frequency distribution of **sprat (Sprattus sprattus)** in trawl catches taken in April 2011 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*

5.4 Discussion

The pelagic fish community in the proximity of OWEZ analysed in the present study consisted mostly of clupeid species (herring, sprat, and sardine) and anchovies. Investigation into the abundance and distribution of these fish species, revealed a high degree of small scale migration and inter-annual variability. In all of the three different time periods analysed (T0, T1 and T5), no significant difference in abundance of the analysed pelagic fish could be observed in the April surveys. This suggests that the wind farm did neither act as an attractant or deterrent. The significant trends observed over time were consistent between all the areas, with an initial decrease from T0 to T1 and a subsequent increase again from T1 to T5 (Figure 5-10). Such results may suggest large scale changes in the local pelagic fish community over the time period analysed that were not influenced by the wind farm. Observed differences in abundance and distribution of pelagic fish observed inside and outside the wind farm may therefore more likely be caused by natural migration and fish behaviour related factors like temperature, salinity, currents or food availability (Slotte et al. 2004). OWEZ and the reference areas are located in the Dutch coastal zone (approximately at 20m depth). Going from coast to open sea there is an increase in water depth and salinity and a decrease in turbidity. Temperature in summer and autumn decreases with distance from coast. In winter the temperature at the coast is relatively warm and increases towards open sea. In spring, specifically in April – the main survey period – coastal water starts to warm up, but the timing differs per year (see paragraph 3). For temperature the wind farm in April is in the middle of a transition zone from high to low temperatures and vice versa in terms of distance and time. Any potential differences may thus be due to the dynamic nature of the coastal zone.


Fishing with the semi pelagic trawl near the wind farm.

The high catches of Raitt's sandeel in April 2007, is an example of how the timing of environmental changes can lead to differences in fish distribution. This species is mainly buried in the sand during winter and starts to swim pelagically during spring. The higher temperatures early 2007 (Figure 3-5) must have triggered the appearance of sandeel earlier than normal. Analysis of the October T5 survey data suggests some differences between the analysed areas. However, these were associated with significant date effects and not consistent, as the wind farm contained mean densities at levels between those of the northern and southern reference areas. Analyses of clupeid and anchovy abundances along transects parallel to the coast, running along depth contours, showed a very weak increase when moving away from the OWEZ in a northern direction (Figure 5-11). Again the result is inconclusive, as the trend was not consistent for all transects and years and most probably again reflected the dynamic nature of the pelagic fish community.

Examination of the length-frequency distributions of the dominant pelagic fish that occurred in the surveys may reveal a protection effect of the wind farm. This could be caused by increased shelter provided by the individual wind turbines and increasing biomass of epifauna. Any effects would have to show a significant difference between length-frequency distributions of individual species inside the OWEZ area from those outside. Slight proof for such a situation could be observed for anchovy and sprat. In T1 and T5, anchovies caught in the OWEZ and the adjacent REFZ, had a significantly larger frequency of larger fish compared to the REFN and the hauls taken outside the specified areas. The same pattern was true for sprat, but only in the T5 survey. For these species, smaller fish may have been an easier target for predators outside the wind farm. Positive effects on length-frequency distributions of fish inhabiting artificial reef structures versus those living outside have previously been observed (Anderson et al. 1989). The Anderson et al. (1989) study provides evidence for the protective function of reef structures and its positive effect on some pelagic fish species. However, an opposite effect in reef fish: natural mortality increased in small preys fish, caused by aggregation of predatory fish near artificial reefs was found in another study (Leitão et al. 2008).

6 Sub-project 3: Effects on fish near the monopiles using gillnets

6.1 Survey Design

6.1.1 *Area*

The monitoring with gillnets was executed only in the wind farm as it was expected that the main changes in fish abundance would be found near the monopiles. The gillnets, a type of static gear, were set near four monopiles and at three locations in between the monopiles. The four selected monopiles were WT21, WT26, WT27 and WT29. These were selected because they have no power cable at the south-eastern side or north-western side. This enables the placement of the gillnets, taking into account the dominant currents, without risks of entanglement and damage to the power cables. For logistic reasons, the three locations in between the monopiles were selected to be in the vicinity of the nets near the monopiles and away from the planned trawl tracks in sub-project 1 and 2 (Figure 6-1).

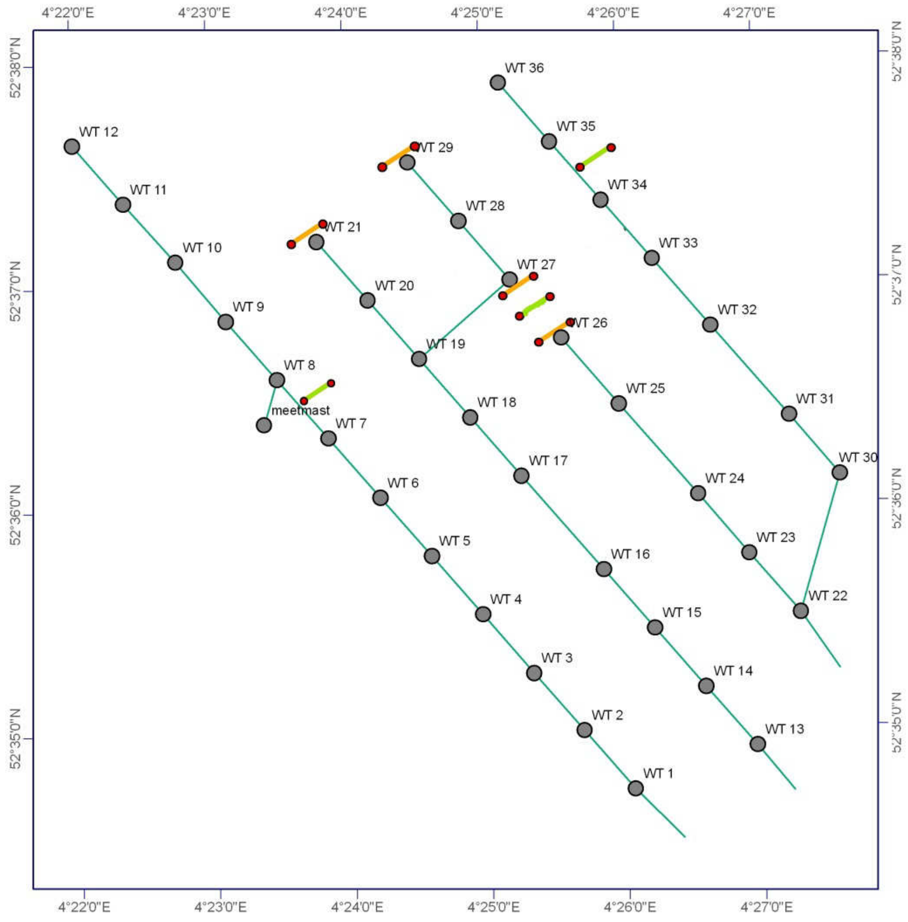


Figure 6-1: Locations of the gillnets, the orange lines represent the locations near the monopiles (WT) and the green lines those in between the monopiles (AT). The grey dots represent the monopiles and the measurement pile and the green lines connecting the dots are the ground cables.

6.1.2 Period

The monitoring with gillnets was only executed in the T5 (2011). Monitoring took place in spring (9, 11, 15 and 18 April), in summer (8, 16, 27 June and 11 and 12 July) and summer/autumn (25, 27, 29 September and 1 October). The complete fieldwork within each season was setting and hauling the nets 4 times. In the second period this was done 5 times as one of the attempts had limited success owing to strong tidal currents (Table 6-1).

Table 6-1: Number of setting events and the number of nets per period. WT= near the monopiles, AT= in between the monopiles.

	P1		**P2**		**P3**	
WT	4	16	5	16 (4 invalid)	4	16
AT	4	12	5	15	4	12

6.1.3 Methods and equipment

Using static gear in a North Sea monitoring program was new for IMARES, and there were no historic plans or regular surveys that could be used for the design of the program. This created the freedom to develop our own gear and plan. The set-up of the fieldwork was however restricted by the strict safety rules in place, due to which many possible gears were not allowed to be used (e.g. trawled gears, fyke nets set on the scour bed, angling).

Commercially used gillnets have a single mesh-size catching a specific target species or length class of species. Here, the goal was to catch all species in the vicinity of the monopiles, therefore a multi-mesh gillnet was used, that is very similar to the gear used by Danish investigations in the Horns Rev 1 Offshore Wind Farm (Leonhard et al. 2011). The smallest mesh size was much smaller than used in commercial fisheries enabling to catch the very small species such as sandeel and dragonet (*Callionymus lyra*). The largest mesh-size used was similar to that used in commercial fisheries for cod. Larger mesh-sizes are used commercially to catch turbot (*Scophthalmus maximus*) or halibut (*Hippoglossus hippoglossus*), but it is unlikely that these would be found near the monopiles.

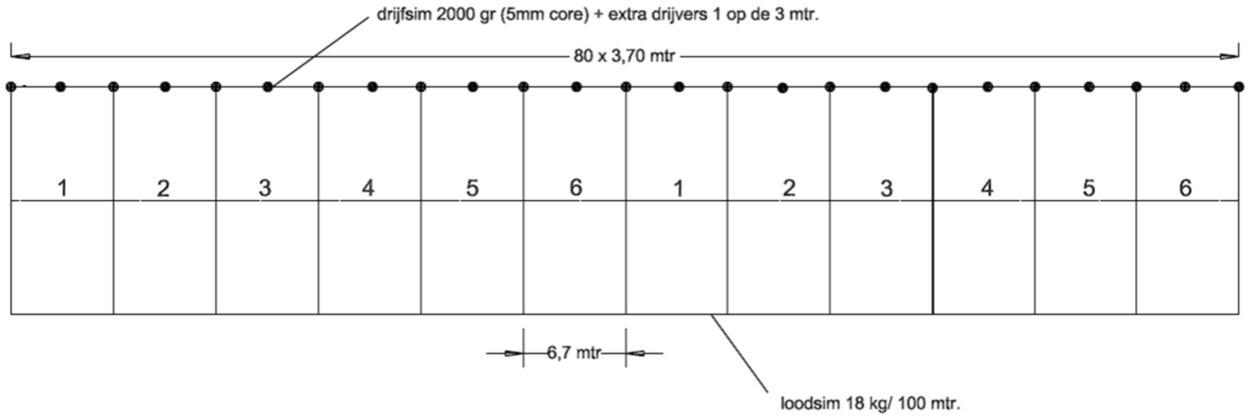
Hauling the multi-mesh gillnet, which caught some clupeids.

In our multi-mesh gillnet, six different mesh sizes were used. Each mesh size formed a single panel of 6.7 m in width and every mesh-size panel occurred twice in each net. A complete net consists of 12 panels and has a length of about 80 m (Figure 6-2). The height of commercial nets rarely exceeds 2 m. However, nets of this height only stand about 1.5 m above the seabed. The aggregations of (pelagic) fish were expected to occur higher in the water column; therefore in a pilot study a 1.5 m and a 3.7 m net were tested. The 3.7 m net was standing higher above the bottom

according to DIDSON recordings of both nets. Furthermore, it caught fish and fish was spread over the full height of the net indicating that the net fished properly.
In total eight nets with a height of 3.7m were made that were used to fish the seven locations shown in Figure 6-1. Each net had another order of the panels such that different mesh sizes were at the ends and in the middle of the net (Figure 6-2), making each of the eight nets unique and randomizes the effect of the different mesh-size panels.

The nets were placed on the ground cable free side of the monopiles, taking account of the predominant current direction. Setting started with the deployment of the anchor outside the scour bed at a distance of about 90 m from the monopiles. Then the net was set on the scour bed as close as possible to the monopile (5-10 m) followed by the second anchor outside the scour bed on the other side. The middle of the net is nearest to the monopile, while the end panels of the net are just outside the scour bed (Figure 6-3). Determining the exact position of the panels in relation to the monopiles was not possible. The nets in between the monopiles were set in the same direction so that the water current acted on these nets in the same way.

The nets were left on their position overnight and then recovered the following day, allowing catching day- and night-active fish. When the nets were hauled, each panel was sorted separately, resulting in 12 different samples per location. The net ID and the mesh size were recorded, such that the order of the panels could be reconstructed. All fish in the nets were identified to species level and measured to the cm-below. Edible crabs (*Cancer pagurus*) were measured to the mm and their gender was recorded, all other crabs were counted.



Net id	panel order
A	1-2-3-4-5-6-1-2-3-4-5-6
B	6-1-2-3-4-5-6-1-2-3-4-5
C	5-6-1-2-3-4-5-6-1-2-3-4
D	4-5-6-1-2-3-4-5-6-1-2-3
E	3-4-5-6-1-2-3-4-5-6-1-2
F	2-3-4-5-6-1-2-3-4-5-6-1
G	2-4-6-1-3-5-2-4-6-1-3-5
H	1-1-2-2-3-3-4-4-5-5-6-6

Panel-number	mesh-size (mm)	material	width of material
1	65	multimonofil	1.5 x 3
2	34	monofil	0.33
3	40	monofil	0.2
4	55	multimonofil	1.5 x 3
5	12	nylon	210/4
6	48.5	monofil	0.2

Figure 6-2: Drawing of the gillnet used, with the order of the panels in the table left and the mesh size and material used for each panel in the right table.

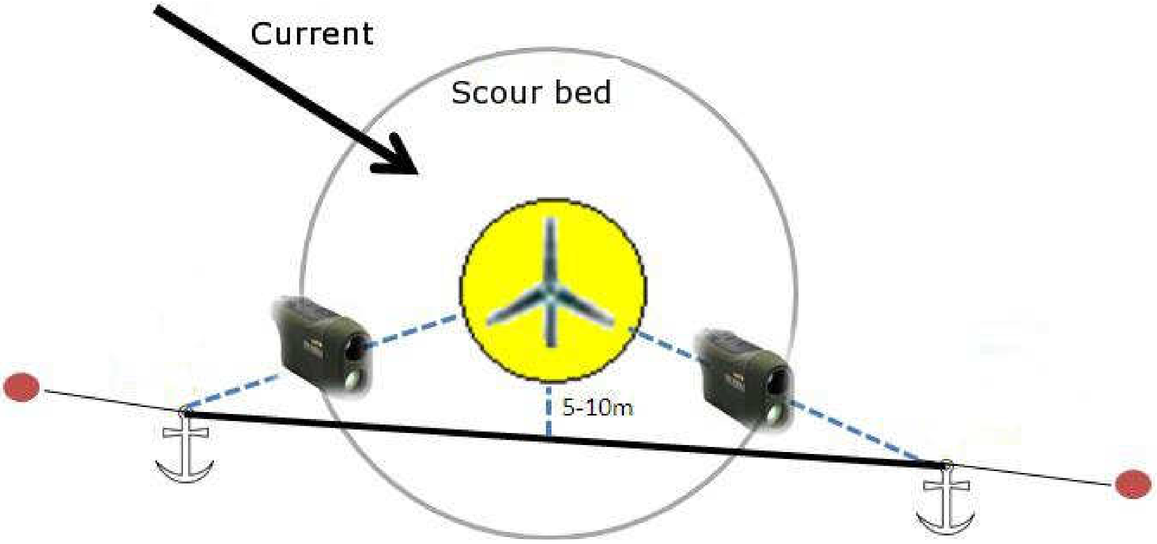


Figure 6-3: Setting the net, taking account of the current. Anchors outside the scour bed with balloon attached to it. Distance between the net and the monopile was 5-10 m. The distance of the anchor to the monopile was measured using a laser meter.

6.2 Analysis

The analysis of the gillnet data had to answer if 1) other species occurred on the new habitat near the monopiles; 2) the composition of the fish community differs; 3) the length composition differs and4) which species were visible on the DIDSON recordings near the monopiles. Added to these questions is the seasonal variation.

The first question is answered by the overview of the species caught (Table 3-2) and the seasonal variance of the occurrence of species is presented.

The second question is answered using a non-parametric statistical method. This method is able to test if species occurred more often in the nets in the vicinity of the monopiles (WT) or on the sandy bottom area in the middle of the farm (AT), without the assumptions and limitations of parametric tests.

The analysis is done per species and season. The available data was the number of individuals per species caught in each panel of a net. For each net the mean over the 12 panels was calculated ($\bar{X}_{\text{net1}}$, $\bar{X}_{\text{net2}}$ etc.). Thus for season 1, 28 mean values were calculated of which 16 were from nets near the monopiles (WT) and 12 from the sandy bottom (AT). Per habitat (AT or WT) the mean over the nets was calculated resulting in two values ($\bar{X}_{\text{AT}}$ and $\bar{X}_{\text{WT}}$). The difference between these two is the observed difference ($\bar{X}obs$, $\bar{X}obs = \bar{X}_{\text{AT}} - \bar{X}_{\text{WT}}$). A negative values for $\bar{X}obs$ indicates that the mean number of individual fish caught near the monopiles larger is than on the sandy bottom and the opposite. While a value for $\bar{X}obs$ around 0 indicates that the mean values of the nets in both habitats were very similar.

To test the null-hypothesis that the catches in the WT-nets are equal to those in the AT-nets, a randomisation is performed. Each mean value of a single net ($\bar{X}_{\text{net1}}$, $\bar{X}_{\text{net2}}$ etc.) was randomly assigned to a location, either WT or AT, keeping the number of nets placed at WT and AT the same as in the original survey design (see the example below). For the new distribution of the nets over the locations the mean per habitat is calculated, and these are subtracted from each other resulting in a value ($\bar{X}run1$) comparable to $\bar{X}obs$. This randomisation of the nets was done a 1000 times, resulting in $\bar{X}run1$ to $\bar{X}run1000$ plus $\bar{X}obs$, in total 1001 values.

Example:

Habitat	Run1	Run2	Run1000
AT	Net1	Net4	Net2
AT	Net2	Net2	Net3
WT	Net3	Net1	Net1
WT	Net4	Net3	Net4

The 1001 outcomes were ranked from lowest to highest. The rank that is assigned to $\bar{X}obs$ indicates how "extreme" the original observation was in comparison to randomly distributing the catches over the locations. Using a significance level of 0.05 means that all ranks smaller then 26 and larger than 974 reject the null-hypothesis (catches in WT and AT are equal). Working with a significance level of 0.1, all ranks smaller then 53 and larger than 948 reject the null-hypothesis. Rejecting the null-hypothesis means that there is a significant difference in catches between the two habitats.

This paragraph describes a similar randomisation analysis performed on only the data from the nets near the monopiles (WT). The length of each net is 80 m and it was set in a straight line, therefore it was impossible to set the total net close to the monopile or even on the scour protection. Furthermore, for safety reasons, each anchor had to be placed outside the scour protection and therefore at least the first and the last panels of each net were outside the scour protection.

For these analysis each net was split in a middle section, being the middle 6 panels, placed nearest to the monopile and very likely on the scour protection. The 3 outer panels on each side (also 6 panels) were combined and named the transition zone. For these panels it is assumed that they are placed on the sandy bottom or on the edge of the scour protection. In this setup, two means are calculated per net, e.g. the mean value of fish over the 6 panels in the middle (scour protection) and the mean value over the outer 6 panels (transition zone). Now, a similar randomisation procedure was performed redistributing the means per net for the scour protection and those for the transition zone. After which the mean per zone is calculated and subtracted from each other. The original observed value is then again compared to those of the 1000runs.

The third question focusses on the length composition of the fish community near the monopiles. For this a length-frequency (LF) was determined for each habitat (WT vs. AT) and also for each zone (scour bed, transition zone). Furthermore, summary statistics, mean and median lengths were calculated per habitat or zone. It was tested, using analysis of variance and Tukey multiple comparisons of means, with a confidence level of 95%, if these mean lengths differed between the habitats or zones.

The fourth question is related to sub-project 4 the DIDSON (chapter 7). It was not possible to identify species on the DIDSON images, therefore the gillnet catches were compared to the fish seen on the DIDSON images. The DIDSON can only discriminated fish that swim above the bottom, making it very unlikely that the fish on the DIDSON images are flatfish. Therefore the flatfish are removed from the gillnet data and the comparisons with the DIDSON are done based on the non-flatfish part of the gillnet catches. For this part the length data is presented in the same way as described for question three.

A further comparison with the DIDSON data is done based on the ratio of the number of fish between the three zones (scour protection, transition zone and sandy habitat). This is calculated by summing all non-flatfish species per panel and then calculating the mean over the panels per (part of the) net. Followed by the mean over the nets per zone. In this way, for each zone a mean catch per period is calculated, the ratio between the catches per period is visualised.

6.3 Results

6.3.1 Species

In all gillnets set during this project 3092 individuals were caught, consisting of 34 different fish species (Table 3-2) and three invertebrate species. The most abundant ten species accounted for 92% of the individuals caught. With the most abundant species being edible crab (*Cancer pagurus; N=879 fraction=0.28*), secondly dab (*Limanda limanda; N=734 fraction=0.23*) and thirdly sole (*Solea solea; N=519 fraction=0.17*). It were also ten species that were caught in all three periods, all other 24 species were missing in at least 1 period.

Two species, grey triggerfish (*Balistes carolinensis*) and goldsinny wrasse (*Ctenolabrus rupestris*), were exclusively caught in the gillnets. For both species a single individual was caught in a net set near a monopile, respectively WT29 and WT26. These two species are rarely caught in IMARES surveys in the North Sea, with only very few observations in all the fishing done since 1970.

The first period (P1) spring:
One Ammodytes sp. was caught. This is the only record of sandeel in the gillnets.
The large number of solenette (*Buglossidium luteum*) in the first period stood out with 82% of all individual solenette caught in the three periods.

The second period (P2) summer:
Seven species were caught only in this period, among others striped red mullet (*Mullus surmuletus*), sprat and lemon sole (*Microstomus kitt*).
Furthermore, the large number of mackerel (*Scomber scombrus*) with 87% of all individual mackerel caught in the three periods, horse mackerel (*Trachurus trachurus*) with 99% of all individuals and herring with 95% of all individuals stood out.

The third period (P3) summer/autumn:
Eight species were only caught in the third period, all single individuals except for sea scorpion (*Taurulus bubalis*) and hooknose (*Agonus cataphractus*).
The large number of bib (*Trisopterus luscus*) with 91% of all individuals caught in the three periods was striking.

6.3.2 Vicinity of monopile versus sandy bottom

Owing to the large seasonal variation in the occurrence of species, the non-parametric analyses to test if the null-hypothesis (catches near the monopiles are similar to those on the sandy bottom) were performed per period (Table 6-2). Period $\bar{X}obs = \bar{X}_{AT} - \bar{X}_{WT}$ was calculated as the observed difference between At and WT. A negative value indicates dominant presence of the species near the monopiles and on the scour protection, while a positive value indicates dominant presence on the sandy bottom. The observed difference $\bar{X}obs$ is compared to the values of the 1000 runs. Some examples of the distribution of $\bar{X}run1$ to $\bar{X}run1000$ are shown in Figure 6-4, with $\bar{X}obs$ as a red line. The extremer $\bar{X}obs$ is compared to the distribution of the randomisation outcomes the less likely it is that the observed difference occurred by chance. Thus in the first two examples it is very unlikely that it occurred by chance and therefore the null-hypothesis is rejected. While in the third example the null-hypothesis is not rejected, e.g. no significant difference observed between catches near the monopiles and those on the sandy bottom.

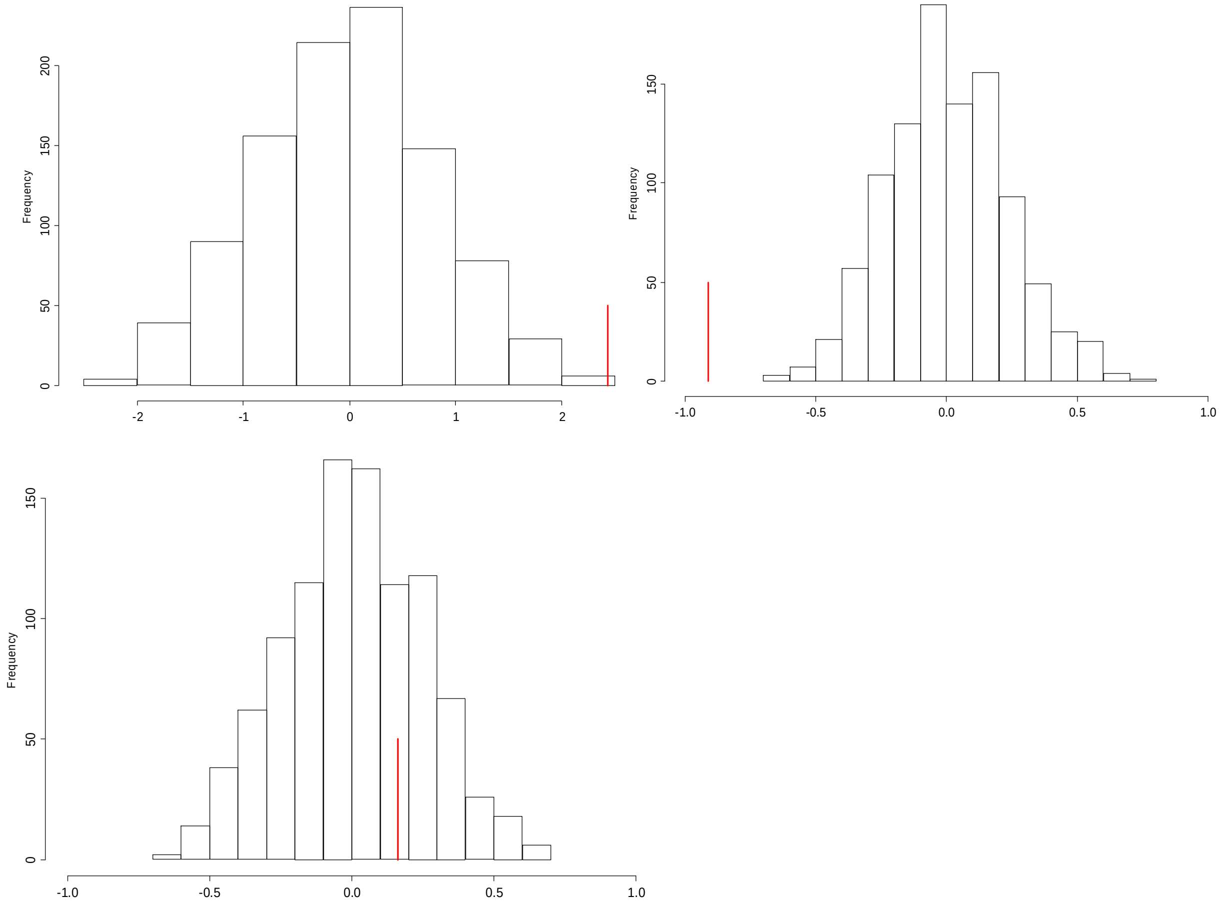


Figure 6-4: Three examples from period 2 of the distribution of $\bar{X}run1$ *to* $\bar{X}run1000$, $\bar{X}obs$*, the actual observed value is the red line. Upper left: Dab with* $\bar{X}obs$ *far right; Upper right: Cod with* $\bar{X}obs$ *far left; Under: Horse mackerel with* $\bar{X}obs$ *in the middle.*

Seven species indicated significant dominant presence in the new hard substrate habitat near the monopiles compared to the sandy bottom. Cod and edible crab had a rank of 1, which indicates a very strong dominant presence. Bib was not caught in the first period, but shows a significant dominant presence in the second and third period, while common dragonet and the sea scorpion indicate dominant presence only in the third period. Bullrout and velvet crab indicate a dominant presence only in the first two periods.

Four species indicate the opposite, significant dominant presence on the sandy bottom. Three of the four are flatfish species, dab, sole and solenette, the fourth species being whiting. The other flatfish species caught in reasonable numbers is plaice, plaice showed a slight dominant presence on the sandy bottom as well, however its rank was not significant.

The pelagic species horse mackerel, mackerel, herring and sprat showed no significant difference indicating that the catches in AT and WT were similar.

*Table 6-2: The rank of the randomisation of nets in the vicinity of the monopiles (WT) and those on the sandy bottom (AT) by species and period. (**Bold values:** two-tailed P-value<0.05; underlined values two-tailed P-value <0.1), blue is lower presence in the vicinity of the monopiles; red is dominant presence near the monopiles. Grey is not caught, while blank is caught but in too small numbers to perform the analysis (#<9).*

Dutch name	English name	Scientific name	P1 spring	P2 summer	P3 summer autumn
Dwergtong	Solenette	Buglossidium luteum	**998.5**	973.5	
Pitvis	Common dragonet	Callionymus lyra	109		**19**
Noordzee krab	Edible crab	Cancer pagurus	**1**	**1**	**1**
Haring	Herring	Clupea harengus		648	▨
Kabeljauw	Cod	Gadus morhua	**1**	**1**	**1**
Schar	Dab	Limanda limanda	**1000**	**1001**	**1000**
Wijting	Whiting	Merlangius merlangus	886.5	**1000**	**966**
Mul	Striped red mullet	Mullus surmuletus	▨	327.5	▨
Zeedonderpad	Bullrout	Myoxocephalus scorpius	**15.5**	**17.5**	64.5
Fluwelen zwemkrab	Velvet crab	Necora puber	**23**	**3**	126.5
Schol	Plaice	Pleuronectes platessa	762.5	937.5	891.5
Makreel	Mackerel	Scomber scombrus	▨	785	788
Tong	Sole	Solea solea	**996**	887.5	**1000.5**
Sprot	Sprat	Sprattus sprattus	▨	837.5	▨
Groene zeedonderpad	Sea scorpion	Taurulus bubalis	▨	▨	43
Horsmakreel	Horse mackerel	Trachurus trachurus	▨	746.5	
Steenbolk	Bib	Trisopterus luscus		**4.5**	**3**

6.3.3 Scour protection versus transition zone

On a smaller scale spatial, close to the monopile versus just outside the scour protection differences in presence of species are possible. Therefore similar randomisation analyses were done using only the data of catches in WT-nets, splitting this in two zones: scour protection and transition zone. These analyses were performed for all periods combined; by period the catches of most species were too small to perform the analyses.

Significant larger catches on the scour protection versus transition zone were shown for common dragonet (rank 39), cod (rank 11), edible crab (rank 12), bullrout (rank 27), velvet crab (rank 46) and sea scorpion (rank 17). For these species the analysis AT vs. WT would indicate an even larger dominance than presented in Table 6-2 if the complete net was placed on the scour bed.

Significantly smaller catches on the scour protection versus transition zone were shown for plaice (rank 953). Combining this with the results in Table 6-2 indicates that plaice has a lower presence in the vicinity of the monopiles compared to the sandy bottom.

Although not significant, also whiting (rank 921), turbot (rank 942) and sole (rank 905) showed smaller catches on the scour bed compared to the transition zone. The dominant presence of these species on the sandy bottom on the spatial scale of the wind farm (Table 6-2) is also shown on the smaller spatial scale near the monopiles.

6.3.4 Length distribution of fish

Overall the length distribution of fish caught in the gillnets had a median of 21.0 cm and a slightly higher mean of 21.9 cm. The smallest fish caught was 6 cm (solenette) and the largest was 58 cm (cod). These values varied only slightly between the periods, where period 3 had a mean of 20.8 cm, period 1 a mean of 21.5 cm and period 2 a mean of 22.6 cm.

There was some difference between the habitats, the mean length near the monopiles was 23.3 cm, while the mean length on the sandy bottom was 20.6 cm and splitting the nets near the monopiles (WT) resulted in 23.7 cm on the scour protection and 22.9 cm in the transition zone.

Using an analysis of variance (AOV) combined with a Tukey-test, a significant difference in mean length is found between the three zones for all fish and for non-flatfish. It shows that the mean length in the sandy bottom habitat is significantly smaller than in the two other habitats (Table 6-3).

The length frequencies (LF) are presented by WT and AT for the different periods in Figure 6-5, for the three different zones in Figure 6-6, The first figure shows that in all periods more of the larger fish (>35 cm) occurred near the monopiles (WT). The other two figures show that these larger fish were caught on the scour bed as well as in the transition zone.

In total 120 specimens were caught with a length larger than 35 cm. Of these, 104 were caught in WT-nets. The main species having a larger length were cod (WT 90; AT 6), sole (WT 7; AT 5) and mackerel (WT 1; AT 5).

Table 6-3: The results of analysis of variance of the mean length of all fish. The difference in mean between zone1 and zone2, the lower and upper limit the 95%-confidence level and the adjusted p-value.

Zone1	**Zone2**	**difference in mean**	**lower limit**	**upper limit**	**Adjusted p-value**
scour bed	sandy bottom	3.06	2.16	3.96	**0.000000**
transition zone	sandy bottom	2.24	1.30	3.18	**0.000001**
transition zone	scour bed	-0.82	-1.91	0.27	0.1794650

The length frequencies for mackerel, horse mackerel, bib and cod are presented in appendix D. Their seasonal occurrence is clearly visible in these figures (Appendix figure D-2, Appendix figure D-3, Appendix figure D-4, Appendix figure D-5, Appendix figure D-6), as well as the differences between the lengths of the fish caught in WT or AT. Mackerel is only caught in period 2 and 3 and shows no difference between the locations. Horse mackerel, except a single individual, is only caught in period 2 and shows slightly larger individuals caught in WT.

Bib shows no catches in AT in period 1 and 2, in period 3 the catches in AT were slightly smaller than in WT. However, this smaller length range was caught in WT in period 2. Cod was caught in all periods and mainly shows a difference in catches between WT and AT.

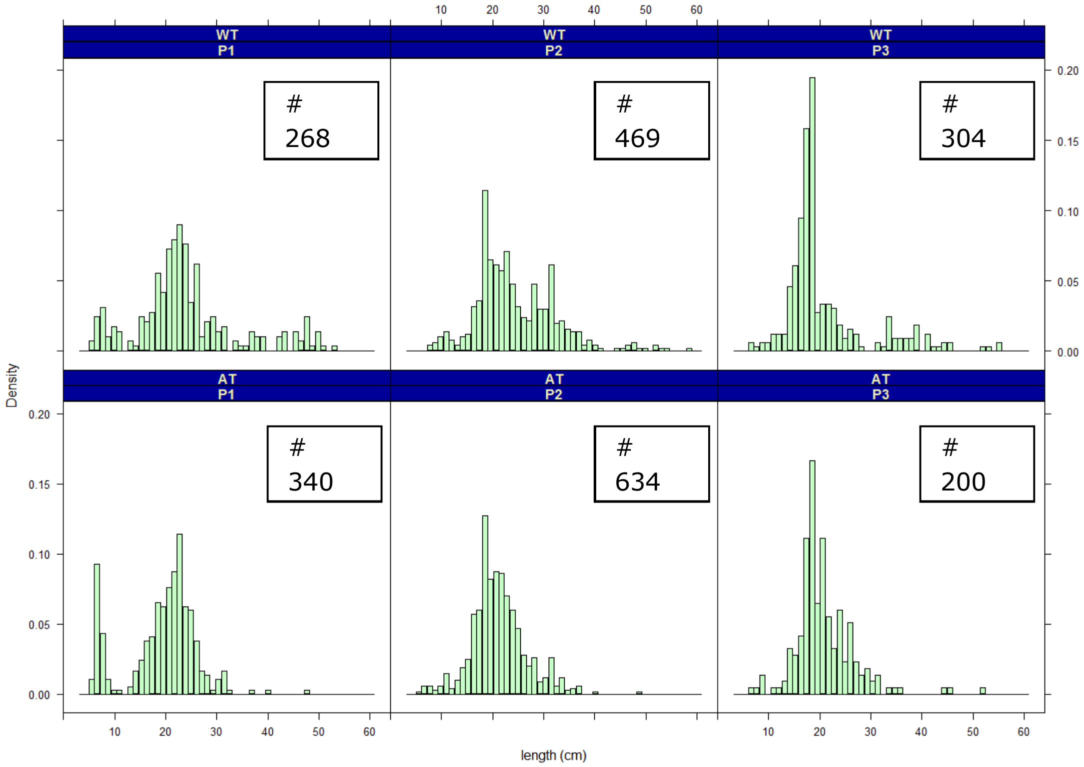


Figure 6-5: Density plot of the length of all fish species per period (P1=spring, P2=summer, P3=autumn). Upper row are results from the WT-nets and the lower row from the AT-nets. The values in the right corner are the total number of fish in that figure.

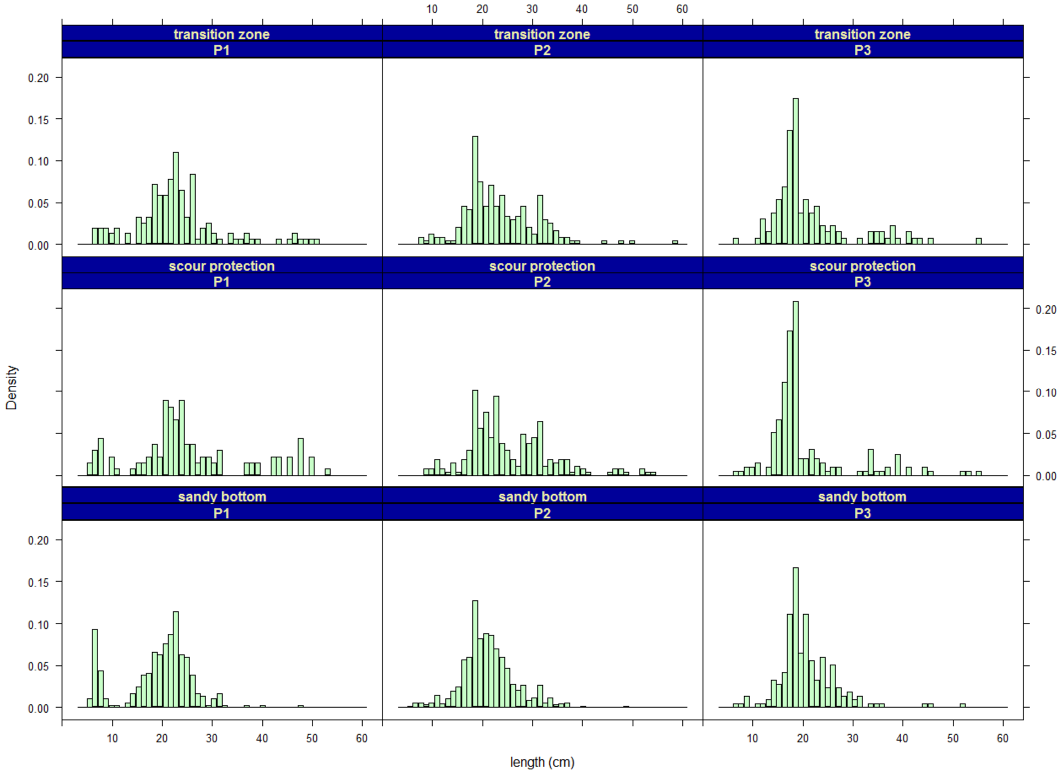


Figure 6-6: Density-plot of the length of all fish species per period (P1=spring, P2=summer, P3=autumn). Upper row are results of the transition zone, middle of the scour protection and the lower row of the sandy bottom.

6.3.5 Comparison with the DIDSON

To compare the catches in the static gear with those in the DIDSON observations, the flatfish are removed as it is unlikely that flatfish are visible on the DIDSON images.
If the flatfish species are excluded from the data, the mean length increase. The overall mean length becomes 24.8 cm. For the catches near the monopiles it becomes 25.6 cm and on the sandy bottom 22.8 cm. For this data the mean length of the transition zone (25.9 cm) is slightly larger than the mean length on the scour protection (25.5 cm). However, this is not significantly different (Table 6-4). The length frequency of the data without flatfish is presented in Figure 6-7.

Table 6-4: The results of analysis of variance of the mean length of all non-flatfish. The difference in mean between zone1 and zone2, the lower and upper limit the 95%-confidence level and the adjusted p-value.

Zone1	**Zone2**	**difference in mean**	**lower limit**	**upper limit**	**Adjusted p-value**
scour bed	sandy bottom	2.71	0.69	4.72	**0.00470**
transition zone	sandy bottom	3.16	0.85	5.46	**0.00383**
transition zone	scour bed	0.45	-1.68	2.58	0.87348

For comparison with the number of fish seen in the different habitats, the percentage of the number of non-flatfish species per habitat and season is visualised (Figure 7-7 d). This indicates that the ratio of non-flatfish species in the second period was higher on the sandy bottom compared to the other two periods (or the numbers on the scour bed were lower).

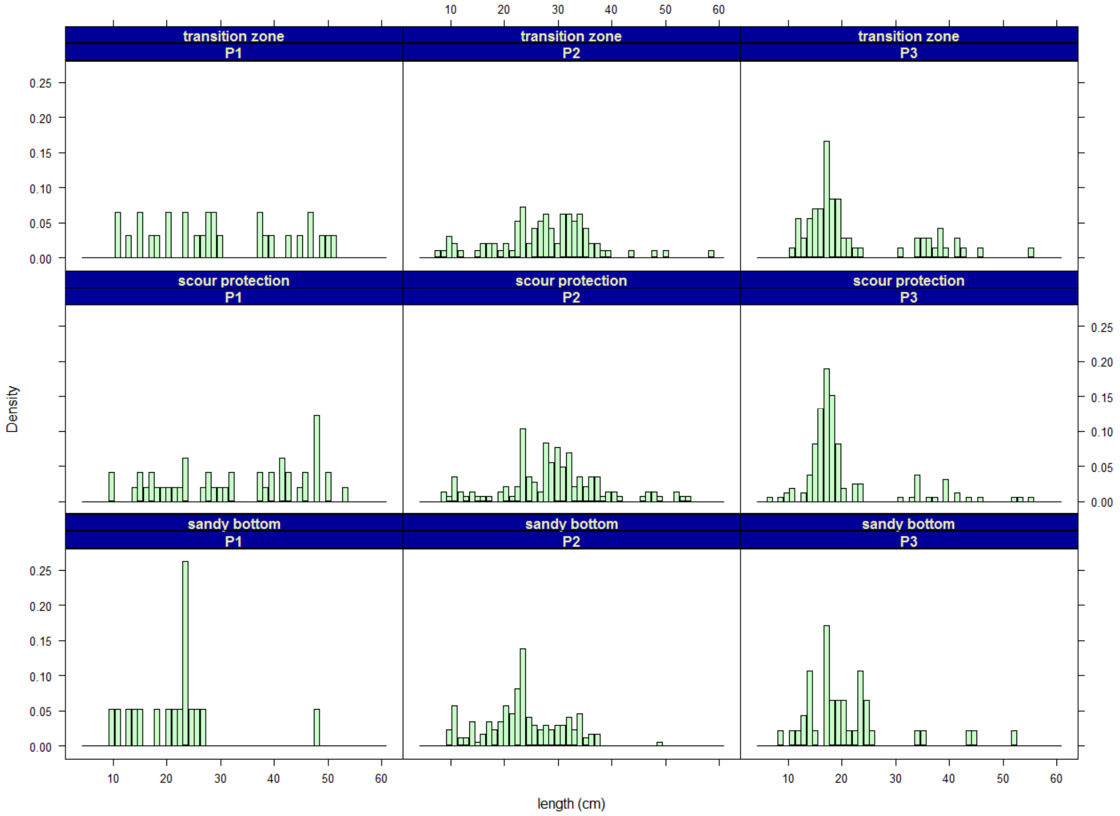


Figure 6-7: Density-plot of the length of all non-flatfish species per period (P1=spring, P2=summer, P3=autumn). Upper row are results of the transition zone, middle of the scour protection and the lower row of the sandy bottom.

6.4 Discussion

The catches in the gillnets show that there are clear differences in the use of the wind farm habitats by different species. The results confirmed many of the expectations. It was expected that the hard substrate attracts fish species as bib and cod but also species such as edible crab (Langhamer & Wilhelmsson 2009). Avoidance of the scour bed was expected for many of the flatfish species as their normal habitat is the sandy North Sea bottom, in which they can dig in themselves. Even though many features influence the catches of the gillnets, the collected data proved robust enough to determine significant effects between the different habitats.
Gillnets are a passive gear which means that they can only catch fish when the fish are active, and swim into the net themselves. This means that numbers caught reflect both abundance and activity. That the species have to swim into the net makes it possible for them to avoid the net when they see it. A smaller mesh size is better visible and also entangled fish or crab in the panels improves the visibility of the net. This reduces the chance of more fish entering the net. Entangled fish and especially crab not only make the panel more visible, but also lowers the height of the net. In case of many crabs the whole net sticks together. As much more crab were found near the monopiles this happened more often on the scour bed than on the sandy bottom. This means that larger abundance and/or activity might be masked in the catches here.

The gillnets were 3.7m in height, this however does not mean that the net was standing 3.7m above the seabed. Depending on the current, the net is straighter or more curved, meaning a different height over a tidal phase. This means that it is not certain till which height above the bottom the net has fished. DIDSON images showed that one of the nets was at that time at least 1.5 to 2m above the seabed. This means that only the lowest part of the water column is fished, even though some pelagic species have been caught in the nets. The catches of sprat, herring and sandeel were however lower than could be expected for these species based on the abundance of these species in the other surveys.

When our findings are compared with other studies, the most striking differences were the lower presence in the scour protection area by whiting and the result for mackerel and horse mackerel showing no attraction to the monopiles.
In the North Hoyle offshore wind farm (UK) large shoals of juvenile whiting were observed feeding on the amphipod *Jassa falcata* from the underwater structures of the monopiles (May 2005). *Jassa* sp. were observed in high numbers on the monopiles of OWEZ as well (Bouma & Lengkeek 2009). However, in our data more whiting individuals (n=51) were caught in the nets on the sandy area. The individuals caught here were mostly in the range of 15-25 cm, but also the smallest whiting of 10 cm was caught in the sandy habitat. The limited numbers of whiting (n=21) caught in the nets near the monopiles had similar lengths. Looking at the results it is important to remember that a higher number of nets was placed near the monopiles, making the difference larger. Potentially there is a difference in behaviour of fish near the monopiles compared to those on the sandy bottom. It is likely that in the sandy habitat they are near the bottom the whole time, increasing the catchability of our nets. While near the monopiles it could be that they are higher in the water column feeding on *Jassa* sp. distributed over a large part of the underwater structure, reducing the catchability for the gillnets. Another explanation could be competition or interference with other species in the small habitat around the monopiles.

Similar behavioural differences might be the explanation for the results for mackerel (n=68, 22 – 37 cm) and horse mackerel (n=100, 14 -34 cm). Another more likely explanation for these species, however, is a difference in behaviour during day and night. In daylight the mackerel might be attracted by the monopiles, while at night they use the larger area of the wind farm and are caught

in the AT nets. This might also explain the difference between the DIDSON observations in period 2, more fish on the scour protection, compared to the gillnet results in that same period, with more non-flatfish in the sandy habitat. The length distribution of mackerel is similar in the different habitats.
The length distribution of horse mackerel indicates that on the sandy bottom the full length range is caught, while slightly larger horse mackerel were caught near the monopiles. That the smaller individuals are found on the sandy bottom was shown near the Belgian wind farm as well. Contrary to our findings, no larger horse mackerel were found on the sandy bottom (Reubens et al. 2011a). However their results were based on beam trawl data which makes it unlikely that they would catch the larger horse mackerel, related to the catchability of the species. The gillnets used here, thus presents probably a better comparison, however still affected by the behaviour of the fish species.

7 Sub-project 4: Effects on fish near the monopiles using the DIDSON

7.1 Introduction

7.1.1 *Earlier research in wind farms using the DIDSON*

Artificial substrate introduced by the construction of a wind farm, could attract several fish species in search for e.g. refuge or food or deter fish species by disturbance. To our knowledge limited research has been done to investigate the effects of artificial substrate within a wind farm on fish abundance and behaviour. This sub-project focusses on the possible effects of the artificial reef upon fish. The abundance and behaviour of fish in relation to the monopiles was observed using a DIDSON (Dual-Frequency Identification Sonar). The DIDSON is a high frequency sonar outside the hearing range of fish and therefore a useful tool to get insight in fish behaviour and fish abundance. Using this method, negligible disturbance by the researchers in the field is assumed. With the DIDSON, individual fish can be counted and measured and linked to the local habitat and distance to the monopile.

Previous work with the DIDSON in OWEZ was done in the WE@SEA-project (Couperus et al. 2010). The main purpose of this study was to analyse if potential higher abundances of fish near the monopiles caused underestimation of the abundances calculated based on the pelagic survey that was not allowed within 200 m of the monopiles. The DIDSON results from June 2009, indicated higher abundances of fish near the monopiles, but these aggregation were unlikely large enough to cause underestimations in the pelagic survey abundance estimates.

The number of recordings produced within the WE@SEA-project was limited and only from summer. Furthermore, it was impossible to identify species based on these DIDSON observations, therefore it would be beneficial to combine the DIDSON observations with a method to obtain information on species composition and identification (e.g. gillnets).

7.2 Survey Design

7.2.1 *DIDSON*

The high resolution DIDSON sonar (http://www.soundmetrics.com/) uses acoustic lens technology which forms acoustic images with greater detail than found in conventional sonars. DIDSON allows observing fish (behaviour) in turbid water. Methods for processing fish counts are available in the DIDSON software. The DIDSON is relatively easy to handle, operating it from a small boat allows for a close, but safe approach to the monopiles. The standard DIDSON operates at two frequencies and provides images of objects from 1 m to over 30 m in range. Considering the average depth of the wind farm which is approximately 17-20 m, the DIDSON was only used in low frequency mode (1.1 MHz, 7 – 9 frames per second) perpendicular to the seabed floor, to cover the whole water column from surface to bottom.

7.2.2 *Interpretation of the DIDSON videos*

Previous studies of the DIDSON suggested that a vertical position (perpendicular to the seabed floor) of the equipment is the best way to collect data for this study (Couperus et al. 2010). Therefore the DIDSON was fixed in a vertical position on a frame placed on the boat (Figure 7-1). Placing the DIDSON in a vertical position, results in an image parallel to the seabed floor. The videos are showing an image from the surface of the water to the sea bed floor (Figure 7-1). Individual fish counts are possible; however, the vertical position is likely to lead to an underestimation of the number of fish within a school, since the DIDSON image lacks depth of field. This should be taken into account in a quantitative comparison with other studies.

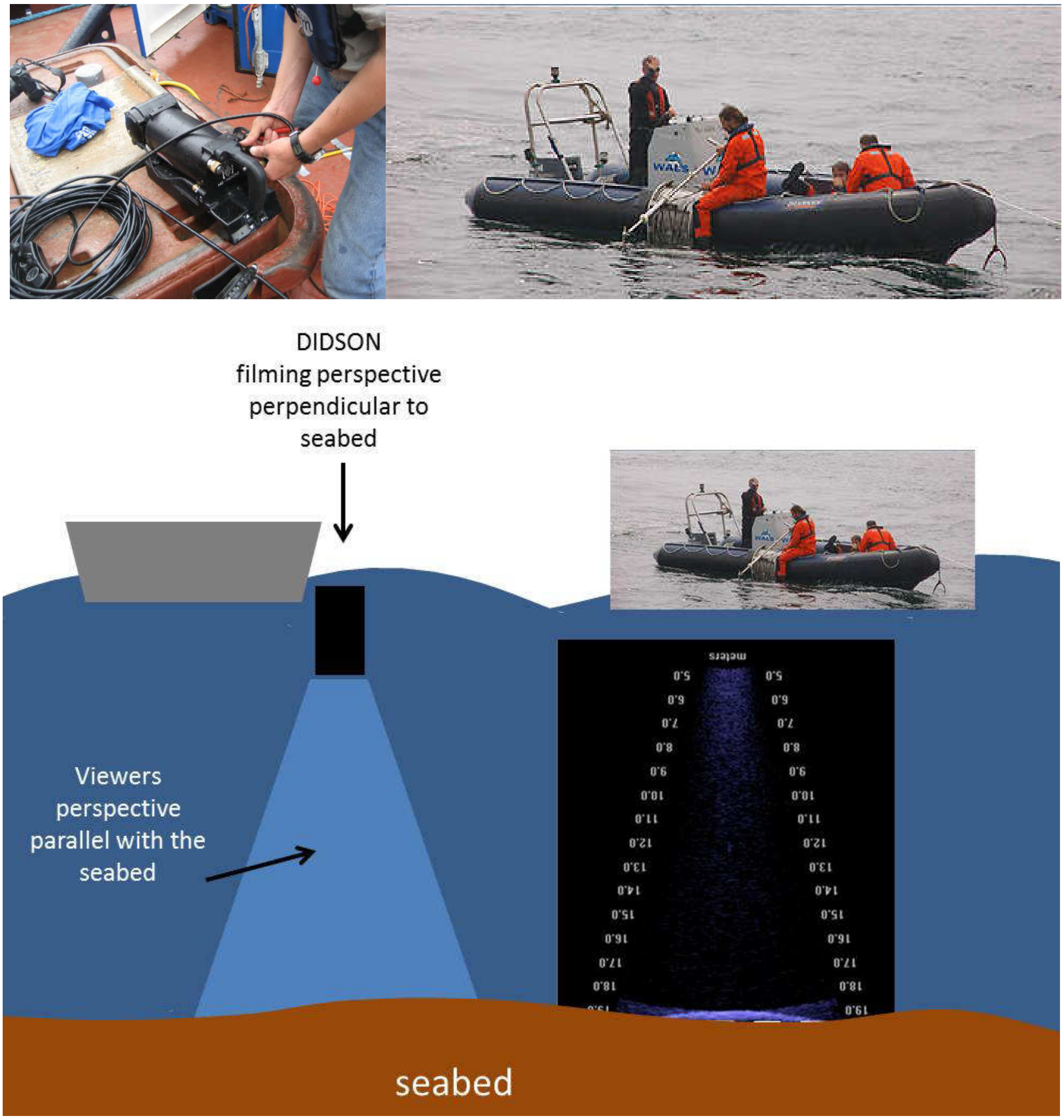


Figure 7-1: DIDSON experimental setup. Top left: The DIDSON. Top right: The DIDSON fixed on a frame. The DIDSON filming perspective was perpendicular to the seabed floor. This will result in an image parallel with the seabed floor as shown in the figure bottom right.

7.2.3 Sampling period

The DIDSON monitoring was only executed in the T5 (2011) in the wind farm. Monitoring took place in spring (14 and 18 April), in summer (5 July), and in autumn (24 and 30 September). This overlapped with the gillnet periods. Due to poor weather conditions the data collected on the second day in summer could not be used.

7.2.4 Sampling design

Each of the five sampling days, the DIDSON recorded continuously for approximately 6 hours, producing videos of 5 minute intervals each. The RIB sailed between the monopiles in a straight line, while monopiles were circled as close as possible (Figure 7-2). As many as possible monopiles per sampling day were monitored (Figure 7-3). In all, 29 hours and 30 minutes of DIDSON recordings were collected during five field trips divided over the three periods. These recordings cover a total distance of 98.4 km (Table 7-1).

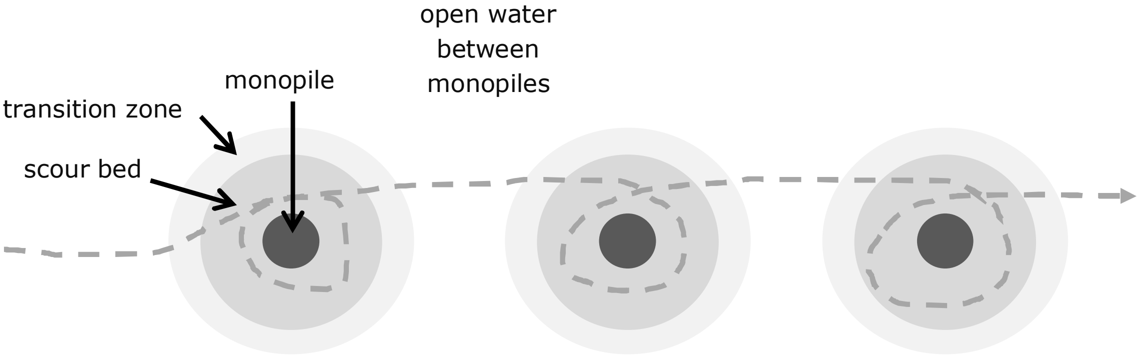


Figure 7-2: Top view of sampling design: The boat sailed around the monopiles (dark grey) and in a straight line between the monopiles. This results in videos of three habitats: Open water (white), transitions zone (light grey) and scour bed (darker grey) as presented in Figure 7-4.

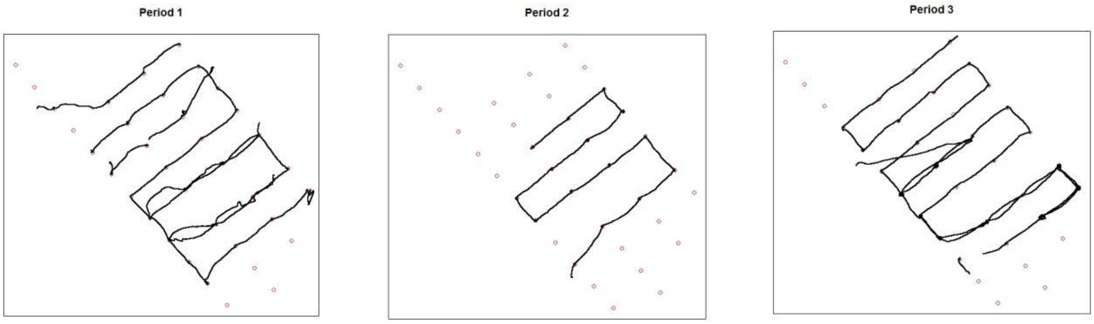


Figure 7-3: Transects monitored in the different periods. Period 1 and 3 consisted of 2 days of sampling, while period 2 consisted of 1 day.

7.2.5 Habitat types

Three habitat types were determined within the sampling area (Figure 7-4). ***scour bed*** the scour protection around the monopiles with a radius of ±15 metres. ***transition zone*** the zone between the scour protection and the open water. This transition zone is assumed to be 15-20 m from the monopile. The transition zone can either be considered as the edge of the scour protection or the edge of the open water habitat. Finally the ***open water (sand)*** the open water habitat is assumed to be further than 20 m away from a monopile. The distance in kilometres covered for each habitat type by the DIDSON recordings is shown in Table 7-1.

Table 7-1: Sampled distance per habitat in kilometres. OW = Open Water habitat. (e.g. OW 20-50 is all habitats within 20 – 50 metres to nearest monopile.)

Period	scour bed	transition zone	OW 20-50m	OW 50-75m	OW 75-100m	OW 100-125m	OW 125-150m	OW 150-175m	OW 175-200m	OW >200m	Total
1	2.7	0.8	2.6	1.9	2.0	2.1	2.0	1.9	1.9	21.5	**39.4**
2	0.9	0.5	1.4	0.8	0.8	0.7	0.7	0.7	0.7	8.0	**15.4**
3	3.0	1.0	5.3	2.7	2.1	2.1	1.9	1.9	1.9	21.6	**43.5**
Total	6.7	2.4	9.3	5.4	4.8	4.9	4.7	4.6	4.5	51.1	**98.4**

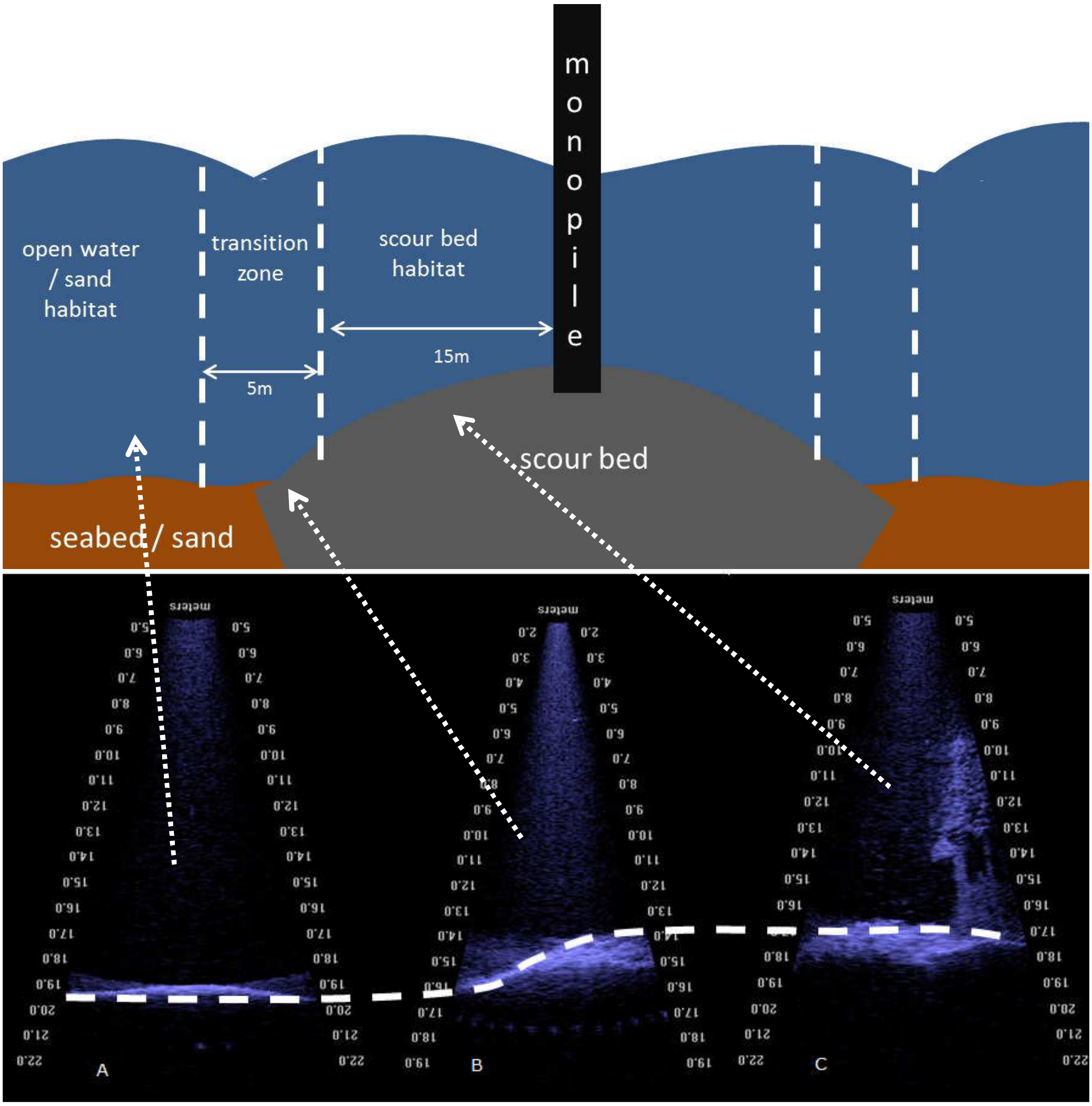


Figure 7-4: Three different habitat types: open water habitat, transition zone and scour bed.

7.3 Analysis

7.3.1 Fish counting

The DIDSON recordings were analysed using DIDSON software (DIDSON software version 5.25.35) and data were processed by using R (http://www.R-project.org) and the VMS tool package (Hintzen et al. 2012).
The DIDSON software enables automatic counting of fish, however manual counting was necessary due to the experimental setup. For automatically fish counting the DIDSON should have been stationary, so all moving objects were fish. Here, the DIDSON was fixed to a frame, but the frame was moving with the boat and therefore not stationary (e.g. the seabed floor is moving in the movies due to movements of the boat). The other reason for counting manually instead of automatically was that automatic counting was not accurate for several reasons. Firstly some dense and large schools of fish would be identified as large individual organisms. Secondly some schools were located close to the sea bed and would be missed if counted automatically. Thirdly small individual fish would be missed since they were too little to make an automatic distinction between noise and fish: the absolute minimum threshold of the reflected sound, to make a distinction between noise and fish, would be too high for some small individuals. And finally there is no automatic function to register fish behaviour (e.g. do fish cluster). For these reasons it was decided for manual counting.

Manual counting means that all 7-9 frames per second of the 29 hours and 30 minutes of recordings should be looked at. In each frame the number of fish were counted and registered along with the following parameters: movie ID, frame number, tilt angle of the DIDSON in relation to the sea bottom (80° - 90°), depth of the DIDSON, depth of the sea bottom (m), and visual interpretation of the bottom type (sand or stones). Since there were 7 – 9 frames per second it was obvious that successive frames could contain the same fish. Therefore it was chosen to forward the frames in the DIDSON software until new individual fish were seen. At that point the data processing continued. Sometime there were very large schools of fish, which were too large to fit in one frame of the DIDSON video. These large schools were cut into pieces using different successive frames. After the first frame containing a large school, the frames were forwarded until new individuals of the same school occurred in a new frame. At that point fish counting continued.

Each observation was placed in one of five categories.

1) *single fish*: 1-5 individual fish in one frame and no clear schooling behaviour can be determined. Fish were quantifiable
2) *aggregation:* No clear schooling pattern can be seen and fish are randomly distributed within the water column (Figure 7-5C). Fish were quantifiable
3) *quantifiable school:* Individual fish can be counted within a school (Figure 7-5A).
4) *compact school:* A compact group of fish, too dense to count individual fish (Figure 7-5B). Fish were not quantifiable. A minimum estimate of fish number was done by comparing the surface of the unquantifiable schools and the fish / m2 from these quantifiable schools. In this case called: ‘fish calculated’ instead of ‘fish observed’.
5) *other:* other objects that cannot be identified as fish (i.e. squids, sea mammals, jellyfish, debris etc.)

In the first three categories each individual fish was counted. However, some schools were too dense for individual fish counting, these were classified as *compact school* (unquantifiable). For the categories *quantifiable* and *compact school* also the height and length of the school (2D) were estimated, with these parameters the surface of each school was estimated. For each quantifiable school the average number of fish per m^2 could be calculated. A minimum estimate of the number of fish in compact schools was made, based on the maximum density of fish found in quantifiable schools. This roughly calculated number of fish per compact school was used in some of the analyses and indicated as 'calculated number of fish' instead of 'observed number of fish' (by counting).

If individual fish could be distinguished also the length of the fish was estimated, furthermore the position of the fish in the water column (minimum depth and maximum depth) was recorded.

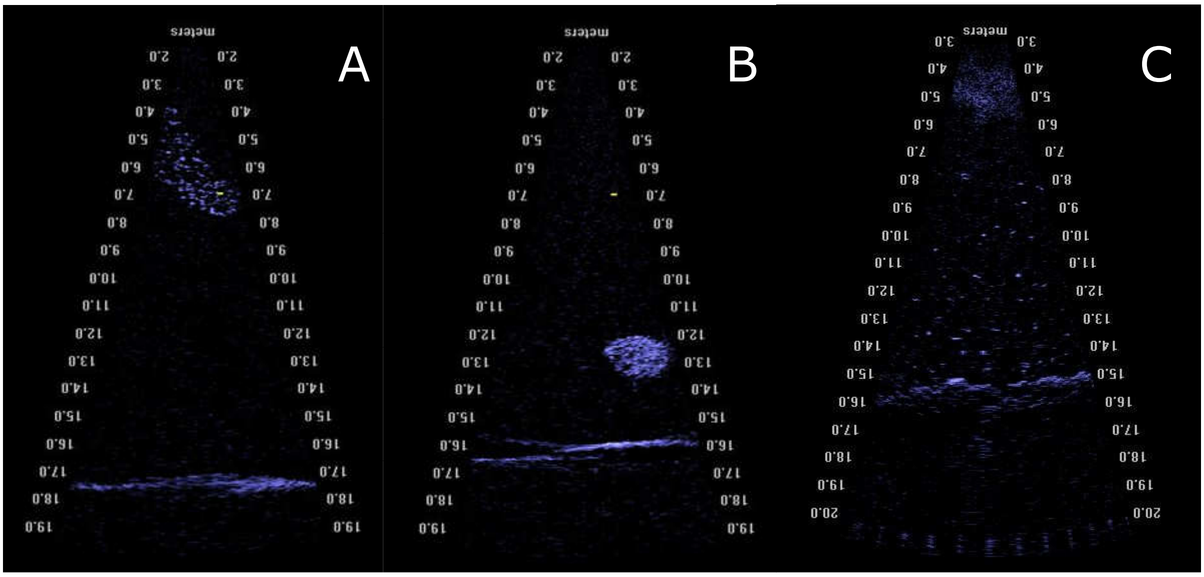


Figure 7-5: DIDSON schooling behaviour interpretation: A) quantifiable school of fish B) school compact: unquantifiable dense school of fish. C) aggregation of fish, fish randomly dispersed through the image.

7.3.2 Linking observations to habitat and distance to the monopiles

The frames in which fish was observed were manually given a habitat type, based on the visual interpretation of the sea bed (sand or stones) (Figure 7-4). No distinction between scour bed and transition zone was made. Frames without fish were scanned quickly and no habitat information was recorded for these frames manually.

To assign a habitat type to each frame and to calculate the distance to the nearest monopile, each frame was given its GPS coordinates. Based on these coordinates the distance to the nearest monopile of each frame was calculated in R (package VMS tools (Hintzen et al. 2012). It was assumed that the scour bed around each monopile is within a radius of 15 metres (Figure 7-4) and the transition zone is at 15-20m of each monopile. All frames that fall within these distances of a monopile were assigned this habitat type. All frames outside 20 m of a monopile were assigned the open water habitat type.

The habitat calculations based on GPS coordinates and distance to the nearest monopile were compared with the manually assigned habitat types and matched in 94.8%. Difference between these two occurred when the actual scour protection was larger or smaller that the assumed 15-20 metres. Miscalculations do not have any influence on the calculations on location of fish in relation to distance to nearest monopile, but may cause some bias in the mean density per habitat.

The sandy open water habitat was further divided in classes: open water (OW) 20-50 m, OW 50-75 m, OW 75-100 m, OW 100-125 m, OW 125-150 m, OW 150-175 m, OW 175-200 m, OW >200 m. The last class, OW >200m, extended till 600 meters. This maximum distance of 200 m was chosen since the trawled fishing activities (e.g. pelagic survey) were not allowed in a radius of 200 m from the monopiles, so this last class was in the area also monitored by the trawled surveys.

7.3.3 Estimation of numbers per distance or volume

A quick and easy method is presenting the numbers of fish and fish events per distance sailed, using the length of the transects in kilometres. This was done for the total transect and the length of the transect per habitat type. This resulted in number of fish per kilometre and is presented in a table.

Besides this overview, four different methods were used to present the numbers (two) and density (two) of fish. All methods are relatively straight forward and give a quick overview of the results in fish numbers, fractions and density per habitat.

Numbers: *Number of fish event per kilometre per habitat*
The first method presents the number of fish events (aggregation, single fish or school) per kilometre for each habitat and each period. Quantifiable and unquantifiable schools were both categorized as schools. The figure is giving insight in possible differences in fish events between habitats and periods.

Numbers: *Fraction of fish per kilometre per habitat*
The second method presents the fraction of fish per habitat per period. Contrary to method one this method takes into account the actual number of fish. However, it does not take into account if fish occurred in schools, aggregations or as individuals. The fractions were calculated with observed and calculated number of fish per kilometre. This method gives insight in the distribution of fish on each habitat and secondly it can be used for comparison with the gillnet experiments (chapter 6).

The difference between the DIDSON observations and the gillnet experiments was that the gillnet experiment caught the fish in the lower parts of the water column while the DIDSON observed the whole water column. The fractions of fish in the DIDSON observations were therefore corrected for the height of the gillnet. The multi-mesh gillnet used has a height of 3.7 m. At low tidal currents, the height of the net was assumed to be 3 m from the seabed, while with high tidal current the height was assumed to be 1 m from the seabed. This difference in height of the gillnets is due to the fact that the net is squeezed by the strong currents of the seawater. In total four figures were produced. The first one is presenting the fractions for the whole water column, the second is corrected for fish occurring within 3 metres from the seabed, the third one is corrected for fish occurring within 1 metres from the seabed and the last one is presenting the gillnet experiment results.

Volume: *Local density of fish*
The third method was used to present the local density of fish. The DIDSON filmed continuously with 7 – 9 frames per second. Since the depth of the sea bottom and the dimensions of the beam were known the volume was determined for each second. The volume was calculated in m^3 and the results presented in numbers of fish per m^3. These fish density (#/m^3) were spatially plotted were each frame containing fish was presented as symbol.

Volume: *Average density per habitat*
Furthermore the average densities were calculated by habitat class and plotted per period in order from scour bed to the open water habitat class with a distance >200m. This method gives a relatively quick overview of fish density in relation to the distance to the nearest monopile.

7.3.4 Artificial reef effect? Presence and absence in relation to distance to nearest monopile

Statistical analyses were done to see if more fish were observed in the vicinity of the monopiles. The continuous recordings by the DIDSON give a great insight in how many organisms occurred and how they behaved on different habitats within the wind farm. However, the method also has some drawbacks.

1) There were many locations where no fish was observed, >90% of the frames contained no fish.
2) the estimation of number of fish in compact schools has a large error.

The large amount of zeros and the discrepancy between "estimated" and "observed" data limits statistical analysis. Therefore it was chosen to statistically analyse the data with a presence-absence approach. If a fish occurred in a DIDSON frame, regardless of whether there were one or thousands, it was classified as "*presence"* or fish event = 1. Vice versa if no fish was seen, it was described as "absence" or fish event = 0. This was done for all fish, single fish separately, schools separately and aggregations separately. This analysis answers the question if fish or schools occur more often near the monopiles. It does not answer the question if more fish or more schools occur near the monopiles.

The presence and absence data were visualised by boxplots. These present the presence or absence of fish in relation to the distance to the nearest monopile for the different periods and the different fish events (all events, aggregations, schools or single fish). A distinction was made between distance to nearest monopile being less than 600 metre and less than 200 m. The latter boxplots (distance <200 m) were assumed to be better for possible artificial reef effect interpretation within close distance to the monopiles.

A Generalized Linear Model (GLM) with a binomial distribution (presence / absence) was used to determine whether there were more frames with fish or schools in the vicinity of the monopile.

Two GLM models were evaluated, the first one with all data collected combined to test whether the period is a significant explanatory variable for the occurrence of more fish events. In the second model the data per period was used to test the effect of distance to the nearest monopile on the occurrence of fish events.

Model I
On the full dataset a binomial GLM of the following form was tested:

*Fish event (presence/absent) ~ distance (m) * factor(period) + ε*

The analysis was done with all fish events not depending on if it was a school of fish or just a single fish. The * indicates that the interaction between distance and period was tested, rather than the separate explanatory variables. A significant interaction indicates a different slope per period for the linear relationship between distance and fish events. A different slope does not directly mean that there is a significant relationship between distance and the occurrence of fish events. Therefore the second model per period was used.

Model II

The second model on the data per period was a Binomial GLM of the following form:

Presence absence ~ distance (m) + ε

This model was calculated for all fish events, single fish events, aggregation events and school (quantifiable and unquantifiable together) events. This results in four models (all fish, single fish, school and aggregations) for three periods which gives a total of twelve outcomes. Each outcome indicates if there was a significant effect of distance to the nearest monopile in that period on the occurrence of the specific event. A negative effect, e.g. a negative slope for the linear relationship over distance, indicates more fish events near the monopiles than further away.

7.3.5 Length

Fish length was determined of fish when possible. This could be done using the DIDSON software measuring tools. In some cases the resolution of the DIDSON images, due to the low frequency, was limiting the length measurements of the fish. It was then hard to determine how a fish was positioned in the image e.g. it could have been a fish of 50cm with the head pointing to the observer. The DIDSON image will than show the diameter of this particular fish which could be 10cm. To prevent this kind of bias, it was chosen to measure several fish (3-5) in a school and taking the mean length of these fishes. It was assumed that if the length did not differ 5 centimetres between each fish, the mean length was assumed to be correct for all the fish in that school. Here, it is assumed that schools are formed by similar sized fish, e.g. fish from the same cohort, which is often the case for schooling fish.

To prevent any bias in measuring the length for individual fish, several frames on which the same fish is seen, were used to determine how the fish was positioned in the image. The frame with the longest length of the fish was assumed to be the actual length of the fish, from head to tail. Length of fish in unquantifiable schools could not be measured as individual fish could not be distinguished in these schools. This most likely leads to an overestimation of the average fish length in the area as these unquantifiable school are expected to be schools of many small fish.

Considering the possible bias of the length estimations due to the low resolution in the DIDSON images, length classes of 5 cm were chosen to compensate for possible underestimated or overestimated fish lengths. The results were presented in length frequency (LF) distributions and are presenting number of fish for each length class. Two approaches were used: one is presenting a LF distribution for each habitat per period, and the other one is presenting a LF distribution for each schooling behaviour (aggregation, single fish or aggregation).

As with the method "*fraction of fish per kilometre per habitat*" (section 7.3.3) LF distributions were made for the whole water column as well as for the lower parts of the water column: 3 and 1 metre from the sea bed floor. These figures were made for comparisons with the gillnet fish length estimations.

7.4 Results

7.4.1 Fish counts and Schooling behaviour

A total of 98.4 km of water column above the seabed in the wind farm was sampled. Within this sampled distance 964 schools (quantifiable and unquantifiable), 817 individual fish, 307 aggregations and 13 other organisms (squids, porpoises, seals, jelly fish or unknown) were observed. In total 79223 fish (sum of fish in schools, aggregations and individual fish) and 13 other organisms were either observed or calculated (compact schools), for all three periods (Table 7-2).

The absolute number of fish for each unquantifiable or *compact school* was calculated with 81 fish/m^2 multiplied by the surface of each compact school. This 81 fish/m^2 was the maximum number of fish that could be counted in quantifiable schools and is assumed to be the discriminating capacity of the DIDSON software. If a dense or compact school was observed and fish could not be counted accurately it was assumed that more than 81 fish/ m^2 were present within these compact schools. The calculations were assumed to be a minimum estimation since it was likely that more than 81 fish/m^2 were present in these compact schools.

Table 7-2: Number of school, single fish, aggregations and other organisms in the sampled area

	Period 1		**Period 2**		**Period 3**		**total**	
	n	**n/km**	**n**	**n/km**	**n**	**n/km**	**n**	**n/km**
school	382	**9.7**	47	**3.1**	144	**3.3**	573	**5.8**
school compact	161	**4.1**	33	**2.1**	197	**4.5**	391	**4.0**
single fish	156	**4.0**	165	**10.7**	496	**11.4**	817	**8.3**
aggregation	31	**0.8**	234	**15.2**	42	**1.0**	307	**3.1**
other		**0.0**	2	**0.1**	11	**0.3**	13	**0.1**
number of fish*	35446	**900**	9510	**618**	34267	**788**	79223	**805**
distance sampled		39.4 km		15.4 km		43.5 km		98.4 km

*partially calculated

7.4.2 Habitat use

The habitat use by fish per period was calculated with the observed and calculated number of fish per km. Firstly the fish event per kilometre were calculated and presented in Figure 7-6. From this figure is can be seen that in general more aggregations of fish occurred in the vicinity of the monopiles in period 2 compared to period 1 and 3.

Secondly the fraction of fish per kilometre per habitat was calculated. For a similar comparison the aggregations and schooling events were transformed in absolute observed and calculated number of fish. For each period the fraction of the total number of fish per habitat is presented (Figure 7-7A). This indicates that in period 2 there is clearly a larger number of fish per km near the monopiles compared to the open water habitat.

Similar figures are made for different parts of the water column, e.g. from the bottom up to 3 m from the seabed (Figure 7-7B) and from the bottom up to 1 m from the seabed (Figure 7-7C). The differences between Figure 7-7B and Figure 7-7C were minor, except that there were slightly more fish observed in the transition zone in period 1 (Figure 7-7B). This is vice versa for period 3 where very few fish were observed in the transition zone in period 3 (Figure 7-7B). A comparison with Figure 7-7A (whole water column) and Figure 7-7B & Figure 7-7C showed that in periods 1 and 3 more fish were observed on the scour bed and transition zone in the range of 3 m from the bottom to the surface. This suggests that fish were not restricted to the lower parts (1 – 3 metres from the bottom) of the scour protection fundaments of the monopiles and occurred throughout the whole water and were slightly more abundant in the upper parts of the water column in periods 1 and 3. For the second period there was no difference between Figure 7-7A, B and C suggesting that the fish were similarly distributed over the water column in the three habitats.

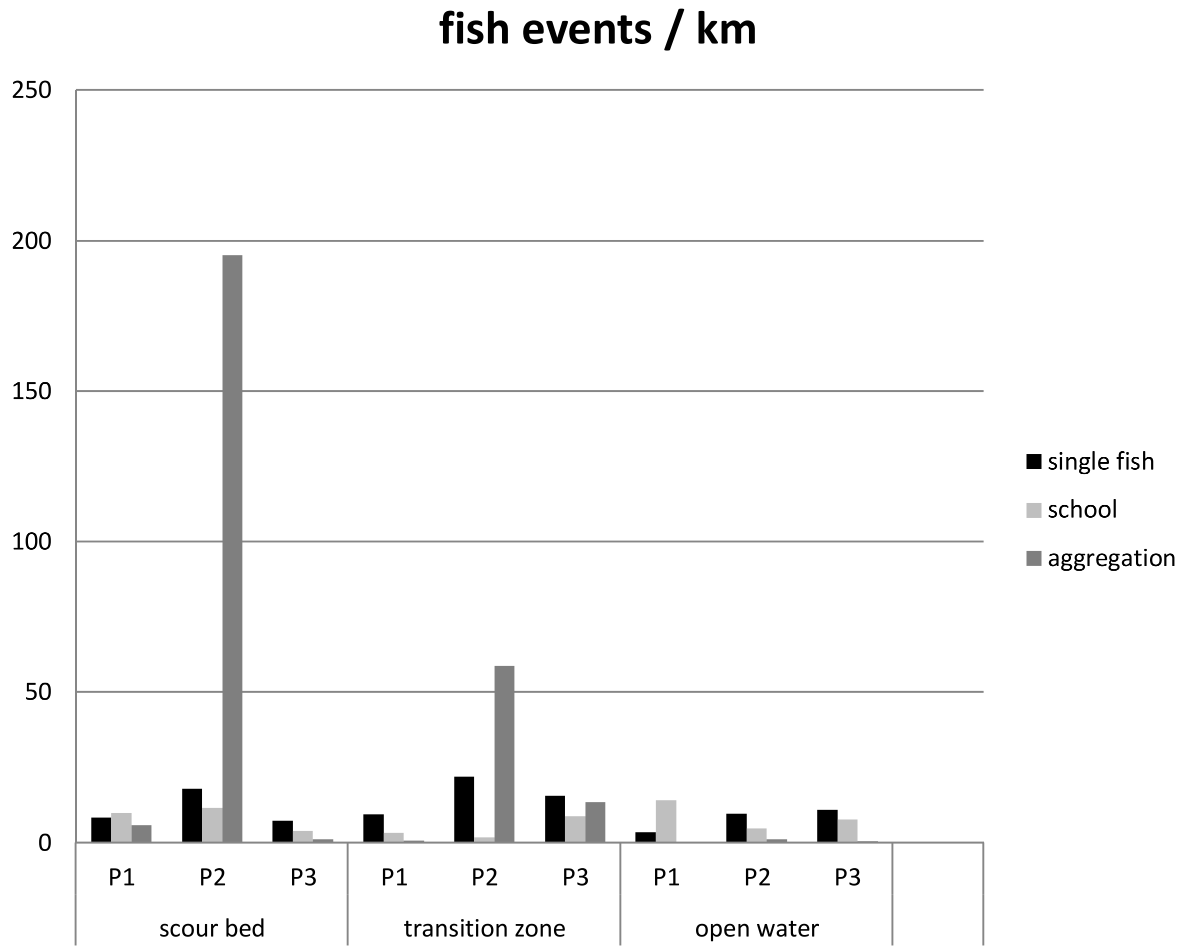


Figure 7-6: Number of fish event per kilometre per habitat. Numbers are counts of events and not absolute numbers of individual fish. Schools are events of quantifiable and unquantifiable schools.

The two categories of water depth were chosen to compare the data with the catches in the gill nets (Chapter 6). At low current the gillnet of 3.7 meters height is estimated to fish till a maximum of 3m from the bottom, while at stronger currents the gillnet is pulled down nearer to the bottom and is likely to fish only up to 1 meter above the sea bed.

The gillnet experiment shows a different and opposite distribution of fish compared to the DIDSON analyses on the same habitats. During the gillnet experiments a higher fraction of fish were caught in the open water in period 2, compared to the scour bed and transition zone (Figure 7-7D), while during the DIDSON observations more fish were observed on the scour bed and transition zone in period 2 (Figure 7-7B & Figure 7-7C). This opposite pattern in habitat use was the same for periods 1 and 3.

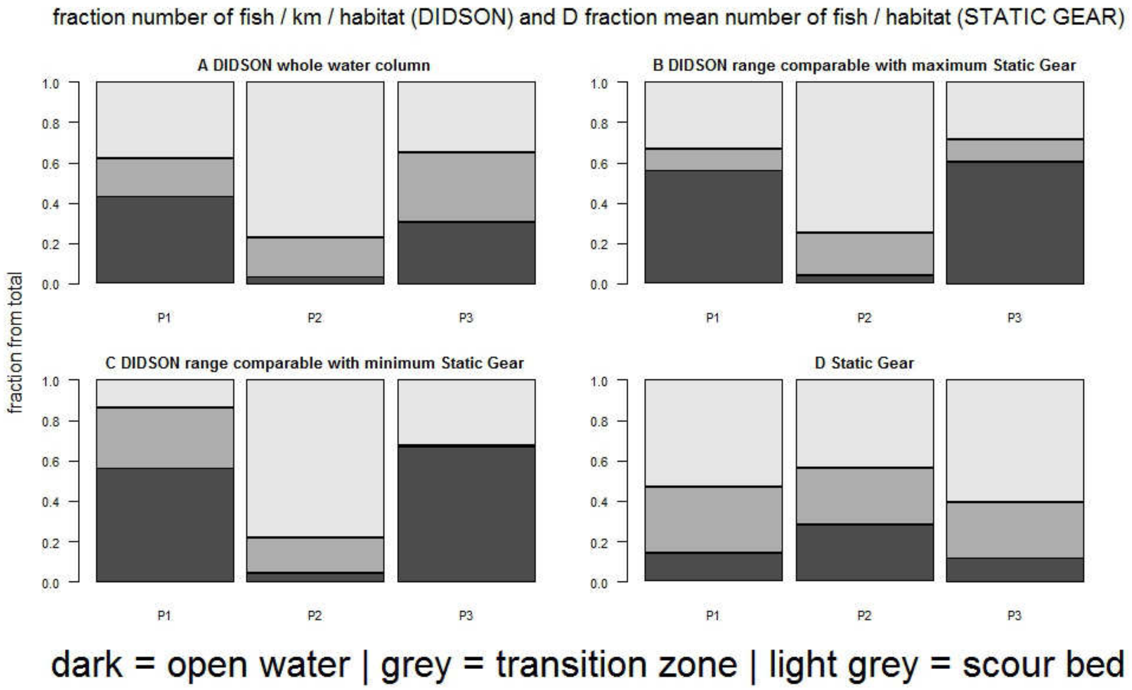


Figure 7-7: Panels A, B and C: fraction of the number of fish per habitat per period observed and calculated. Panel D represents the average numbers of non-flatfish per panel by zone and period in the gillnets.

7.4.3 Density calculations in relation to distance to the nearest monopile

The local density of fish (m^{-3}) was calculated per period (Figure 7-8, Figure 7-9 and Figure 7-10). The volume of the DIDSON beam was calculated taking into account the beam dimensions, depth and start window of the DIDSON frames. Since the analysed frames represent a more or less 2-dimensional perspective (vertical position ~90° of the DIDSON device) and volume is 3-dimensional, local densities of fish are underestimated but are comparable within periods.

All observed and calculated numbers of fish in categories schools, aggregations and single fish were used to calculate the mean density of fish per habitat class (Figure 7-11). In period 2 the mean density in the vicinity of the monopiles was higher than in period 1 and 3, while in period 2 the open water habitat had a slightly lower mean density of fish compared to period 1 and period 3 in the range of 20 – 100 m to the nearest monopile. It should be noted that the numbers presented in Figure 7-11 are lower than the local densities presented in Figure 7-8, Figure 7-9 and Figure 7-10. This is caused by the many frames which did not contain any fish (> 90% of the frames). This analyses was done with all data aggregated, the results for each monopile separately are available in appendix E.

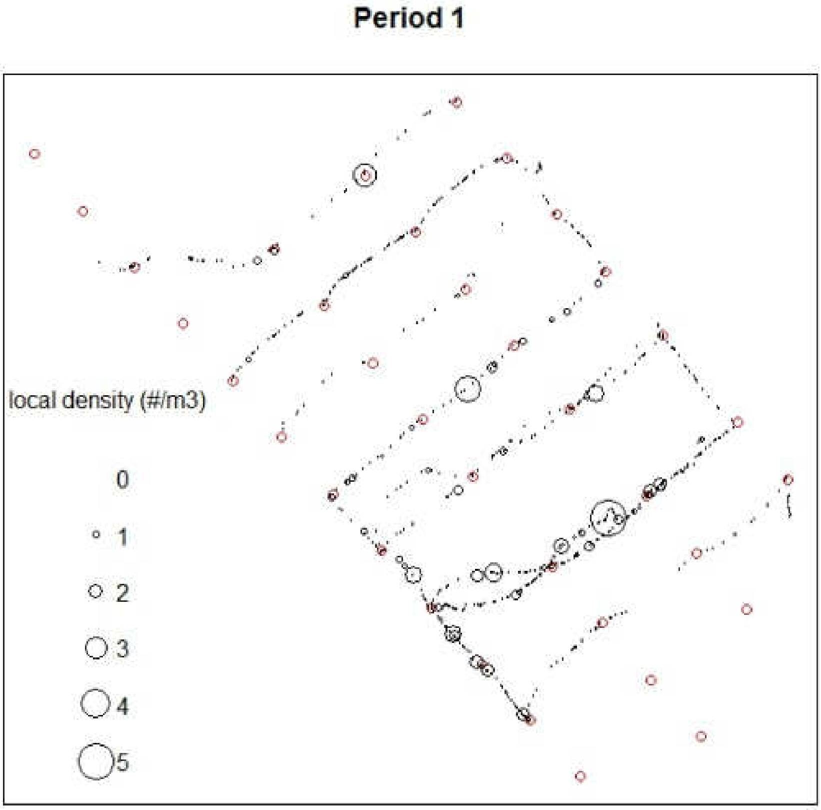


Figure 7-8: Local density (fish/m3) for period 1. The red dots represent the monopiles.

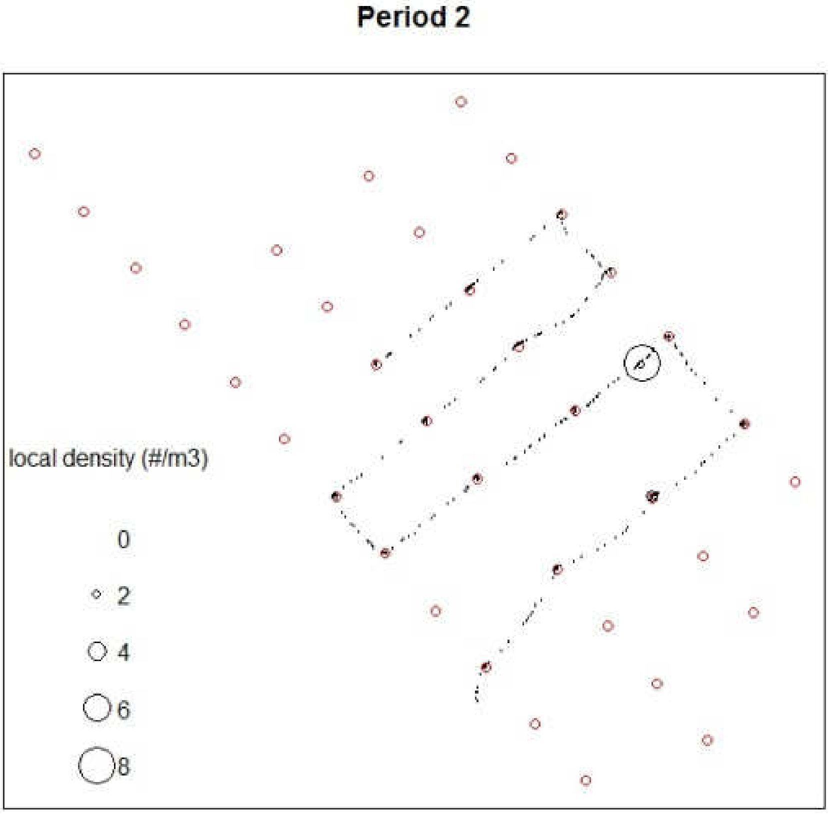


Figure 7-9: Local density (fish/m3) for period 2. The red dots represent the monopiles.

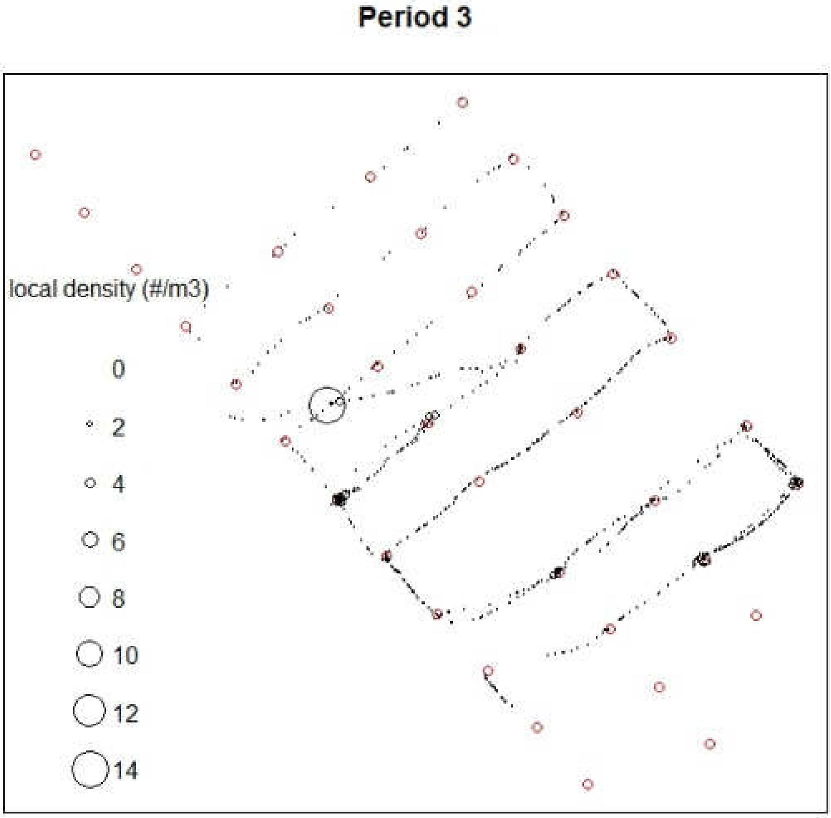


Figure 7-10: Local density (fish/m3) for period 3. The red dots represent the monopiles.

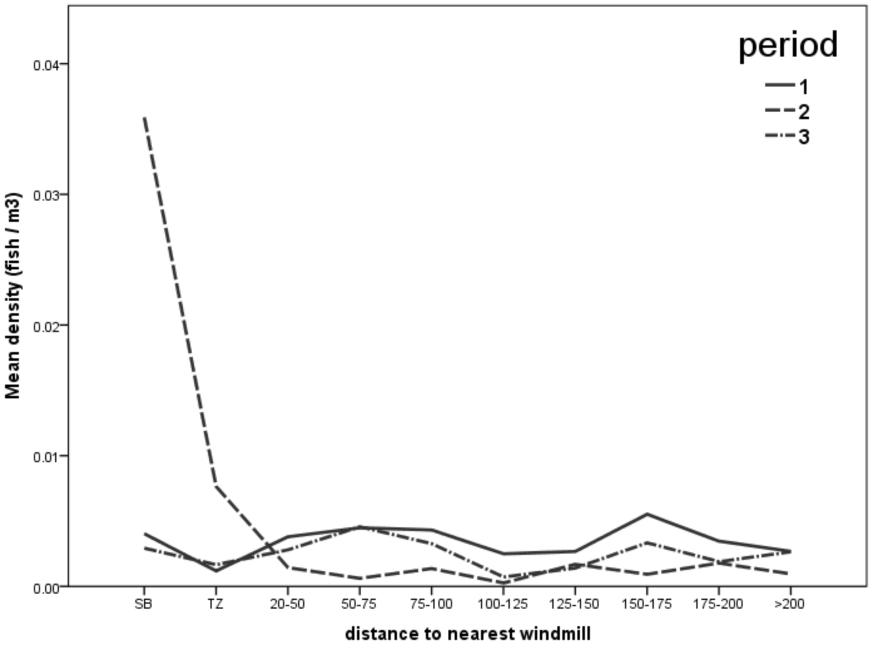


Figure 7-11: Density of fish (n/m^3) in relation to distance to the nearest monopile. Mean density is calculated for distance classes of 25 – 30 m classes up to a mean class of > 200 m to the nearest monopile.SB= scour bed (distance 0-15m); TZ = transition zone (distance 15-20m); all other classes are considered open water.

7.4.4 Presence and absence in relation to distance to nearest monopile

A generalised linear model (GLM) with a binomial distribution was fitted for the presence-absence of all fish, schools and aggregations. The results indicate whether more events (e.g. presence=1) occur near the monopiles.

The results of model I testing the interaction between period and distance are presented in Table 7-3 and the results of model II testing the relation with distance to the nearest monopile per period are presented in Table 7-4. In Figure 7-12 these results were made graphical by presenting the presence (1) and absence (0) data in boxplots. Each sub figure presents six boxplots, which are three pairs, two boxplots for each period. The left boxplot of a pair presents the absence data (0), and the right boxplot presents the presence data (1).

The absence boxplots (0) present the distribution of the empty frames over the distance to the nearest monopile in a single period. More than 90% of the frames were empty so these absence boxplots contain most of the data points. It is thus no surprise that the boxplots indicate that empty frames are found over the full distance. It shows that most of the data was collected in the range of approximately 100 – 300 metres from the monopiles.

The presence (1) boxplots are more interesting as these contain only a small part of all data points and the whole question of these analyses is are these presence data points distributed evenly over the whole distance or are they aggregated at a specific distance. The closer the median (horizontal black line) of the boxplot is to the monopile (distance = 0 m), the closer the fish were observed to the monopile. If pairs of absence and present boxplots are more or less similar for a specific fish event and the medians of both boxplots were at the same distance from the monopile, there was no difference between occurrence of presence data and absence data in relation to distance.
If the medians of a pair of boxplots were at different distances from the monopile than this indicates that presence of fish is aggregate at a specific distance which makes it likely that an effect of distance will be found in the GLM models.

Clearest effects of the distance on the presence of events can be seen for period 2 in the *all fish* events and aggregation events (49% of the presence data in period 2 are aggregations). In the *all fish* events, the boxplot indicates that even as a lot of fish events were observed over the full distance (the dots outside the whiskers clearly visible in the <200m figure), the main part of the observations was within 30 meters of the monopiles.

In the figure of the aggregation events it is shown that only a very few aggregations were found further away than 100 m. And that the majority of the aggregations were seen within 30meters of the monopiles. In period 2 and 3 the full box is within this distance.

Table 7-3: GLM model I results of all fish events *in relation to distance with a period interaction. Period1 = spring, period 2 = summer and period 3 = autumn. Note: these results do not explain any difference in fish assemblage between the periods.*

question	all fish events	estimate	standard error	Z value	probability	**answer**
spring different compared to summer	intercept period 1	-3.837	0.0659	-58.225		spring **differs** from summer
	distance (m):period 2	-6.312e-03	4.967e-04	-12.707	**$p < 0.001$**	
spring different compared to autumn	distance (m):period 3	-9.902e-05	3.373e-04	-0.294	$p = 0.77$	spring does not differ from period autumn
summer different compared to autumn	intercept period 2	-2.245	0.0669	-33.55		summer **differs** from autumn
	distance (m):period 3	6.212e-03	4.875e-04	12.74	**$p < 0.001$**	

The results of GLM model I show that the slope of the relationship between presence and distance differs in period 2 compared to the other two periods (Table 7-3). This means that period 2 has a different relation between fish occurrence and distance to nearest monopile. A similar outcome was seen with density comparisons (Figure 7-11).

The second step was to evaluate if there was a relationship between fish occurrence and distance to nearest monopile (Table 7-4). This was done for: all fish events, single fish separately, schools separately and aggregations separately.

When all fish events (aggregations, schools and single fish combined) were used in the model there was a significant ($p < 0.001$ and $p < 0.05$) relationship in period 2 and 3 between fish occurrence and distance to nearest monopile. The estimate for distance in these models was negative indicating that there is a higher chance of observing fish events near the monopiles than at a further distance.

There was no relation between distance and fish occurrence in period 1. This indicates that the chance of observing fish events is equal at all distances from the monopiles.

Table 7-4: GLM model II results for fish events in relation to distance for each period separate. A relation (indicated with p < 0.05) means that there are significantly more presence data (1) in the vicinity of the monopiles than absence data (0). The percentage in period shows the percentage of the total observed events that were classified in this category per period.

period	**fish event**		**estimate**	**Standard error**	**z value**	**probability**	**Relation distance and fish occurrence**	**number events**	**Percentage in period**
1	all	intercept	-3.836	0.0658	-58.2				
		distance	-4.64E-04	2.48E-04	-1.875	p = 0.0608	NO		
2	all	intercept	-2.245	0.0669	-33.55				
		distance	-6.77E-03	4.31E-04	-15.75	**p < 0.001**	**YES**		
3	all	intercept	-3.553	0.0551	-64.49				
		distance	-5.64E-04	2.29E-04	-2.462	**p < 0.05**	**YES**		
1	aggregation	intercept	-5.9504	0.2476	-24.03				
		distance	-7.51E-03	1.73E-03	-4.334	**p < 0.001**	**YES**	31	4%
2	aggregation	intercept	-6.31636	0.145512	-4.56				
		distance	-8.65E-02	7.92E-03	-10.94	**p < 0.001**	**YES**	234	49%
3	aggregation	intercept	-5.6966	0.20536	-27.75				
		distance	-7.99E-03	1.73E-03	-4.632	**p < 0.001**	**YES**	42	5%
1	school	intercept	-4.265	7.87E-02	-54.18				
		distance	9.89E-05	2.84E-04	0.348	p = 0.728	NO	543	74%
2	school	intercept	-4.9231	1.89E-01	-25.99				
		distance	-1.09E-03	7.68E-04	-1.421	p = 0.155	NO	80	17%
3	school	intercept	-4.398	8.51E-02	-51.71				
		distance	-1.21E-03	3.74E-04	-3.234	**p < 0.05**	**YES**	341	39%
1	single fish	intercept	-5.2064	1.34E-01	-38.67				
		distance	-1.37E-03	5.44E-04	-2.518	**p < 0.05**	**YES**	156	21%
2	single fish	intercept	-4.144	1.31E-01	-31.68				
		distance	-1.33E-03	5.40E-04	-2.477	**p < 0.05**	**YES**	165	34%
3	single fish	intercept	-4.3053	7.62E-02	-56.46				
		distance	2.87E-04	2.96E-04	0.97	p = 0.332	NO	496	56%

The model results for aggregations only, show a strong significant effect for all three periods. Which was already clearly visible in the boxplots (Figure 7-12B). The chance of observing aggregations is thus much larger closer to monopiles than at a further distance. There is however a clear difference between the periods in occurrence of aggregations. In period 2, 49% of the presence absence data was classified as an aggregation while in period 1 and period 3 this was only 4% and 5% respectively.

In period 3 there were significantly more schools found in the vicinity of the monopile compared to the open water habitat and 39% of the presence data was classified as school. Although this relationship was found, most of the schools did not occur within a distance of 100 metres from the monopile (Figure 7-12C). Thus compared to aggregation event which clearly accumulated near the monopiles, the accumulation of school events is at a larger distance from the monopiles.

In period 1 and period 2 there were significantly more single fish found in the vicinity of the monopile compared to the open water habitat and respectively 21% and 34% of the presence data was classified as single fish.

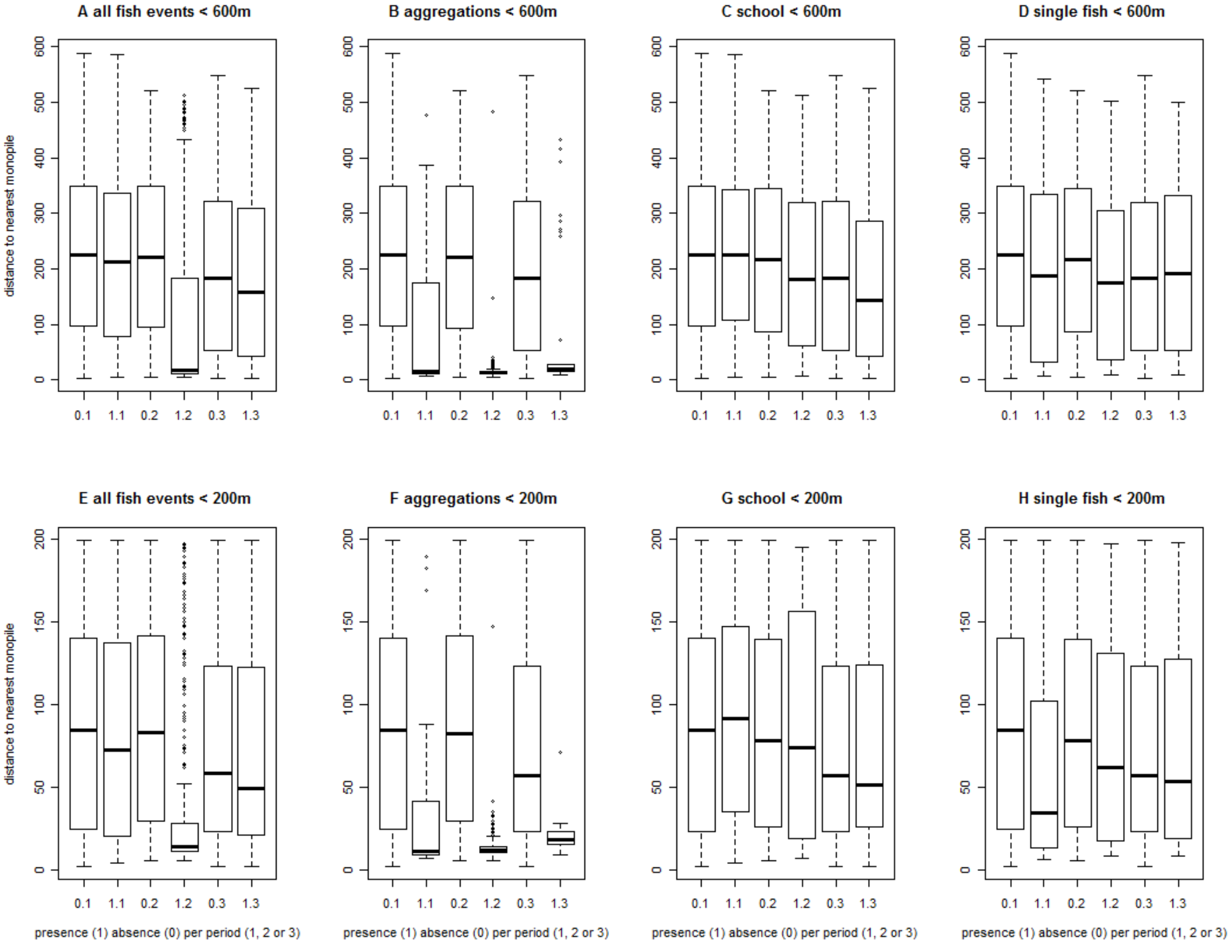


Figure 7-12: Presence absence data of all fish events (single fish, school or aggregation) in a range of 0 -600 m to the nearest monopile (used in GLM analysis) and in a range of 0 – 200 m to the nearest monopile. X-axis: 0.1=absence period1, 1.1=presence period 1 etc. The dark horizontal line is the median observation.

7.4.5 Length frequency distributions per habitat and per schooling behaviour

The aim of producing length frequency (LF) distributions was to compare fish length of the DIDSON observations with the static gill net experiments and based on this identify the fish species on the DIDSON images. It should be noted that for LF distributions only the observed fish lengths were used, since it was impossible to make good length estimations for fish occurring in unquantifiable schools. This causes bias in the LF distribution interpretation. However all LF distributions are giving some insight in the length of fish near the monopiles and further away. In Figure 7-14 - Figure 7-19 LF distributions are shown for either schooling behaviour or occurrence on a specific habitat. Some figures were corrected for gill net experiment comparisons. Figure 7-16 and Figure 7-17 present the fish length for the maximum gill net height (up to 3 meters from the seabed floor). And Figure 7-18 and Figure 7-19 present the minimum gill net height (up to one meter from the seabed floor).

Dealing with missing fish lengths in LF distributions

Most of the unquantifiable schools occurred in period 1 (41%) and in period 3 (50%). In period 2 there were far less schools (both quantifiable and unquantifiable) observed compared to the other periods. From Figure 7-13 it can be seen that in period 2 and 3, there is an overlap in centred depth range of the schools between quantifiable and unquantifiable schools. The depth of the centre of the school is defined as the minimum and maximum depth divided by two. In period 1 there is a difference in depth range in the observations between unquantifiable and quantifiable schools. There is a possibility that the LF distributions for this period are therefore lacking a large group of fish (unquantifiable schools). However it was assumed that in most cases unquantifiable schools were small fish (>0 – 15cm) and from the LF distributions (Figure 7-15) it can be seen that schools in period 1 already were in the smaller lengths classes, but in reality this lengths class may be more abundant than presented in the LF distribution. In period three there was an overlap in depth rang between quantifiable and unquantifiable schools (Figure 7-13) and again in reality the smaller lengths classes (>0 – 15cm) may be far more abundant than presented in the LF distribution.

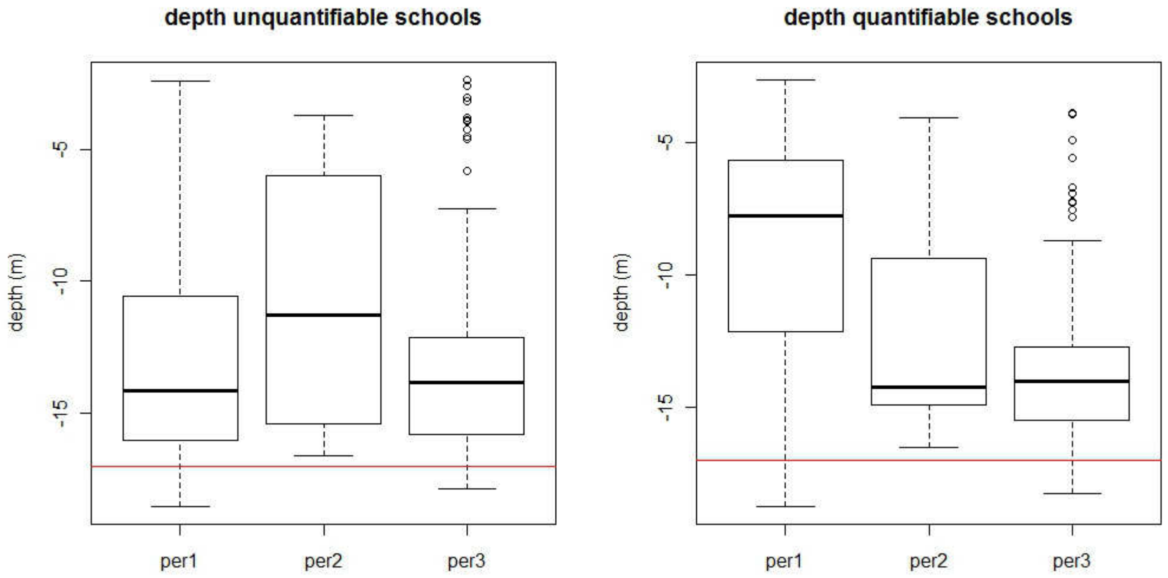


Figure 7-13: Depth of the centre of the school. On the left the unquantifiable schools and on the right the quantifiable schools. The red line indicates the mean depth of which fish were observed.

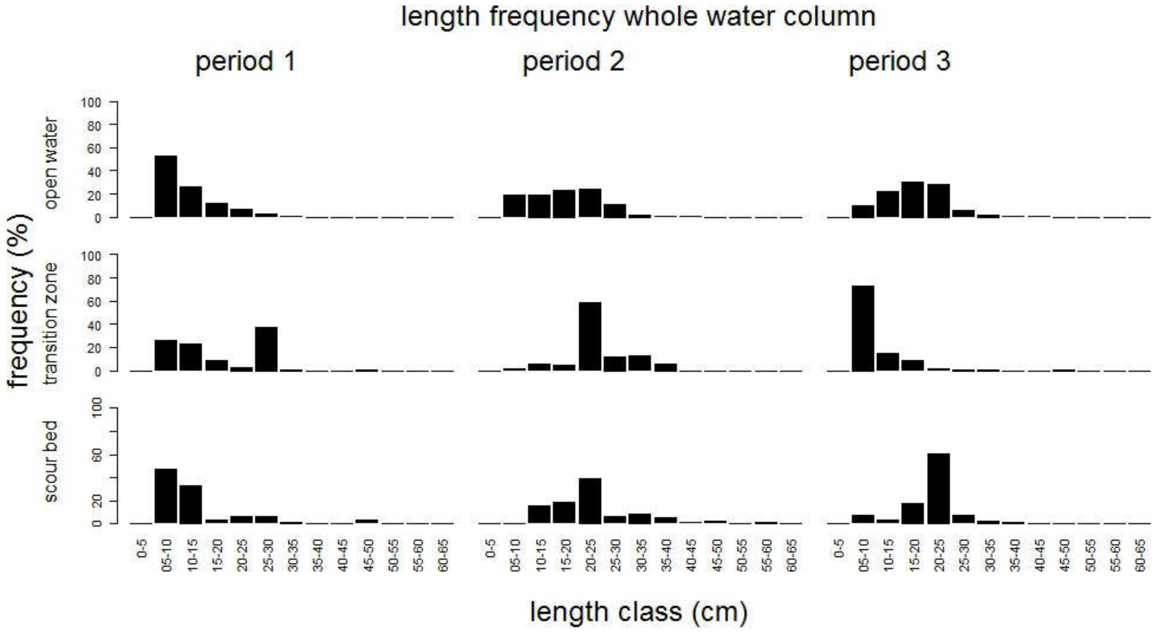


Figure 7-14: *Length frequency per habitat per period for the whole water column. The length data for the schools were processed with observed length only. The calculated number of fish in a compact school was not taken into account.*

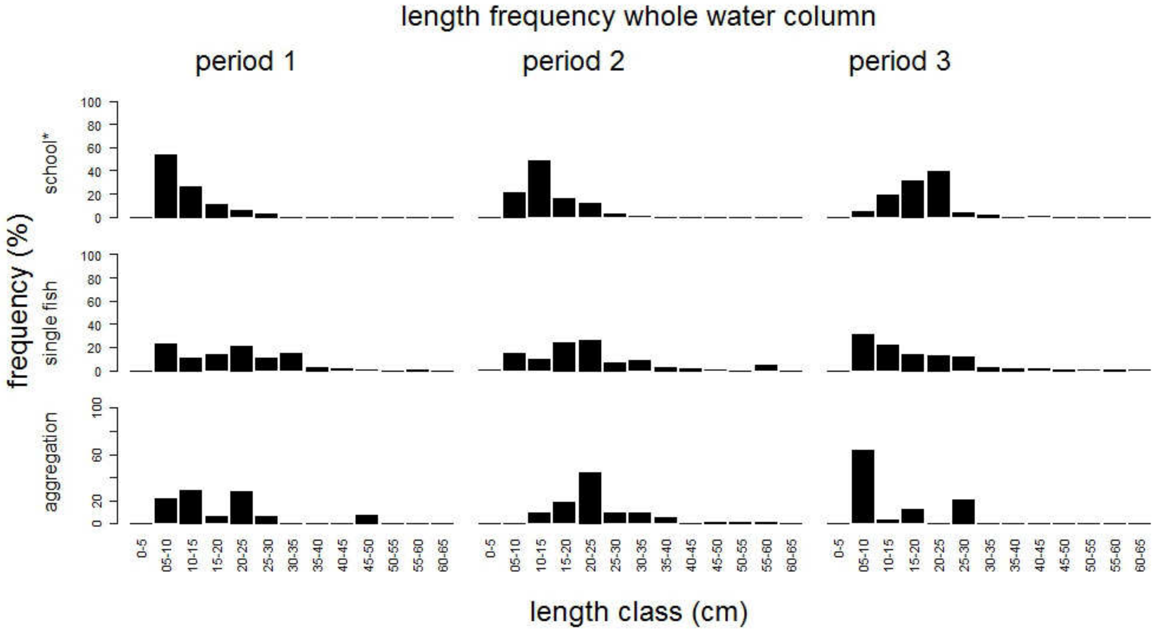


Figure 7-15: *Length frequency per schooling behaviour per period for the whole water column. The length data for the schools were processed with observed length only. The calculated number of fish in a compact school was not taken into account.*

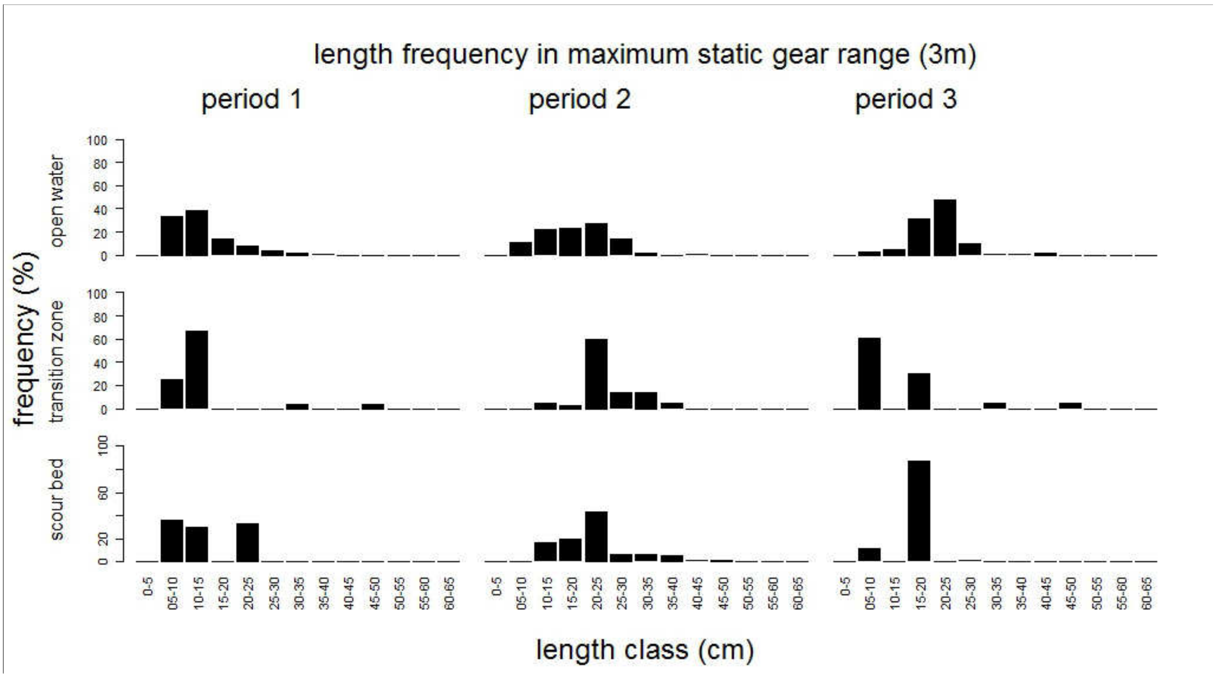


Figure 7-16: Length frequency per habitat per period for the maximum gill net range (up to 3 metres from the seabed floor). The length data for the schools were processed with observed length only. The calculated number of fish in a compact school was not taken into account.

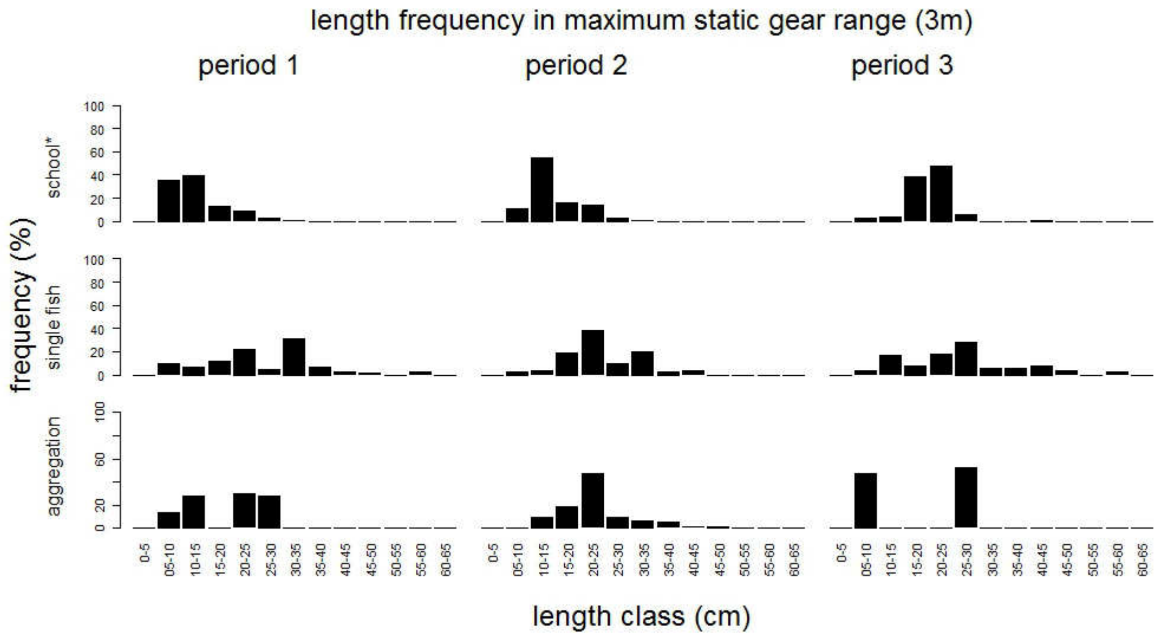


Figure 7-17: Length frequency per schooling behaviour per period for the maximum gill net range (up to 3 metres from the seabed floor). The length data for the schools were processed with observed length only. The calculated number of fish in a compact school was not taken into account.

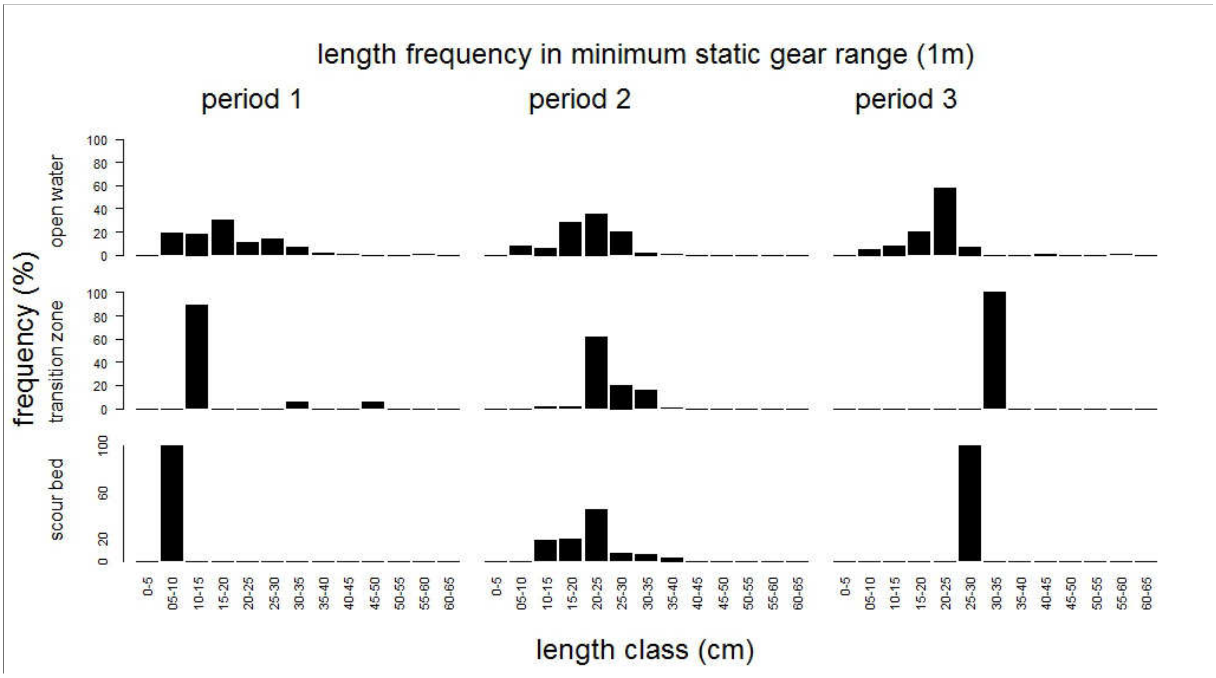


Figure 7-18: Length frequency per habitat per period for the maximum gill net range (up to 1 metre from the seabed floor). The length data for the schools were processed with observed length only. The calculated number of fish in a compact school was not taken into account.

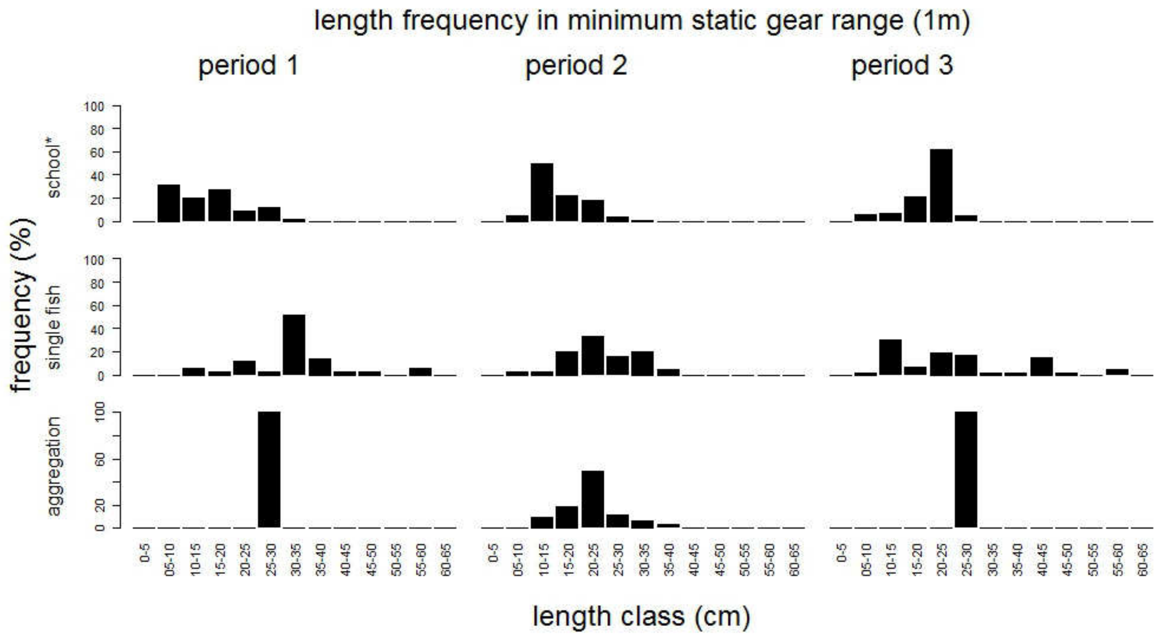


Figure 7-19: Length frequency per schooling behaviour per period for the maximum gill net range (up to 1 metre from the seabed floor). The length data for the schools were processed with observed length only. The calculated number of fish in a compact school was not taken into account.

7.5 Discussion

7.5.1 *Artificial reef effect?*

The artificial reef effect is the attraction of fish by an artificial reef, in this case the monopiles. The effect is frequently observed and was therefore also expected in OWEZ. Our results indicate however that it is not a consistent effect as actual higher or more occurrences of fish were only seen in the summer period (Period 2).
The studies (Lokkeborg et al. 2002, Soldal et al. 2002, Reubens et al. 2011b) that found aggregations around vertical structures in the ocean, suggest that several explanations are possible for the attraction of fish by these structures. According to Reubens et al. (2011b), the reasons for fish occurring in the vicinity of monopiles could be:

1) shelter against currents and predators (Jessee et al. 1985, Bohnsack 1989);
2) additional food and favoured prey types (Pike & Lindquist 1994, Fabi et al. 2006, Leitao et al. 2007);
3) provision of nursery and recruitment sites (Bull & Kendall 1994).

The question is whether these explanations are applicable to the aggregations found in this study. The first explanation concerns shelter against high currents. Based on our observation this explanation is unlikely to be the major explanation why these fishes occur in aggregations around the monopiles in period 2. One of the reasons why it is unlikely is that not that many aggregations were found in spring and autumn while there were many fish observed in the open water habitat. For these fish observed in the open water habitat it was possibly not urgent to find shelter against high currents and predation. While both are assumed to be present throughout the day as in the summer period. Shelter against tidal currents and predation is unlikely to explain the large aggregations in the summer period, but it could explain a fraction of the fish found within the vicinity of the monopiles in the different periods.

The currents of the sampling day in the summer period were considered not to be very strong for two reasons:
1) The DIDSON experiments were performed during calm weather conditions.
2) The tidal differences during sampling were not that large (+50 cm NAP to – 50 cm NAP) and aggregations of fish were observed throughout the day at all monopiles even when tidal difference were limited.

The other two reasons for fish to be around the monopiles were food provision and provision of nursery or recruitment sites. Both could explain the fact that fish occurred in high aggregations around the monopiles in the summer period. But both reasons are hard to discuss since it is unknown which fish species we are dealing with.

In all periods fish were observed near the monopiles on the scour bed or the transition zones. However in the summer, fish tended to aggregate around the monopiles more than in other periods. It is unknown whether the same fish species that occurred in the aggregations near the monopiles in period 2 occurred in schools in period 1 or 3 in the open water.
A possibility is that the schools of fish migrated from the open water to the monopiles for shelter, food or other reasons. In this case the monopile may provide shelter against predators and the need for fish to swim in a dense school may be not needed or is impossible considering the limited space around the monopile. On the other hand it could be a different species, that was not present in period 1 or 3 and specifically entered this part of the North Sea for certain reasons (for instance spawning or food).

Presence/absence analysis indicated that the model for the summer period significantly differed from the spring and autumn periods when it concerns fish occurrence in relation to distance to nearest monopile. There was no difference in the models between the spring and autumn period. The difference between the models was mainly due to the presence of large aggregations of fish in the vicinity of the monopiles and the lack of fish in the open water habitat during the summer period (Figure 7-12 B & F). Almost all aggregations were found in the vicinity of the monopiles in all periods, but in the second period 49% of the presence data was classified as aggregation. Therefore the difference between periods found by the GLM analyses, approach II step 1 (Table 7-3), was mainly due to the occurrence of these large aggregations of fish around the monopiles, and the absence of schools / single fish in the open water habitat. In period 1 and 3 schools were dominating the presence absence analysis while aggregations were dominating the analysis in period 2. However the density analysis (Figure 7-11) showed that the density around the monopile in the summer period was higher than in the other periods. This difference near the monopiles between periods was larger than the difference in the densities in the open water habitat.

Approach II step 2: Individual period analysis (Table 7-4) showed that there was a significant difference between fish occurrence in relation to distance in the summer period and the autumn period ($p < 0.001$ summer and $p < 0.05$ autumn Table 7-4). But Figure 7-12 showed that the difference (comparing *median* from presence and absence data) between distance and presence and absence data was higher in the summer period compared to the autumn period. Therefore it was assumed that the relationship between fish occurrence and distance in autumn was more related to spring than it was to summer. In the summer period the DIDSON observations showed that fish were gathered around all the observed monopiles and the fish were distributed from surface to bottom, while in the other periods this seemed to be an occasional event. This was in line with the DIDSON study carried out in 2009 (Couperus et al. 2010) were also in the summer period large aggregations were found around the monopiles. They suggested that these aggregations could also occur in other periods, which seems less likely interpreting our results.

In the summer period fewer schools and less single fish were observed in the open water habitat compared to the spring and autumn period. The fish in de summer period mainly occurred in aggregations around the monopile. As mentioned earlier it could be that fish shifted from the open water to the scour bed near the monopiles for multiple possible reasons or that another fish species entered the wind farm in the summer period.

The question remains what fish species could cause this difference in behaviour between the periods? From the DIDSON images, species could not be identified, since the images of fish were too small to identify species specific features. Species identification of the fish that was abundant in these large aggregations in summer may be explained by comparison with other studies were the same events, aggregations of fish around vertical obstacles, were occurring.

Oil platform studies showed large aggregations of cod, large schools of mackerel and saithe around the poles (Lokkeborg et al. 2002, Soldal et al. 2002), indicating a possible artificial reef effect, however the responses were complex and results were inconclusive regarding species-specific temporal and spatial patterns.

Other approaches to identify the fish species occurring in aggregations during summer are by abundance in comparable habitats and by length frequency comparison with gillnet experiments (Chapter 6).

7.5.1 Artificial reef effect – species identification by abundance

Species identification could be interpreted with other studies or surveys. According to results from a Belgian study (Reubens et al. 2011a) and a Dutch study (Couperus et al. 2010) these aggregations could exist of mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*), cod (*Gadus morhua*) and bib (*Trisopterus luscus*). From other studies it is known that cod may aggregate around vertical structures (Lokkeborg et al. 2002, Soldal et al. 2002) and are highly attracted by the monopiles according to the gillnet study results (Chapter 6) and telemetry studies (Chapter 8). But this could not explain the high aggregations present only in the summer period since cod was present throughout the year (Chapter 6 and Reubens et al. (2011)) It is therefore unlikely that the aggregations consists only of cod. Bib is also a species which is attracted by the monopiles (Reubens et al. 2011b) and showed significant attraction of the monopiles during period 2 and 3 (Chapter 6). However both cod and bib are considered to be benthopelagic where mackerel and horse mackerel both are pelagic. The occurrence of aggregations were not explicitly dependent on the first few meters from the sea bed floor (Figure 7-7), which suggests that these aggregations were either horse mackerel or mackerel, or other pelagic species such as herring or sprat.

A Belgian research (Reubens et al. 2010) showed that with line fishing throughout the year around monopiles mackerel and horse mackerel were only caught during summer and early autumn. This is in line with the gillnet experiments (Chapter 6) where mackerel (summer and autumn) and horse mackerel (summer) were found in the same periods. This is in accordance with the typical migration pattern of mackerel and horse mackerel in the North Sea (Macer 1977, Villamor et al. 1997) and they are only temporarily abundant in the wind farm for e.g. searching for food, shelter or spawning habitats. Visual census by SCUBA divers (Couperus et al. 2010) confirmed that horse mackerel were abundant in the vicinity of the monopiles. Besides the fact that horse mackerel only occurred during period 2 (Chapter 6, only one individual is caught in period 3) and that aggregations were explicitly abundant (49%) in this period, horse mackerel are also mentioned in other wind farm and ship wreck studies to be attracted by artificial reefs (Zintzen et al. 2006, Couperus et al. 2010, Reubens et al. 2011b). Therefore, we think at least part of the fish seen in the aggregations near the monopiles was horse mackerel.

7.5.2 Artificial reef effect – species identification by length distribution

In summer most of the fish present in aggregations or present on the scour bed habitat had a length between 20-25 cm (Figure 7-14 and Figure 7-15). When these results were compared with the mean length of mackerel, horse mackerel, cod and bib from the gillnet (Table 7-5), horse mackerel showed slightly larger lengths (mean is 25.9 cm) in the vicinity of the monopiles in period 2. Bib mean length was 15.7 cm, mean length of cod was 35.1 cm and mackerel had a mean length of 29.6 cm which were respectively lower, higher and higher than the most abundant length class of the DIDSON measurements. Mean length of whiting falls within the range of 20-25 cm but this species was also abundant in period 1 and period 3 and could therefore not explain the temporal aggregations in the summer. Based on length comparison of the gillnet and the DIDSON experiments it is likely that the aggregations in period 2 are explained by the abundance of horse mackerel. For detailed length frequency plots see appendix D. As stated earlier it is unlikely that the aggregations in period 2 are explained by benthopelagic fish species, therefore it is unlikely that striped red mullet, only caught in period 2 with a mean length of 25 cm, can explain the aggregations in period 2. Based on these results the aggregations present in period 2 may be horse mackerel. Reubens et al (2011) found a length range for horse mackerel of 21-29 cm and for mackerel 24-31 cm. A length comparison between both studies suggests that both fish species could explain the aggregations in the summer, since both have an overlap with the 20-25 length class, however the overlap is larger with horse mackerel. Although these comparisons are very rough, they are in line with the earlier suggestions that fishes occurring in large aggregations in the vicinity of the monopiles are thought to be horse mackerel.

Table 7-5: Numbers of fish and mean length (cm) of the gillnet experiment (Chapter 6) for the summer period.

		mean length (cm)		number (n)	
fish species		scour bed	open water	scour bed	open water
Cod	*Gadus morhua*	35.1	32.9	101	9
Horse mackerel	*Trachurus trachurus*	25.9	22.9	44	55
Mackerel	*Scomber scombrus*	29.6	31.5	22	37
Bib	*Trisopterus luscus*	15.7		15	
Striped red mullet	*Mullus surmuletus*	25.3	25.3	11	3
Whiting	*Merlangius merlangus*	20.8	20.7	8	30
Herring	*Clupea harengus*	10.6	11.3	9	12
Sprat	*Sprattus sprattus*	11.5	13.1	2	7

7.5.3 Horse mackerel and artificial reef effect

Even though literature suggests that the aggregations in the vicinity of the monopiles could be horse mackerel or mackerel, the gillnet (Chapter 6) showed no significant attraction of horse mackerel and mackerel for the monopiles. It might be differences in the distribution of length classes, Reubens et al. (2011) found more fish of 21-29 cm in the vicinity of the monopiles compared to the sandy habitat, where they found fish of 6-15 cm .This phenomenon could cause a bias in the analysis of the gillnet experiments in which the data was analysed for all fish not separated by length. However, as described in Chapter 6, length frequency distributions of horse mackerel showed the same pattern on different habitats. Thus contrary to Reubens et al. (2011), our study found large horse mackerel on the sandy habitats well.

The gillnet experiments caught fish during day and night while the DIDSON experiments only sampled during the day. Differences in day and night behaviour of fish may explain the non-significant attraction of horse mackerel and mackerel by the gillnet experiments. A difference in behaviour of the fish was shown for fish within wind farms (Winter et al. 2010, Leonhard et al. 2011). This could explain the difference in observations in the gillnet experiments (Chapter 6) and the DIDSON experiments.

There is a slight opposite result in the fraction of fish per habitat (Figure 7-7 C and D). The DIDSON experiments showed a higher fraction in the open water habitat in spring and autumn compared to the summer. This may be explained by a difference in species composition when fish are either attracted to the monopiles, are indifferent or are avoiding the monopiles. During the summer period a high percentage of fish was seen in the vicinity of the monopiles. The gillnet experiments showed higher ratios in the vicinity of the monopiles during all periods but in the summer period there were slightly more fish caught in the open water habitat compared to spring and autumn. Although there are restrictions and drawbacks in comparing these two different methods, these results suggest that fish behave different between day and night and / or that a different species composition per period determines the differences in habitat use.

8 Sub-project 5: Residence time and behaviour of sole and cod

8.1 Introduction

A tagging and telemetry experiment was carried on the behaviour of cod and sole in response to the operation of the wind farm (Winter et al. 2010). Here the results of this study are summarized as the full report on it is available. Wind farms can have either negative or positive effects on fish, for instance by disturbance due to noise or by acting as a refuge because fisheries are banned within the wind farm. An important feature to determine if positive effects might occur is residence time: the longer individual fish spend in the wind farm, the stronger potential benefit of wind farms can be expected. To our knowledge this was the first study on individual behaviour of fish within wind farms.

8.2 Survey Design

To study the potential effects of wind farms on fish behaviour, we used two approaches: tagging experiments (mark-recapture) and telemetry experiments by following individual fish equipped with small transmitters in time. We selected two target fish species that are important for fisheries: sole (*Solea solea*) as a target species potentially representing fish that use sand habitats and Atlantic cod (*Gadus morhua*) as a target species potentially representing fish that use artificial reefs such as the monopile and scour bed habitats in the wind farm.

Using tagging experiments with sole, we compared return rates of fish caught, tagged and released within the wind farm to return rates of fish caught, tagged and released in a reference area outside the wind farm. If individual residence time in the wind farm is larger, then a significant lower return rate is expected for the wind farm batch over the reference area batch. And in addition, a stronger difference is expected between return rates in the period directly following the release than at longer time intervals after release. Two paired tagging experiments were performed: 300 tagged sole (150 caught, tagged and released in OWEZ, and 150 in a reference area) in October 2007, and 800 (400 in OWEZ and reference area) in June 2008.

With telemetry experiments with sole and cod, we assessed individual residence time and individual behavioural patterns. During early 2008, different telemetric deployment methods were tested in the wind farm and found to be robust against severe winter storm conditions. In July 2008, an array of detection stations on the sea floor covering 16 out of 36 monopiles (Figure 8-1) was installed. In August 2008, transmitters were implanted in 40 sole (length range sole 25-34 cm), 40 cod in September 2008, and 7 cod in January 2009 (length range cod 22-46 cm, i.e. predominantly juveniles).

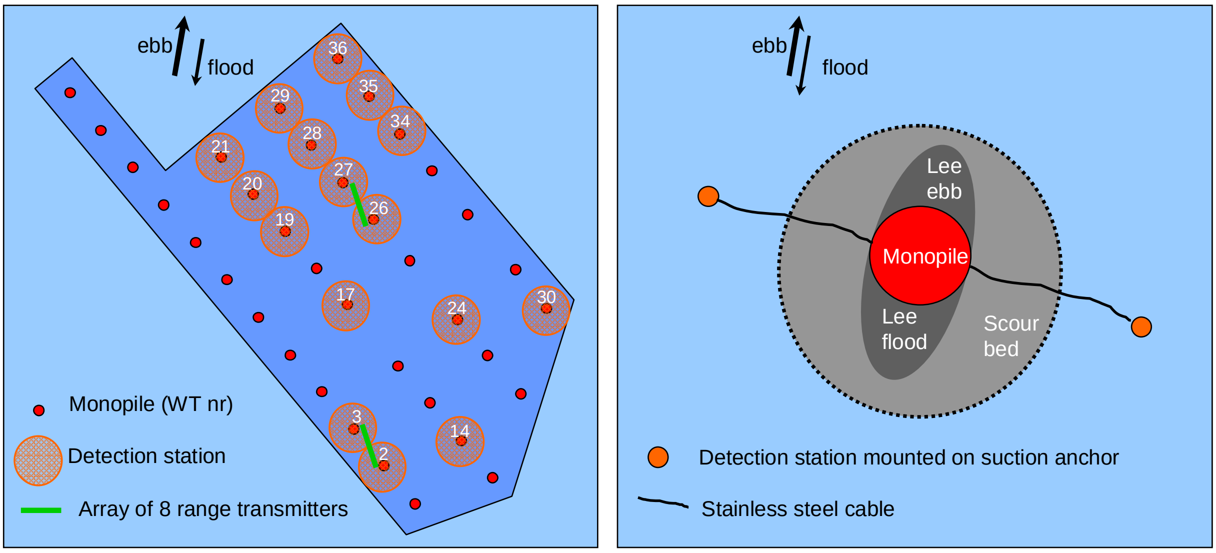


Figure 8-1: Experimental set-up of the array of detections stations and continuous range measurements by arrays of test transmitters (left). Each receiver was placed in an angle of 90° to the direction of the tidal currents. This will maximize the chance of detecting fish with transmitters in case they were 'resting' in the lower water velocities on the lee side of the monopile during either ebb or flood currents (right, showing the 2 potential positions of receiver placement that we favoured). A cable connecting the J-tube to the suction anchor was used to facilitate finding the detection station by divers.

In June-July 2009, all 16 detection stations could be retrieved and the telemetric data were extracted. We determined the duration between first and last detection in the wind farm for each fish as a proxy for individual residence time. We also determined the fraction of the time between first and last detection (detection rate). We compared detection rates as observed from fish with transmitters with detection rates as hypothesized for different behavioural scenarios (Figure 8-2): a) if random movement within the wind farm (associated expected detection rate would then be 7%, i.e. detection area/wind farm); b) if random movement occurred within the area where monopiles were present (expected detection rate: 14 %, i.e. detection area/wind turbine area); c) if strong attraction to the monopile habitats occurred (expected detection rate: 44 %, i.e. 16 out of 36 wind turbines covered with detection stations); or d) if extreme site fidelity occurred (expected detection rate: 100%, i.e. stationary at catch and release site).

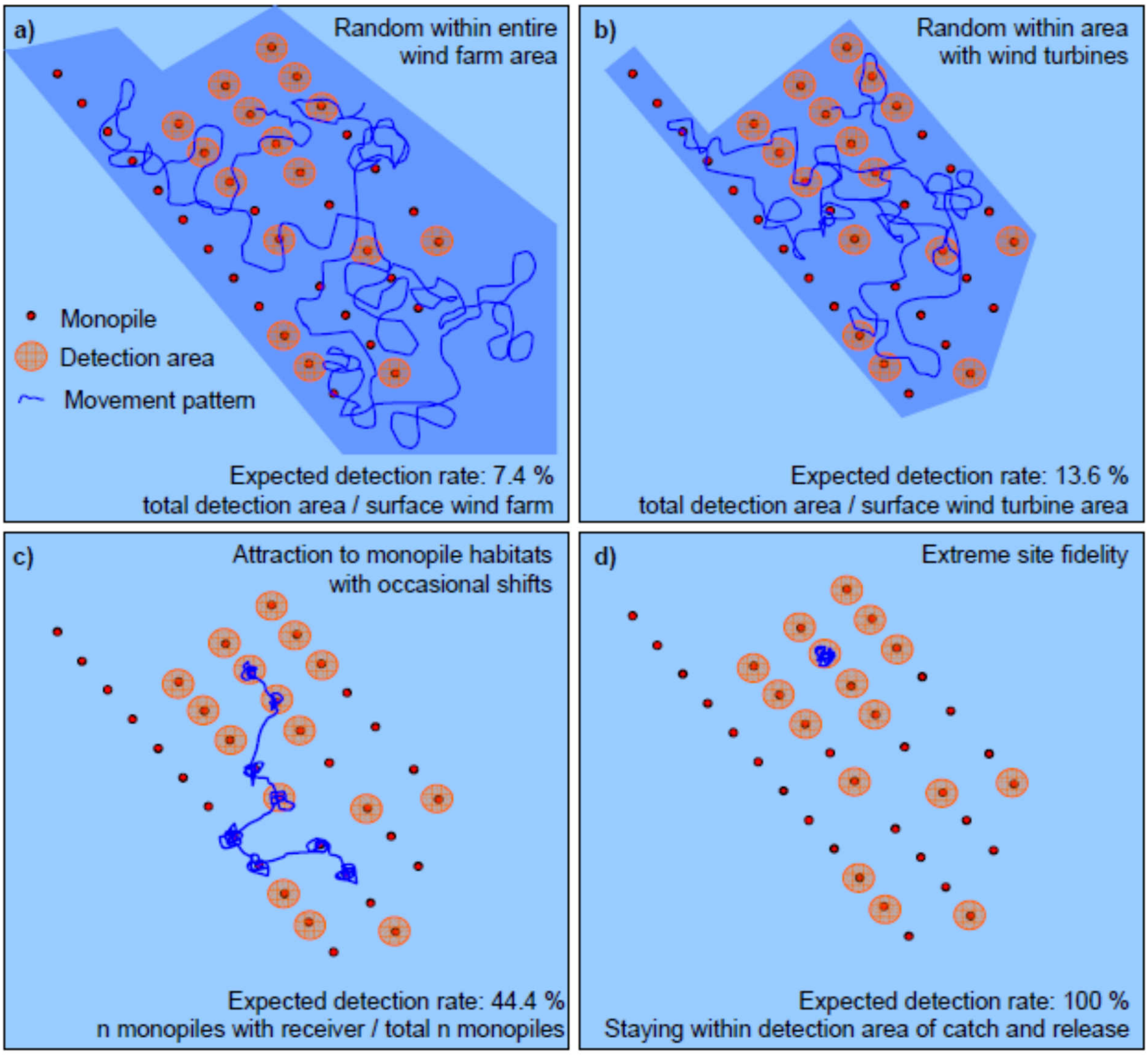


Figure 8-2: Examples of movement patterns for four different hypothesized behavioural scenarios and the detection rate that is expected to be observed if the underlying behaviour pattern is in accordance with a hypothesized pattern. For scenarios a, b and c the number of detection stations per individual fish with a transmitter is expected to be > 1, whereas for scenario d this is limited to 1.

8.3 Results

For tagged sole, there was no overall significant difference in return rate between OWEZ and reference area batches (Table 8-1). The telemetry data showed relatively short individual residence times for sole and low detection rates (Figure 8-3).

Our combined results of the tagging and telemetry for sole indicate that the majority of movements take place at spatial scales larger than the wind farm of OWEZ. Some individuals use the wind farm for periods up to several weeks during the growing season, which indicates that there is no large scale avoidance of the wind turbines, at least in part of the sole population. On the other hand there were no indications found for attraction to the monopile habitats either. All of the individual soles showed detection rates well below the 44% as expected when attraction to monopile habitats had indeed occurred.

Table 8-1: Overview of the numbers of returned tagged sole from fisheries ('recaptured') and numbers of sole that were tagged but not returned by fisheries ('not recaptured') for each of the batches: OWEZ and Reference Area in June 2007, October 2008 and combined for both periods. Differences between groups were tested by a 2x2 G test of independence.

	OWEZ	**Reference**	*totals*	2x2 G-test of independence	
Batch oct 2007					
recaptured	25	19	*44*	Observed G=	0.96
not recaptured	125	131	*256*	William's correction=	1.01
totals	*150*	*150*	*300*	p-value=	0.33
Batch jun 2008					
recaptured	35	55	*90*	Observed G=	5.05
not recaptured	365	345	*710*	William's correction=	1.01
totals	*400*	*400*	*800*	p-value=	**0.03**
Both batches combined					
recaptured	60	74	*134*	Observed G=	1.67
not recaptured	490	476	*966*	William's correction=	1.00
totals	*550*	*550*	*1100*	p-value=	0.20

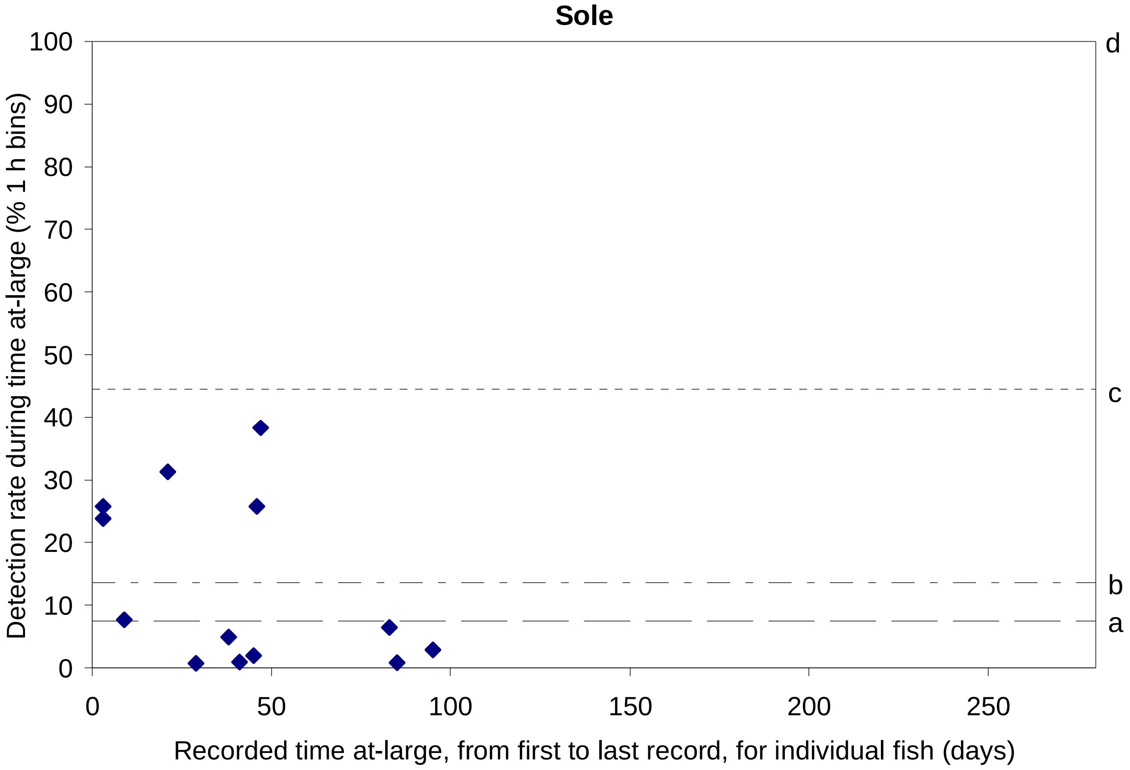


Figure 8-3: Observed detection rate, expressed as percentage of one hour bins detected during the period between the first and last detection (time at-large), for individual sole with transmitters. The lines represent the expected detection rates from different behavioural scenarios, see Table 8-2.

Table 8-2: Comparison of expected detection rates, expressed as percentage of one hour bins detected during the period between the first and last detection (time at-large), and number of detection stations where detected for different behavioural scenario's with the observed detection rates for sole and cod that were present in the wind farm for more than one day following release.

Hypothesized behaviour and expected detection rates	Detection rate % (n receivers/ind)
a) Random movement within entire wind farm: Expected rate = surface area covered by receivers / surface area wind farm	7.4 % (>1)
b) Random movement within area with wind turbines (and detection stations): Expected rate = surface area covered by receivers / surface area with turbines	13.6 % (>1)
c) Strongly attracted to monopile habitats with occasional 'monopile hopping': Expected rate = n monopiles covered by receivers (16) / n monopiles (36)	44.4 % (>1)
d) Extreme site fidelity, i.e. all sole are continuously recorded at the site of release: Expected rate = 100 % and number of receiver where recorded is 1	100 % (1)
Observed detection rate for sole*	
Sole released in August 2008	13.2 % (3.2)
Observed detection rates for cod*	
September 2008 batch	
- Cod released in centre of square where all monopiles were covered by receivers	45.2 % (3.4)
- Cod released at border of square where all monopiles were covered by receivers	46.2 % (4.0)
- Cod released in the wind farm part where 7 out of 27 monopiles were covered	46.5 % (2.1)
All cod released in September 2008 combined	46.1 % (3.3)
January 2009 batch	
- Cod released in centre of square where all monopiles were covered by receivers	48.6 % (2.0)
- Cod released in the wind farm part where 7 out of 27 monopiles were covered	26.6 % (1.5)
All cod released in January 2009 combined	41.3 % (1.8)

* cod and sole that were never detected after the day of release were excluded from this analysis.

For cod, as measured by telemetry, large variation in individual behaviour was observed. About 30% of the cod were detected for only a few days after release and appeared to use spatial scales larger than the wind farm. About 55% of the cod with transmitters were detected for several weeks to just over two months. About 15 % of the cod with transmitters was detected in the wind farm for 8-9 months (the duration of the experiment). Individual detection rate averaged 46 % (Table 8-2, Figure 8-4). Typically, cod stayed within a detection area for prolonged periods and sometimes switched to a different detection area within a short time interval. Cod staying within the wind farm showed clear cyclic daily patterns that changed throughout the seasons (

Figure 8-5). Varying from continuous presence (especially during autumn), to mostly at night (especially during winter and early spring) to mostly during the day (especially during late spring and early summer). Even though the degree of 'station hopping' and percentage of the time being present within the detection range of a station varied between these cod, the basic pattern is very similar. High site fidelity to a single station during prolonged periods, with only short time intervals in between 'hopping' to a next station and diurnal patterns that clearly change in the course of the seasons in a similar way.

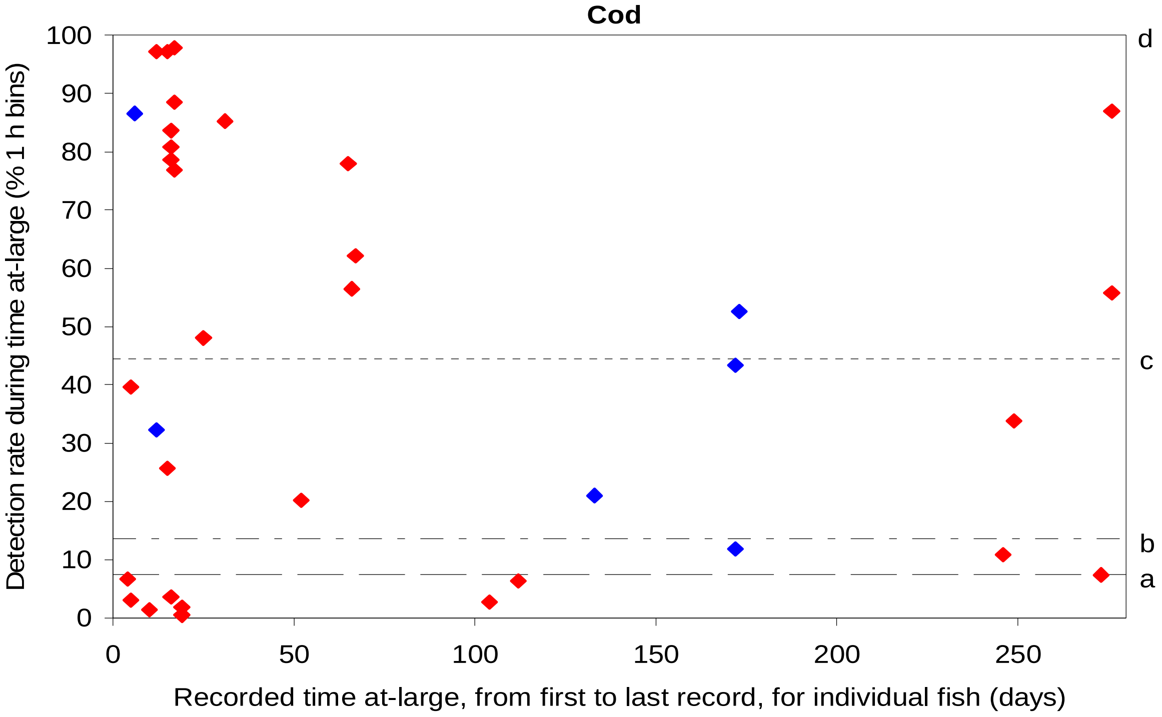


Figure 8-4: Observed detection rate, expressed as percentage of one hour bins detected during the period between the first and last detection (time at-large), for individual cod with transmitters of the September 2008 batch (red) and January batch (blue). The lines represent the expected detection rates from different behavioural scenarios, see Table 8-2.

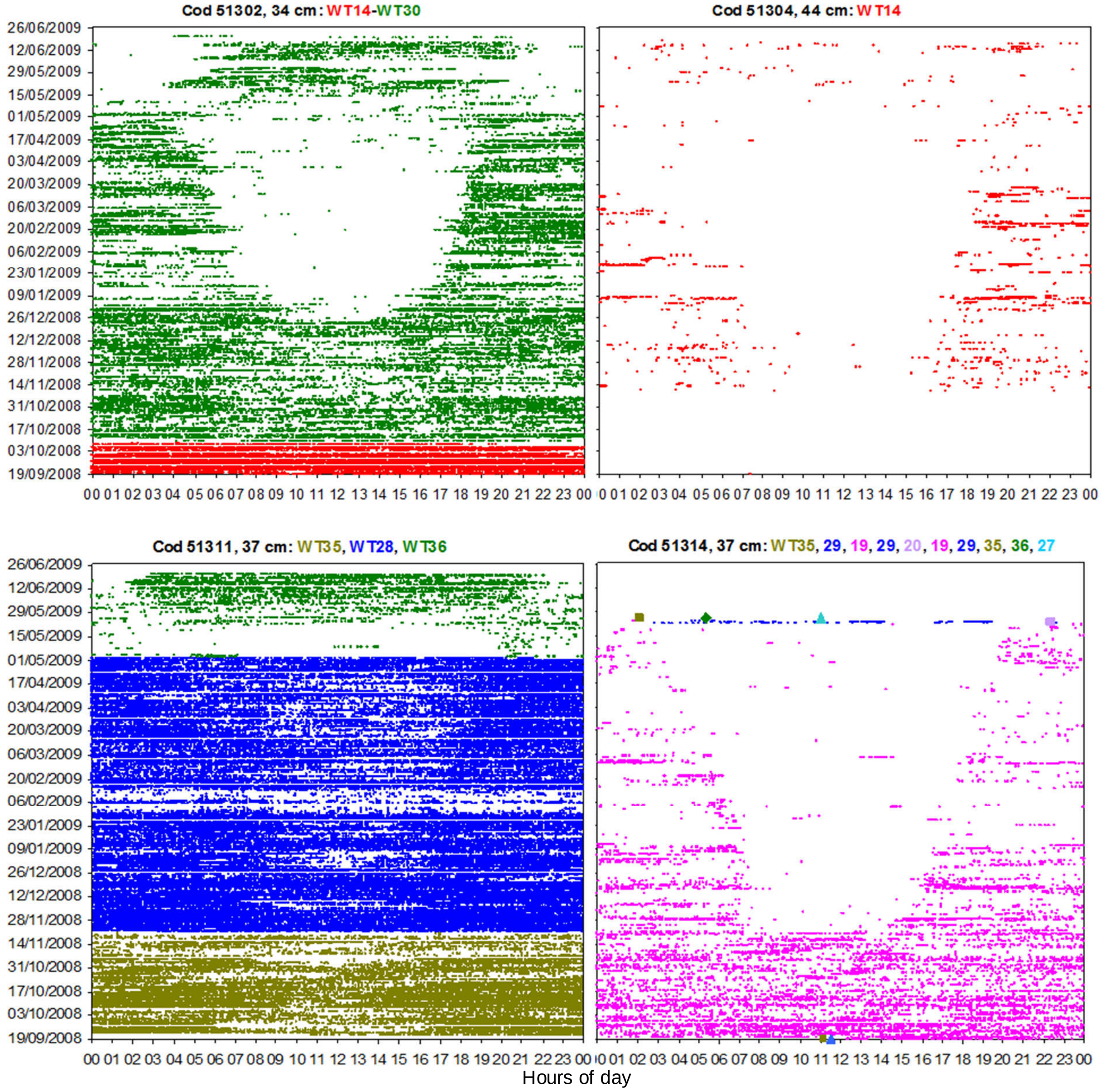


Figure 8-5: Four examples of diurnal detection pattern of four different cod of the September 2008 group during the course of the entire telemetry experiment. Each symbol represents a different detection station. The order of detection stations where these cod were detected is given in each caption.

8.4 Discussion

The results of the tagging and telemetry experiments indicate that sole use the southern North Sea at different scales throughout the seasons. However, no prolonged small scale use of the wind farm area was observed. There was no consistent difference in return rates within the tagging experiment for the group tagged and released within the wind farm compared to the reference group tagged and released outside the wind farm. This result is confirmed with the telemetry data where 55 % of the individual sole were not detected for more than one day following release, suggesting emigration of sole outside the wind farm within short time intervals for a substantial part of the sole tagged. This is supported by the observation that 5 of the 6 soles with transmitters that were recaptured by fisheries were detected in the wind farm for less than a few days.

No evidence was found for attraction to the monopile habitats. In fact, the observed telemetry data best matched a random use of the area with wind turbines during the period that soles with transmitters were detected. The telemetry data does not exclude the possibility that extreme site fidelity for the sand habitats where they were caught occurs because the sole might have returned to these sand habitats in between the monopile habitats outside the detection range of the detection stations (150-250 m). However, if this strong site fidelity and large residence time was indeed the true underlying behaviour then a significantly much lower return rate for the wind farm group than for the reference group should have been observed in the tagging experiment, which was not the case. Therefore, our combined results indicate that the majority of sole movements take place at spatial scales larger than the wind farm area of OWEZ. Some individuals use the wind farm area for periods up to several weeks during the growing season, which indicates that there is no large scale avoidance of the wind turbines, at least in part of the sole population. On the other hand there were no indications found for attraction to the monopile habitats either. All of the individual soles showed detection rates well below the 44 % as expected when attraction to monopile habitats had indeed occurred.

Our results show that at least part of the juvenile cod population spends long periods within the OWEZ. No larger adult cod were caught in the wind farm at the time of these experiments, length range caught fish 24-47cm. Whether this is due to a difference in behaviour between juveniles and adults or due to the 'young' age of the wind farm (just over a year at the start of the telemetry experiments) and subsequent later development or colonization of a 'resident' adult cod population within the wind farm, cannot be determined at this stage. Somewhat larger cod were caught in the gillnet (chapter 6) done 3 to 4 years later.

We also compared presence of cod near monopiles prior, during and after events when wind turbines were temporarily out of order and found no evidence for disturbance by the operation of wind turbines. Of course, by sampling only cod in the presence of monopiles we might have selected for individuals that are less susceptible to disturbance by wind turbine noise or vibrations. However, at least part of the cod population shows no signs of disturbance or avoidance of the wind turbines during the operation phase. Moreover, there appears to be a strong attraction to the newly created monopile habitats. Individual behaviour in cod varied considerably from moving out of the wind farm shortly after catch and release, to moving out in autumn after spending several weeks to months in the wind farm to high degrees of residency, even up to the level of long-term stays around single monopiles. Whether cod uses the wind farm for spawning is at present unknown. Given its presence year-round, it is likely that the wind farm is used for foraging and refuge, but because most, if not all, of the individuals were immature cod, its significance for spawning cannot be determined.

Cod behaviour as observed in OWEZ in combination with the fact that all fisheries are banned within the wind farm, make it that the wind farm acts as a refuge against fisheries for at least part of the cod population.

9 General discussion

This Monitoring and Evaluation Program was developed to study the potential effects of a wind farm in the Dutch coastal zone on the fish community in the area and the total North Sea. Previous work in this part of the North Sea, came from long running surveys (mainly demersal), short-term individual projects and the baseline study as executed prior to the construction of the wind farm. The long-running surveys concentrated mainly on annual fluctuations in abundance of the various species (Tulp et al. 2008). This project extended the knowledge with seasonal and behavioural information and information on the small spatial scale within the wind farm. Especially, the pelagic survey as part of the baseline and this study resulted in new general knowledge as the number of studies on the pelagic fish community in the Dutch coastal zone were limited.
Eventhough this is interesting information, the main focus of the program was on the impact of the wind farm on the fish community and this is the focus of this general discussion.

Operational phase of the wind farm: effects on fish species composition and abundance
The surveys indicate that the species composition in the Dutch coastal zone has been relatively constant over time. As is shown for a longer period based on the data of the long-running North Sea fish surveys (Tulp et al. 2008).

Seasonal variation in species richness was observed, mainly related to seasonal migration, e.g. mackerel and horse mackerel. These species appeared in all summer surveys, but were absent in winter surveys which matches with their known migration pattern (Daan et al. 1990).
The differences in species richness between years were mainly caused by low abundant or vagrant species. This makes it likely that these differences are caused by the low chance of rare species to be caught rather than an introduction or disappearance of species. It is always difficult to study the status of rare species using standard sampling surveys as applied within this project. Usually huge datasets are required to draw solid conclusions.
Considering the list of species that occurred only in a single year, two species stand out that were only detected in the T5. The goldsinny wrasse and the grey triggerfish that are known to favour hard substrate, as was introduced by the construction of the wind farm. The occurrence of goldsinny wrasse on the hard substrate of artificial structures has also been shown in the Danish Horns Rev I wind farm (Leonhard et al. 2011).

Contrary to the consistency in species richness the abundance of species fluctuated strongly spatially, inter-seasonally and inter-annually. To a large extent this is determined by migration and recruitment pulses. Also the impact of natural mortality and fishing mortality in the previous period/year affects abundance. Furthermore variations in environmental conditions, e.g. temperature, affect the occurrence of some of the species. The varying environmental conditions also affect the catchability of species, for example temperature affects the activity of species, while wind conditions affect the visibility which in turn affects the ability of fish to eventually detect the gears and thus the response time of the fish species to escape. A difference in temperature as seen between the T1 and T5 pelagic spring survey (Figure 3-4) as well as the occurrence of storms just prior or during

Bullrout

some of the survey periods are likely to increase the variability in the data on top of the seasonal and yearly fluctuations.

The power analysis done with the data of the baseline demersal survey (Paragraph 4.4, Tien et al. 2004) indicated, due to the large natural variability in the baseline, that the sampling design used in the demersal survey allows for the detection of a 30% downward or a 40% upward trend in fish biomass when comparing the impact area with the reference area or comparisons between years. Every difference within this range is considered as natural variability, and can thus not be assigned to an effect of the wind farm. This clearly limits finding effects of the wind farm, but is what you expect in a highly variable environment.

To study the potential effects of the wind farm on the abundance of species, two questions had to be answered:
1) Does a difference exist between the impact area and the reference areas in the last year surveyed (T5)?
2) Does a difference exist in trend over time between the impact area and the reference areas?
By this approach we attempted to disentangle natural variation and the effects of the wind farm, while considering the limitation shown by the power analysis. The overall conclusion for question 1 is that the wind farm did not result in changes in demersal fish abundance between the impact and reference areas outside the range of the power analysis. Neither, differences in abundance of pelagic species between the areas were observed. Also the answer on the second question is negative; the analysis indicated no changes in trends over time for demersal or pelagic species.

On individual species level some significant results were found for demersal species. Most of these results on differences between the areas indicated that only a single reference area differed from OWEZ, while the reference areas differed significantly from each other as well.
Also some trends over time were significantly different (Table 4-3). However, these significant trends were unlikely to be related to OWEZ or the trends in all four areas were so different from each other that the difference in trend could neither be related to OWEZ. As with the abundance analysis on individual species level, significantly different trends were only found between OWEZ and a single reference area.

Two demersal species, sole and bullrout, showed significant differences that indicated a potential effect of OWEZ.
For sole the summer data indicated that the variance between hauls increased in OWEZ. This indicates that while the average abundance in the farm stayed ,ore or less the same, the spatial distribution of sole in the farm changed. If sole was caught in a haul, it was caught in a larger amount in the T1 and even larger amount in the T5 compared to the baseline. It thus seems as if sole aggregates more within the farm area than they do outside the area. The change in variance did not affect the average catch of sole in OWEZ, and as only average catch is used in estimating the trend over years no effect was found here. In the reference areas, the variance between hauls was similar in the three years.

For bullrout the summer data indicated that the catches in the T5 were smaller in the wind farm than in two of the three reference areas. The trend analysis showed that the abundance of bullrout increased in all areas over time, however the increase in OWEZ is smaller than in the other areas. This indicates that the abundance of bullrout in the sandy area where the demersal survey was executed was lower than might have been expected from the results in the other areas. The gillnets however showed a significant attraction of the scour protection habitat for bullrout. It might thus be that the increase in abundance also occurred in the OWEZ areas similar to the other areas, but that these bullrout spend at least part of their time on the scour protection where the beam trawl could not be used.

The results of sole and bullrout suggest that even though their total abundance might not have changed much compared to the reference areas, their behaviour and distribution patterns might be different within the wind farm.

Creation of new habitat: effects on local species composition and abundance

On a small spatial scale, within the wind farm itself, this study has shown some significant effects. These can mainly be attributed to the introduction of the new habitat, the monopile structure and the scour protection surrounding it. Around the rocky hard-substrate of the scour protection, species occurred that were not found in the area before (e.g. goldsinny wrasse) or occurred in lower numbers (cod and bib). These fish in the vicinity of the monopiles could not be caught by the demersal or pleagic surveys and thus could their increased abundance not be detected by these surveys.

Especially, for cod this is the case as much larger numbers were found in gillnets near the monopiles compared to the gillnets placed in the sandy areas within the wind farm. About 6 to even 30 times (depending on the season) more cod was caught in the gillnets near the monopiles. This is more than found near an oil platform in the North Sea (Lokkeborg et al. 2002) where a doubling of the catch rates was observed. However, in that study fishing near the artificial reef was done at a farther distance.

The specimens of cod that were caught in the gillnet had a length up to 58 cm (likely age 3 or 4), these were slightly larger than those caught a couple of years earlier in the telemetrey study. The telemetry showed that at least part of the juvenile cod population spends long periods within the OWEZ and appeared strongly attracted to the monopile habitats. Based on the gillnet results this might also be the case for older and larger fish.

The DIDSON results indicate aggregations of fish near the monopiles in the summer period. Direct identification of the species is impossible, but based on the length distribution, their location in the water column and comparison with other research results it most likely concerns horse mackerel. However, the gillnet catches of horse mackerel were comparable for the nets placed near the monopiles and those on the sandy bottom. This was also found for mackerel or any other likely candidate. This clearly is a discrepancy between the DIDSON observations and the gillnet catches. Potential explanations are that the observed species in the DIDSON occured higher in the water column above the gillnet or that their behaviour differs near the monopiles compared to the sandy bottom influencing their catchability. Another explanation might be that aggregations observed with the DIDSON only occur during daytime and that the fish spread out during night and are then caught in the gillnets on the sandy bottom. A day–night migration of pelagic fish was observed in Horns Rev 1. In daytime higher abundance and biomass was observed inside or close to the wind farm compared to the control area outside the wind farm, whereas during night the opposite distribution pattern was observed (Leonhard et al. 2011).

Lower risk of predation, higher prey densities, and shelter from the currents have been suggested as possible explanations for the tendency og fish to congregate at artificial reefs (Bohnsack 1989). Our data are not suitable for exploring the explanation behind the attraction. It only provides data to support the hypothesis of attraction of some species by the new habitat. The stomach data in this study were partially collected to show a potential effect of prey densities in the new habitat. However, no prey items unique for the scour protection were found. These stomachs were collected during the demersal survey executed on the sandy bottom, making it unlikely that the fish have been feeding on the scour bed just before they were caught.

Disturbance caused by the operation of the wind farm

The work done in this project can only be used to hypothesise on potential disturbance by the wind farm. There is no connection made between the actual operation of the wind turbines, the potential noise and electromagnetic fields and the fish. Neither was the spatial or temporal resolution small enough to detect potential effects of noise or electromagnetic fields in the different studies. Except for the telemetry study that addressed the issue directly (for cod and sole).

Within the T0-T1-T5 surveys, no large scale avoidance of the wind farm was detected. This suggests that there are no negative effects due to large scale avoidance of the wind farm related to e.g. noise or magnetic fields. This is very similar to results of studies on the Danish Horns Rev 1 (Leonhard et al. 2011) and the Belgian Thorntonbank and Bligh bank wind farms (Vandendriessche et al. 2011). As an effect has not been found on the scale of the wind farm it is unlikely that the farm will negatively affect North Sea fish populations.

The results of the studies on small scale distribution of fish within the wind farm, i.e. the gillnet and DIDSON surveys and the tagging and telemetry experiments, showed that fish use all habitats within the wind farm. The telemetry showed that sole can spend some days to weeks within the vicinity of a monopile (<150 m). For cod spending much longer periods of time within the OWEZ, no evidence was found that areas directly around wind turbines that were out of operation, were favoured over wind turbines that were in operation. This indicates that potential noise of the turbines is not disturbing them a lot. The gillnet showed some species occurring in higher abundances in the area directly around monopiles and some species that occurred less. Small scale avoidance was mainly found for the flatfish species, but also for whiting. These species were caught less in the nets set over the scour protection, it is hypothesised that it is a preference for the sandy habitat rather than an avoidance response to disturbance. Thus, preference or avoidance related to habitat features appears the most likely explanation over avoidance due to disturbance that might act over a larger range than the scour protection and the fish species were caught in the edges of the net which was just outside the scour protection. The normal behaviour of the flatfish is to dig themselves into the bottom for ambush or protection. This behaviour cannot be performed on the hard-substrate making it likely that they prefer the sandy bottom. For whiting it is different, as the whiting is very similar to cod, a similar response was expected. Why whiting occurs in lower numbers near the monopiles is unclear.

The low abundance of these species on the scour protection means that due to the introduction of the new habitat these species might have lost habitat. Considering a scour protection with a radius of 20 m around all the 36 monopiles (plus one monopile for measurements) this means a total surface of 0.046 km^2. This is about 0.1% of the surface area of the wind farm, which is considered a negligible loss of habitat.

Exclusion of fisheries in the wind farm and its safety zone

It was hypothesised that if the wind farm acts as a refugium for fish then the length structure of the fish community would be altered as larger fish targeted by the fisheries would be safe within the boundaries of the wind farm. Very similar to the abundance and trend analysis the length structure analysis of the demersal survey indicated significant differences only between a single reference area and OWEZ. These significant results indicate a smaller average length in OWEZ compared to a single reference area. As it is not a consistent result between OWEZ and all three reference areas it is unlikely that this is related to the presence of the wind farm.

The results of the pelagic survey indicated however a change in length distribution for anchovy and sprat. In the T1 and T5, anchovies caught in OWEZ and the adjacent reference area REFZ, had a significantly larger frequency of larger fish compared to the REFN and the hauls taken outside the specified areas. The same pattern was found for sprat, but only in the T5 survey. As these species were not targeted by fisheries in the Dutch coastal zone, it is unlikely that this is directly related to the exclusion of fisheries. A possible explanation might be that the monopiles provide shelter and protect these species from predators, while outside the area visual predators first catch the larger specimens. Positive effects on length-frequency distributions of fish inhabiting artificial reef structures versus those living outside have previously been observed (Anderson et al. 1989). These other studies provide evidence for the protective function of reef structures and its positive effect on some pelagic fish species.

It was also hypothesised that the exclusion of fisheries would lead to changes in the benthic community, which was expected to lead to improved food conditions for fish. However, as the study by Bergman et al. (2012 draft) shows only very limited if any changes are observed in the benthic community. As a result it is unlikely to expect changes in the food conditions. The only exception is the changes in the benthic community on the introduced habitat as shown by Bouma and Lengkeek (2009). The stomach samples collected are however from the area studied by Bergman et al. (2012 draft) and in line with their findings no differences in content were found that could be contributed to the wind farm.

The tagging and telemetry showed that sole use the wind farm but their residence time is limited. The residence time is a prerequisite for the wind farm to act as a refugium for fish. The limited residence time of sole does not enhance the protection by fisheries for sole, which is likely the case for more species. It is therefore very unlikely that the farm acts as refugium or MPA for sole and species having a similar residence time.

The tagging and telemetry showed that the residence time of a part of the cod living within the wind farm area was high. The combination of more cod occurring around the monopiles and the evidence that they stay long periods within the farm makes it likely that the farm acts as a refugium for this species. Even though the demersal surveys on the sandy bottom were unable to show an increase in abundance.
The cod used in the tagging and telemetry study were juveniles and therefore these gave no information on the spawning of cod in the wind farm. If cod would not only stay for prolonged periods of time, but would also spawn in the area it enhances the role of the wind farm as refugium for the species. Cod spawning grounds appear to be wide-spread and not restricted to specific areas. In fact, spawning aggregations may be found offshore all over the North Sea (Heessen et al. 2005). Thus, spawning of cod in the wind farm might occur. The eggs are however pelagic and will drift with the current out of the wind farm, but the conditions seem suiteable for the settlement of larvar form other areas drifting into the OWEZ area. Therefore the wind farm might potentially protect a significant part of the life-cycle of this species from fisheries.

Also for edible crab attraction of the new habitat was shown for all three periods. It is known that this crab species uses the crevices in the scour protection as hiding place and prefers this over sandy bottoms (Langhamer & Wilhelmsson 2009). There is a fishery for this species in the North Sea, and the aggregations near the monopiles create a possibility for a low risk commercial fishery using pots (Verhaeghe et al. 2011).

For bib, bullrout, sea scorpion and common dragonet a higher abundance in the new habitat was only shown for a part of the year. This might be due to low numbers occurring in the area and low catchability for these species in the gillnets, which is likely the case for bullrout, sea scorpion and common dragonet. It may also be caused by the migration behaviour of some species, which is likely the case for bib. Bib was only caught in the second and third period, and in these periods it was clearly attracted by the new habitat. Similar attraction was seen in the Belgium wind farm (Reubens et al. 2011b), where, bib was caught the whole year round. For species with migration behaviour the refugium function of the farm is lower than for stationary species which are protected in the farm for their full life-cycle. In case critical periods of their life history e.g. spawning or settling, take place in the season they occur in the farm, this might increase the refugium function of the farm relative to the time spent in the farm.

During their life cycles most fish use a much larger area than just the wind farm, which is confirmed by the tagging and telemetry study of sole in the farm. For these species it is most likely that the farm is too small to function as a marine protected area (MPA), which is similar to the conclusions drawn from the study on the Danish wind farm Horns Rev 1 (Leonhard et al. 2011). This does however not exclude such effects when more and larger wind farms are constructed in the future.

10 Conclusions

1) The presence of the wind farm and the exclusion of fisheries in the wind farm area and its safety zone did not lead to a detectable increase in the occurrence or densities of demersal and pelagic fish. Nor did it lead to a detectable decrease of the fish based on the demersal and pelagic surveys.
2) It neither affected the size structure of the demersal fish community compared to the reference areas surrounding it.
3) There is some evidence of a change in the length structure of anchovies and sprat. For these species more large specimens were observed within the area of the wind farm. Most likely this is related to a reduction in predation pressure in the wind farm.
4) The introduction of new habitat attracted species such as cod, edible crab, bib, bullrout, sea scorpion and common dragonet, as could be expected from their preference for hard substrate habitats and artificial reefs.
5) Disturbance by noise from the operating wind farm did not appear to play a role for the species attracted by the new habitat, neither was an avoidance reaction of the fish seen on the scale of the wind farm.
6) Lower abundance on the stony habitat was observed for the flatfish species sole, dab, and plaice and for whiting, but the habitat loss for these species concerns only 0.1 % of the surface area of the wind farm and is assumed negligible.
7) Two ”new” species were caught on the scour protection, both were only caught once but are an indication in favour of the hypothesis that the new habitat attracts other fish species and would thus have a positive effect on the biodiversity.
8) Large aggregations of fish near the monopiles during day time were observed with the DIDSON mainly in summer. It is hypothesised that these aggregations were horse mackerel, but the available data are insufficient to confirm this.
9) The tagging and telemetry study showed difference in use of the wind farm by two example species sole (indifferent) and cod (attraction). This difference in use is confirmed by other data showing clear seasonal differences. Owing to differences in behaviour, the potential effect of the wind farm and especially the refugium function of the farm, differs between species.
10) Concluding, the presence of the wind farm seems to have limited, if any effect, on the fish community of the Dutch coastal zone. For some species local benefits due to a combination of the creation of new hard substrate habitats and exclusion of fisheries might have occurred.

11 Lessons learned

The complete program was a pilot study to evaluate the effect of an offshore wind farm on the fish community. Many plans were made of which only a part was feasible and is executed. During the fieldwork not everything has gone as planned, and afterwards doing analysis and having the discussions on the results makes clear that things could have been done better or in a different way. The ones considered most valuable for future projects are described here.

- Fieldwork conditions

Most of the fieldwork done by IMARES is limited by the weather conditions, which is no different for the fieldwork done in this project. Most of the fieldwork prior to this project however consisted of long-running large scale surveys that are performed to deliver a tuning series for the assessments and although not desired, missing some hauls due to the weather conditions has limited effect on the results.

In this projects fieldwork misisng even a limited number of hauls or sampling day directly effects the result as it affects the power of the analysis. This is for example very clear in the October 2011 pelagic survey, where acoustic sampling could still be executed however fishing could not. Due to this no species identification could be done on the data collected in that period. Similar issue occurred with the DIDSON recordings in summer, due to the rough weather conditions the data that was collected during the second sampling day is useless and therefore no replicates were available in summer. Similar aspects have also occurred in the demersal and gillnet surveys, not directly visible in the number of hauls or nets placed. But in the demersal survey for example in the number of stomach samples collected. In rougher weather conditions it is still possible to fish; however securely gutting fish of only a couple of cm's and keeping all the equipment complete is a different story. Besides weather conditions, the sea is also a harsh environment for equipment, e.g. damaging the nets. This might lead to extra delay even during great weather conditions.

These types of fieldwork need a different approach on how to collect the data and plan the work. Rather than a fixed period to do the work and if not finished within this period than it is so. The work should continue until all the planned or at least a minimal number of samples is collected. This makes it very difficult to plan the staff but also equipment as both are needed for other projects. And also the vessels needed have to be reserved for a much longer time, which means extra expenses.

It is not only the planning but also in the attitude of the staff working in the field that needs some adjustments. The last is not as simple as it sounds. If for many years you have been sampling the fish in a certain way most of the time focussed on the tuning series, and now catches have to be sorted in a more precise way and the focus of the work is on different aspects it needs some time to adjust to that and fully understand what is requested from you.

- Natural variability

The fish community in the study area shows a large spatial and temporal natural variability. No location sampled is the same, not in the number of species neither in the composition of the (abundant) species. This variability is enhanced by the catchability issue, where catchability is not the same for all species or lengths of a species, neither is it the same under all environmental conditions.

This makes it difficult to detect effects and as shown in the power-analysis of the demersal survey a very large number of hauls is needed to detect small changes in abundance. These numbers of hauls are often unrealistically high to be executed. This makes the realisation and with that the use of a BACI-approach as used here rarely worth the effort for the questions that need to be answered with it.

A consequence of a smaller survey program is that only major changes can be detected, which is the case in this program. It is necessary to make this clear prior to the sampling campaigns as else unrealistic expectations might occur at the side of the contractors. Only at that time it is possible to alter or extend campaigns in order to better match some of the expectations.

- Adjustments to the program during the project

The pelagic survey was changed from the T0 to the T1 and again in the T5. The changes after the T0 were mainly driven by the feasibility of executing the full program in the available time rather than by the questions asked. In the T0 was revealed that extended program with the long transects was impossible to sail within the availed time especially considering limitations owing to the weather conditions. A double change was made, the sampling period was extended and the transects were altered.

Bad luck was that the environmental conditions in the T1 were quite different from those in the T0. This affected the presence of species, e.g. the appearance of sandeel during the T1 survey. The change in environmental conditions could not be disentangled from potential effects of making adjustments to the survey design. Two differences occuring at the same time further complicated the analyses.

Thus even as with the best intensions adjustments are made to the program, it is important to keep in mind the natural variability and especially keep the main question(s) in mind to ensure that the adjustments do not worsen the power of the sampling scheme or even the comparability with earlier work.

- Stomach sampling

Another adjustment occured in the demersal survey. Here, a change from collecting otoliths in the T0 demersal survey to stomach content in the T1 and T5 was made. The reasoning was that the otoliths used for age determination did not contribute much to the knowledge already available from other programs. Stomach content seemed a good replacement and to be able to answer questions on differences in food availability and prey items in the different areas.

Collecting stomach samples, each stomach labelled and stored in its own jar, was much more time consuming on board than the collection of otoliths also weather conditions are sooner a limiting factor for this work. The sample size at the end of a survey period is thus much smaller for stomach content than for otoliths.

The sample size is reduced further, because especially in winter a large part of the stomachs was empty and empty stomachs give no information on the presence of prey items. Empty stomachs were used in the analyses on food availability, but an empty stomach can also be a strategy of the fish to save energy rather than lack of food in the area.

Drawing conclusions especially on differences in prey items between the areas, based on the content of the full stomachs is complicated. Many of the species sampled are opportunistic feeders that can consume a large number of different prey species, but each stomach often contains only a single prey type. Many stomachs from to same area thus contain complety different prey types and the variability with an area is thus large. Similar as with the power analysis of the demersal survey a very large number of samples is needed to test differences between the areas with the variability within area is large.

This variability is increased further as different lengths of the same species consume different prey items. The stomach samples were collected over the full length range of a species, making the number of stomachs per length class very small.

Collecting stomachs for answering the questions asked isn't as easy as tried in this project. It will need much more stomachs per species in each area, which is difficult to collect besides running the sampling scheme in a limited period of time as discussed in the first point of this chapter. It will be nearly impossible to collect enough stomachs for all the species as mentioned in this project. A focus on a single maybe two species should be made.

- Condition

The question related to stomach sampling, e.g. is the food availability improved due to the exclusion of fisheries, did also asked if the condition of the fish improved in the wind farm. A simple method for condition is weight vs. length (Fulton's K). In the program weighing of the fish from which stomachs were collected is mentioned and it has been done in some cases. However the facilities on board of a commercial eurocutter are limited and it was difficult to keep the scale stable in the experienced sea states, especially for weighing fish of only just some grams. Besides that slightly more advanced methods measuring condition in the lab should be considered in following projects.

- Knowledge gaps

The main gaps in knowledge in relation to the effect of a wind farm are related to the behaviour of species. The expectation is that similar species behave similarly, however when you look at the results it was expected that whiting would be attracted similarly as cod. Or that all flatfish would have reduced abundance on the scour protection. As this is not the case it means that the individual behaviour of species (or individuals) is important knowledge to be able to predict the effect of the wind farm.
Behavioural data is available for cod and sole from the telemetry and tagging study and this type of data enables predicting the actual effect rather than a causal relationship between abundance in an area and the presence of the wind farm.
The telemetry data also provided information on residence time. Residence time is probably the main aspect needed to predict the protective function of the farm. This project has shown that species occur on the sandy bottom in the wind farm. But as residence time in the farm is limited as shown for sole, the protection by the farm from fisheries is limited. Residence time alone is not enough, it should be studied which part of the life-cycle takes place in the wind farm. If spawning and settlement take place in other areas the protective function of the farm is limited when they are fished already prior to arriving in the farm.

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13 Quality Assurance

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

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Justification

Report Number: C059/12
Project Number: 4302500804

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

Approved: Henk Heessen
onderzoeker

Signature:

Date: 2 October 2012

Approved: Han Lindeboom
Senior onderzoeker

Signature:

Date: 2 October 2012

A. Appendix A. Basic information

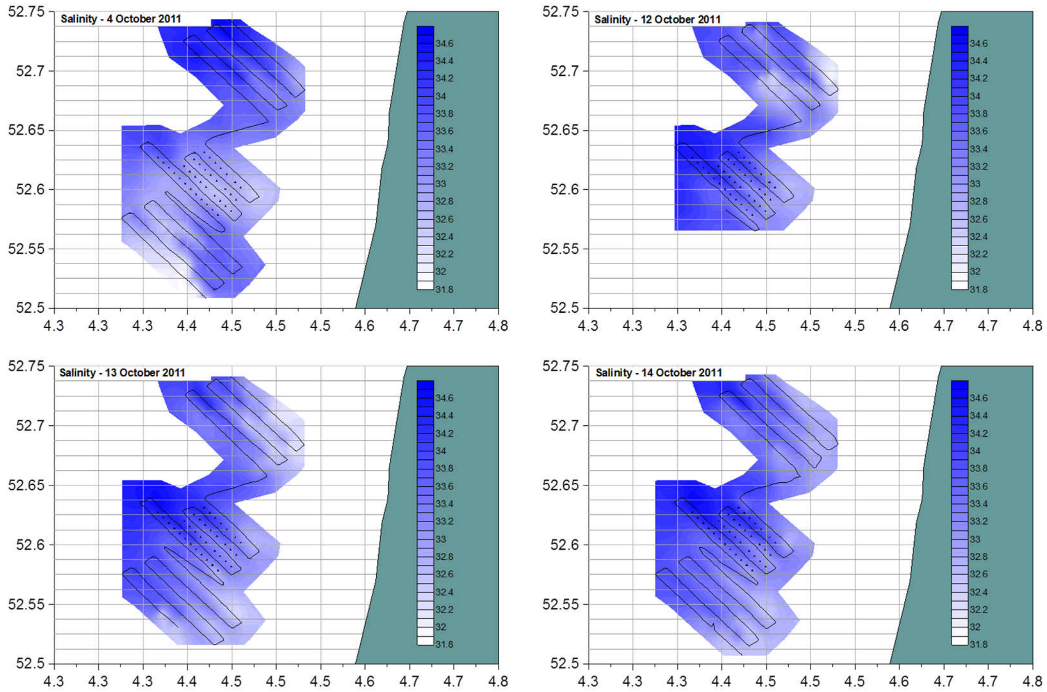
Benthic species overview based on the catches of all surveys.

Appendix table A-1: All benthic species caught in the three sub-projects by period and quarter. NSWDEM=Sub-project 1 demersal survey; NSWPEL= Sub project 2 pelagic survey; NSWGILL= Sub-project 3 gillnet. T0=2003/2004; T1=2007/2008 and T5=2011.

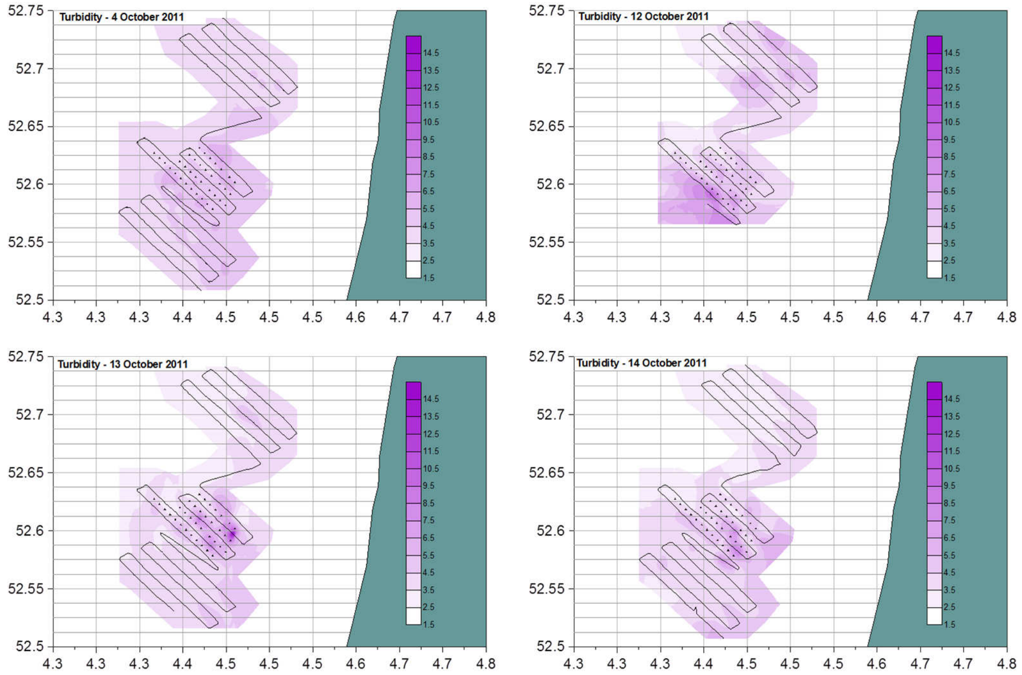
			NSWDEM						**NSWPEL**				**NSWGILL**	
			T0		**T1**		**T5**		**T0**		**T1**	**T5**	**T5**	
	Dutch name	**Scientific name**	**S**	**W**	**S**	**W**	**W**	**S**	**Sp**	**Au**	**Sp**	**Sp**	**Sp**	**Au**
1	Oorkwal	Aurelia aurita										x		
2	Zeeanemonen	Anthozoa	x				x	x						
3	Zeedruif	Pleurobrachia pileus							x		x			
4	Fluwelen zeemuis	Aphrodita aculeata					x							
5	Patella	Patella sp.	x											
6	Glanzende tepelhoorn	Lunatia alderi	x					x						
7	Grote tepelhoorn	Euspira catena					x							
8	Gevlochten fuikhoorn	Nassarius reticlatus					x	x						
9	Mossel	Mytilus edulis	x				x	x						
10	Spisula	Spisula sp.	x				x	x						
11	Grote strandschelp	Mactra corallina	x											
12	Otterschelp	Lutraria lutraria					x							
13	Ensis	Ensis sp.	x				x	x						
14	Tafelmesheft	Ensis siliqua	x											
15	Nonnetje	Macoma balthica						x						
16	Zaagje	Donax vittatus	x				x	x						
17	Venus	Venus sp.	x											
18	Venusschelp	Chamelea gallina	x				x	x						

19	Sepiola	Sepiola sp.	x					x				x		
20	Sepia	Sepia sp.						x			x			
21	Loligo	Loligo sp.	x					x	x	x	x		x	
22	Steurgarnaal	Palaemon sp.										x		
23	Crangon sp.	Crangon sp.	x				x	x	x		x	x		
24	Driepuntsgarnaal	Philocheras trispinosus	x											
25	P. bernhardus	Pagurus bernhardus	x				x	x				x		
26	Hooiwagenkrab	Macropodia rostrata	x					x	x					
27	Helmkrab	Corystes cassivelaunus	x				x	x						
28	Noordzeekrab	Cancer pagurus	x				x	x				x	x	x
29	Breedpootkrab	Portumnus latipes	x											
30	Strandkrab	Carcinus maenas	x				x	x						
31	Zwemkrabben	Macropipus sp.	x											
32	Blauwpootzwemkrab	Liocarcinus depurator	x				x	x	x					
33	Gewone zwemkrab	Liocarcinus holsatus	x				x	x	x		x	x		
34	Fluwelen zwemkrab	Necora puber	x					x	x				x	x
35	Gemarmerde zwemkrab	Liocarcinus marmoreus	x					x						
36	Nagelkrab	Thia scutellata	x					x						
37	Zeester	Asterias rubens	x				x	x	x		x	x		
38	Slangster	Ophiura ophiura	x				x	x	x					
39	E. cordatum	Echinocardium cordatum	x				x	x						

Maps based on CTD measurements from the October 2011 pelagic survey.



Appendix figure A-1:Salinity (ppt) in the reference areas and the wind farm in October 2011 based on CTD measurements.



Appendix figure A-2: Turbidity (NTU) in the reference areas and the wind farm in October 2011 based on CTD measurements.

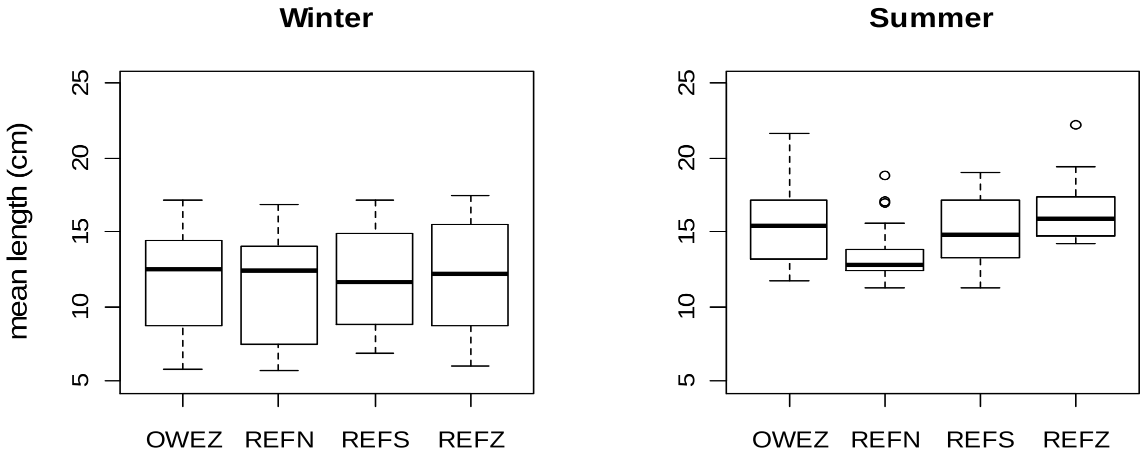
B. Appendix B. Demersal fish community

Haul locations of the demersal survey.

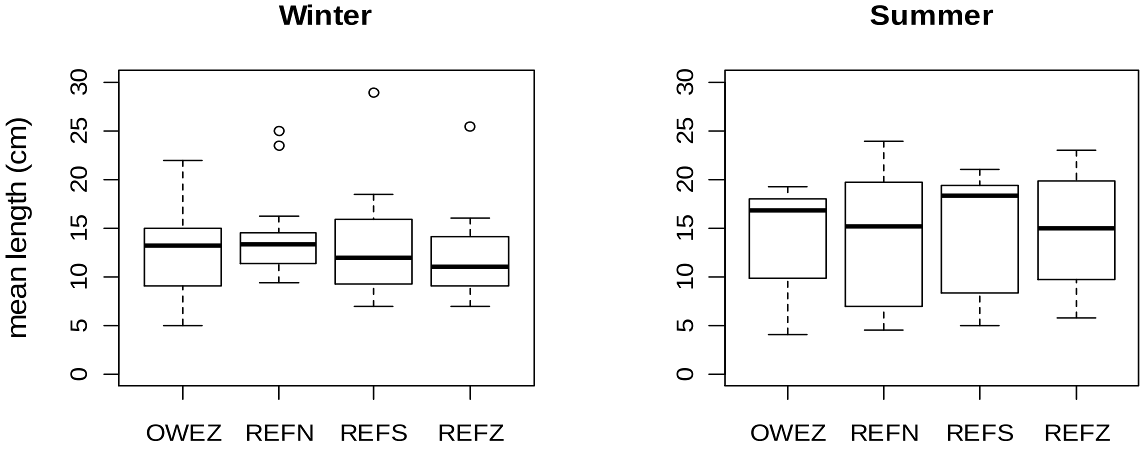
Appendix table B-1: Haul locations

	Shoot latitude	Shoot longitude	Haul latitude	Haul longitude	station	Shoot latitude	Shoot longitude	Haul latitude	Haul longitude
OWEZ01	52.619	4.373	52.607	4.390	**REFN01**	52.702	4.404	52.690	4.422
OWEZ02	52.599	4.403	52.586	4.420	**REFN02**	52.691	4.432	52.679	4.450
OWEZ03	52.636	4.369	52.623	4.386	**REFN03**	52.673	4.478	52.660	4.495
OWEZ04	52.616	4.396	52.604	4.413	**REFN04**	52.714	4.419	52.701	4.436
OWEZ05	52.596	4.424	52.584	4.441	**REFN05**	52.698	4.449	52.685	4.467
OWEZ06	52.631	4.395	52.618	4.412	**REFN06**	52.674	4.506	52.661	4.523
OWEZ07	52.613	4.421	52.601	4.438	**REFN07**	52.666	4.527	52.654	4.544
OWEZ08	52.593	4.450	52.581	4.467	**REFN08**	52.665	4.548	52.653	4.564
OWEZ09	52.636	4.407	52.624	4.424	**REFN09**	52.741	4.439	52.729	4.456
OWEZ10	52.616	4.435	52.604	4.453	**REFN10**	52.730	4.461	52.717	4.479
OWEZ11	52.598	4.462	52.585	4.479	**REFN11**	52.718	4.485	52.706	4.501
OWEZ12	52.634	4.429	52.622	4.446	**REFN12**	52.694	4.546	52.682	4.563
OWEZ13	52.613	4.458	52.601	4.475	**REFN13**	52.687	4.567	52.675	4.584
REFS01	52.466	4.288	52.454	4.305	**REFZ01**	52.603	4.301	52.590	4.319
REFS02	52.457	4.335	52.445	4.352	**REFZ02**	52.581	4.345	52.568	4.362
REFS03	52.444	4.372	52.432	4.389	**REFZ03**	52.562	4.384	52.550	4.401
REFS04	52.476	4.306	52.463	4.323	**REFZ03**	52.549	4.424	52.537	4.442
REFS05	52.466	4.351	52.454	4.368	**REFZ04**	52.612	4.317	52.600	4.335
REFS06	52.453	4.387	52.441	4.405	**REFZ05**	52.591	4.360	52.579	4.377
					REFZ07	52.572	4.400	52.560	4.417
					REFZ08	52.559	4.440	52.547	4.458

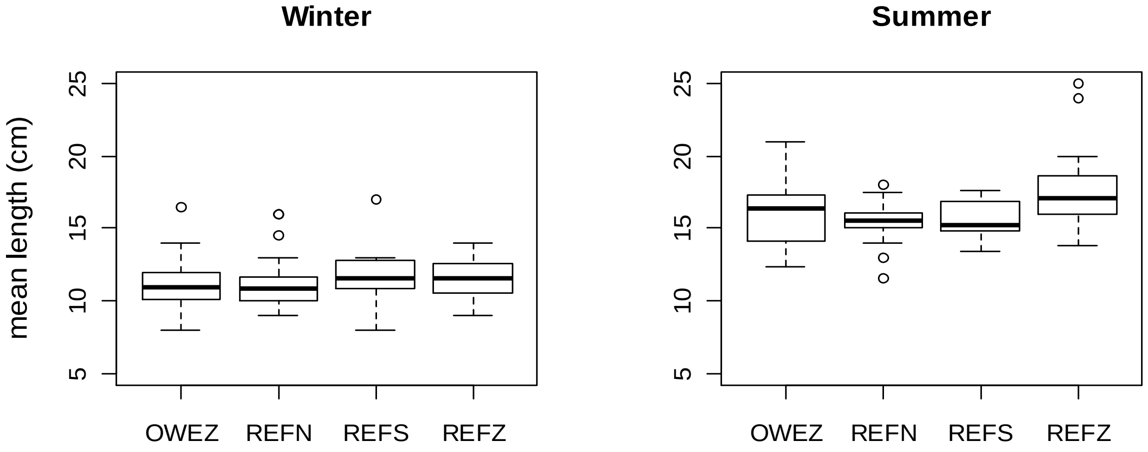
Mean lengths by species in the different seasons.



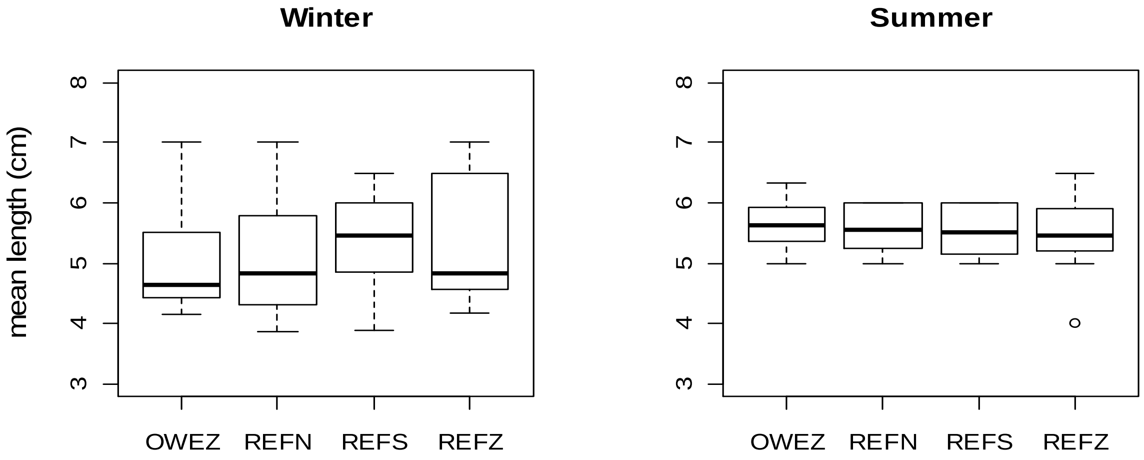
Appendix figure B-1: Mean lengths of dab (cm) during T5 in winter and summer.



Appendix figure B-2: Mean lengths of whiting (mean per station) during T5 in winter and summer.

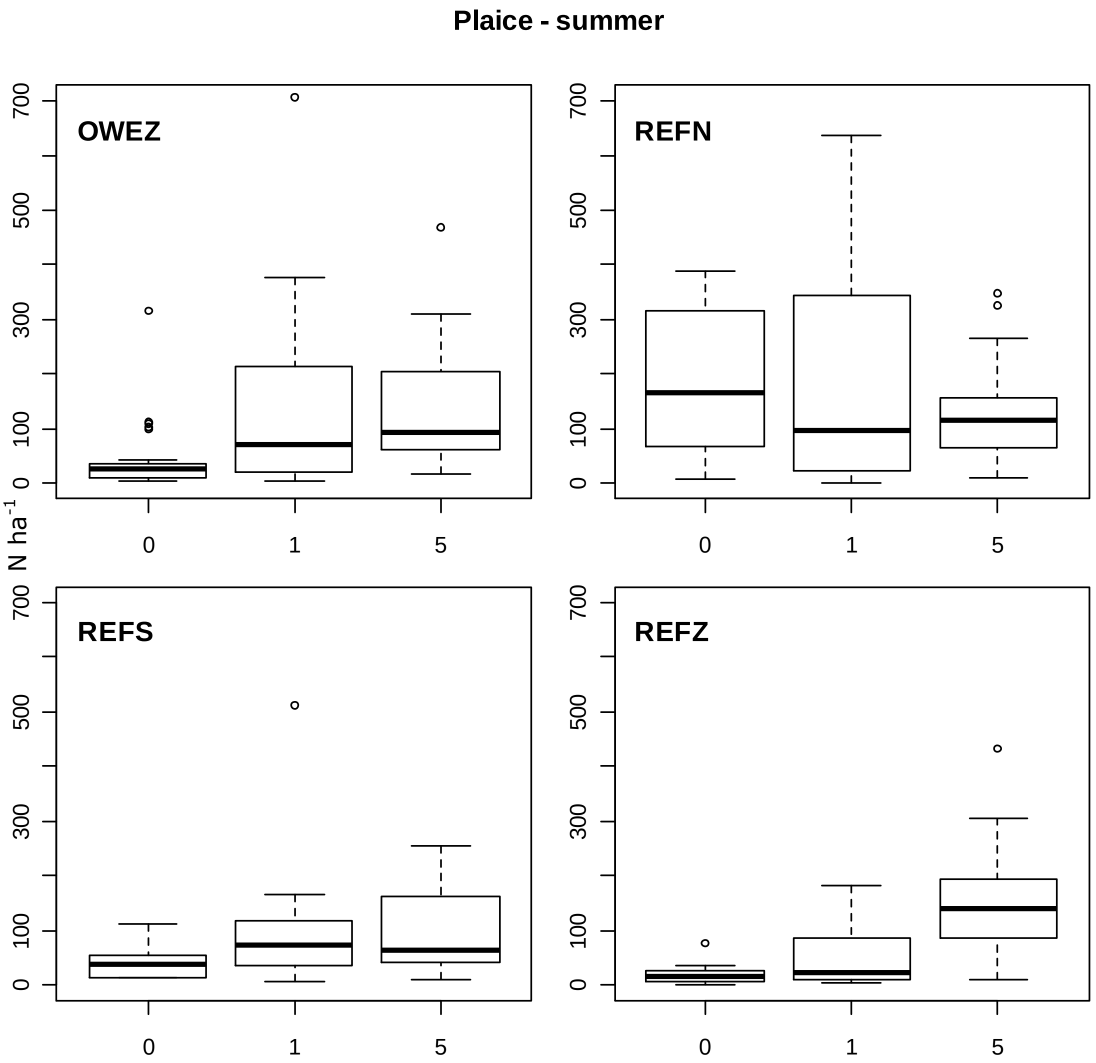


Appendix figure B-3: Mean lengths of bullrout (mean per station) during T5 in winter and summer.

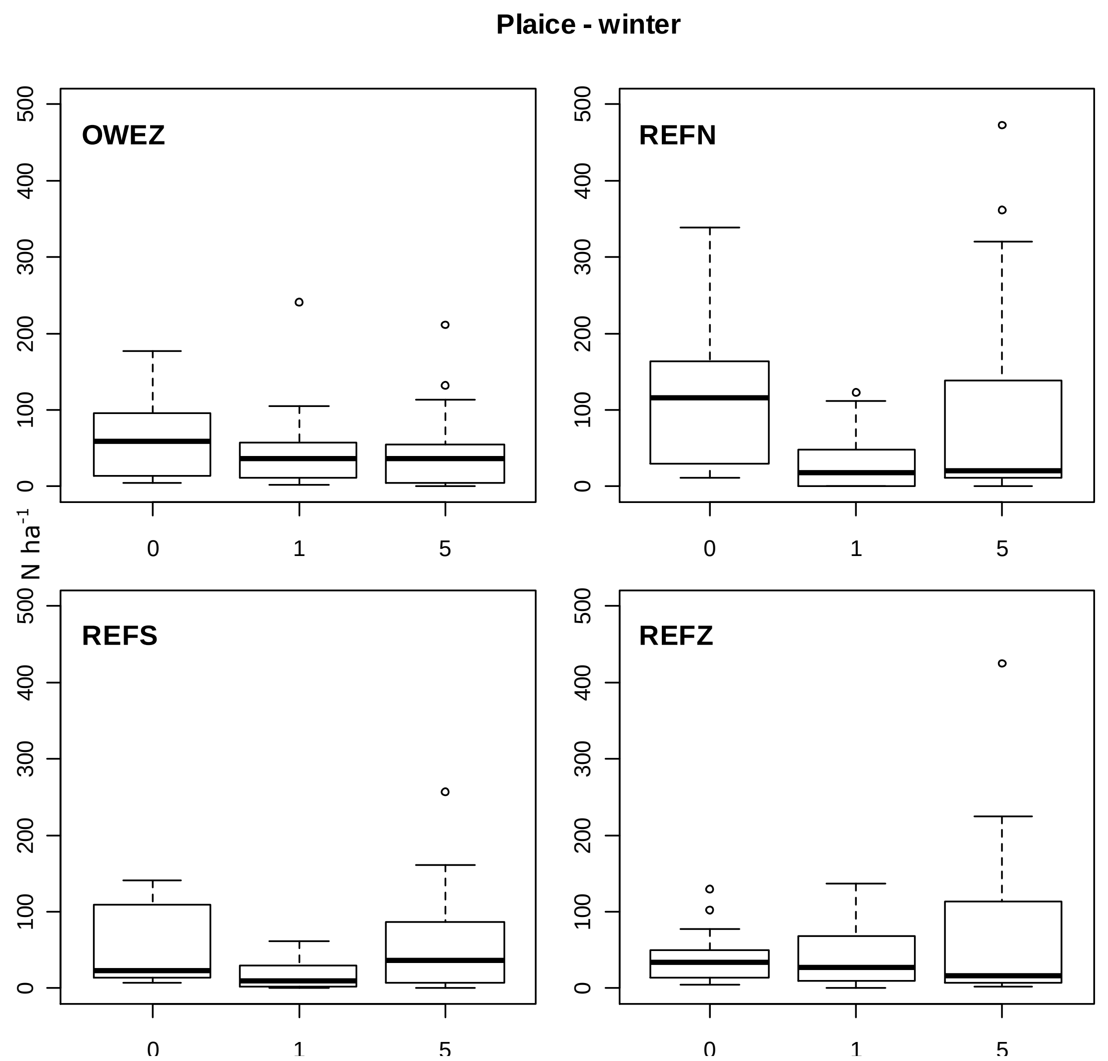


Appendix figure B-4: Mean lengths of gobies (mean per station) during T5 in winter and summer.

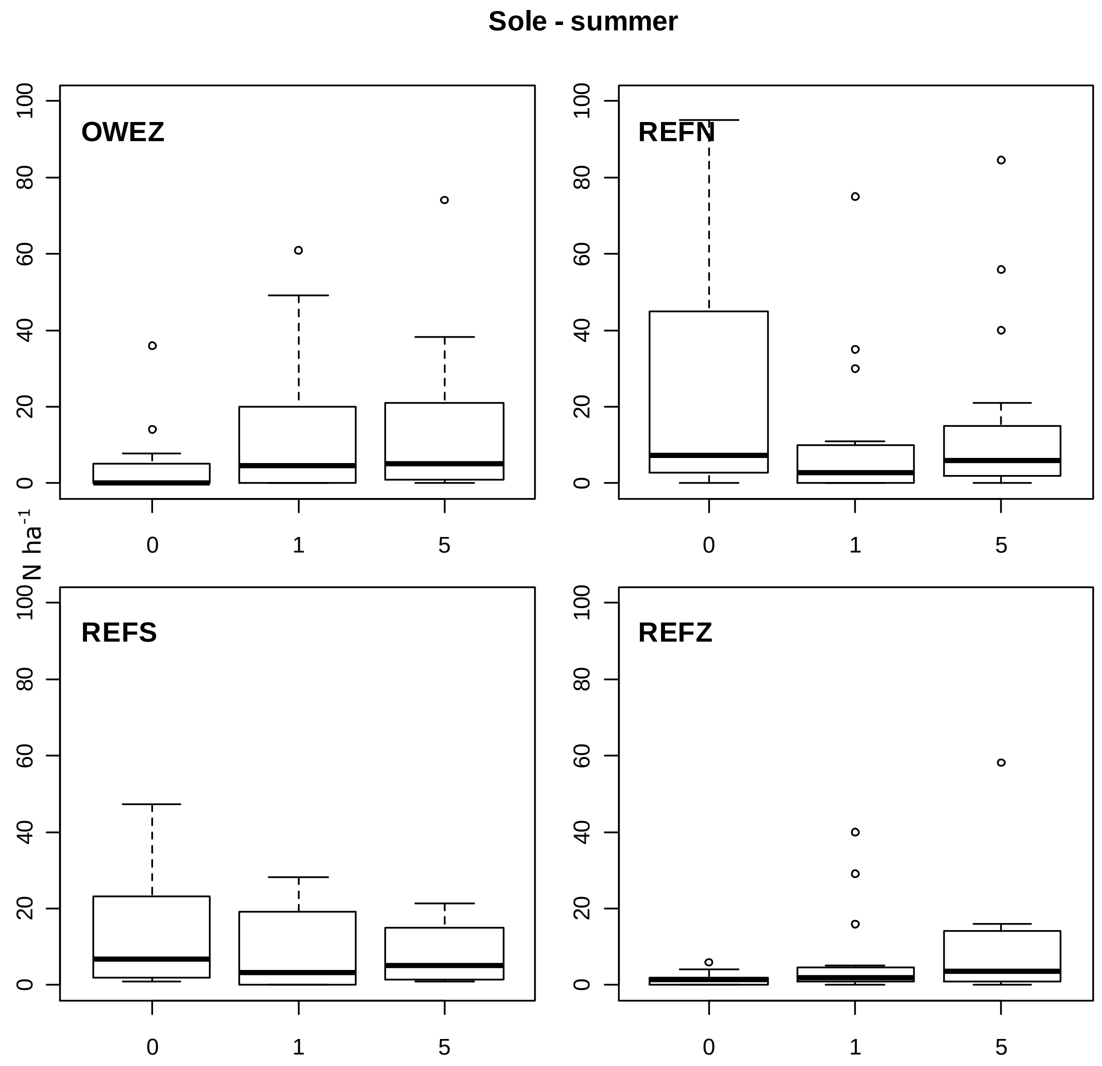
Comparison of abundances by species between T0, T1 and T5.



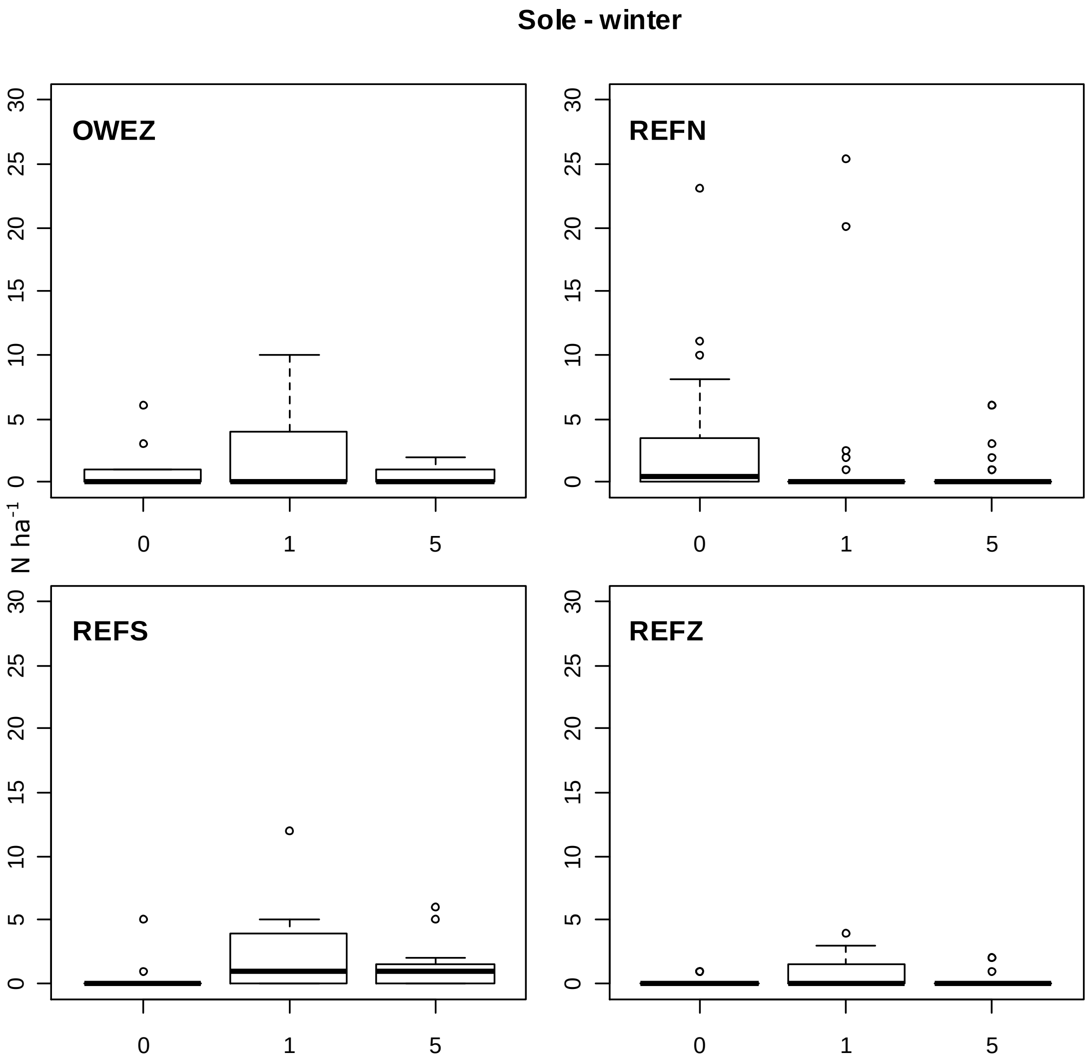
Appendix figure B-5: Differences in catches of plaice (numbers per ha) between years and by area during summer both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2003, 1= T1 2007 and 5=T5 2011.



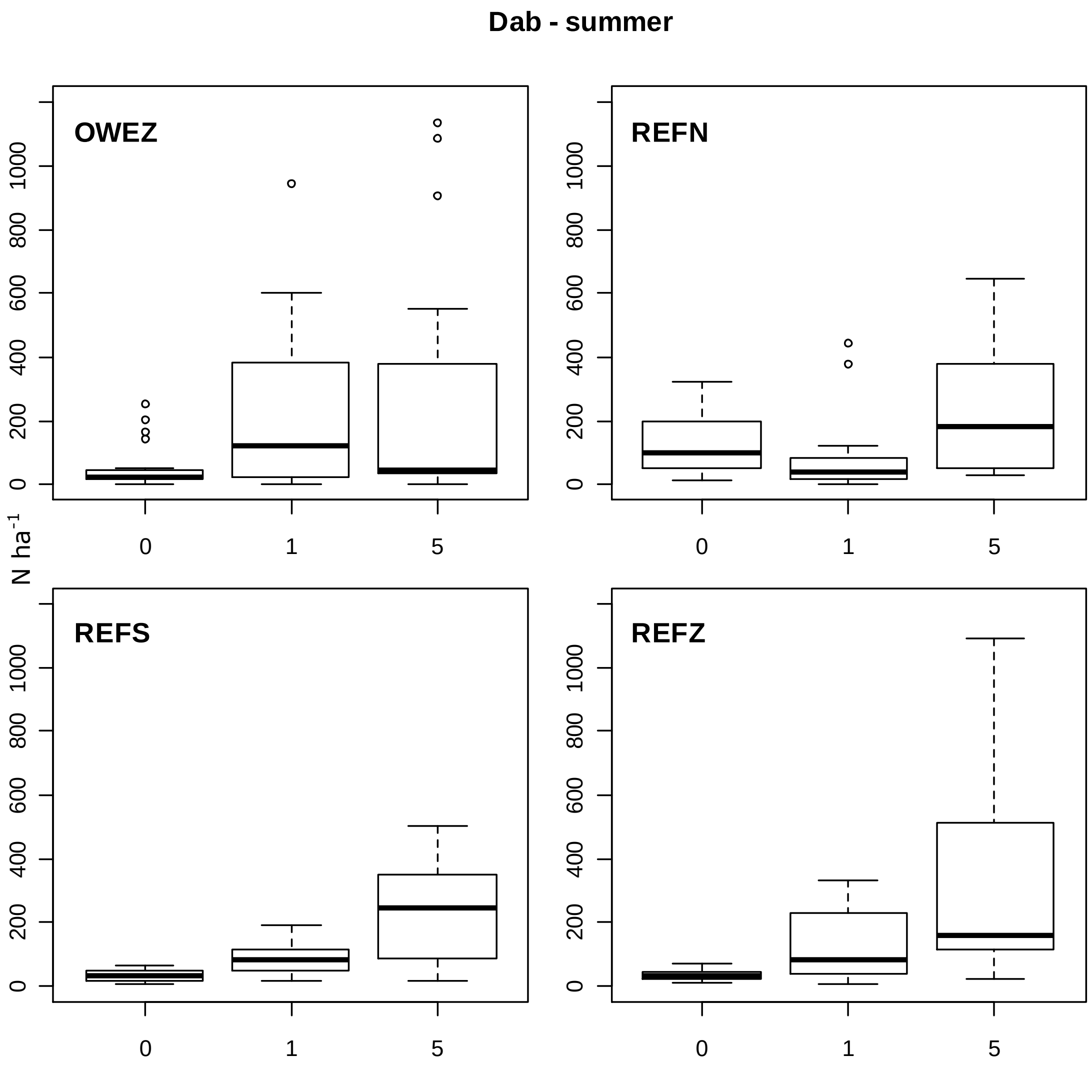
Appendix figure B-6: Differences in catches of plaice (numbers per ha) between years and by area during winter both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2004, 1= T1 2007 and 5=T5 2011.



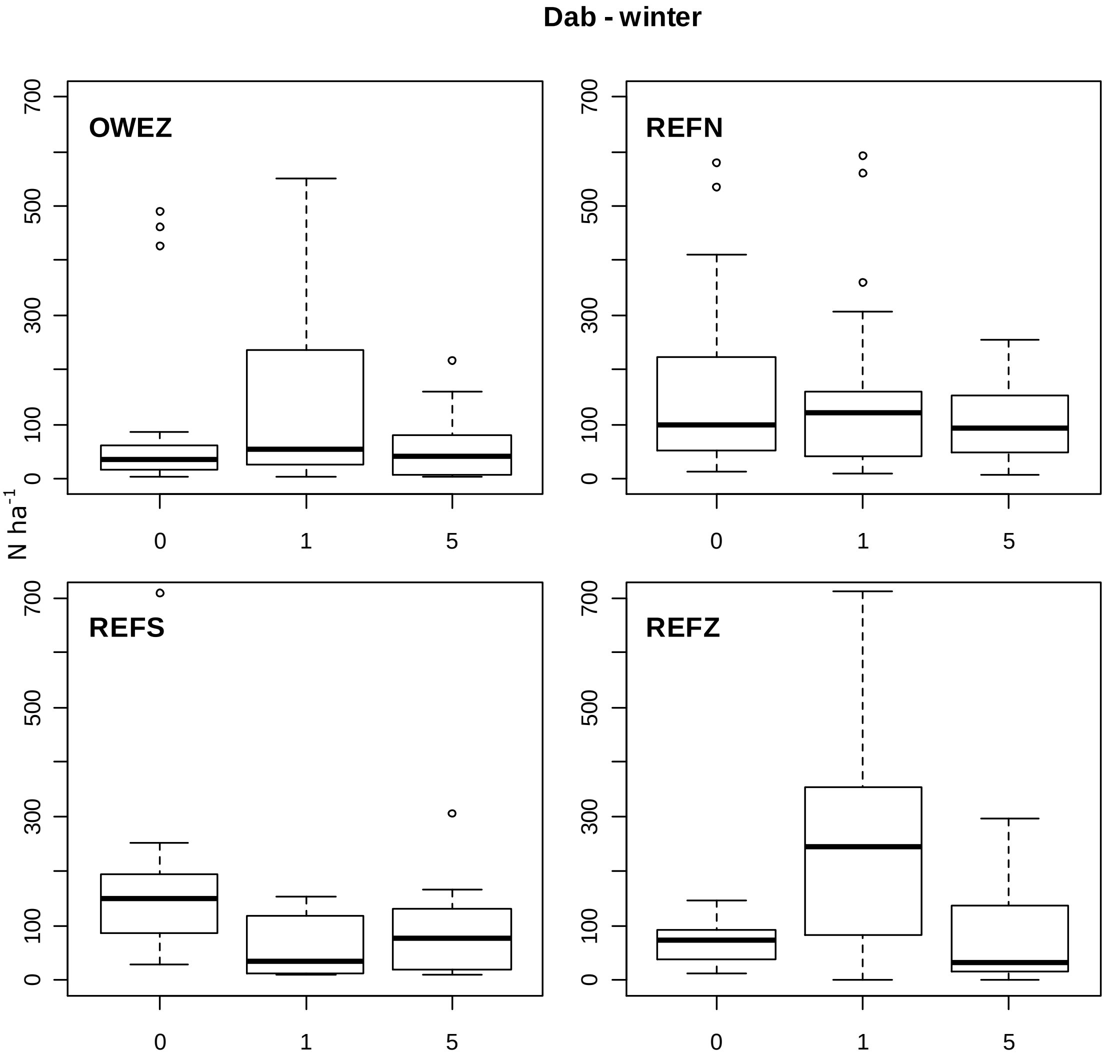
Appendix figure B-7: Differences in catches of sole (numbers per ha) between years and by area during summer both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2003, 1= T1 2007 and 5=T5 2011.



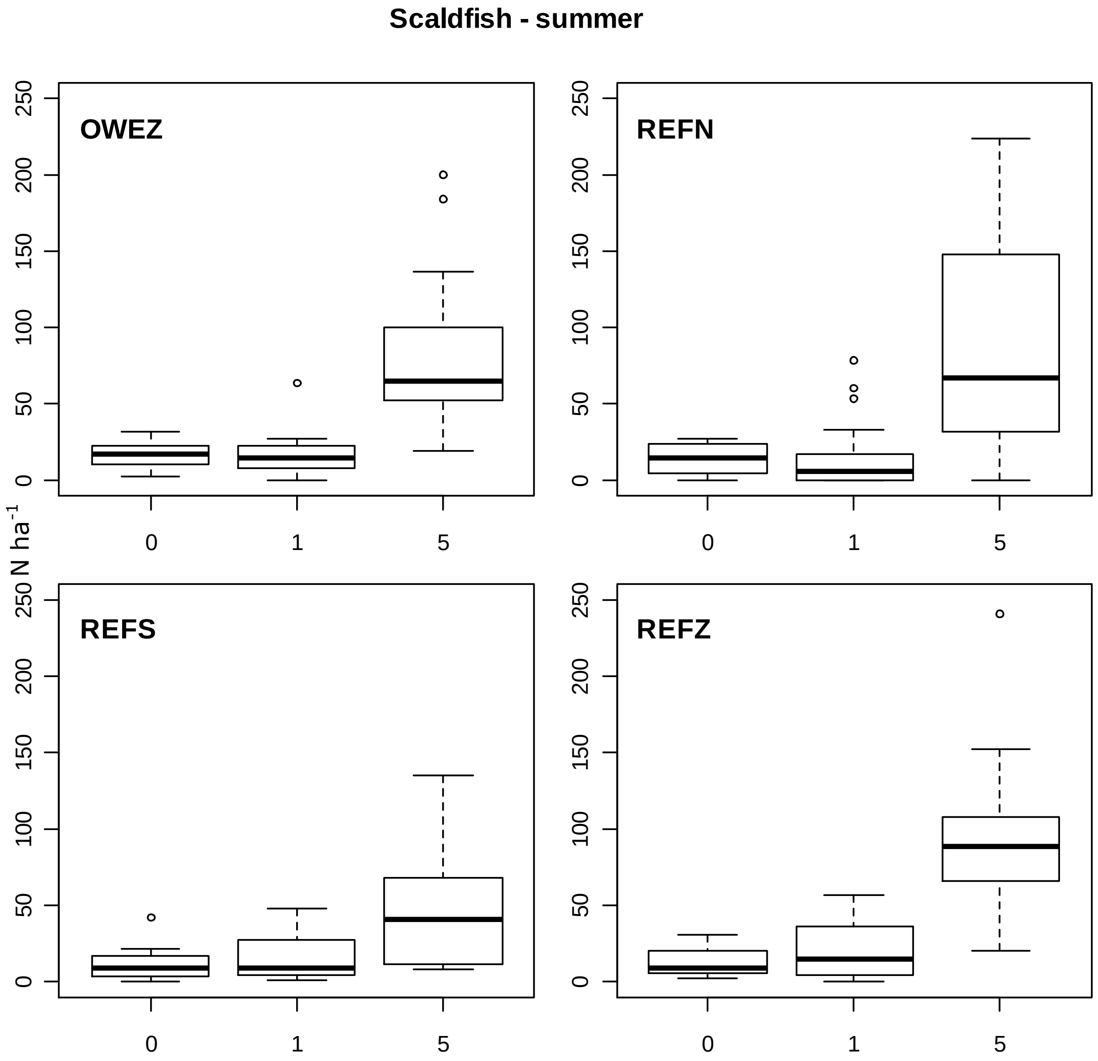
Appendix figure B-8: Differences in catches of sole (numbers per ha) between years and by area during winter both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2004, 1= T1 2007 and 5=T5 2011.



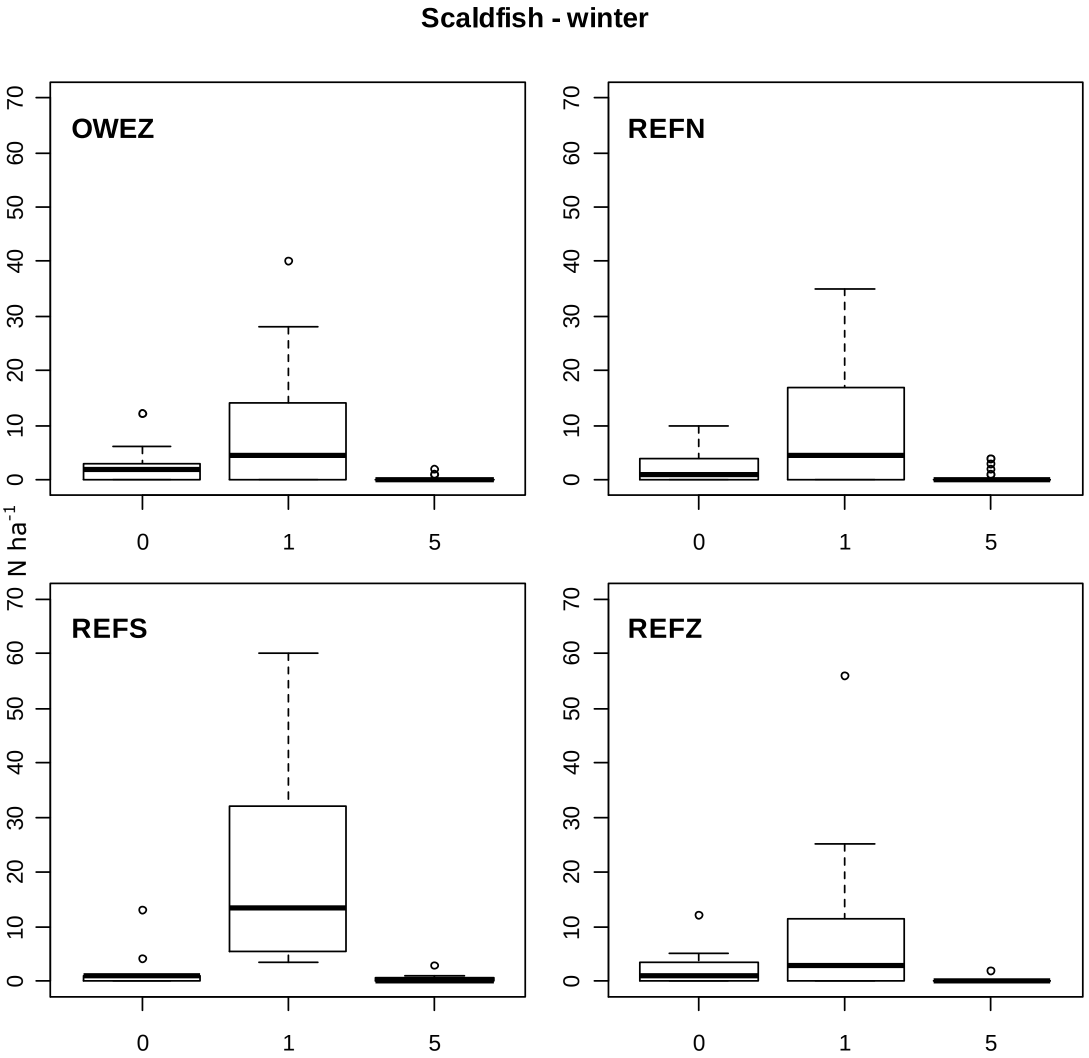
Appendix figure B-9: Differences in catches of dab (numbers per ha) between years and by area during summer both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2003, 1= T1 2007 and 5=T5 2011.



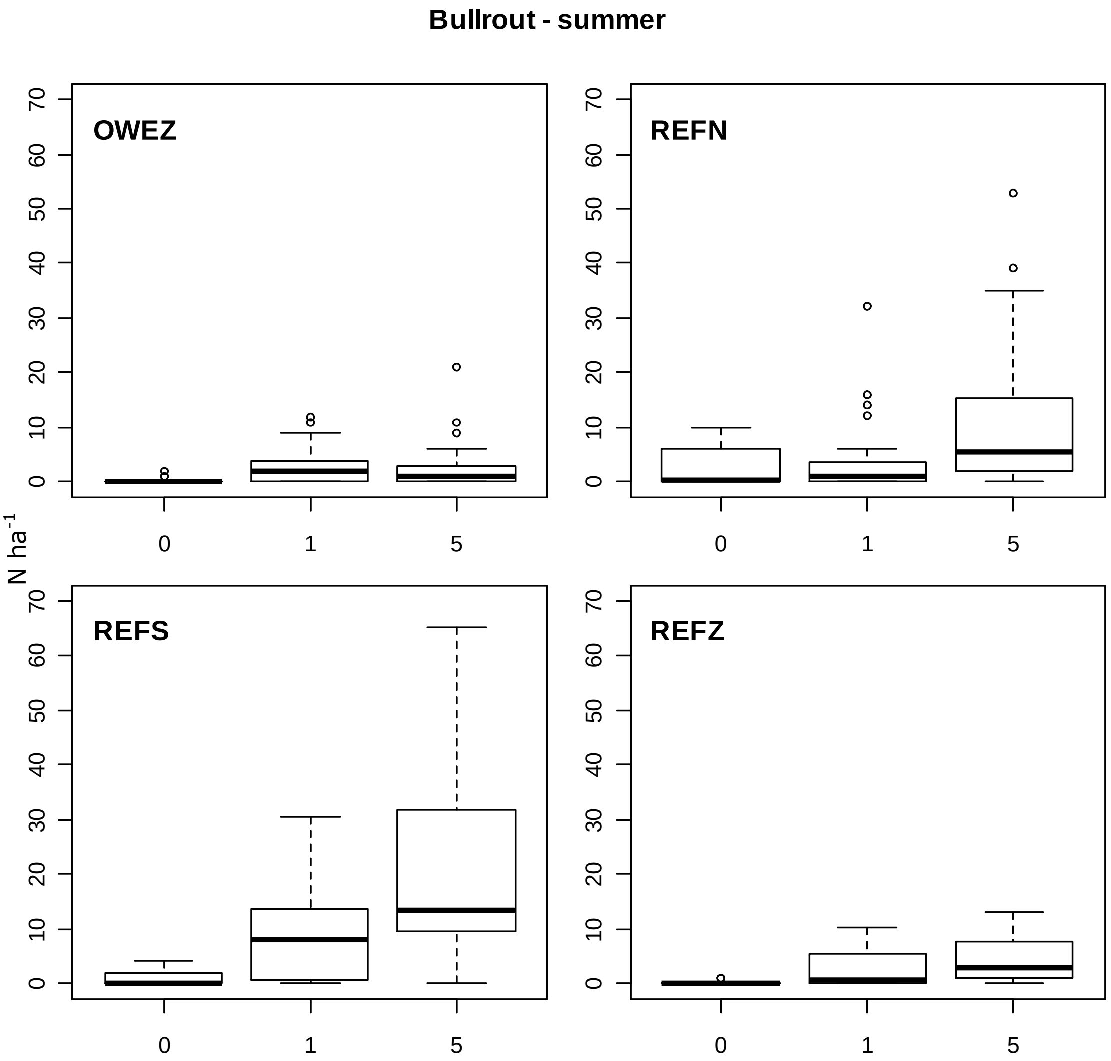
Appendix figure B-10: Differences in catchtes of dab (numbers per ha) between years and by area during winter both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2004, 1= T1 2007 and 5=T5 2011.



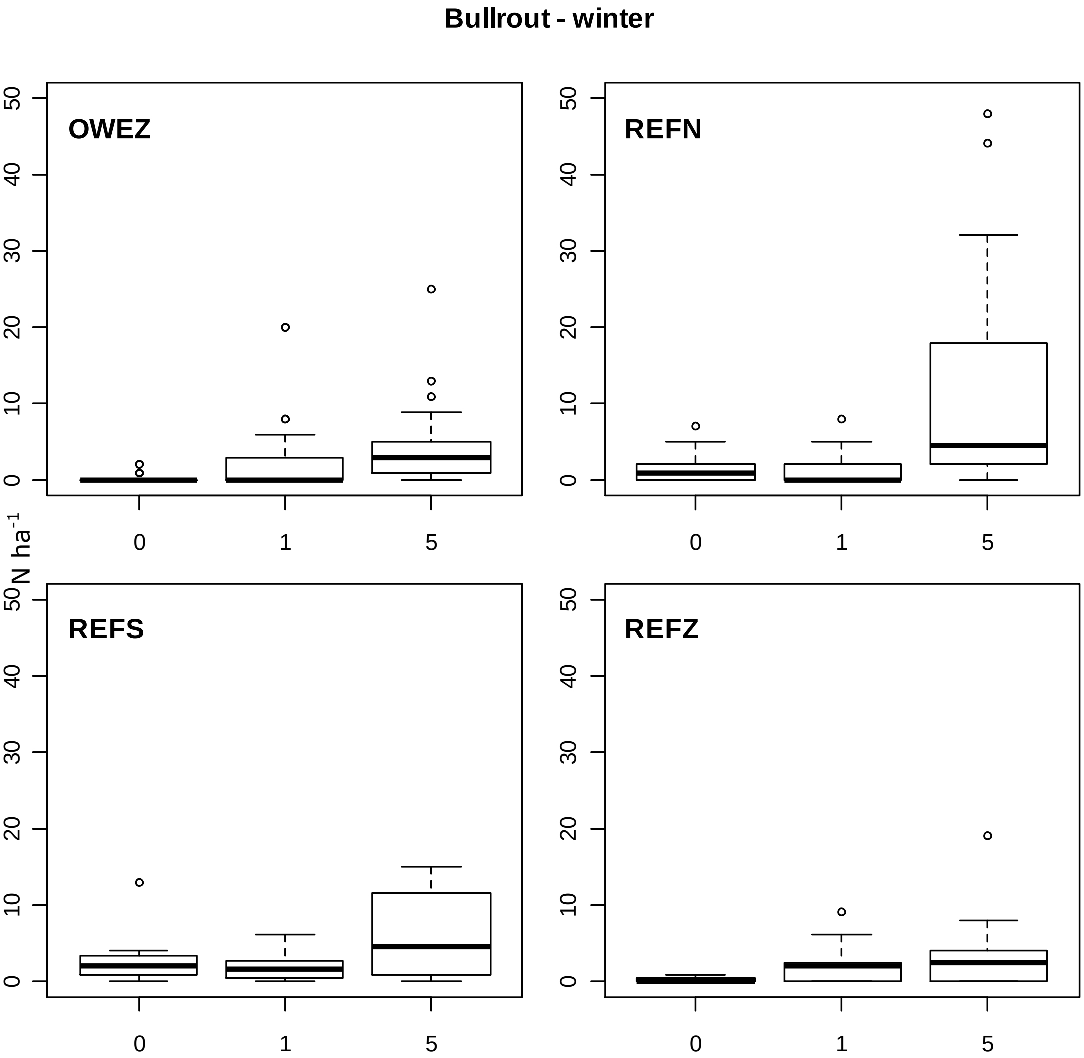
Appendix figure B-11: Differences in catches of scaldfish (numbers per ha) between years and by area during summer both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2003, 1= T1 2007 and 5=T5 2011.



Appendix figure B-12: Differences in catches of scaldfish (numbers per ha) between years and by area during winter both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2004, 1= T1 2007 and 5=T5 2011.



Appendix figure B-13: Differences in catches of bullrout (numbers per ha) between years and by area during summer both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2003, 1= T1 2007 and 5=T5 2011.

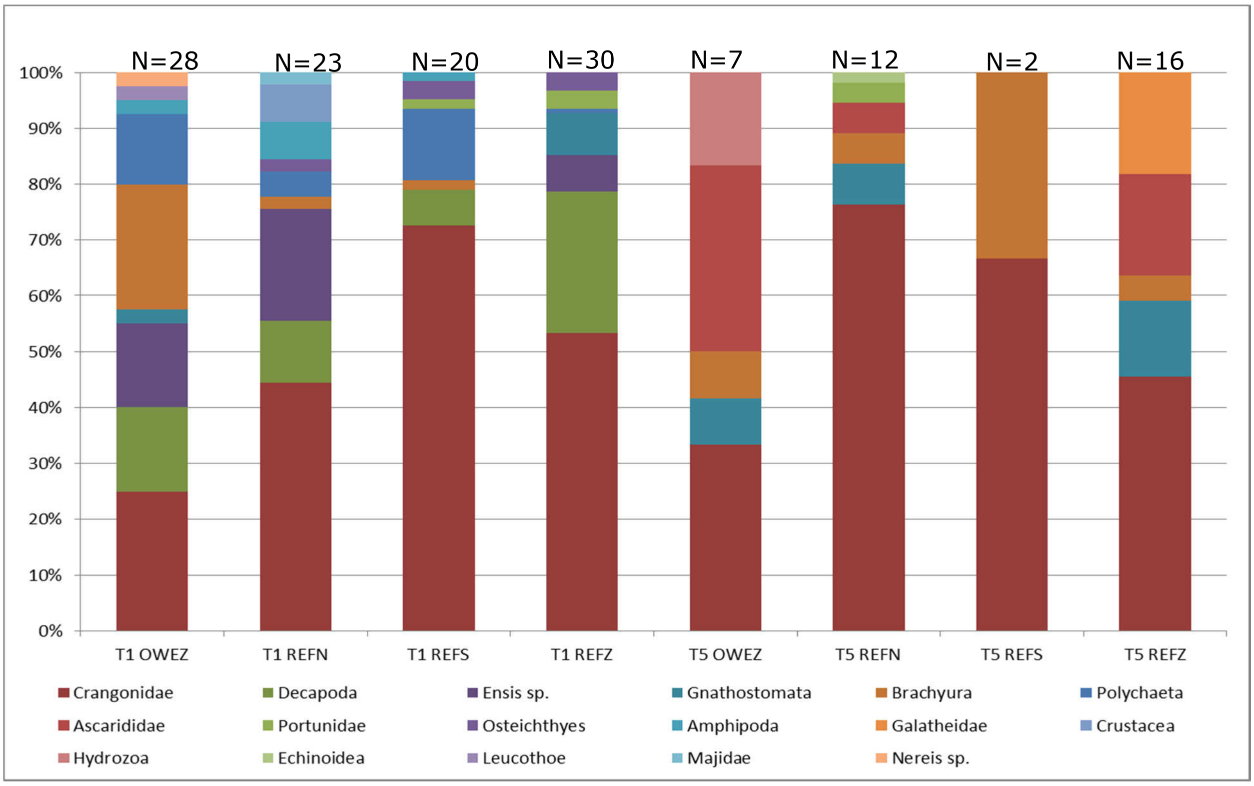


Appendix figure B-14: Differences in catches of bullrout (numbers per ha) between years and by area during winter both gears (beam trawl with mesh size 0.02m and 0.04m) presented as individual data points in a single box. X-axis: 0=T0 2004, 1= T1 2007 and 5=T5 2011.

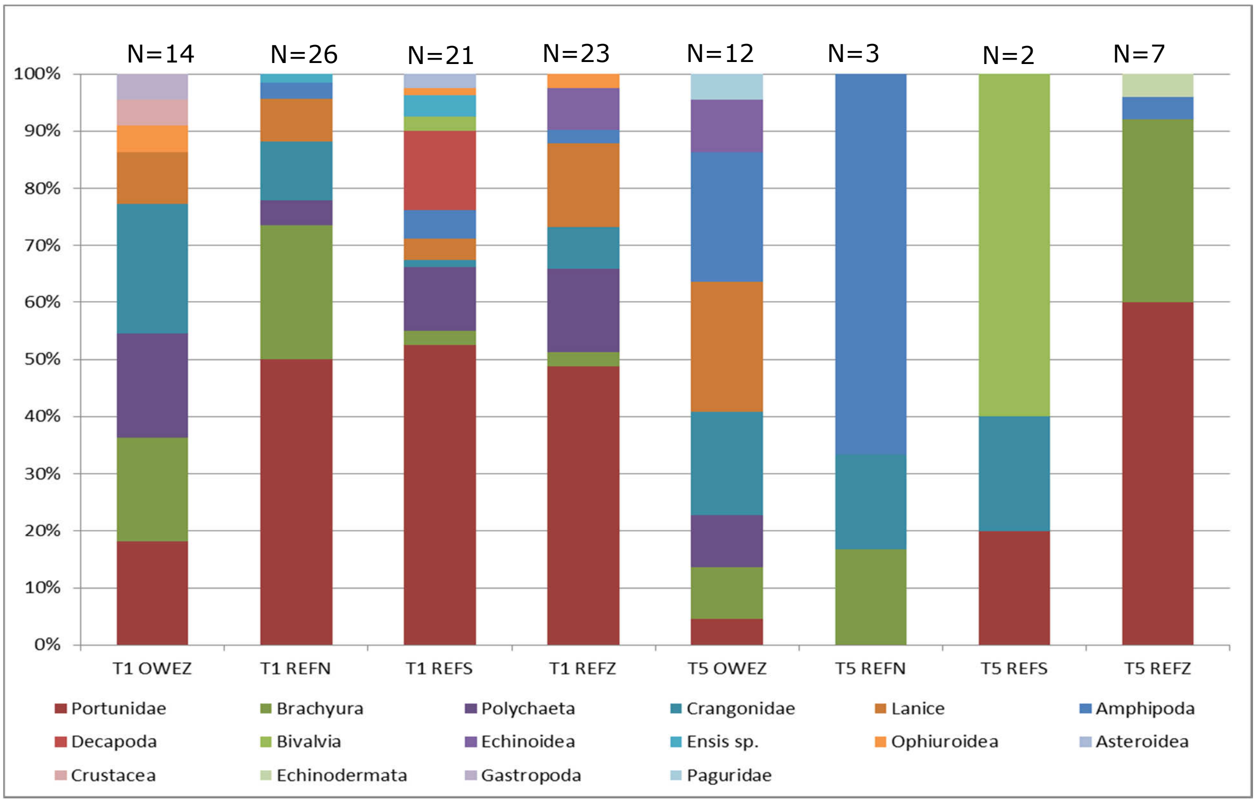
Overview of the stomach data.

Appendix table B-2: Prey species found in the stomachs by area.

	2007	**2011**	**2007**	**2011**	**2007**	**2011**	**2007**	**2011**
Prey species	**OWEZ**	**OWEZ**	**REFN**	**REFN**	**REFS**	**REFS**	**REFZ**	**REFZ**
1 Agonus cataphractus	**x**							
2 Amphipoda	x	x	x	x	x	x	x	x
3 Annelida						x		
4 Arenicola		x		x		x		
5 Ascarididae		x		x				x
6 Asteroidea					x			
7 Bivalvia	x	x	x		x	x	x	x
8 Brachyura	x	x	x	x	x	x	x	x
9 Buccinum undatum								x
10 Crangonidae	x	x	x	x	x	x	x	x
11 Crustacea	x		x					
12 Decapoda	x		x		x		x	
13 Echinodermata						x		x
14 Echinoidea		x		x		x	x	x
15 Ensis sp.	x	x	x	x	x	x	x	x
16 Eteone			x		x			
17 Eumida bahusiensis	**x**							
18 Galatheidae								x
19 Gastropoda	x							x
20 Gnathostomata	x	x	x	x		x	x	x
21 Gobiidae		x				x		
22 Hydrozoa		**x**						
23 Lagis koreni			x					
24 Lanice	x	x	x	x	x	x	x	x
25 Leucothoe	**x**							
26 Majidae			x					
27 Mysidacea	x		x					
28 Nemertea		x		x		x		x
29 Nephrops			x					
30 Nereididae								x
31 Nereis sp.	**x**							
32 Oligochaeta	x		x					
33 Ophiuroidea	x	x			x		x	x
34 Ostracoda				x				
35 Osteichthyes			x		x		x	
36 Paguridae		**x**						
37 Pectinaria		x						x
38 Phyllodocidae		x					x	x
39 Polychaeta	x	x	x	x	x	x	x	x
40 Portunidae	x	x	x	x	x	x	x	x
41 Talitridae		x		x				
42 Varia	x	x	x	x	x	x	x	x



Appendix figure B-15: Whiting stomach contents in percentage of the number of prey items. N= the number of full stomachs used to calculate these values.



Appendix figure B-16: Dragonet stomach contents in percentage of the number of prey items. N= the number of full stomachs used to calculate these values.

C. Appendix C. Pelagic fish community

Haul locations of the pelagic survey.

Appendix table C-1: Positions of pelagic hauls carried out in the T1 and T5 and numbers by species.

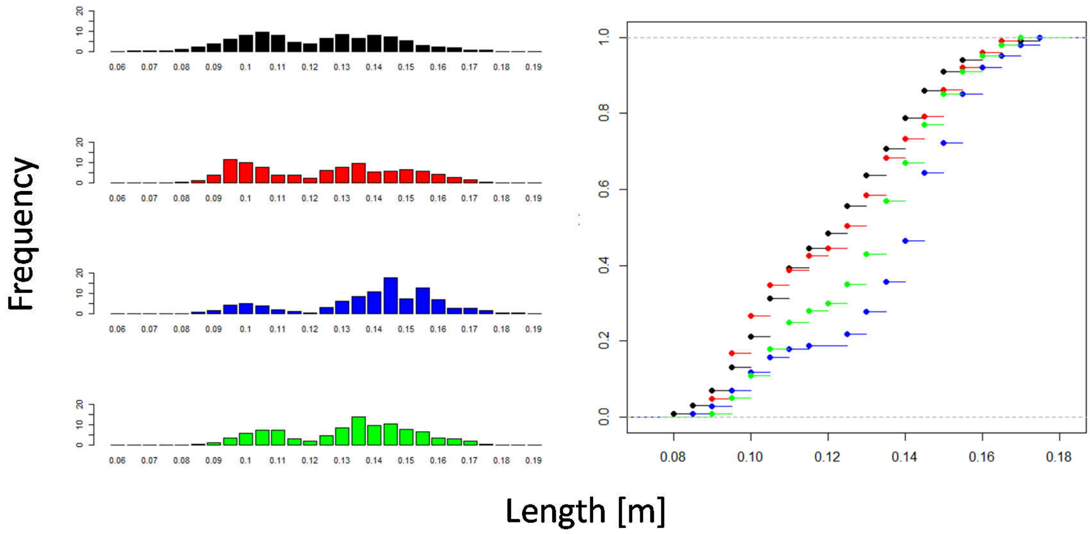
year	sample ID	latitude	longitude	date	secci	Ammodytes marinus	Ammodytes tobianus	Hyperoplus lanceolatus	Engraulis encrasicolus	Clupea harengus	Sprattus sprattus	Sardina pilchardus	Scomber scombrus	Trachurus trachurus	others
2007	5000001	52°22.17'	004°22.41'	4-4-2007		288	52	56			64				0
2007	5000002	52°31.37'	004°25.39'	4-4-2007		5632	896			8	194				2
2007	5000003	52°38.00'	004°27.43'	4-4-2007		2560	48	32		19	6				0
2007	5000004	52°45.25'	004°29.49'	4-4-2007		968	4				248				0
2007	5000005	52°34.38'	004°25.44'	5-4-2007	3	35600	1202	201		140	96				0
2007	5000006	52°37.34'	004°22.41'	5-4-2007	2.5	16080	600	240			135				0
2007	5000007	52°36.13'	004°28.12'	5-4-2007	2	19	7	6		33	23				3
2007	5000008	52°36.21'	004°27.58'	5-4-2007		1008	328	1	1	33	90				1
2007	5000009	52°32.59'	004°34.56'	5-4-2007	1.5	53	73	4		21	13				12
2007	5000010	52°32.12'	004°22.51'	6-4-2007	3.1	11760	112	56							0
2007	5000011	52°31.22'	004°24.01'	6-4-2007	2.8	29280	960	2		1					0
2007	5000012	52°34.48'	004°22.41'	6-4-2007		8340	560	360							0
2007	5000013	52°40.06'	004°28.33'	9-4-2007	2.5	26100	4800	3			1				0
2007	5000014	52°43.40'	004°25.47'	9-4-2007		2256	672			240	174				0
2007	5000015	52°44.03'	004°26.53'	9-4-2007	3.8	900	36			18	4320				10
2007	5000016	52°42.01'	004°24.52'	10-4-2007	2.5	4788	144	1							2
2007	5000017	52°51.40'	004°23.44'	10-4-2007	2	15040				5	33				0
2007	5000018	52°45.07'	004°23.32'	10-4-2007	3	3350				50	230	1			3
2007	5000019	52°38.44'	004°20.34'	10-4-2007	2.8	30120	120	1	1		82				0
2007	5000020	52°27.27'	004°24.13'	11-4-2007	2	2424	56	2569							0
2007	5000021	52°29.53'	004°17.50'	11-4-2007	5	12800	400		1	31	250				0
2007	5000022	52°26.04'	004°15.46'	11-4-2007	3.5	21600	400	25		9	550				1
2007	5000023	52°17.46'	004°14.22'	11-4-2007	2.9	120			1	9441	620				21

year	sample ID	latitude	longitude	date	secci	Ammodytes marinus	Ammodytes tobianus	Hyperoplus lanceolatus	Engraulis encrasicolus	Clupea harengus	Sprattus sprattus	Sardina pilchardus	Scomber scombrus	Trachurus trachurus	others
2007	5000024	52°21.35'	004°16.51'	11-4-2007	3.2	345	30			8100	285			1	38
2007	5000025	52°37.10'	004°22.06'	12-4-2007	3.8	3320	160		1						4
2007	5000026	52°34.51'	004°26.32'	12-4-2007	3.4	16080	300			77	615	1			1
2007	5000027	52°36.44'	004°26.10'	12-4-2007	3.6	9408	432			360	108			1	21
2007	5000028	52°36.51'	004°20.28'	12-4-2007	6	3680	160	2	3						4
2007	5000029	52°30.35'	004°25.06'	13-4-2007	3.6	888	24	112		2112	536				62
2007	5000030	52°34.40'	004°19.53'	13-4-2007	5.5	32320	160								1
2007	5000031	52°41.55'	004°28.84'	16-4-2007	2.5	556	140	1		164	90	58			10
2007	5000032	52°42.80'	004°28.27'	16-4-2007		1200	2		62		3290				23
2007	5000033	52°43.19'	004°27.28'	16-4-2007	2.5	508	16	5	31	32	84			1	12
2007	5000034	52°42.72'	004°29.70'	16-4-2007	2.2	15400	400	11	32	78	54				6
2007	5000035	52°20.52'	004°19.93'	17-4-2007	2	3456	256	272	7						0
2007	5000036	52°15.19'	004°16.81'	17-4-2007	1.8	1232	56		4	584	144				27
2007	5000037	52°07.81'	004°08.58'	17-4-2007	2.5	136		6		2	1	1			3
2007	5000038	52°03.56'	004°03.15'	17-4-2007	2.5	512			25	94	10	2			0
2007	5000039	52°07.46'	004°03.61'	17-4-2007	3	6432			10	67	182	1			1
2007	5000040	52°14.50'	004°12.40'	17-4-2007	2.3	1400	56	2	3	1	2				0
2007	5000041	52°09.45'	004°01.90'	17-4-2007	3	3136			27	5					0
2007	5000042	52°14.63'	004°08.34'	17-4-2007	2.4	1580				61	90				3
2007	5000043	52°34.41'	004°24.54'	18-4-2007	2.3	939	13		9	182	39			5	12
2007	5000044	52°35.87'	004°25.05'	18-4-2007	1.3	1256	64	8	16	121	880	392		1	9
2007	5000045	52°36.37'	004°24.40'	18-4-2007	1.8	6528	1344		272	7	1216	368			0
2007	5000046	52°37.66'	004°24.87'	18-4-2007	2.8	11808	576		140	18	268	49			1
2007	5000047	52°38.03'	004°25.48'	18-4-2007	2.5	21120	640	4	23	30	140	814			0
2007	5000048	52°32.78'	004°26.83'	18-4-2007	1.8	1024	88	12	16	77	576	238			1
2007	5000049	52°32.72'	004°24.22'	18-4-2007	1.8	10560	240	2	4	154	648	5			1
2007	5000050	52°32.74'	004°24.52'	19-4-2007	1.9	15680	320	8	110		18				1
2007	5000051	52°31.70'	004°25.75'	19-4-2007	2.2	4352	112	4	8	62	328			2	9

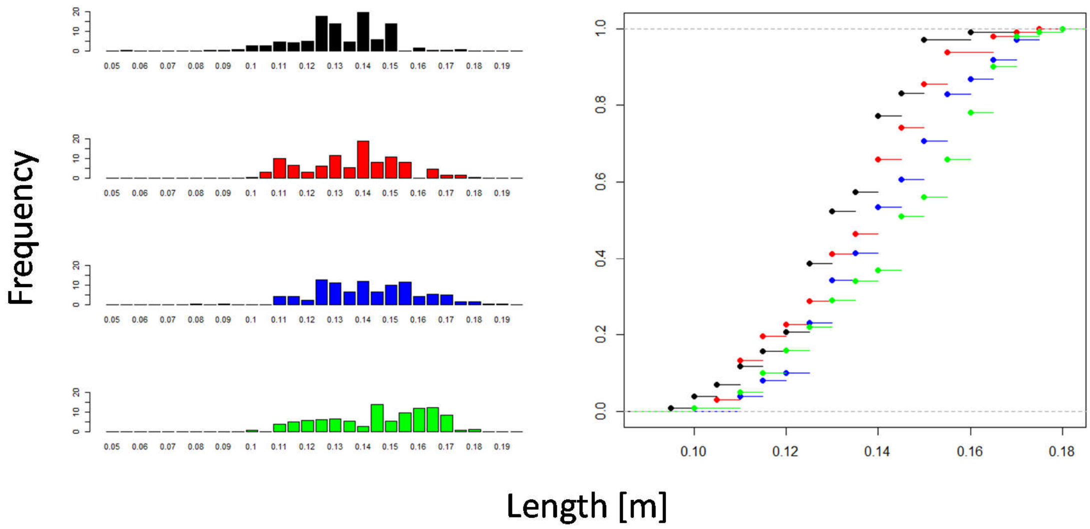
year	sample ID	latitude	longitude	date	secci	Ammodytes marinus	Ammodytes tobianus	Hyperoplus lanceolatus	Engraulis encrasicolus	Clupea harengus	Sprattus sprattus	Sardina pilchardus	Scomber scombrus	Trachurus trachurus	others
2007	5000052	52°33.96'	004°21.79'	19-4-2007	2.3	7440	270	1	42	3	89	38			2
2007	5000053	52°34.72'	004°20.11'	19-4-2007	1.9	10440	420	4	564	46	168	70			4
2007	5000054	52°24.74'	004°30.61'	20-4-2007	1.2	7			34	90					3
2007	5000055	52°30.03'	004°31.83'	20-4-2007	1.9	488	24	3	43	118	182	108			7
2007	5000056	52°34.60'	004°32.19'	20-4-2007	1.1	8	5	2	18	114	23	91		1	5
2011	5001511	52°34.24'	004°26.02'	4-4-2011			206	691		6	686				0
2011	5001512	52°35.24'	004°27.13'	4-4-2011			126	314		1278	4240				12
2011	5001513	52°42.22'	004°26.89'	7-4-2011	4.5		4597	271			267				55
2011	5001514	52°42.83'	004°26.86'	7-4-2011	4		991			16	1056				0
2011	5001515	52°42.67'	004°29.35'	7-4-2011	4		54	342			66				3
2011	5001516	52°42.60'	004°25.03'	7-4-2011	4		124	290		1	18517				105
2011	5001517	52°31.84'	004°23.40'	8-4-2011	4.3		546	405		1	299				13
2011	5001518	52°31.43'	004°26.16'	8-4-2011	4.2		152	19		133	3597				42
2011	5001519	52°35.25'	004°23.05'	8-4-2011	4		196	82		937	2744				21
2011	5001520	52°32.55'	004°25.86'	11-4-2011	4		797	697	1	451	15942				54
2011	5001521	52°45.31'	004°29.95'	11-4-2011	4		1559	232		447	14923				98
2011	5001522	52°52.61'	004°27.19'	11-4-2011	5		9695	146							3
2011	5001523	52°15.94'	004°17.26'	11-4-2011	3		850	1	1	191	7104				81
2011	5001524	52°08.94'	004°10.63'	13-4-2011	3.5		37	35	66	1	146				2
2011	5001525	52°03.04'	004°02.52'	13-4-2011	3		1173		13	718	8133				3
2011	5001526	52°19.81'	004°15.67'	13-4-2011	3.5		136	2		238	3565				58
2011	5001527	52°39.16'	004°20.94'	14-4-2011	4		17516		1	13	9672				2
2011	5001528	52°33.23'	004°18.76'	14-4-2011	4		392	1		199	4492				5
2011	5001529	52°18.13'	004°11.02'	14-4-2011	4.5		1651	1095	2		132				1
2011	5001530	52°35.19'	004°24.88'	18-4-2011	3.5		1440	1	2	126	3915		1		1
2011	5001531	52°34.57'	004°26.92'	18-4-2011	3		368		7	49	1065				907
2011	5001532	52°38.25'	004°25.28'	18-4-2011	3.5		14061	900	7		2992				9
2011	5001533	52°35.85'	004°29.26'	18-4-2011	3.5		956	59	14	2	3387	1	1		30

year	sample ID	latitude	longitude	date	secci	Ammodytes marinus	Ammodytes tobianus	Hyperoplus lanceolatus	Engraulis encrasicolus	Clupea harengus	Sprattus sprattus	Sardina pilchardus	Scomber scombrus	Trachurus trachurus	others
2011	5001534	52°40.50'	004°27.93'	19-4-2011	3.5		3503	2	14	135	9341				0
2011	5001535	52°43.57'	004°23.66'	19-4-2011	4.5		4143	418	2	1829	16986				7
2011	5001537	52°40.41'	004°30.18'	19-4-2011	4		6508	241	3	605	9476				6
2011	5001538	52°31.75'	004°23.55'	20-4-2011	5		1458	221	1	739	16231		2		53
2011	5001539	52°34.74'	004°21.64'	20-4-2011	4.5		8319	446	9		663				1
2011	5001540	52°32.03'	004°26.53'	20-4-2011	4		797	80	35		80	35			3
2011	5001541	52°30.96'	004°24.55'	20-4-2011	3.5		259	6		469	1276	15			96
2011	5001542	52°37.41'	004°23.06'	21-4-2011	4		16382	154	106		1772	2			1
2011	5001543	52°36.84'	004°27.32'	21-4-2011	5		20		1	3	53			1	807
2011	5001544	52°36.87'	004°26.02'	21-4-2011	4		19585	394	96		7967				40

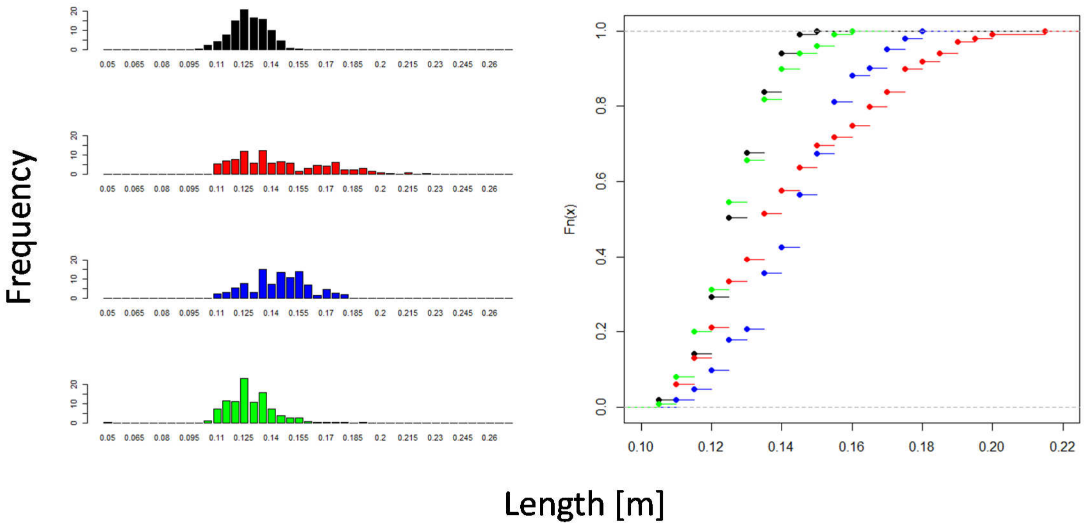
Length frequencies by species.



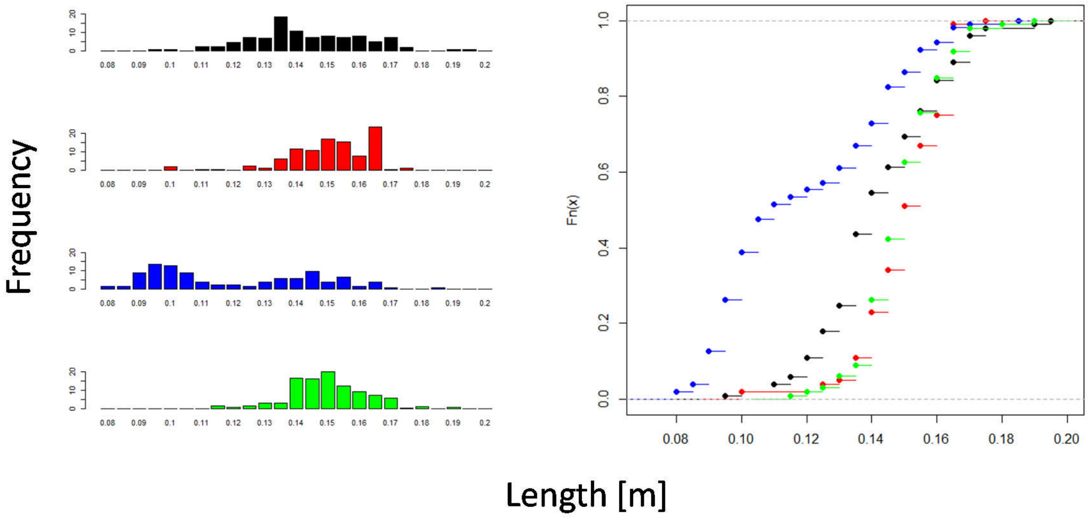
*Appendix figure C-1: (a) density and (b) cumulative length-frequency distribution of **Raitt's sandeel (Ammodytes marinus)** in trawl catches taken in April 2007 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*



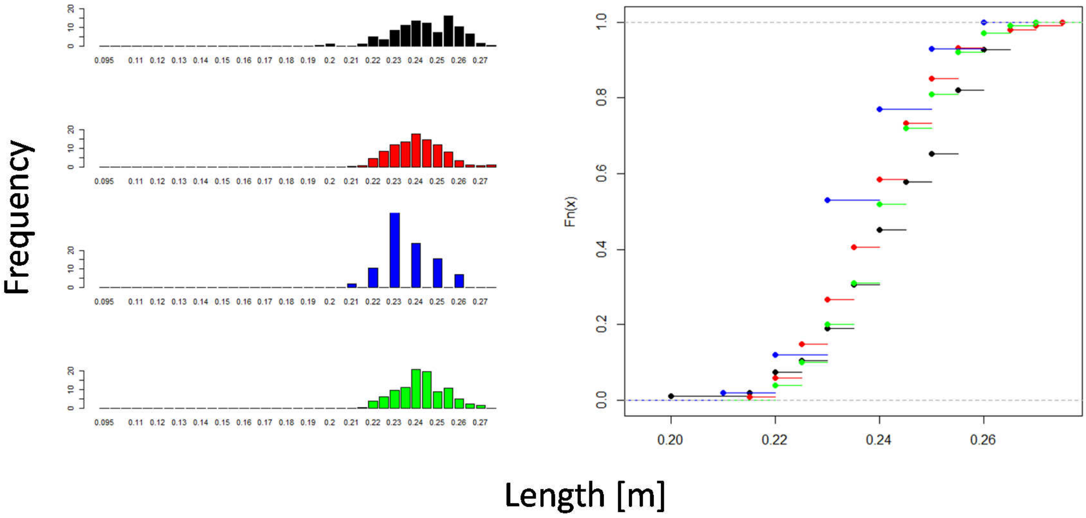
*Appendix figure C-2: (a) density and (b) cumulative length-frequency distribution of **lesser sandeel (Ammodytes tobianus)** in trawl catches taken in April 2007 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*



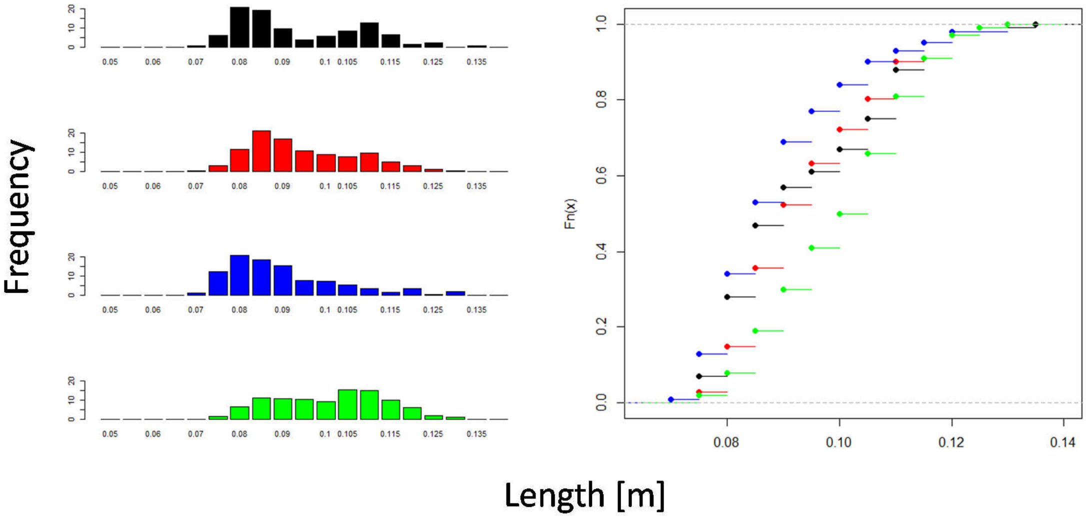
*Appendix figure C-3: (a) density and (b) cumulative length-frequency distribution of **herring (Clupea harengus)** in trawl catches taken in April 2007 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*



*Appendix figure C-4: (a) density and (b) cumulative length-frequency distribution of **anchovy (Engraulis encrasicolus)** in trawl catches taken in April 2007 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*



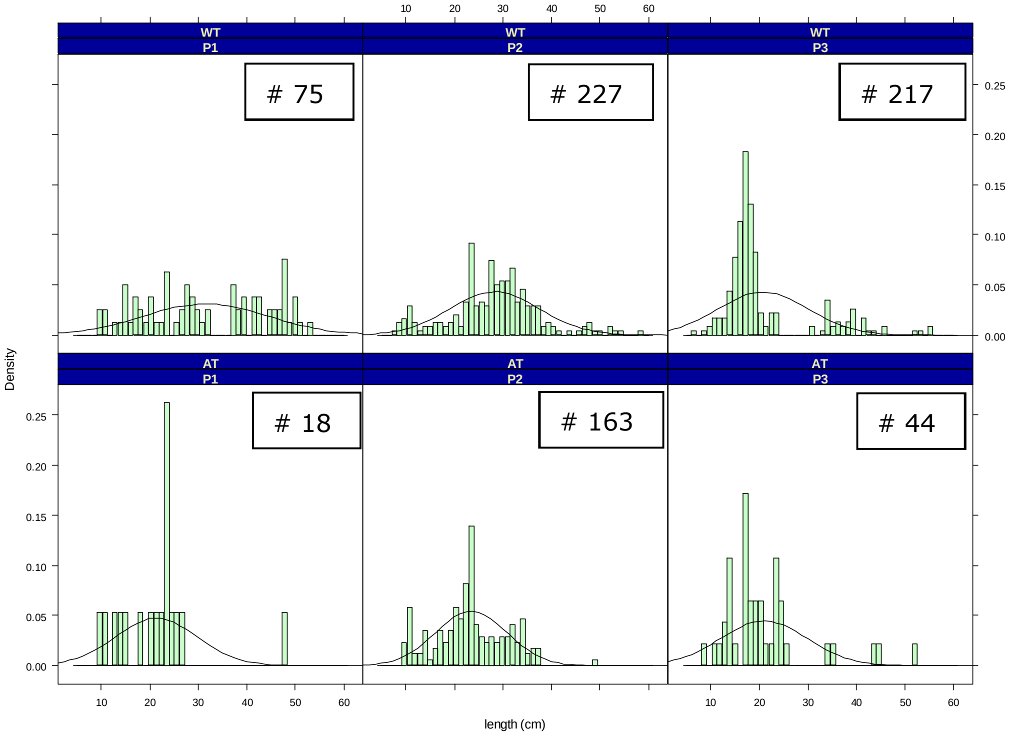
Appendix figure C-5: (a) density and (b) cumulative length-frequency distribution of ***sardine (Sardina pilchardus)*** *in trawl catches taken in April 2007 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*



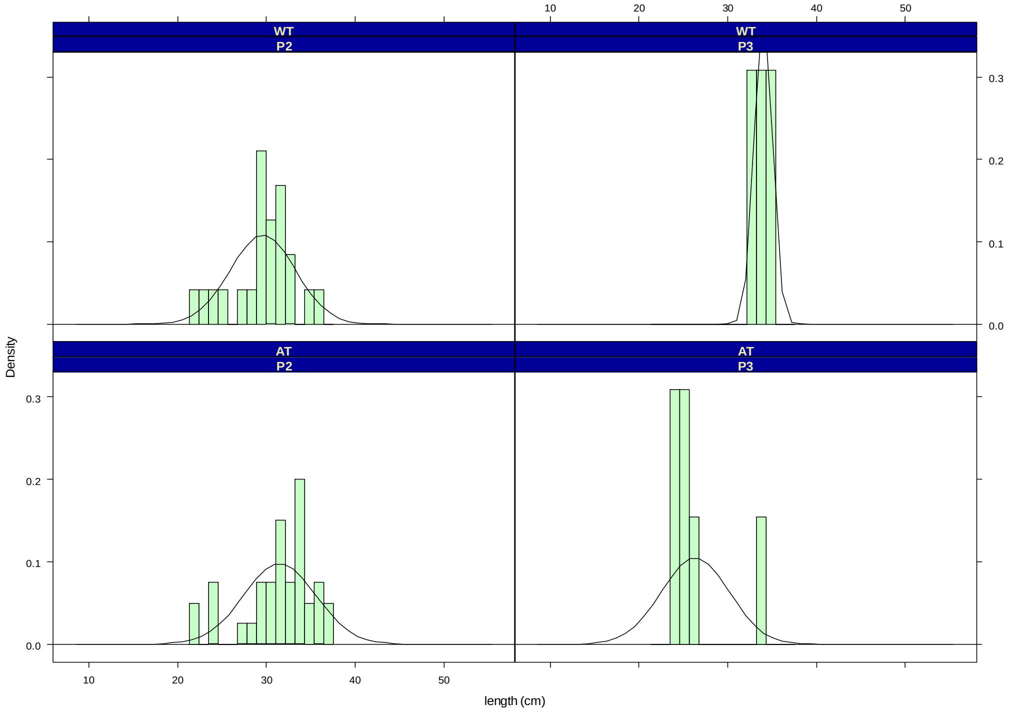
Appendix figure C-6: (a) density and (b) cumulative length-frequency distribution of ***sprat (Sprattus sprattus)*** *in trawl catches taken in April 2007 in the three areas surveyed: blue - northern reference area, red - wind farm, green - southern reference area, black - outside the areas.*

D. Appendix D. Gillnets

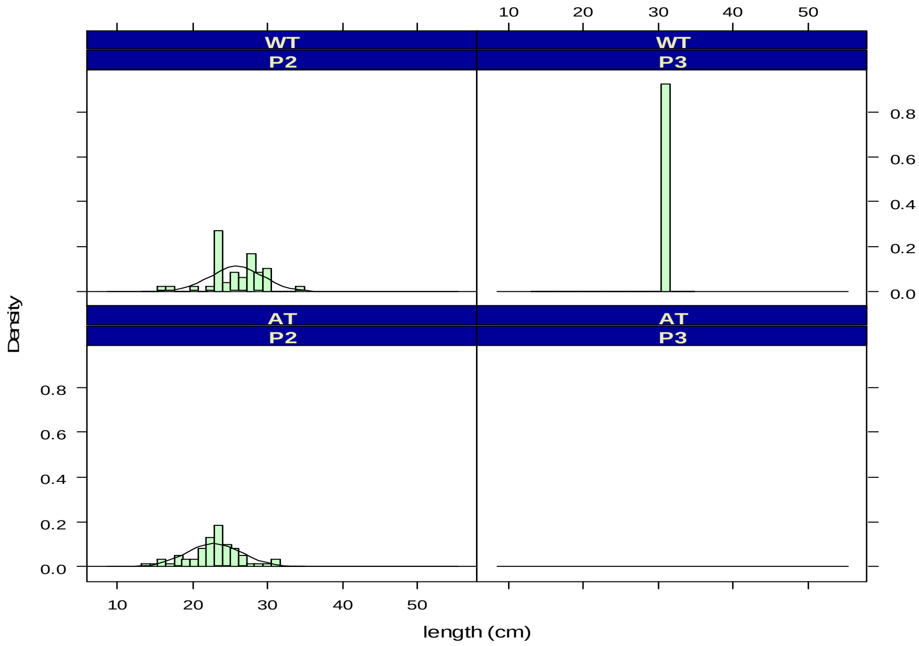
Length frequencies in the gillnets.



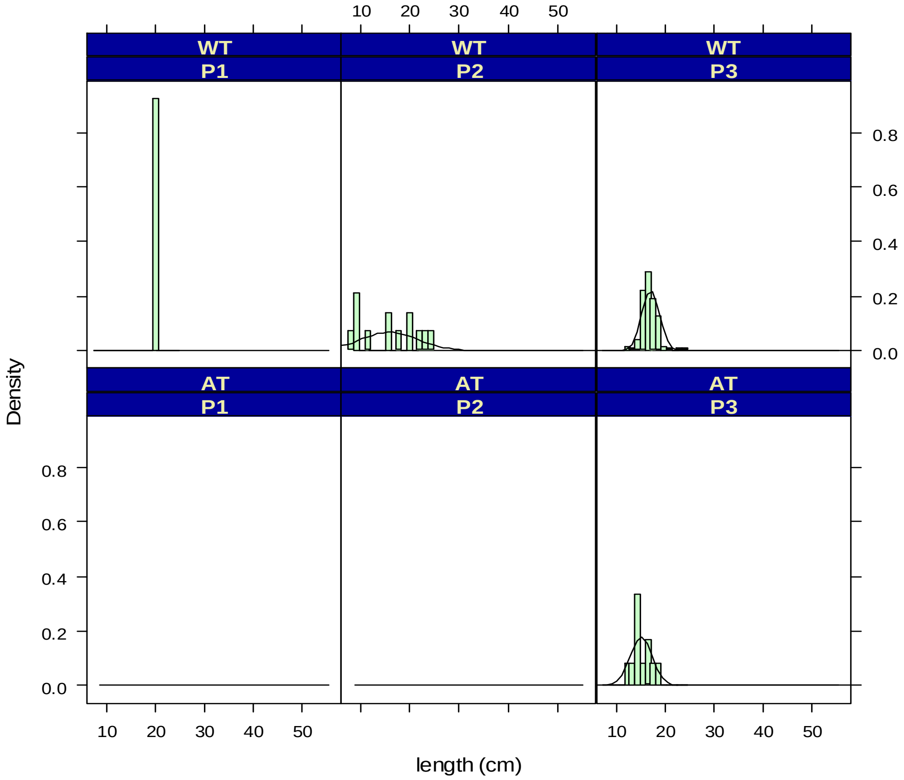
Appendix figure D-1: Length-frequency distribution of all non-flatfish species. Upper row are results from the WT-nets and the lower row from the AT-nets. Left to right Period 1 to Period 3



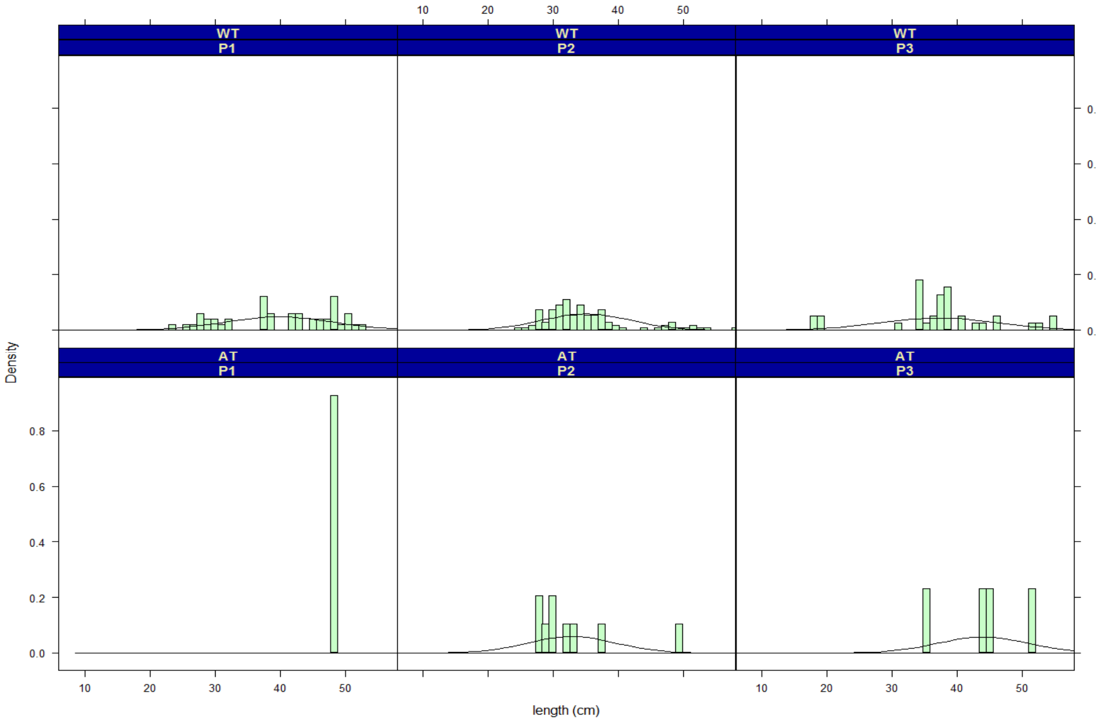
Appendix figure D-2: Length-frequency distribution of mackerel. Upper row are results from the WT-nets and the lower row from the AT-nets. Left to right Period 2 to Period 3.



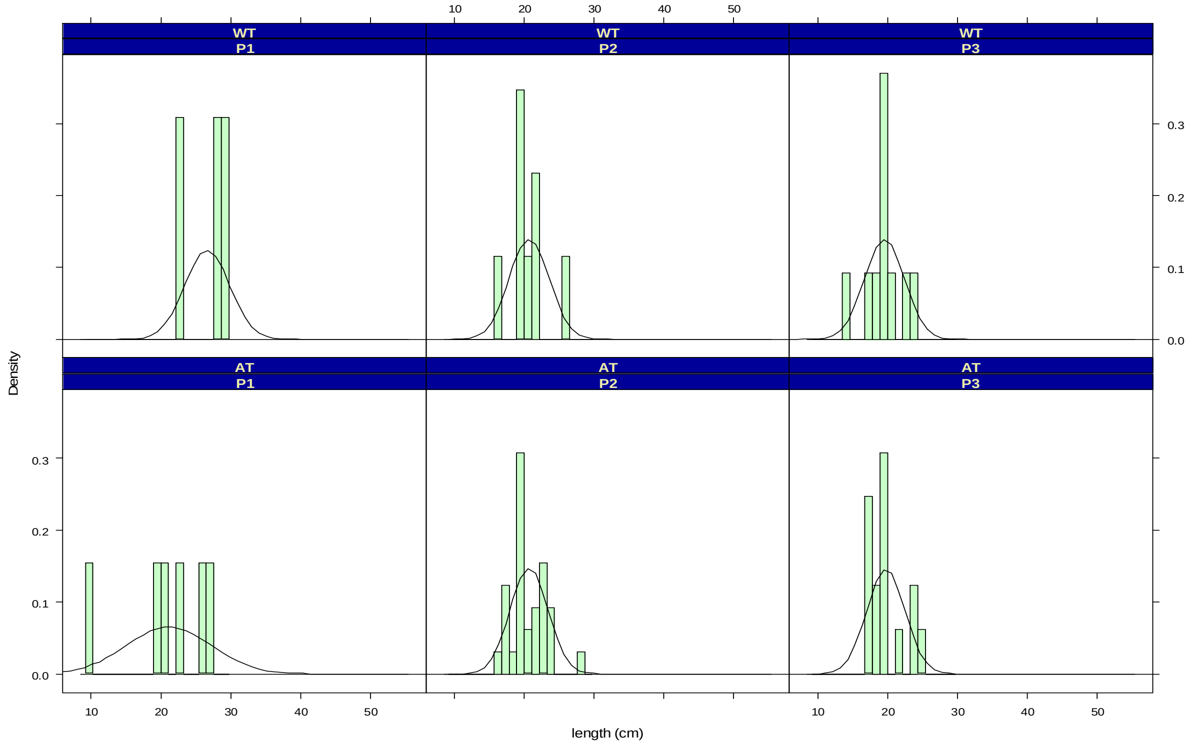
Appendix figure D-3: Length-frequency distribution of horse mackerel. Upper row are results from the WT-nets and the lower row from the AT-nets. Left to right Period 2 to Period 3.



Appendix figure D-4: Length-frequency distribution of bib. Upper row are results from the WT-nets and the lower row from the AT-nets. Left to right Period 1 to Period 3.



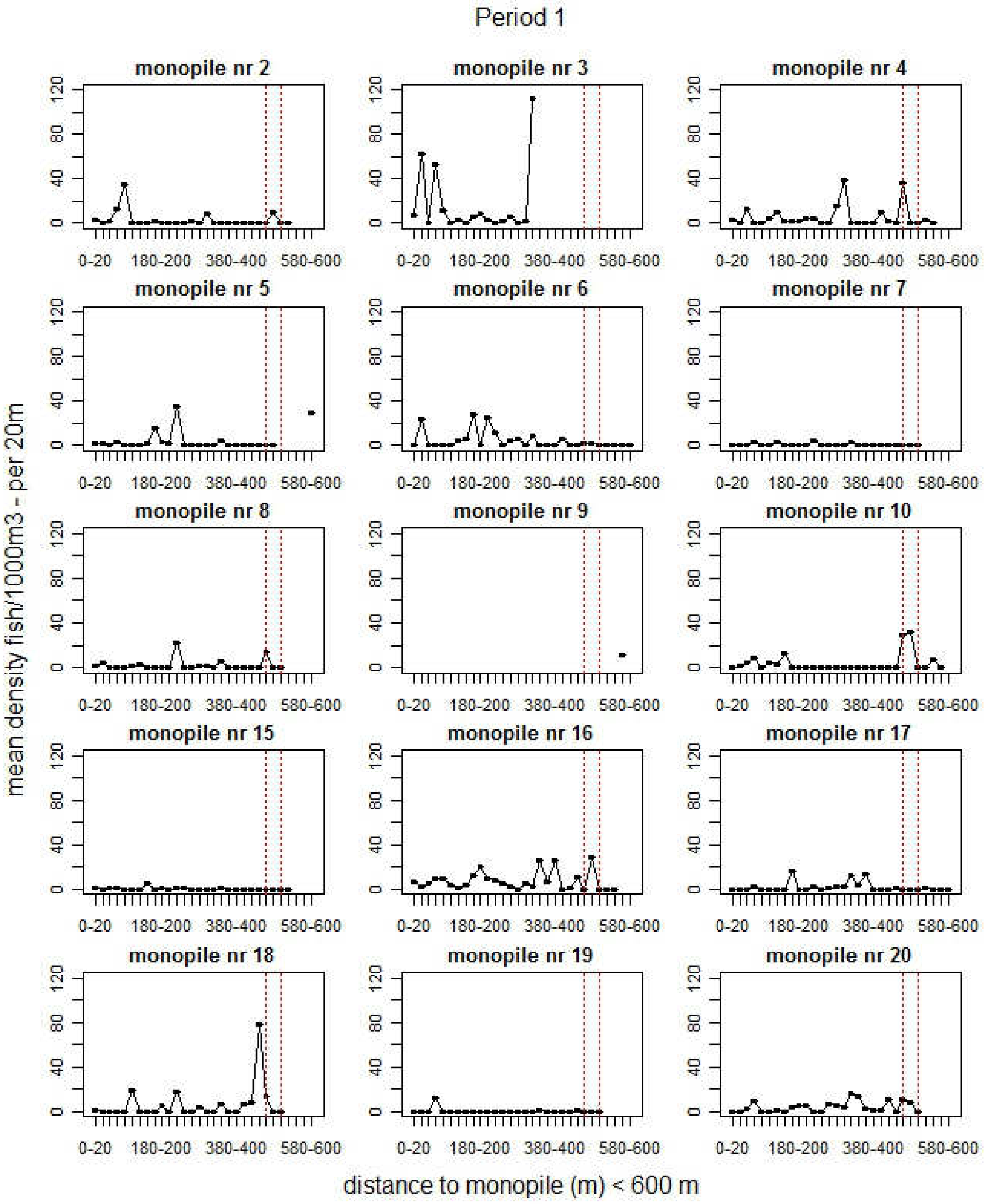
Appendix figure D-5: Length-frequency distribution of cod. Upper row are results from the WT-nets and the lower row from the AT-nets. Left to right Period 1 to Period 3.



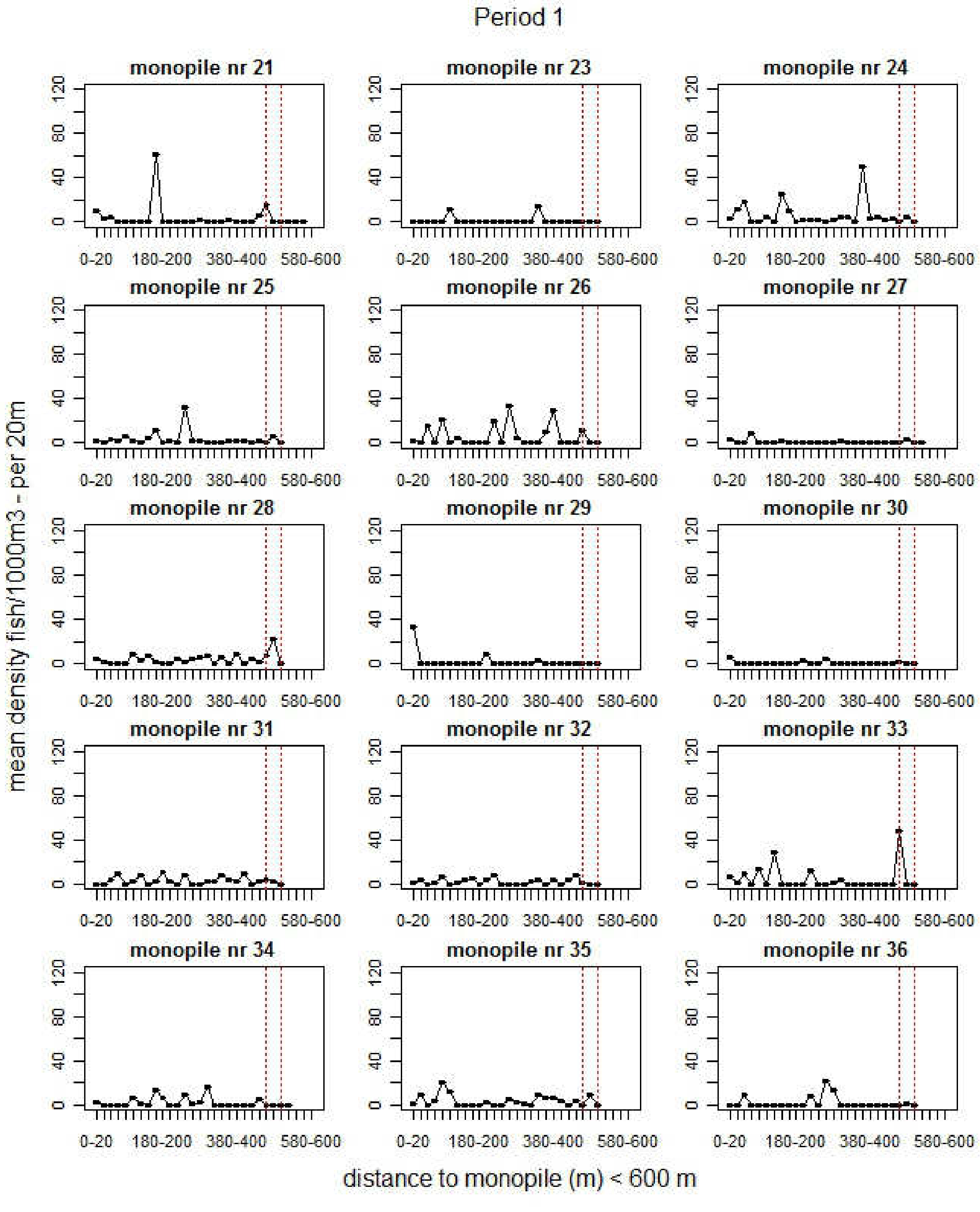
Appendix figure D-6: Length-frequency distribution of whiting. Upper row are results from the WT-nets and the lower row from the AT-nets. Left to right Period 1 to Period 3.

E. Appendix E. DIDSON

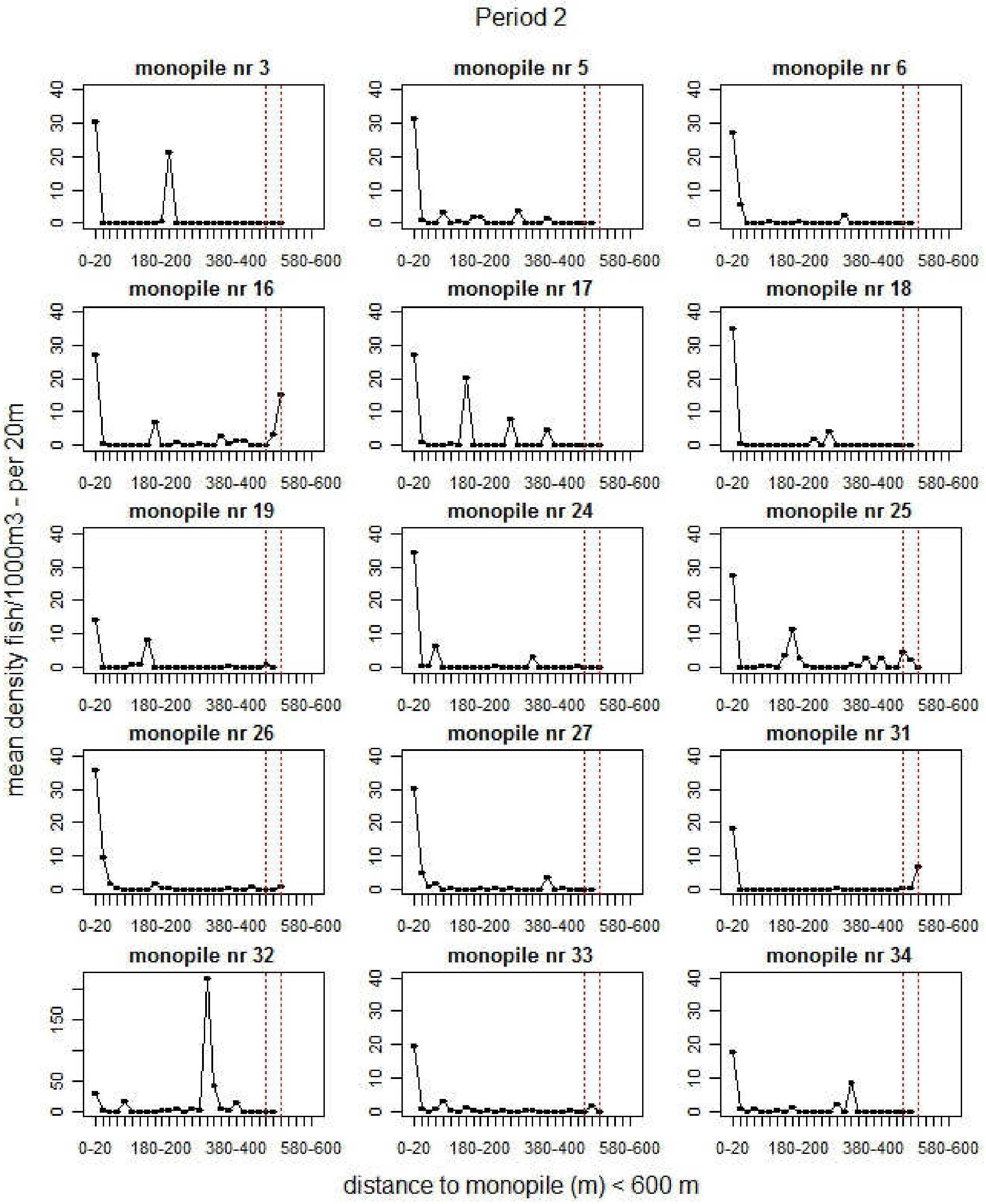
Mean densities at distance of individual monopiles per period.



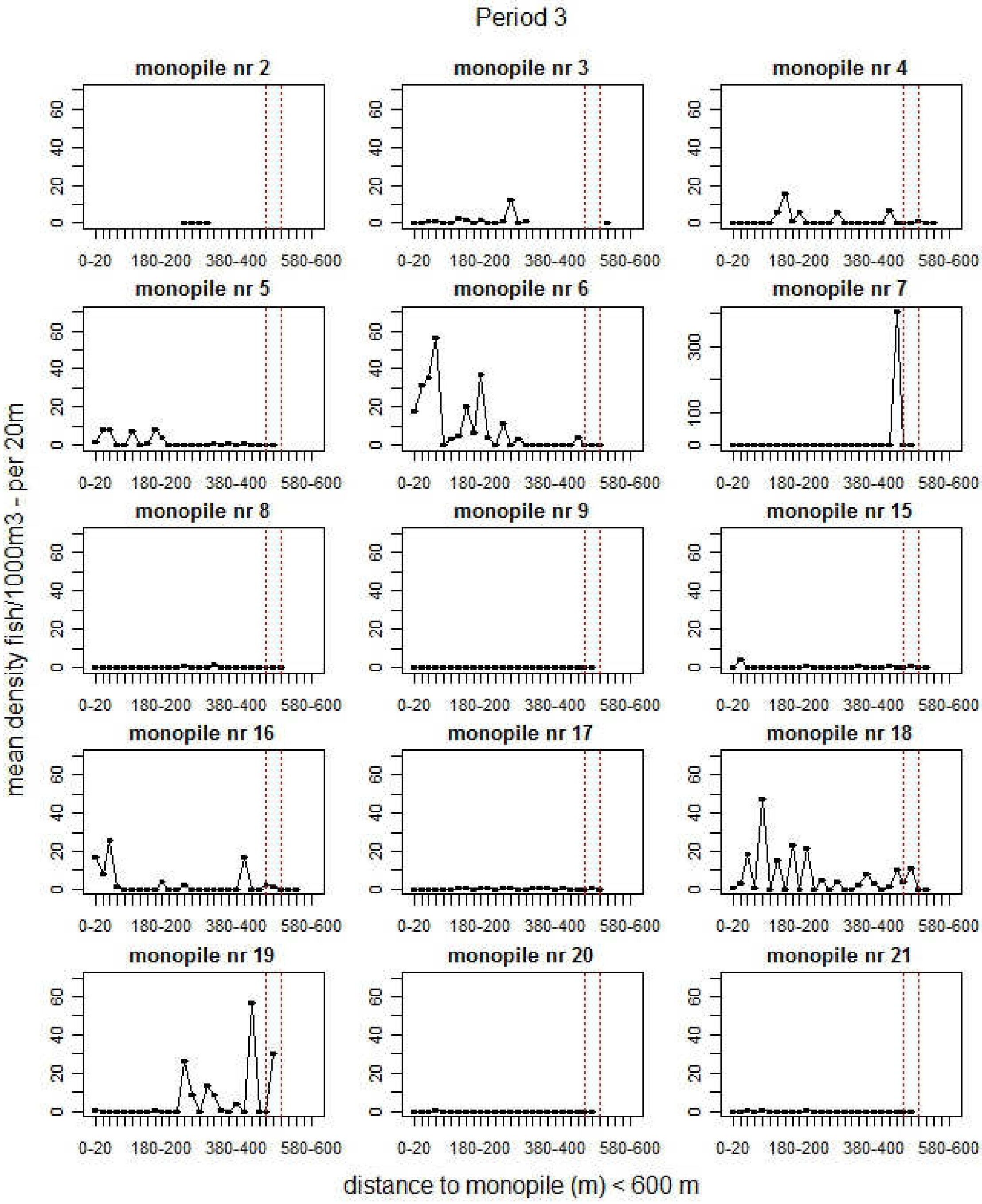
Appendix figure E-1: Mean density for period 1 per windmill (fish / 1000 m^3) calculated over a transect range of 20 metres seabed floor. Red lines indicates the location of the pelagic survey range.



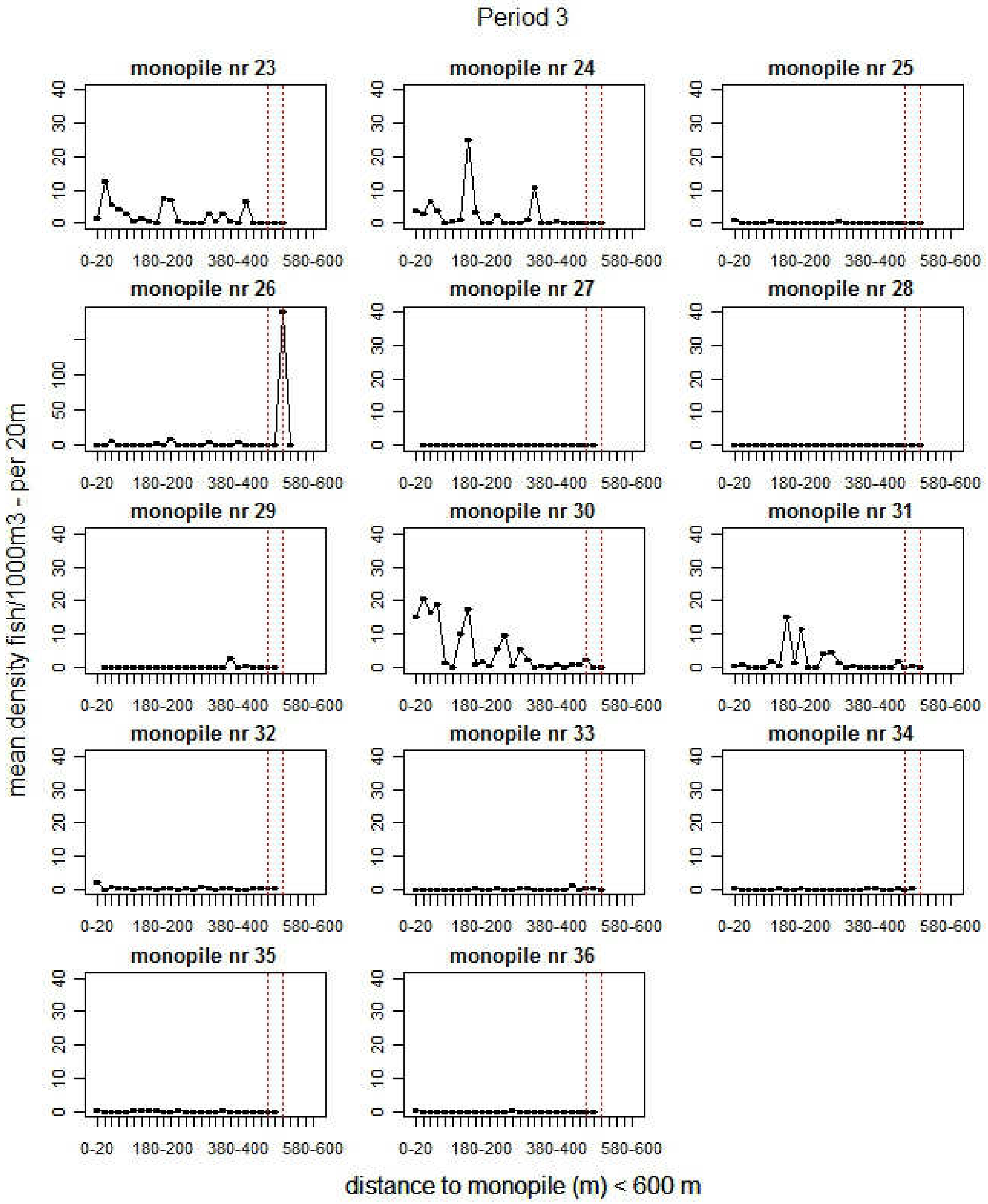
Appendix figure E-2: Mean density for period 1 per windmill (fish / 1000 m^3) calculated over a transect range of 20 metres seabed floor. Red lines indicates the location of the pelagic survey range.



Appendix figure E-3: Mean density for period 2 per windmill (fish / 1000 m^3) calculated over a transect range of 20 metres seabed floor. Red lines indicates the location of the pelagic survey range.



Appendix figure E-4: Mean density for period 3 per windmill (fish / 1000 m^3) calculated over a transect range of 20 metres seabed floor. Red lines indicates the location of the pelagic survey range.



Appendix figure E-5: Mean density for period 3 per windmill (fish / 1000 m^3) calculated over a transect range of 20 metres seabed floor. Red lines indicates the location of the pelagic survey range.