Demersal Fish Monitoring Princess Amalia Wind Farm

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Summary

This report describes the results of field work in the Princess Amalia Wind Farm (in Dutch: Prinses Amaliawindpark, or PAWP). The field work meets the requirements of the Monitoring and Evaluation Programme, which is part of the Wbr-permit of the wind farm. The objective is to determine if the wind farm functions as a refugium for demersal fish. PAWP is expected to act as a refugium because fisheries are excluded in the farm area since 16 October 2007. It is expected that larger and older individuals as well as species sensitive to fisheries would have a better chance to survive, which would result in an increase in numbers and larger individuals.

The methods and design of the field work were decided upon by PAWP and the government and follow closely the protocols of the IMARES statutory task beam trawl surveys. The two beam trawls used were similar to the gear used in the IMARES Sole Net Survey (SNS). One beam was rigged with a SNS type net (mesh size 40 mm, rigged with four tickler chains) while the other beam was rigged with a net used in the Demersal Fish Survey (DFS, mesh size 20 mm, rigged with one tickler chain and bobbin rope). Following the protocols, twelve tows were performed in the wind farm. At each location this resulted in two samples: one SNS-net and one DFS-net. These catches were compared to data collected by the regular SNS and DFS survey in the surrounding area over the past 10 years (2004-2013). The spatial distributions of the two statutory surveys differ from the location of the wind farm. The positions of the DFS were closer to shore. For the SNS a limited number of stations was close to the farm, these were used in the analyses as SNS subset (SNS-close), which contains a maximum of two tows a year.

Data analyses were performed on the number of species caught, the total catch per hectare and the numbers per hectare of a number of target species (sole, plaice, dab, turbot, flounder, brill) and non-target species (solenette, scaldfish, greater sandeel and striped red mullet).

In total 27 fish species were caught in 24 samples, all of which were also caught in the surrounding statutory surveys. The total catch, species richness by tow and the abundance of the analysed species were very similar to the catches in the surrounding surveys. The length range of the species was similar to the SNS and DFS, but the length frequency distribution differed. The catches in PAWP had a lower number of small fish and a larger number of larger fish compared to the SNS catches. A part of this is due to the offshore position of PAWP compared to the total SNS set, however the differences were still visible compared to the SNS-close subset.

The overall impression is that fish species composition is equal inside to outside the wind farm. The expectation that larger and older individuals would have a better chance to survive and so increase in size and numbers, might be supported for the species analysed in this project.

1 Introduction

In March 2005, Eneco and Q7 Holding signed a declaration of intent for the construction and operation of a wind farm situated some 23 kilometres offshore from IJmuiden, in block Q7 of the Dutch continental shelf. The construction of this wind farm named Princess Amalia Wind Farm (in Dutch: Prinses Amaliawindpark, or PAWP) started in October 2006 by laying the first foundation. Foundations measuring 54 metres in length, a diameter of 4 metres and 320 tons in weight were sunk into the sea-floor. The transition pieces weighing 115 tons were placed on the foundations using the Jumping Jack. To support the turbine foundations, a 15 m diameter scour-protection consisting of mixed size rocks was deposited on the soft sediment around the base of each monopile. Cables and wind turbines were installed from May 2007 to April 2008. Fisheries are excluded from the farm area since 16 October 2007 and the wind farm is operational since June 2008.

A Monitoring and Evaluation Programme (MEP) to monitor potential effects of constructing and operating a wind farm on its surrounding is needed according to the Wbr-permit[1] of the wind farm. The MEP for PAWP consists of a number of research topics. Monitoring demersal fish species (mainly flatfish species) is one of those. The objective is to determine if PAWP acts as a refuge area (refugium) for demersal fish species. This report focuses on this objective by analysing the data from field work executed in October 2013, five years after the construction of the farm. The results are placed in the context of data of the past ten years (2004-2013) of two annual statutory task surveys carried out by IMARES using comparable fishing methods.

[1] Wet beheer rijkswaterstaatwerken, the State Water Management Works Administration Act in The Netherlands

2 Assignment

The MEP described in detail the field work that had to be performed as well as the data to be collected as part of the field work. Updated detailed descriptions were approved by Rijkswaterstaat[2] (RWS) Noordzee, June 2011, as described in the programme "Operationeel plan voor het bepalen of het Prinses Amaliawindpark als refugium fungeert voor demersale vis" (Ritzen and Dam, 2011), in-house document in Dutch only). IMARES was requested to execute the described field work. The collected data, analyses and conclusions are presented in this report.

The objective of the Operational plan is to determine whether the wind farm functions as a refugium for demersal fish. PAWP is expected to act as a refugium because fisheries are excluded from the farm. The expectation as phrased in the Operational plan (Ritzen and Dam, 2011) was that larger and older individuals as well as species vulnerable for fisheries would have a better chance to survive and so increase in numbers, or return to the area.

The assignment was to monitor once, in the fifth year (T5) after the construction of the farm. The proposal was to follow the approach used in two annual statutory task beam trawl surveys executed by IMARES, i.e. the Sole Net Survey (SNS) and the Demersal Fish Survey (DFS), as closely as possible. The main difference between these surveys is the type of net. To follow the approach of both surveys, fishing was done using two different nets on either side of the vessel. In this way twelve tows were made, resulting in the collection of 24 samples.

Target species in the Operational plan include:

- *Solea solea* (Sole)
- *Pleuronectes platessa* (Plaice)
- *Limanda limanda* (Dab)
- *Scophthalmus maximus* (Turbot)
- *Platichthys flesus* (Flounder)
- *Scophthalmus rhombus* (Brill)

These are the flatfish species of commercial interest which are caught by the two regular surveys. For plaice and sole the regular SNS and DFS data are input for the stock assessments.

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[2] The executive arm of the Dutch Ministry of Infrastructure and the Environment

3 Materials and Methods

3.1 Field work

The IMARES protocols for the beam trawl surveys as described in the Dutch survey manual (van Damme *et al.*, 2013) were followed.

The field work was conducted on 1 and 2 October 2013, in the same period as the annual SNS and DFS (September/October). The exact days were selected due to good weather conditions for fishing inside the wind farm.

3.2 Vessel and gear

The work was done from the commercial vessel SC-35 "Jacob Senior" of Seefischereibetrieb Hecht GmbH (Figure 3-1), this vessel was hired via the Ekofish group as the vessel is part of the consortium fishing under the flag of the Ekofish group. The Rijksrederij vessel R.V. Isis, which is used in the regular surveys, was unavailable as it was executing those surveys in the same period.

Figure 3-1: The SC-35 "Jacob-Senior" of Seefischereibetrieb Hecht GmbH, fishing within the consortium of the Ekofish group.

The SC-35 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.*, 2013) (Appendix A). The weight is heavier than the beam trawl used in de DFS. The beam trawls were equipped with nets that differed in mesh size and rigging. One side was rigged with a cod end mesh size of 40 mm, similar to the SNS net (Appendix A). The other side was rigged with a finer mesh size of 20 mm in the cod end (Figure 3-2)(Appendix A), similar to the net of the regular IMARES Demersal Fish Survey (DFS) (van Damme *et al.*, 2013). The two nets are used to catch the full length frequency distribution of the fish community. It was shown that the two mesh sizes were complementary and when the data are combined will give a good description of the community (Grift and Tien, 2003).

The used mesh sizes are smaller, the weight of the beam trawl is lighter, less tickler chains are used and the towing speed is slower than those currently used in the commercial beam trawl fisheries (*Table 3-1*). This affects the bottom penetration of this gear which is less, and as a result the catch composition will differ from commercial catches.

Table 3-1: The gear, net and fishing speed of the statutory surveys SNS and DFS, the PAWP-SNS, PAWP-DFS and indication of the methods used in the commercial beam trawl (Rijnsdorp et al., 2008).

	SNS	**DFS**	**PAWP-SNS**	**PAWP-DFS**	**Commercial beam trawl**
Ship	Isis	Isis	SC-35	SC-35	various
Beam trawl type	6m beam trawl	6m shrimp trawl	6m beam trawl	6m beam trawl	12m beam trawl
Tickler Chains	4	1	4	4	>8
Mesh size net	80mm	35mm	80mm	35mm	?
Mesh size codend (stretched)	40mm	20mm	40mm	20mm	80mm
Speed fished	3.5–4knots	3knots	3.5–4knots	3.5–4knots	5.3- 6.8 knots

3.3 Fishing

The towing locations were determined in advance and were fixed as far as possible (*Figure 3-3*). The planned coordinates are given in Table 4-1 and Appendix B. Fishing on these locations occurred with a towing speed of around 6.5 km hr^{-1} (3.5 knots) over the ground. This is the same speed as used in the SNS survey, but is faster than the speed used in the DFS. Fishing occurred for around 15 min in which the total distance of the planned transects was fished.

Figure 3-2: The 6m beam trawl, with the 20 mm DFS net. In the middle of the net, the CTD device is visible (Grift 2004).

After the tow, the catch is brought on board. First an estimation of the weight of the total catch by net was made. This was done by dividing the catch over baskets with a volume estimated to be 35 kg when full.
Then all species, fish and benthic fauna, were sorted per net. All fish were measured 'to the cm-below' (e.g. 5.7 cm is recorded as 5 cm). In case of large catches a subsample of the total catch or of a specific species was measured. The epibenthic fauna was counted per species. Due to time constraints epibenthic fauna was only recorded during the first day.

Additionally, length (mm), weight (g), gender and maturity stage were determined in the lab for a length representative selection of the target species. Gender and maturity stage are determined based on the internal reproductive organs. For smaller individuals of a number of the target species it is possible to determine this by holding the animals in front of a light. By larger individuals and some other species it is necessary to open the fish and look at the reproductive organs in detail; in some cases the organs are removed to inspect them thoroughly. Removal occurs more often by male organs as these are more difficult to find and to determine the maturity stage.

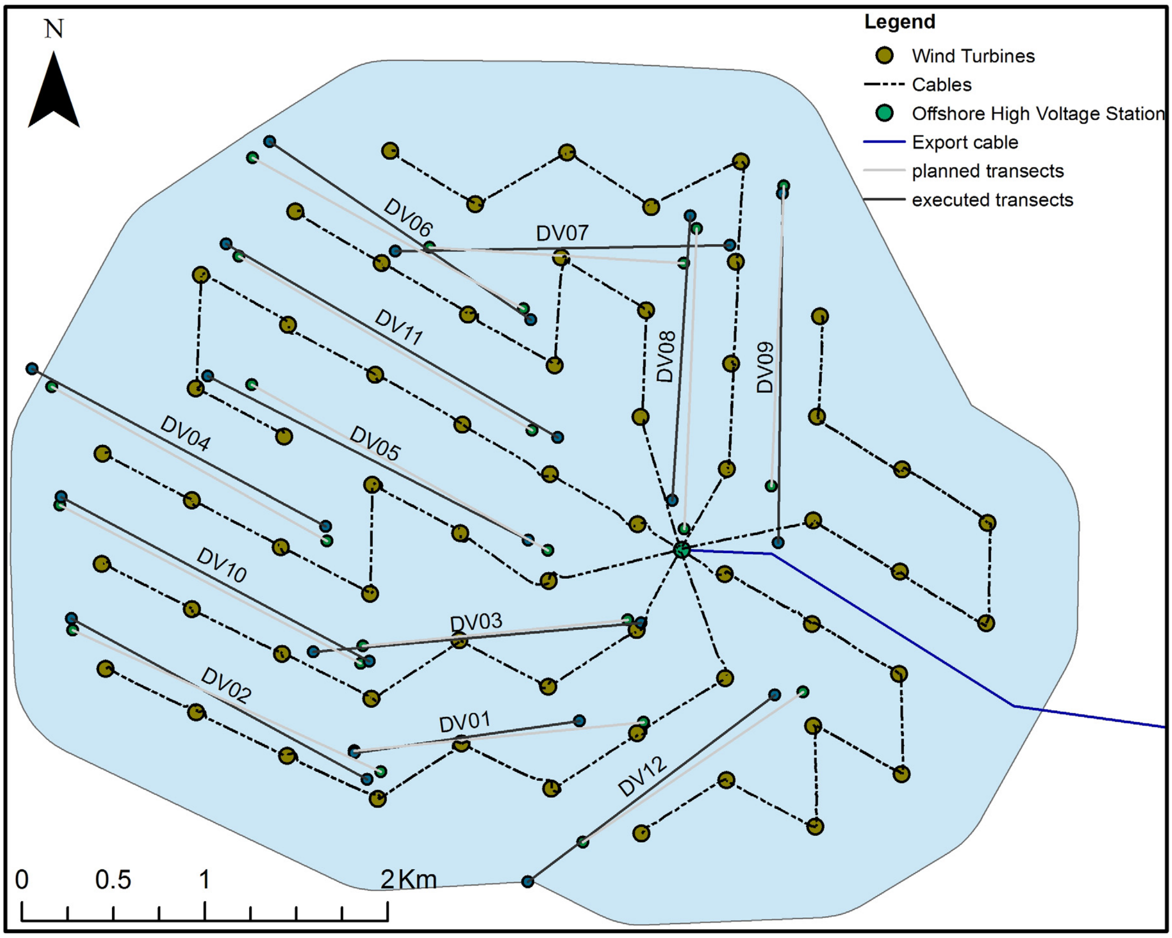

Figure 3-3: The planned and executed transects in the PAWP[3].

We digitized this weight, gender and maturity data while measuring. However, due to a technical issue the data was not saved correctly. We tried to redo the measurements on the same fish (because this was the only sample that was brought to the lab). However, because a part of the fish was cut open and the reproductive organs were removed we were unable to redo all the measurements. This might cause a bias in the gender and maturity information by species, gender and length. For example the information on maturity of the larger sole is lacking now. It is to be noted, that this issue does not affect the length data of the total catch.

It is important to realise that the timing of the monitoring occurred outside the period for reliable macroscopic maturity staging. The macroscopic determination method should only be used in the period from two months before the spawning season until the end of spawning, as is it is not possible to reliably stage the maturity of a fish macroscopically outside this period (ICES, 2012). This is the reason that maturity determination is not done for most species during the SNS and DFS. The data collected on maturity in PAWP should thus be treated with care.

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3 Transects are shorted compared to the Operational plan Ritzen, A., and Dam, J. 2011. Operationeel plan voor het bepalen of Prinses Amaliawindpark als refugium fungeert voor demersale vis. Versie 2.0 voor Rijkswaterstaat. p. 10. to prevent overlap as agreed in a letter approved by RWS on 4 Mach 2013,

All length measurements were written on paper. After the cruise, the data were entered in the IMARES program Billie Turf. These data were checked following standard IMARES procedures and imported in the IMARES database Frisbe, from which they could be extracted for further use.

3.4 CTD measurements

A Hydrolab CTD attached in one of the nets was used to collect data on Conductivity (salinity), Temperature and Depth. Because the CTD is mounted in one of the nets it collected data during each tow. The data was collected by a 10 second interval.

3.5 Comparison with the SNS and DFS data

The SNS and DFS are statutory task IMARES surveys, running since 1969 and 1970 respectively. For comparison of the 2013 PAWP catches, the 2013 results of these surveys were used. To put the catches in PAWP in a historic perspective, the results of DFS and SNS for the period 2004-2013 were used. In these years the SNS was normally done in the last two weeks of September, only in 2012 data was collected in the first week of October. The DFS directly follows the campaign of the SNS and is as a result executed in the last week of September till latest the first week of November. The PAWP campaign was done in early October, during the first days of the 2013 DFS.

The SNS has a fixed-station design on transects parallel or perpendicular to the continental coast (Appendix A). The DFS North Sea is a coastal survey covering the coastal zone from the most southern part of the Netherlands north till Esbjerg (Denmark) (Appendix A).

Only part of the data collected by these two surveys (SNS and DFS) was used in this study. The spatial extent was limited (52-53 N and 3.5-4.5 E) and furthermore only tows with a similar depth range as those in PAWP (15-25 m) (Figure 3-4) were taken into account. The number of tows by year and survey are listed in Table 3-2.

Table 3-2: The number of tows by year and survey. SNS close are included in SNS and are the tows in the two clouds of points near PAWP in Figure 3-4.

year	SNS	SNS close	DFS	PAWP
2004	8	2	5	
2005	9	1	13	
2006	13	2	9	
2007	9	2	15	
2008	10	2	6	
2009	12	2	12	
2010	13	2	11	
2011	11	2	14	
2012	10	1	15	
2013	13	2	14	12

The combined surveys (Figure 3-4) still cover a large surface, and for analyses on a smaller spatial scale only the two clouds of SNS tows nearest to PAWP are used. The figure also indicates that the DFS is closer to shore than PAWP.

The total numbers of individual fish per hectare were compared on a tow-by-tow basis. The catches of the small mesh net in PAWP were only compared to the DFS-survey in which the same small mesh is used and the larger mesh net catches were compared to the SNS-survey. This was done visually with boxplots, and statistically by using analysis of variance (AOV) followed by a TukeyHSD-test. Similar analyses were done for the target species and a number of non-target species. The analyses were done for the SNS, SNS-close and DFS separately.

Length-frequency distributions were created for the total catch and separately for the target and non-target species. The length-frequency distributions were compared statistically with a two-sample Kolmogorov & Smirnov test, for which the function lfclus from the R-package "fishmethods" was used. The function calculates a p-value (p-adj) for this test, the resampling procedure of the function was set at 1000. Detailed description on this package and function can be found here: http://www.inside-r.org/packages/cran/fishmethods/docs/lfclus. The fish were divided in small and large fish for both surveys. For the DFS-survey this split was made at a length of 10 cm, while for the SNS it was made at a length of 16 cm. This was visually based on the peak length of the total catches in the length frequency distributions.

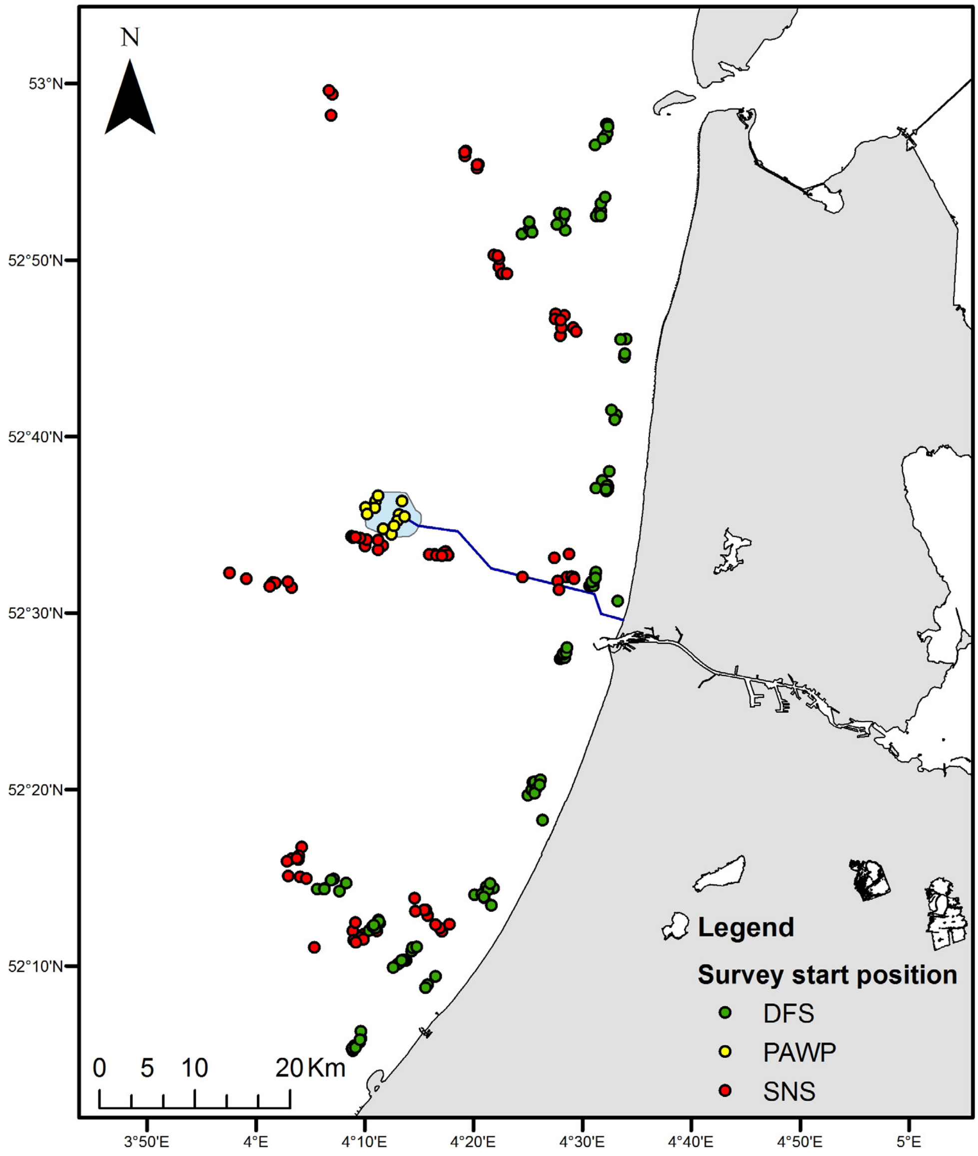

Figure 3-4: The trawl positions of the SNS (red) and DFS (green) used in the comparison with PAWP (yellow).

4 Results

4.1 Field work

4.1.1 Field day

The field work was done on Tuesday 1 and Wednesday 2 October 2013 (Table 4-1). These dates were at the end of the 2013 SNS and start of the DFS. The weather conditions were reasonable, with eastern wind conditions between 3-5 Bft.

On the first day 4 tows were made of which the whole catch, including epibenthos was registered. On the second day 8 tows were made, however in these tows epibenthos was neglected due to time constraints. Recording and analysis of epibenthos was not essential for the investigation of the refugium effect for demersal fish species in PAWP.

Table 4-1: Information for each tow in PAWP. The planned (e.g. pl lat_s) coordinates and the executed coordinates (e.g. lat_s). _s refers to shooting position, _h to hauling position.

Location	pl lat_s	pl lon_s	pl lat_h	pl lon_h	lat_s	lon_s	lat_h	lon_h	date	time	depth	duration	distance
DV01	52.578094	4.23239	52.5769	4.20901	52.57832	4.22722	52.57683	4.209	10/1/2013	922	20	13	1852
DV02	52.583097	4.18643	5.57587	4.21112	52.5755	4.21	52.58367	4.18633	10/1/2013	1112	20	17	1876
DV03	52.583143	4.23125	52.5821	4.20982	52.583	4.23233	52.58183	4.20583	10/2/2013	1111	20	16	1771
DV04	52.595089	4.18506	52.5873	4.20708	52.596	4.1835	52.588	4.207	10/2/2013	1251	21	17	1881
DV05	52.59504	4.2012	52.5867	4.22489	52.5955	4.19767	52.58717	4.22333	10/2/2013	1004	18	18	1652
DV06	52.606212	4.20159	52.5985	4.22325	52.607	4.203	52.598	4.22383	10/2/2013	926	18	16	1727
DV07	52.600663	4.23628	52.6017	4.21574	52.6015	4.24	52.6015	4.213	10/2/2013	1438	20	16	1801
DV08	52.602356	4.23733	52.5876	4.23593	52.589	4.235	52.603	4.23683	10/2/2013	1329	19	14	1551
DV09	52.604387	4.24443	52.5896	4.24303	52.58683	4.2435	52.604	4.24433	10/2/2013	813	18	17	1949
DV10	52.589266	4.18557	52.5812	4.20964	52.58967	4.18567	52.58133	4.21033	10/1/2013	1430	20	18	1922
DV11	52.601365	4.20035	52.5925	4.22378	52.602	4.19933	52.59217	4.22583	10/2/2013	1524	20	18	2000
DV12	52.579456	4.2453	52.5722	4.22731	52.57033	4.22283	52.57933	4.243	10/1/2013	1607	20	14	1694

4.1.2 CTD measurements

The CTD measurements by tow show that the conditions during these two days were constant. The bottom temperature during the first day (16.4 °C) was slightly higher than on the second day (16.1 °C). The salinity was slightly lower during the second day (35.704 compared to 35.987).

Table 4-2: Average and standard deviation of environmental conditions, temperature, salinity and dissolved oxygen (DO) per day, based on the continuous CTD records per tow.

Date	Avg Temperature	StdDev Temperature	Avg Salinity	StdDev Salinity	Average % DO	StdDev of DO%
10/1/2013	16.409	0.080	35.987	0.190	90.354	4.590
10/2/2013	16.081	0.052	35.704	0.139	83.788	3.984
	16.19235793	**0.167146848**	**35.79988974**	**0.20725239**	**86.01526718**	**5.224147699**

4.1.3 Catch data

The volumetric estimation of the catch weight per net ranged between 17.5 kg and 175 kg. On four locations these estimations were the same for both nets. On two locations, the DFS net was estimated to have a larger amount and on the other 6 locations the SNS net had a larger amount.

In total 14.195 fish were caught in the 24 samples (appendix C), counting both nets. These numbers were reasonably divided over the 12 locations; the differences in volumetric estimation were mainly caused by a varying amount of benthic organisms or debris. The location (DV11) with the lowest number of fish still contained 5% of the total numbers caught. The location (DV04) with the highest number of fish contained 13% of the total numbers caught.

Twenty-seven fish species (or genus: *Pomatoschistus* sp. and *Ammodytes* sp. which cannot be identified to species level) were found in the collected fish samples. The most dominant fish species was solenette (*Buglossidium luteum*) followed by plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*). For all those species more than two thousand individuals were caught. These three species were caught on all the twelve locations as were nine other species (Appendix C). By net the number of species caught per location ranged from 11 to 18 species. On three locations the SNS net caught more fish species than the DFS net and on two locations the number of fish species was the same and on seven locations more fish species were found in the DFS net (1 to 6 species).

The length of the caught fish ranged between 3 and 65 cm. The largest fish was a single garfish (*Belone belone*) with a length of 65 cm, followed by plaice with a length of 43 cm. The most dominant lengths were 8, 9 and 10 cm which is the size of most solenette. At these smaller lengths the catches of the DFS-net were larger compared to the SNS-net, most likely due to the smaller mesh size. The SNS-net catches became similar in number of fish to the DFS-net catches at a length of 11 cm. For the larger length classes the numbers in the SNS-net were higher (*Figure 4-1*).

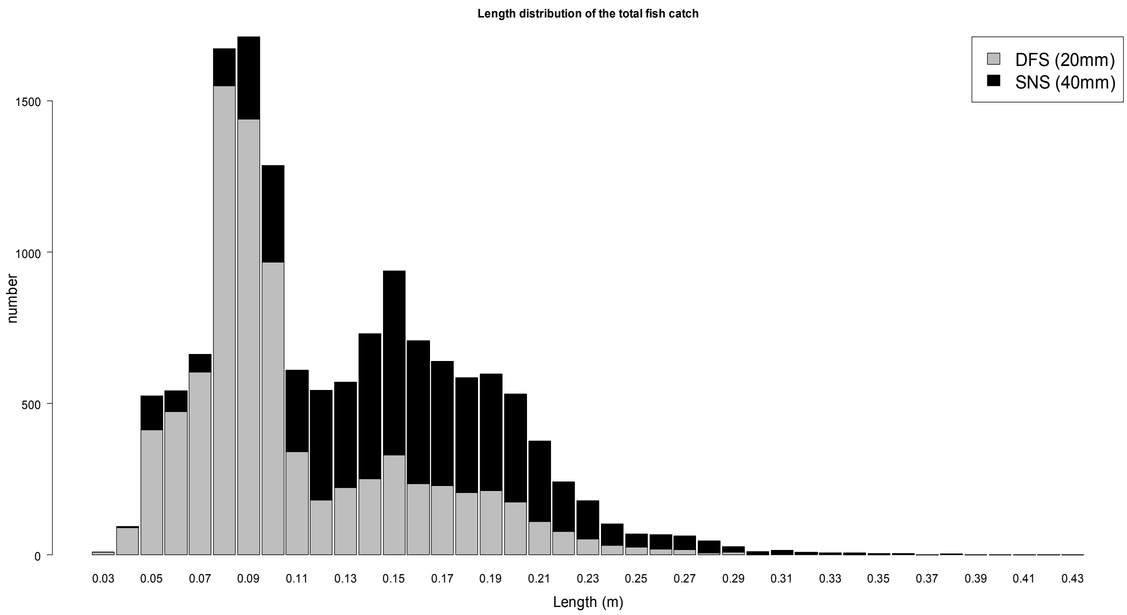

Figure 4-1: The length distribution of the fish part of the total catch by net type as a stacked graph. Grey: DFS; Black: SNS.

Epibenthos was only sampled in the four tows of the first day (except for edible crab *Cancer pagurus*, which was registered for all tows). The most dominant species was the serpent star (*Ophiura ophiura*) followed by the swimming crab (*Liocarcinus holsatus*). The third species was the blue mussel (*Mytilus edulis*). Also a number of other bivalve species were caught, e.g. *Spisula elliptica, Spisula subtruncata, Spisula solida, Donax vittatus, Chamelea gallina* (Appendix D).
The second day the epibenthos was not sampled, however, there was a large number of blue mussels in the catch. According to IMARES crew this was much higher than they had seen at other North Sea locations. The mussels were juveniles as well as consumption size. Besides the mussels, a number of larger *Spisula solida* were found. This is a regular species in these environments however the numbers caught were relatively higher when compared to catches from other locations fished with standard beam trawls. The same observation was made for larger Ascidians.

4.1.4 Target species

<u>*Solea solea*</u> <u>(Sole)</u>
Sole was caught at all twelve locations in both nets, with in total 217 individuals. The numbers caught in the SNS-net were higher than those in the DFS-net (*Figure 4-2*). The lengths of sole caught in PAWP ranged between 13 and 35 cm, with the majority being 20 to 24 cm (*Figure 4-2*).

The secondary data collection of length, weight, gender and maturity left 66 sole. A part, especially larger individuals, could not be measured for a second time after the issue with the data storage. The length representative sample for these measurements had thus been larger than the 66 sole available now. Only three individuals larger than 26 cm were sampled in the secondary data collection, this had been six individuals in the first analysis. From the first analysis it was remembered that these six were females. The smaller fish showed a dominance of male sole (*Figure 4-4*). For the determination of maturity, only 55 sole were left. Of these 9 were immature up to a length of 21 cm. The length and weight data showed the expected positive length-weight relationship (Figure 4-3).

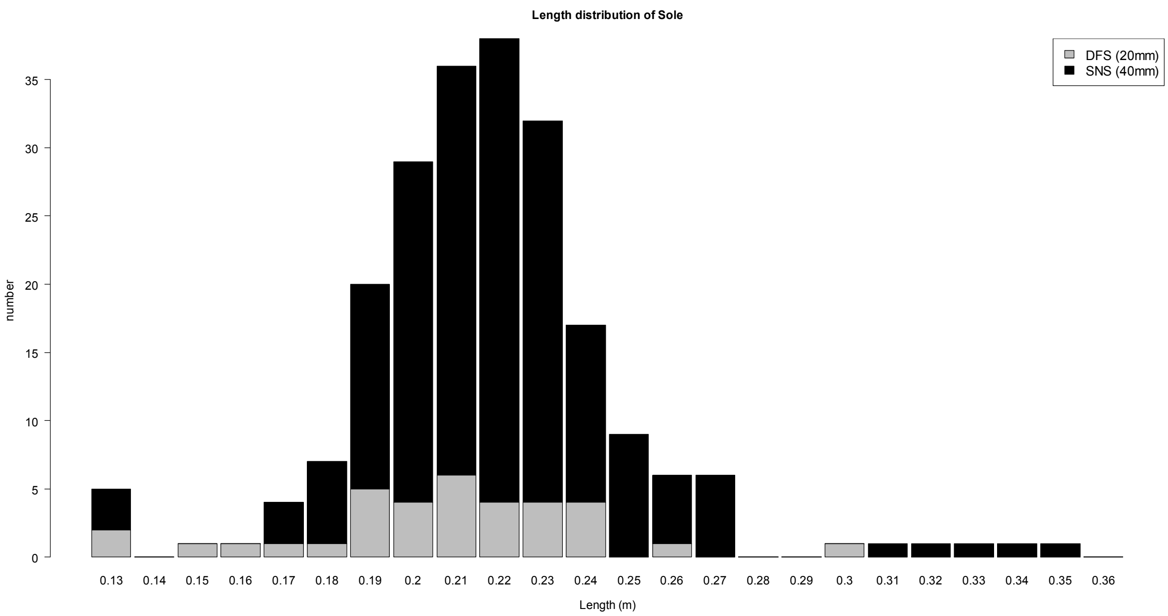

*Figure 4-2: The length distribution of sole (*Solea solea*) by net type as a stacked graph. Grey: DFS; Black: SNS.*

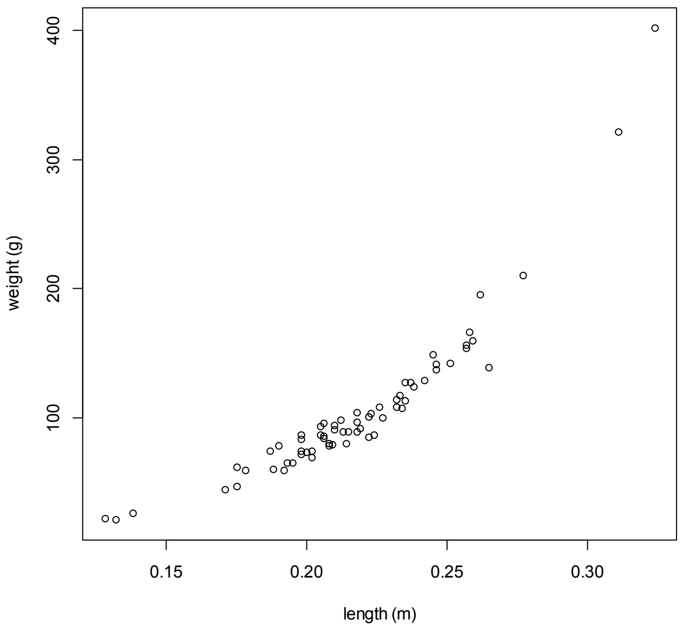

*Figure 4-3: Length-weight relationship for sole (*Solea solea*).*

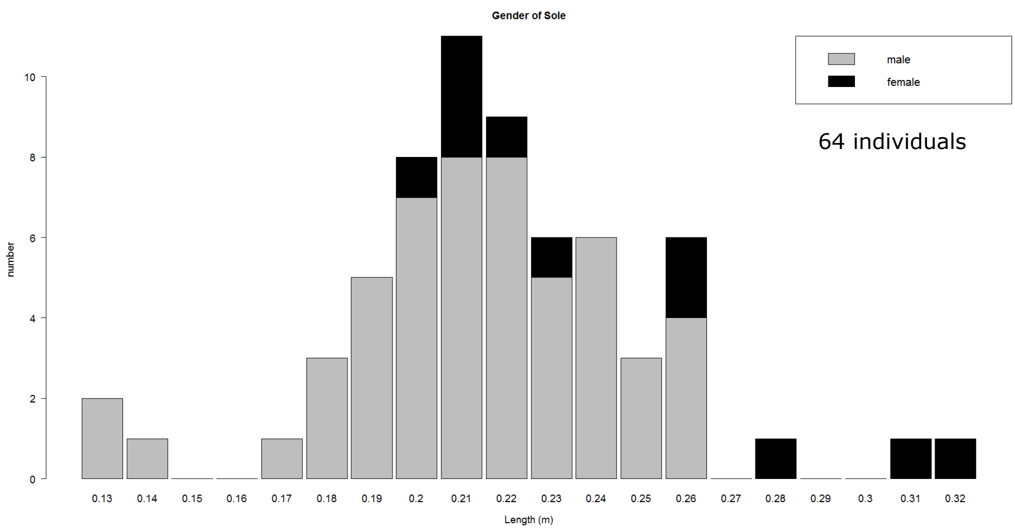

*Figure 4-4: Gender distribution of sole (*Solea solea*) by length.*

<u>*Pleuronectes platessa* (Plaice)</u>
Plaice was caught at all twelve locations in both nets, with in total 3571 individuals. The numbers caught in the SNS-net were higher than those in the DFS-net (*Figure 4-2*). The lengths of plaice caught in PAWP ranged between 8 and 43 cm, with the majority being 14 to 21 cm (*Figure 4-5*).

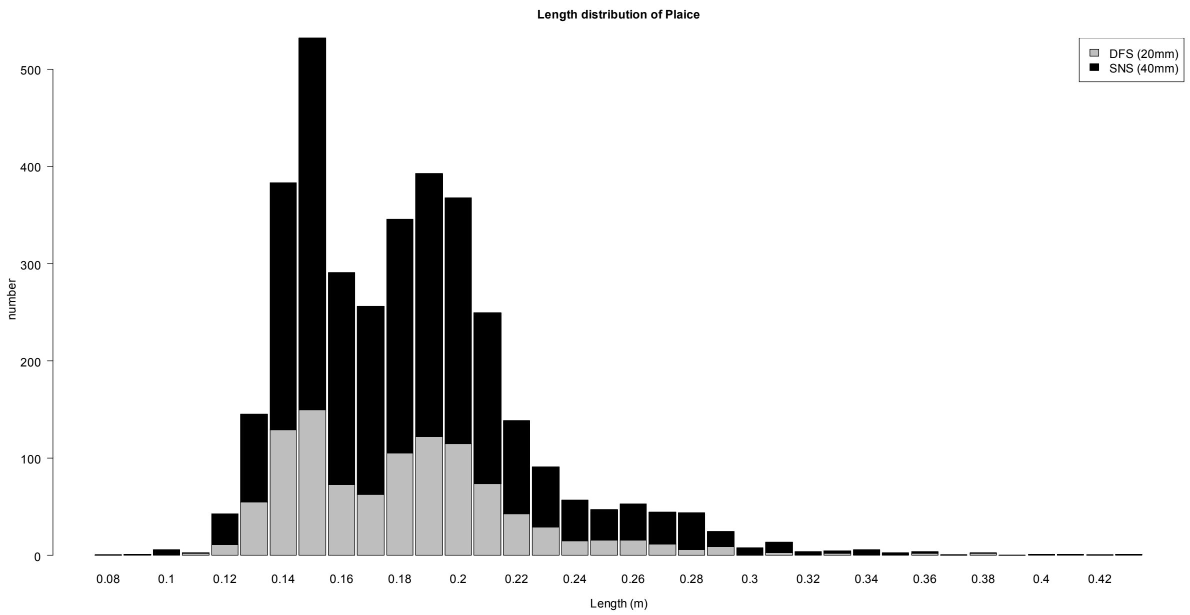

*Figure 4-5: The length distribution of plaice (*Pleuronectes platessa*) by net-type as stacked-graph. Grey: DFS; Black: SNS.*

79 individual plaice were measured and weighed, resulting in the expected positive length-weight relationship (*Figure 4-6*). The larger plaice were mainly females, while in the smaller length classes the males dominated (*Figure 4-7*). Plaice up to a length of 20 cm were mainly staged as juveniles, all the larger plaice were staged as 2 (maturing). This is difficult to determine (ICES, 2012), but is the most likely stage as the spawning period of plaice is much later in the year, or early next year. Thus spawning plaice (stage 3) or spent plaice (stage 4) were not to be expected.

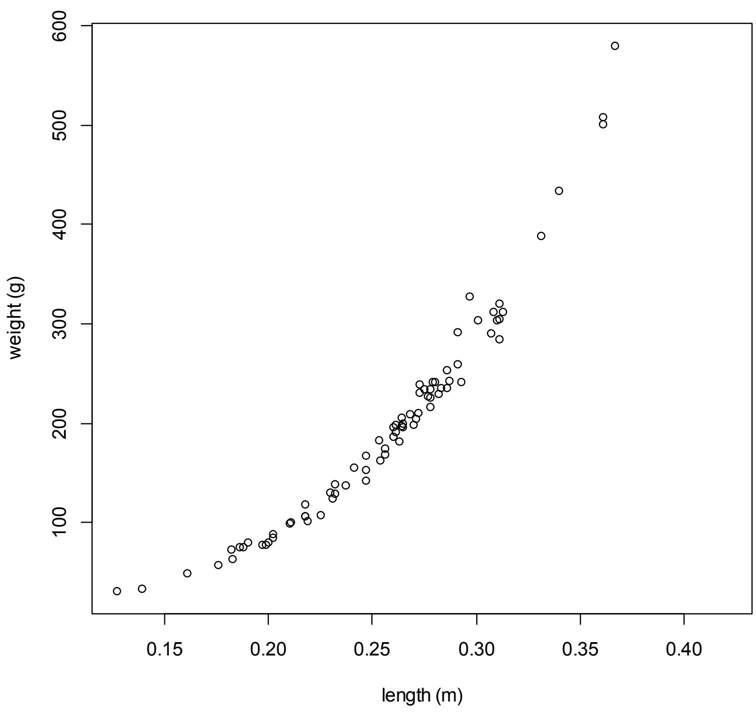

*Figure 4-6: Length-weight relationship for plaice (*Pleuronectes platessa*).*

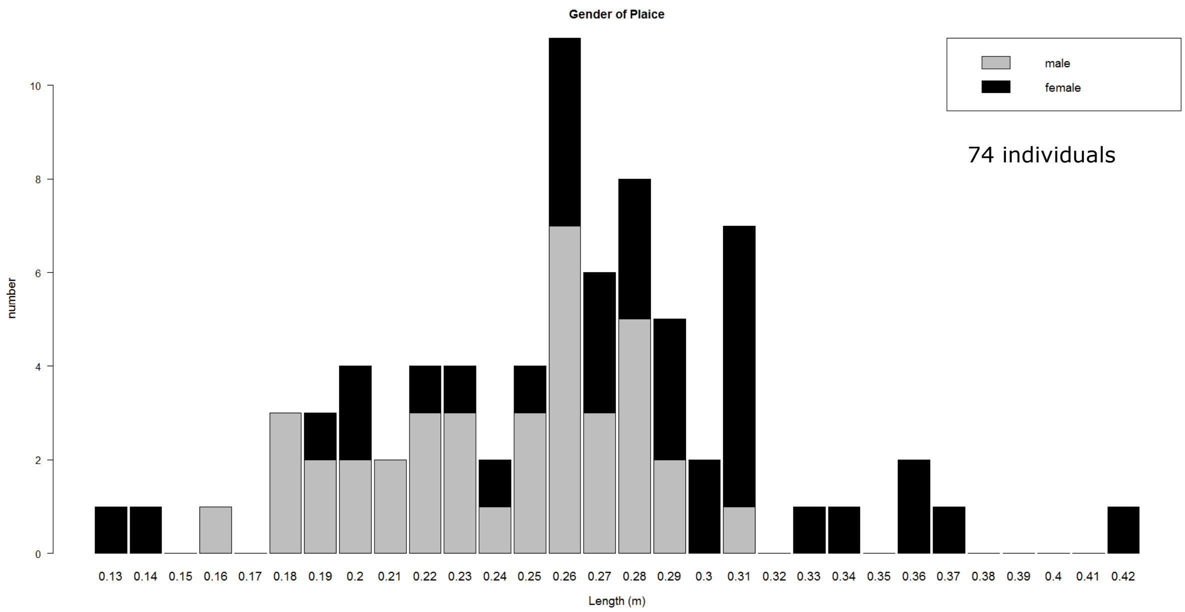

*Figure 4-7: Gender distribution of plaice (*Pleuronectes platessa*) by length.*

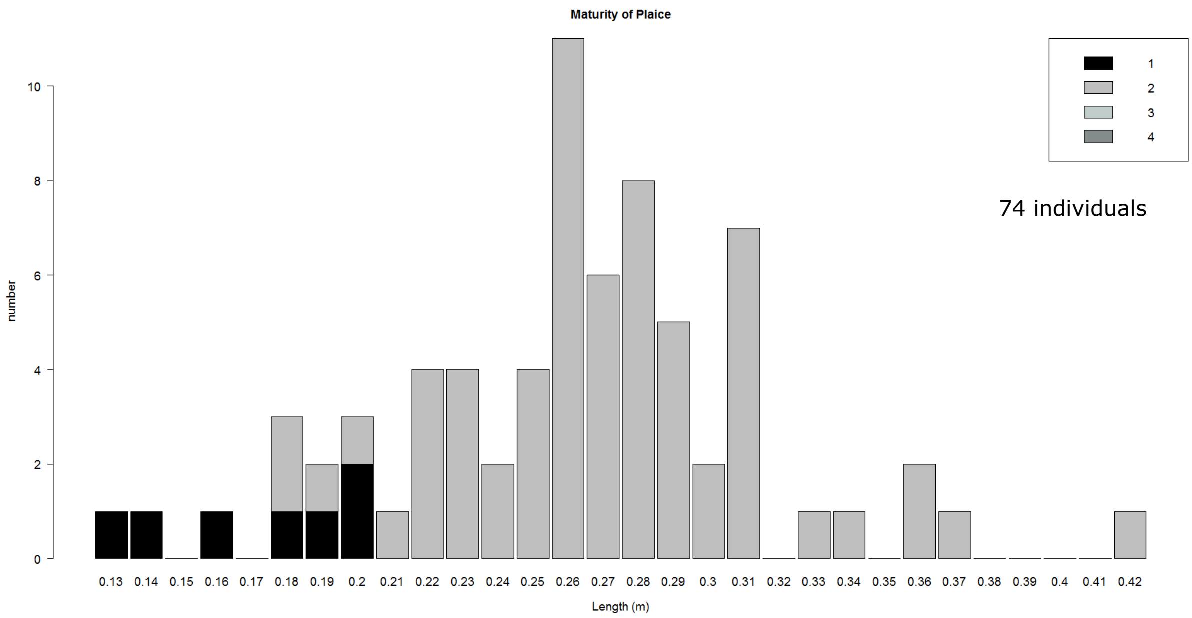

*Figure 4-8: Maturity stage distribution of plaice (*Pleuronectes platessa*) by length. Only stage 1 and 2 were found.*

<u>*Limanda limanda* (Dab)</u>
Dab was caught at all the twelve locations in both nets, with in total 2262 individuals. The catches between the nets were very similar in numbers (*Figure 4-9*). The length of dab ranges from 4 to 28 cm, clearly showing two peaks. Those smaller than 8 cm and those between 14 and 17 cm.

As for sole and plaice, the individual dab measured and weighed showed a positive relationship (*Figure 4-10*). The male:female ratio is skewed in length. All the fish of 20 cm and larger were females, while smaller the ratio was equal or dominated by males (*Figure 4-11*).

All the fish smaller than 13 cm were staged as juveniles. Juveniles were found till a length of 22 cm. A part of the larger dab was staged as spent (stage 4), however here counts the remark of difficulties regarding staging outside the spawning season (ICES, 2012).

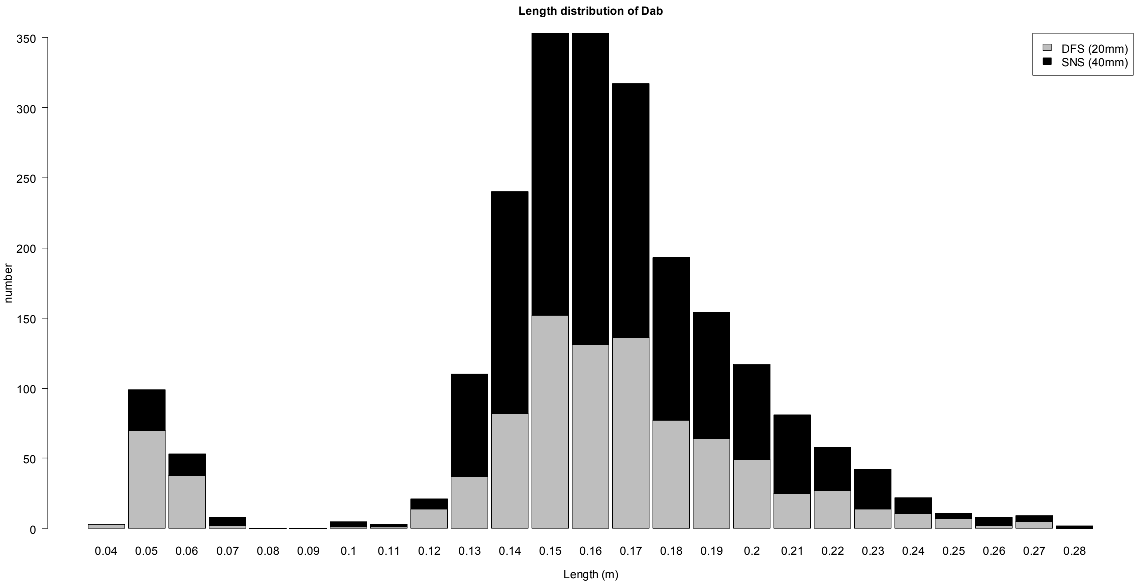

*Figure 4-9: The length distribution of dab (*Limanda limanda*) by net-type as stacked-graph. Grey: DFS; Black: SNS.*

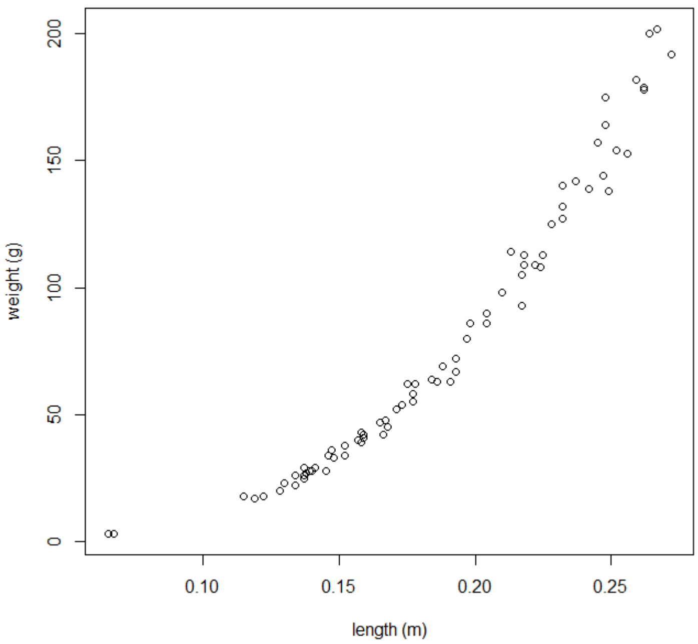

*Figure 4-10: Length-weight relationship for dab (*Limanda limanda*).*

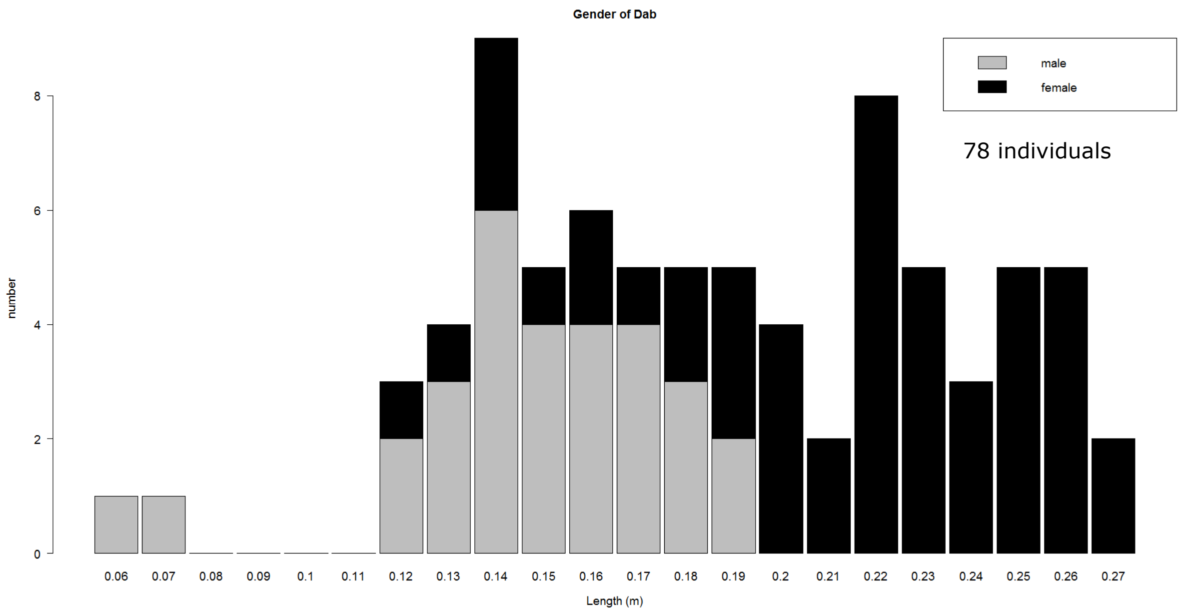

*Figure 4-11: Gender distribution of dab (*Limanda limanda*) by length.*

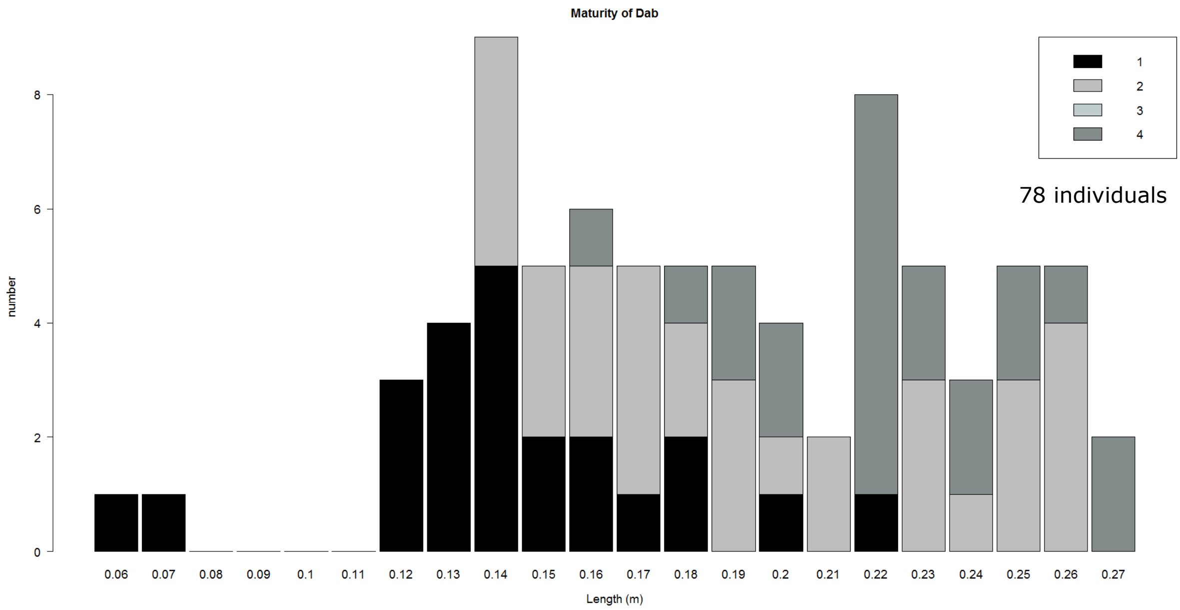

*Figure 4-12: Maturity stage distribution of dab (*Limanda limanda*) by length.*

Scophthalmus maximus (Turbot)
Only five turbot were caught, all of these were caught in the SNS-net on five different locations. The length range of these turbot was 19-27 cm and the weight was between 162 and 353 gram.

Platichthys flesus (Flounder)
Only five individuals on different locations were caught, of which four were caught in the SNS-net. The length of these five fish was between 28 and 32 cm. No further information was collected.

Scophthalmus rhombus (Brill)
Only two brill were caught one was 27 and the other 29 cm. They were caught at different location, but both in the SNS-net.

4.1.5 Non-target species

For a selection of non-target species (solenette, scaldfish, striped red mullet, greater sandeel) information is presented below, the length distribution for hooknose, horse mackerel, lesser weever, grey gurnard, common dragonet, bull-rout, whiting and tub gurnard is shown in appendix E.

Buglossidium luteum (Solenette)
The most dominant species in numbers was solenette. It was found at all locations in both nets. The catches in the DFS net dominated (*Figure 4-13*), which is not surprising, as solenette is small and sole-like shaped making it possible to wring itself easily through the meshes of the SNS net. The length range of solenette is 5 to 12 cm. This might include ages up to 14 years old (van Hal *et al.*, 2010).

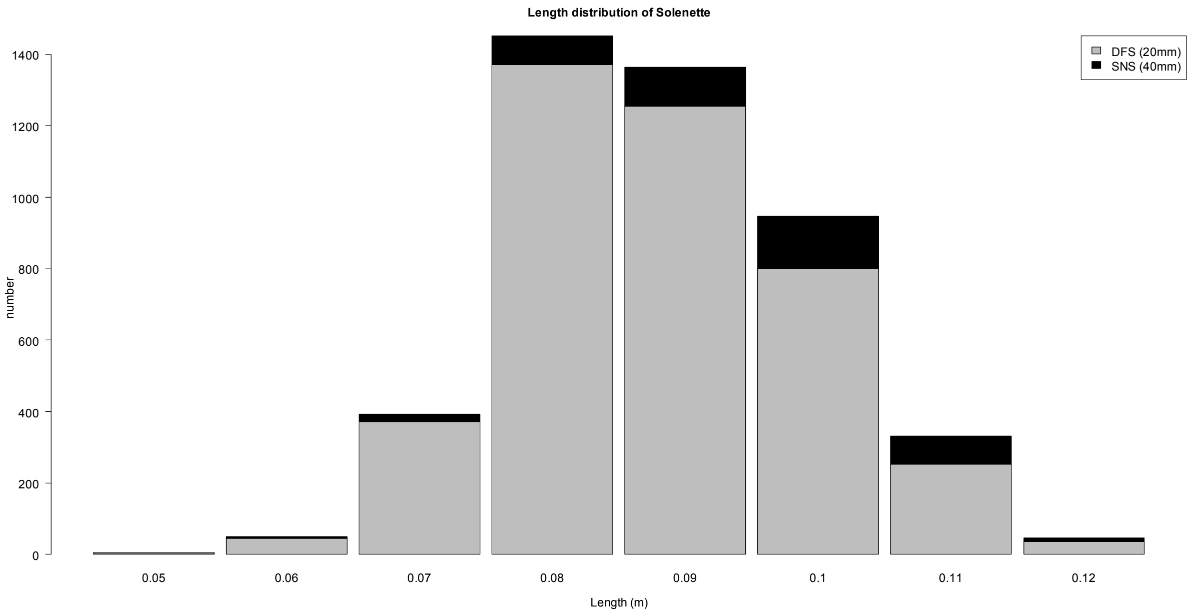

*Figure 4-13: The length distribution of solenette (*Buglossidium luteum*) by net-type as stacked-graph. Grey: DFS; Black: SNS.*

Arnoglossus laterna (Scaldfish)
Scaldfish was the fourth species of which more than 1000 individuals were caught. The species occurred at all twelve locations in both nets. The majority of the scaldfish was caught in the SNS net. The smallest length classes were only caught in the DFS net. The length range was 5 to 15 cm (*Figure 4-14*), which can include ages up to 8 years (van Hal *et al.*, 2010).

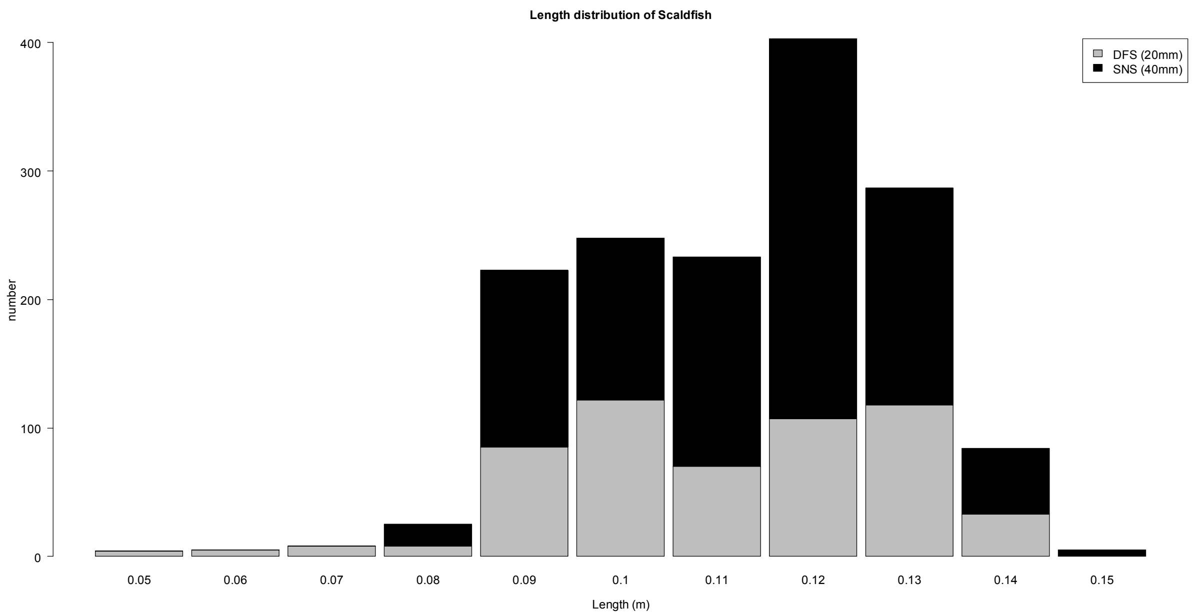

*Figure 4-14: The length distribution of scaldfish (*Arnoglossus laterna*) by net-type as stacked-graph. Grey: DFS; Black: SNS.*

<u>*Mullus surmuletus* (Striped red mullet)</u>

Mainly very small striped red mullet were caught, and the catches were dominated by the DFS net (*Figure 4-15*). The mullet was found at all locations, at DV09 it was only caught in the DFS-net.

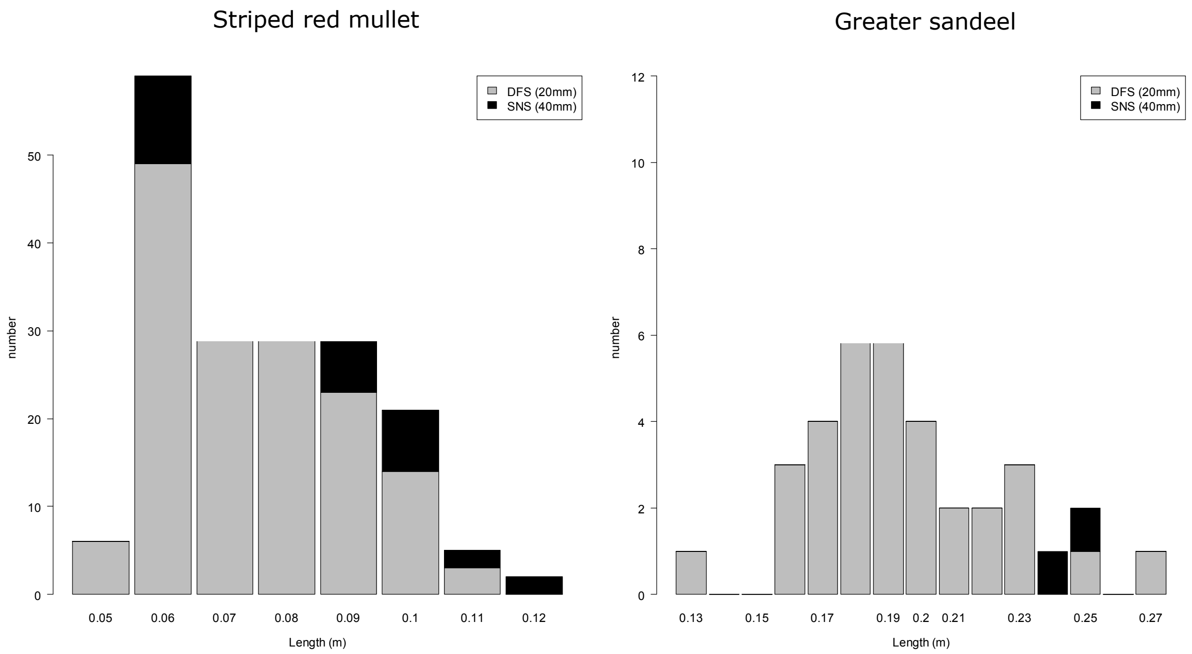

*Figure 4-15: Left: the length distribution of striped red mullet (*Mullus surmuletus*) and Right: greater sandeel (*Hyperoplus lanceolatus*) by net-type. Grey: DFS; Black: SNS.*

Hyperoplus lanceolatus (Greater sandeel)
Greater sandeel were caught at eleven locations, they were not caught at DV06. Due to their snake-like shape they easily escape from the SNS-net and so, this species is mainly caught in the DFS-net, in a length range of 13 to 27 cm (*Figure 4-15*).

4.2 Comparison with the SNS data

4.2.1 Catch data

Comparisons were made for the total catch in number of fish per hectare. The catches of the SNS-net in PAWP were compared to those of the SNS-2013 and with the historic SNS-survey (*Figure 4-16*). The figure shows that the median and the distribution of the total PAWP catches in numbers of fish per hectare per tow were within the range of the catches of the SNS-2013 and historic catches. This was confirmed by the AOV that indicates no significant effect (F: 1.358 P: 0.209). The TukeyHSD results indicated that the PAWP catches were very similar to the catches of the SNS in each of the separate years (Table 4-3). The largest difference was found with the 2011 SNS, indicating that however not significant the catches in 2011 were somewhat larger.

The subset of SNS tows close to PAWP indicates a very similar result as shown for the complete set. The TukeyHSD results indicate that the PAWP catches were very similar to the SNS subset catches (*Table 4-4*). There was no difference between the two SNS catches in 2013 close the wind farm and those in PAWP.

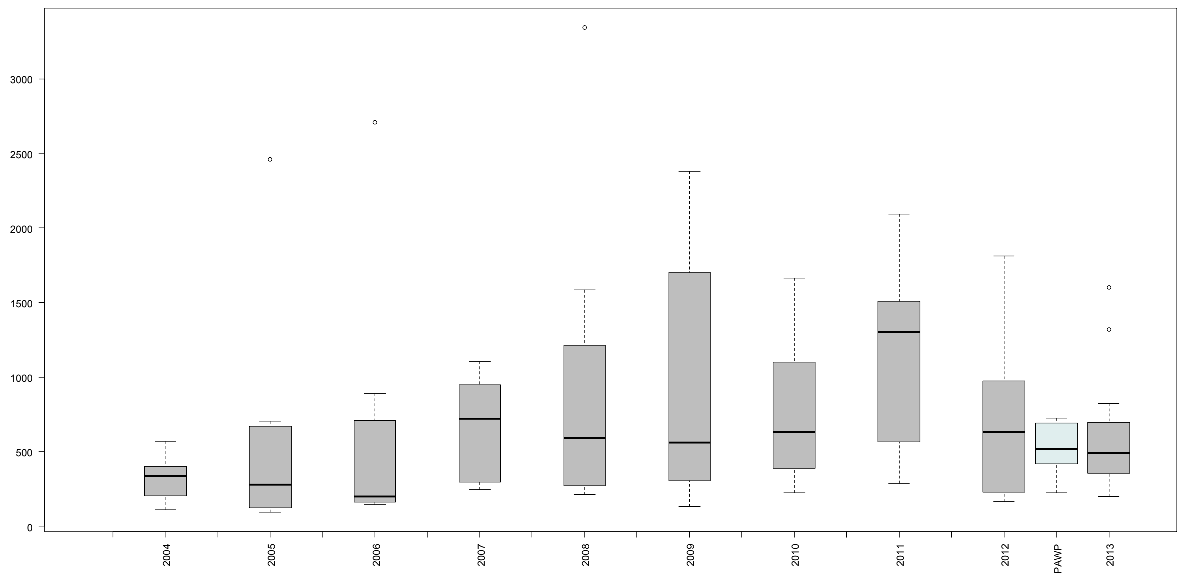

Figure 4-16: Boxplots indicating the distribution of the total SNS fish catches in numbers per hectare by year and the 2013 PAWP-catches in the SNS-net. The black horizontal line is the median. Number of tows by year on which the figure is based is shown in Table 3-2.

Table 4-3: The TukeyHSD results for the PAWP total fish catch compared to SNS for each of the separate years. Diff=difference between the two means, lwr+upr= the minimum and maximum of the Studentized range statistic and P-adj= the adjusted P-value.

	diff	lwr	upr	p adj
SNS2004-PAWPDEM2013	-210.242	-1111.06	690.5802	0.999505
SNS2005-PAWPDEM2013	22.45687	-847.82	892.734	1
SNS2006-PAWPDEM2013	25.49479	-764.579	815.5683	1
SNS2007-PAWPDEM2013	118.2849	-751.992	988.5621	0.999997
SNS2008-PAWPDEM2013	381.2197	-463.827	1226.266	0.92227
SNS2009-PAWPDEM2013	403.1858	-402.534	1208.906	0.858899
SNS2010-PAWPDEM2013	203.1682	-586.905	993.2417	0.998851
SNS2011-PAWPDEM2013	561.5406	-262.288	1385.369	0.481357
SNS2012-PAWPDEM2013	163.2751	-681.771	1008.321	0.999909
SNS2013-PAWPDEM2013	82.32655	-707.747	872.4001	1

Table 4-4: The TukeyHSD results for the PAWP total fish catch compared to SNS subset for each of the separate years. Diff=difference between the two means, lwr+upr= the minimum and maximum of the Studentized range statistic and P-adj= the adjusted P-value.

	diff	lwr	upr	p adj
SNS2004-PAWP2013	-131.118	-926.535	664.2979	0.999904
SNS2005-PAWP2013	-289.126	-1373.1	794.844	0.99454
SNS2006-PAWP2013	-167.856	-963.272	627.5602	0.999172
SNS2007-PAWP2013	36.6828	-758.733	832.099	1
SNS2008-PAWP2013	-112.163	-907.58	683.2528	0.999977
SNS2009-PAWP2013	-227.125	-1022.54	568.2916	0.990899
SNS2010-PAWP2013	-149.819	-945.235	645.5977	0.999688
SNS2011-PAWP2013	868.2231	72.80687	1663.639	0.025536
SNS2012-PAWP2013	113.4714	-970.498	1197.441	0.999999
SNS2013-PAWP2013	56.901	-738.515	852.3172	1

4.2.2 Length

The length-frequency distribution of the SNS-survey indicates a peak around a length of 12 to 13 cm. The SNS-2013 indicates a larger proportion of smaller fish compared to the SNS catches in other years, while the peak length is similar.

The PAWP-SNS data indicates a peak at 15 cm, which is slightly higher than for the SNS 2013. The peak is less pronounced indicating a more even distribution of fish over the length classes (*Figure 4-17*). Statistically comparing this distribution with the other three distributions presented gives a significant result only for the SNS-close set.

PAWP-SNS vs. SNS: Ds: 0.159; P=0.063;

PAWP-SNS vs. SNS-Close: Ds: 0.386, P<0.01;

PAWP-SNS vs. SNS 2013 Ds: 0.090; P=0.993.

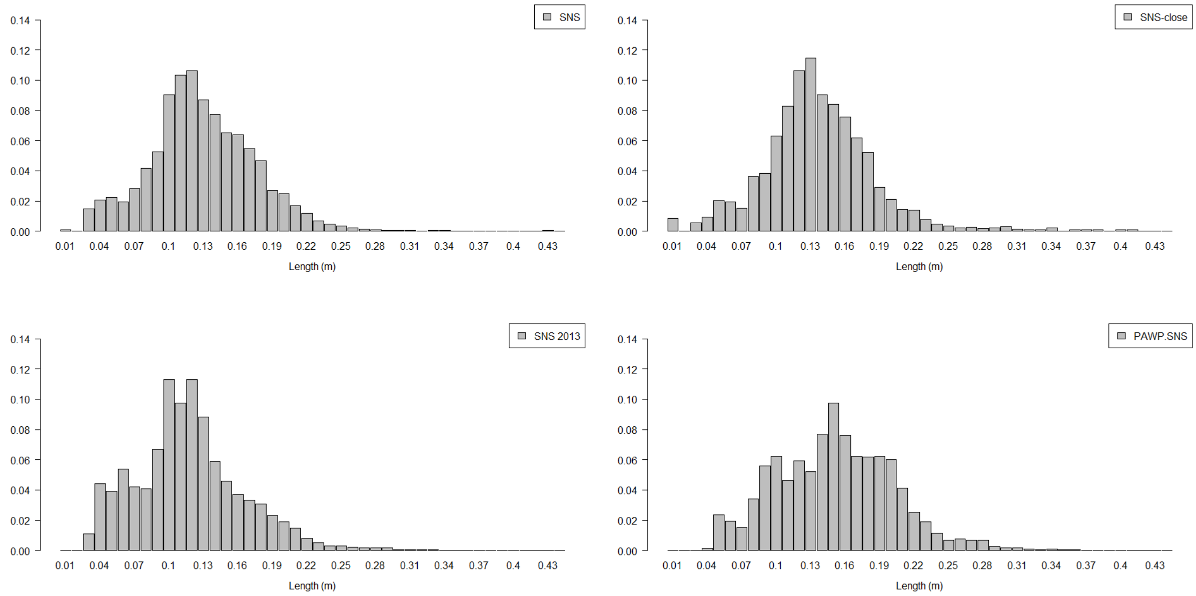

Figure 4-17: Length distributions of the total catch in the SNS as fraction. The total SNS set; the subset of the SNS (SNS close); only the SNS in 2013 and the PAWP tows.

The length distribution of the SNS-PAWP differs due to the catch of slightly less small fish (<16cm) and a slightly higher number of larger fish (=>16cm) compared to the SNS and SNS-close sets (*Figure 4-18*). Testing this with a student t-test indicates that the tows in PAWP had a significantly larger number of large fish per hectare compared to the SNS-2013 and SNS-close set. Also catches of small fish per tow were significantly smaller in PAWP compared to the other SNS and SNS-2013.

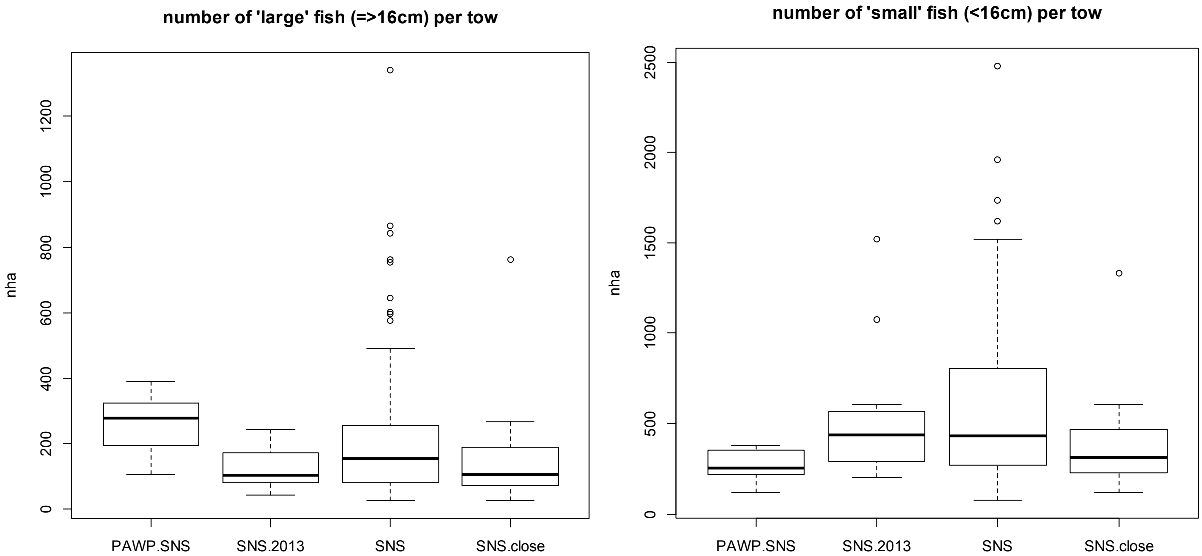

Figure 4-18: Left: large fish (=>16cm) in number per hectare; Right: small fish (<16cm) in number per hectare. The total SNS set, The PAWP tows, the SNS in 2013, the total SNS, and the subset of the SNS (SNS close).

4.2.3 Species richness

The number of fish species caught in the SNS by tow ranged between 7 and 19. The number of fish species caught in the SNS-net in PAWP fall within this range (Figure 4-19). The analysis of variance, however indicated a significant difference between at least two of the boxplots. The TukeyHSD showed a significant difference between the number of species in 2005 and PAWP (Table 4-5). There is no significant difference shown between PAWP and the SNS in any of the other years. Thus the species richness in PAWP is similar to the SNS in 2013.

Table 4-5: The TukeyHSD results for the PAWP number of species compared to SNS of the separate years. The bold value indicates a significant effect. Diff=difference between the two means, lwr+upr= the minimum and maximum of the Studentized range statistic and P-adj= the adjusted P-value.

	diff	lwr	upr	p adj
SNS2004-PAWP2013	-0.75	-3.85721	2.35721	0.999335
SNS2005-PAWP2013	-3.5	-6.50185	-0.49815	**0.009277**
SNS2006-PAWP2013	-2.5	-5.2252	0.225204	0.103064
SNS2007-PAWP2013	-0.05556	-3.05741	2.946295	1
SNS2008-PAWP2013	-1.1	-4.01482	1.814821	0.976151
SNS2009-PAWP2013	-0.58333	-3.36251	2.19584	0.999808
SNS2010-PAWP2013	-1.34615	-4.07136	1.37905	0.868502
SNS2011-PAWP2013	-0.13636	-2.978	2.705271	1
SNS2012-PAWP2013	-1.5	-4.41482	1.414821	0.83635
SNS2013-PAWP2013	-1.57692	-4.30213	1.14828	0.714208

In PAWP, the sea scorpion (*Taurulus bubalis*) was caught. This species was not found in any of the SNS catches used in the comparison. All the other species in PAWP were found in at least one of the SNS tows.

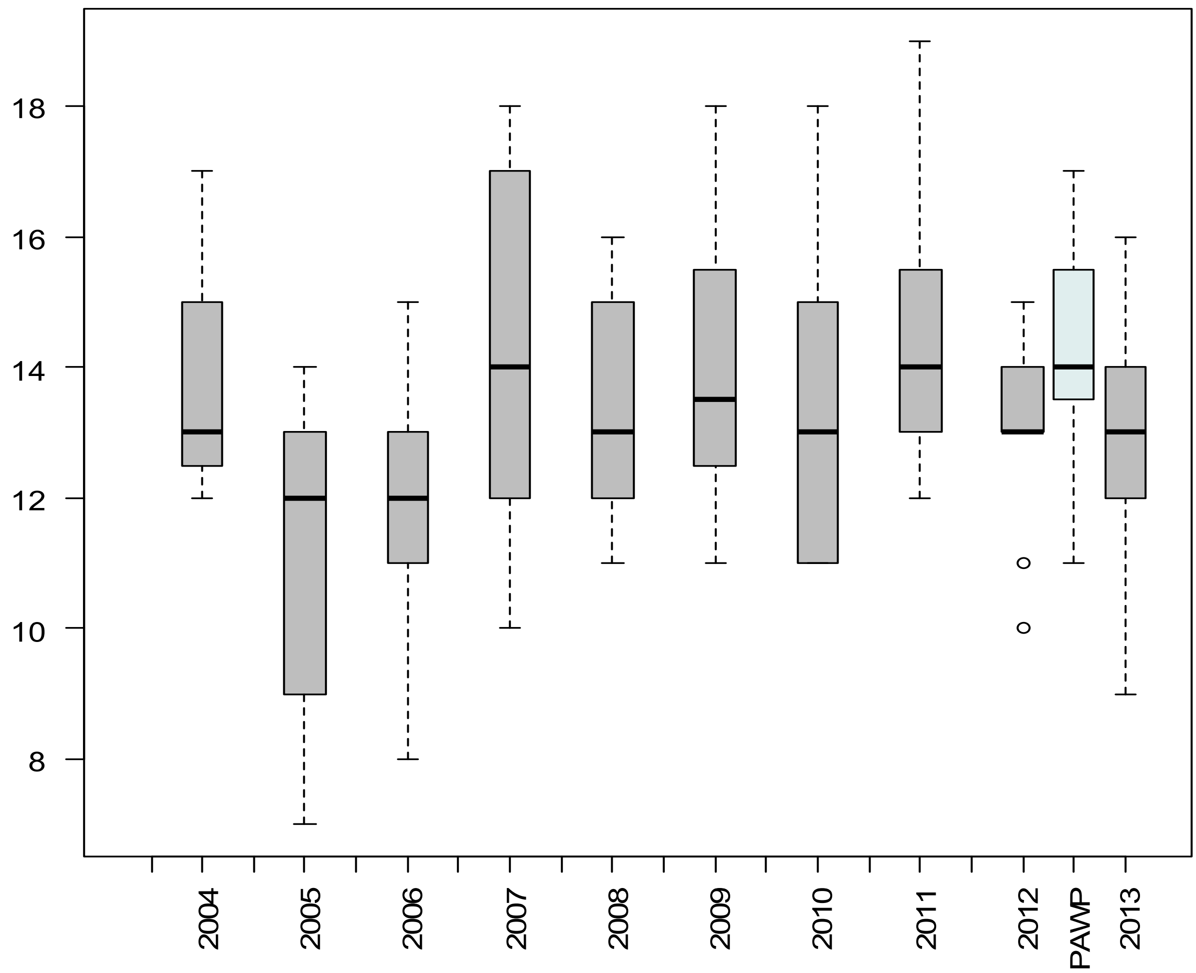

Figure 4-19: Boxplots indicating the distribution of the number of fish species per tow in the SNS by year and the 2013 PAWP-catches in the SNS-net. The black horizontal line is the median. Number of tows by year on which the figure is based is shown in Table 3-2.

4.3 Comparison with the DFS data

4.3.1 Catch data

As described in the section 3.2 there are differences between the gear used in PAWP and the gear used in the regular DFS survey. The fishing speed in PAWP was higher, due to which a larger surface is fished in the same time. The used beam trawl is heavier than the one normally used in the DFS. Furthermore, the spatial distribution of the regular DFS is closer to shore, e.g. PAWP is further offshore. These aspects make an absolute comparison of the catches difficult, and the results should thus be treated with caution.

The total fish numbers per hectare (thus corrected for the larger distance fished) in the DFS-nets used in PAWP are very similar to the DFS-2013 and historic DFS catches (Figure 4-20). The analysis of variance indicated a significant difference between at least two of the boxes in the boxplot (F:2.44 P:0.011). The TukeyHSD showed that this is a difference between the 2007 and 2009 DFS data. The PAWP numbers of fish per hectare did not significantly differ from the catches in the DFS-survey in any of the years.

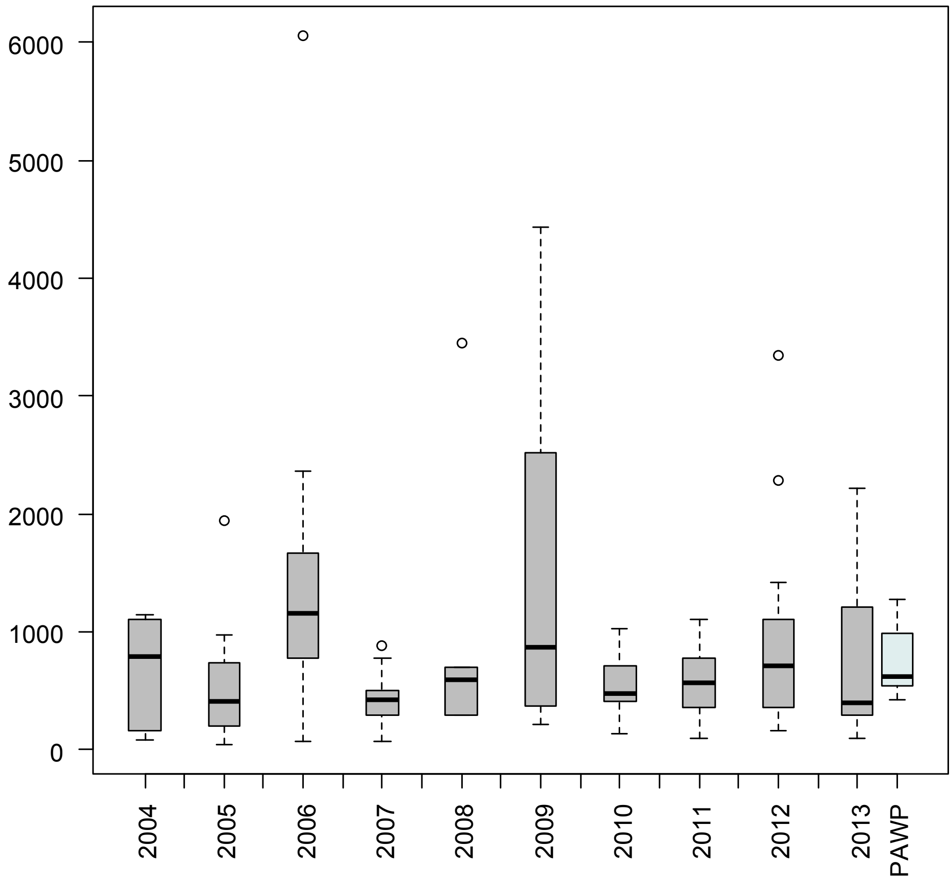

Figure 4-20: Boxplots indicating the distribution of the total DFS-fish catches in numbers per hectare by year and the 2013 PAWP-catches in the DFS-net. The black horizontal line is the median. Number of tows by year on which the figure is based is shown in Table 3-2.

4.3.2 Length

The peak length in the DFS-survey catches was around 7 cm and around 9 cm in PAWP-DFS (*Figure 4-21*). As described before, this peak in PAWP was linked to the length of the dominant species solenette. The catches of this species in the coastal DFS survey are limited as the species lives at the outer limits of the DFS survey area. Looking at the larger lengths, there was a second but smaller peak visible in the PAWP-DFS around 15 cm.

The number of small fish (<10cm) in PAWP is similar to the DFS and the DFS in 2013. The number of larger fish (=>10cm) is larger in PAWP than in the total DFS and even more so compared to the DFS 2013. The larger number of larger fish is most likely related to the offshore distribution.

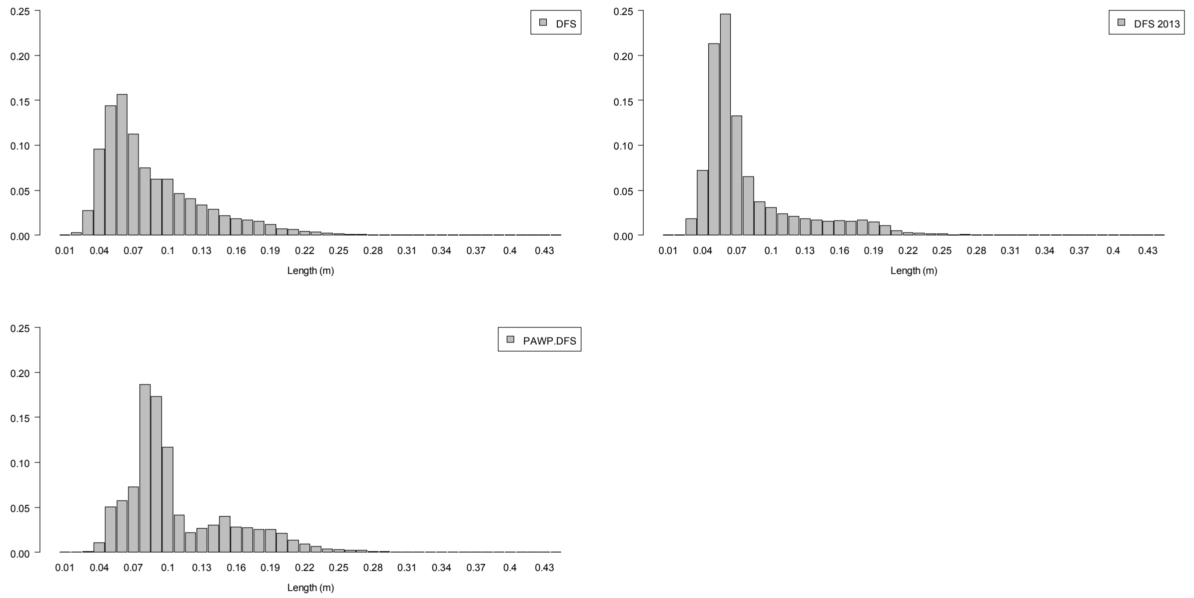

Figure 4-21: Length distributions of the total catch in the DFS as fraction. The total DFS set; only the DFS in 2013 and the PAWP tows.

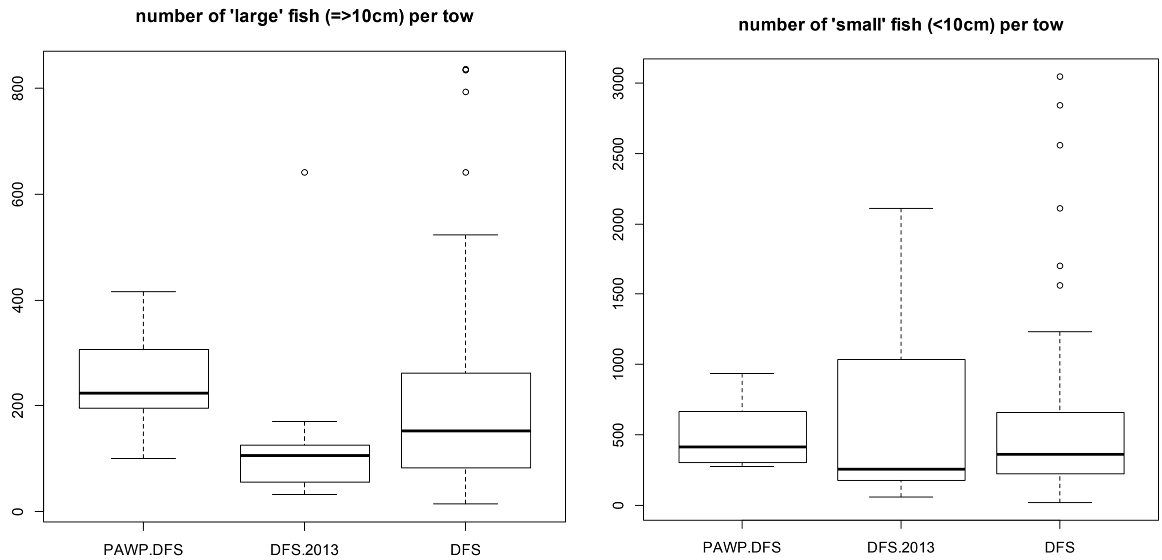

Figure 4-22: Left: large fish (=>10cm) in number per hectare; Right: small fish (<10cm) in number per hectare. The PAWP tows, the DFS in 2013, and the total DFS.

4.3.3 Species richness

The figure on the number of fish species caught by tow indicates that overall in PAWP a higher number of fish species was caught by tow. This difference is significant between PAWP and DFS in the years 2004 to 2008 (P <0.01). In the later years the number of species per tow in the DFS had increased and the difference with PAWP is no longer significant.

Looking at the species level, all 24 species caught in PAWP were also caught in any of the DFS tows. Only three PAWP species were not caught in the 2013 DFS tows. These were garfish (*Belone belone*), sea scorpion (*Taurulus bubalis*) and lumpsucker (*Cyclopterus lumpus*). Of these three species, garfish is a pelagic fish. Most likely it was caught during hauling of the gear. The higher amount of garfish in the PAWP DFS+SNS-net is possibly an effect of handling the gear differently as due to safety issues the gear had to be lifted out of the water outside the farm area. This resulted in steaming with the nets in the water after the tow, the moment that garfish were caught.

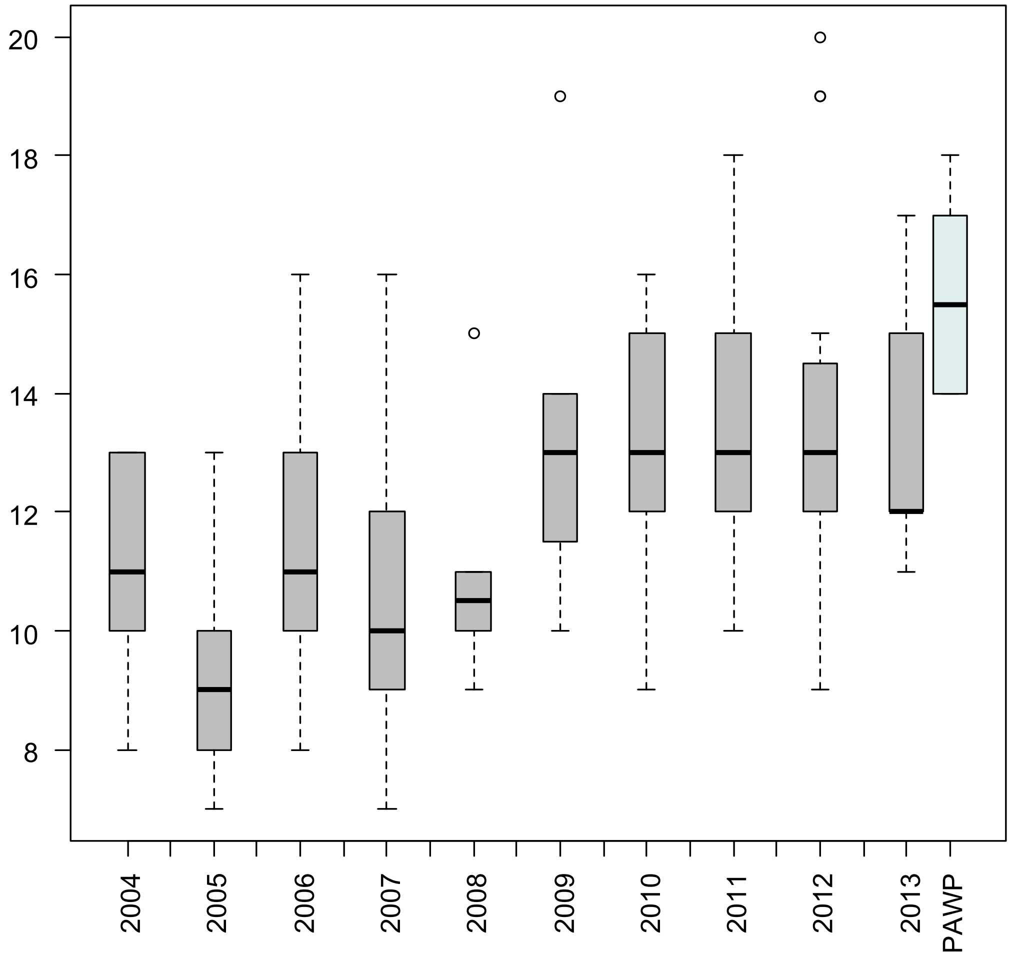

Figure 4-23: Boxplots indicating the distribution of the number of fish species per tow in the DFS by year and the 2013 PAWP-catches in the DFS-net. The black horizontal line is the median. Number of tows by year on which the figure is based is shown in (Table 3-2).

4.4 Comparison on species level

The results of the analysis on the level of target species are combined for the DFS and SNS.

4.4.1 Target species abundance

Comparisons were made between the numbers per hectare found for the target species in PAWP and those in the SNS, SNS-close and DFS.

For the SNS, none of the comparisons by species showed a significant difference between the catches in PAWP and any of the SNS-years (*Figure 4-24*). Using the subset of SNS (only one or two tows a year), there was a significant difference for dab (*Figure 4-25*) indicating that the catches in PAWP were lower than in the two SNS 2011 tows close to the wind farm. The results indicated that dab catches in SNS 2011 were also significantly different to some of the other SNS years.

The DFS data showed a significant difference for plaice in 2006, the catches of plaice in PAWP being lower than those in the DFS. However, 2006 was an odd year for plaice in the DFS as it was also significantly different to some of the other DFS years. The DFS also showed a significant difference for the catches of dab in 2009. Here, 2009 was the odd year for dab, as it differed significantly from some of the other DFS-years as well.

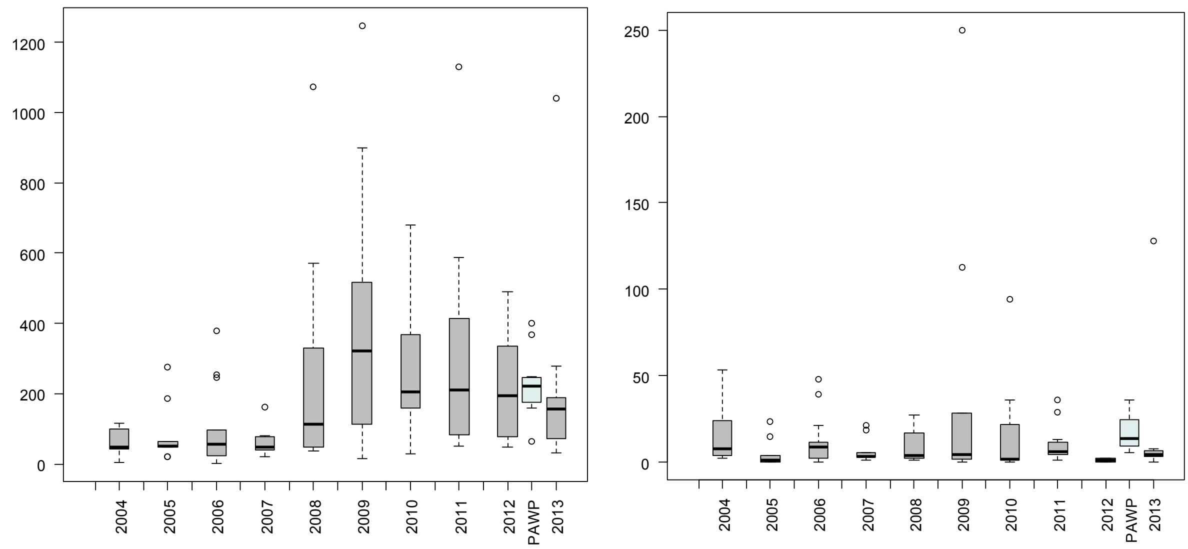

Figure 4-24: Left: Plaice in the SNS, Right: Sole in the SNS. Boxplots indicating the distribution of the number of fish of each species per tow in the SNS by year and the 2013 PAWP-catches. The black horizontal line is the median. Number of tows by year on which the figure is based is shown in Table 3-2.

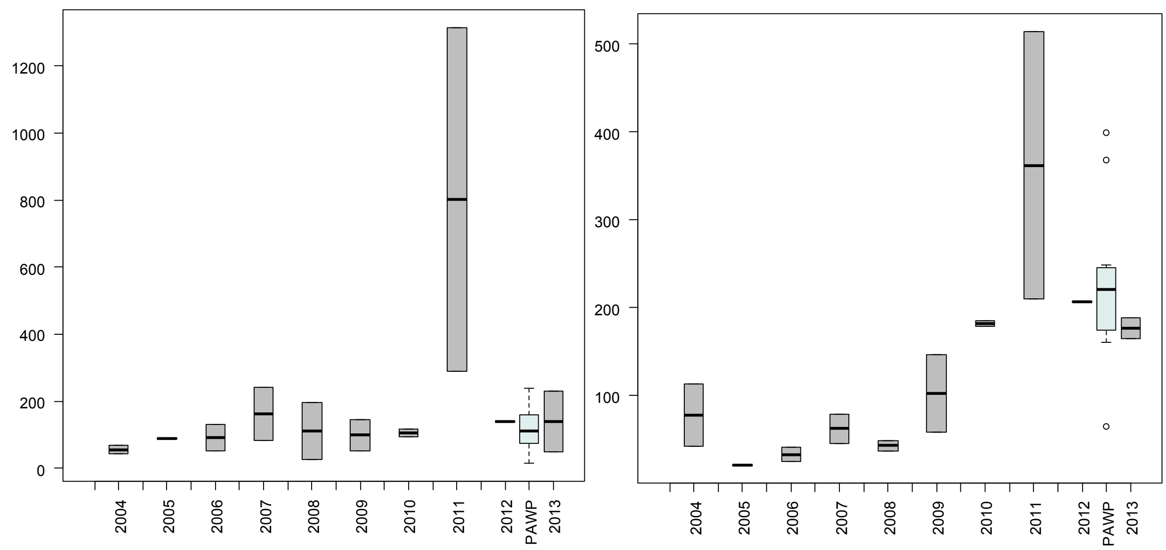

Figure 4-25: Left: Dab in the SNS-close; Right: Plaice in the SNS-close. Boxplots indicating the distribution of the number of fish of each species per tow in the SNS-close by year and the 2013 PAWP-catches. The black horizontal line is the median. Number of tows by year on which the figure is based is shown in Table 3-2.

4.4.2 Target species length

<u>*Solea solea*</u> <u>(Sole)</u>

From the length distributions of sole, it is clear that the DFS-survey caught smaller sole than the SNS or the tows in PAWP (Figure 4-26). The length distribution in PAWP was similar to the SNS-close set. Compared to the total SNS the PAWP samples lacked the smaller lengths, but it had a similar peak around 21 cm. Based on Figure 4-27 it is clear that sole smaller than 16 cm was not caught in PAWP, while the catches of sole large than 16 cm were slightly higher than in the other sets.

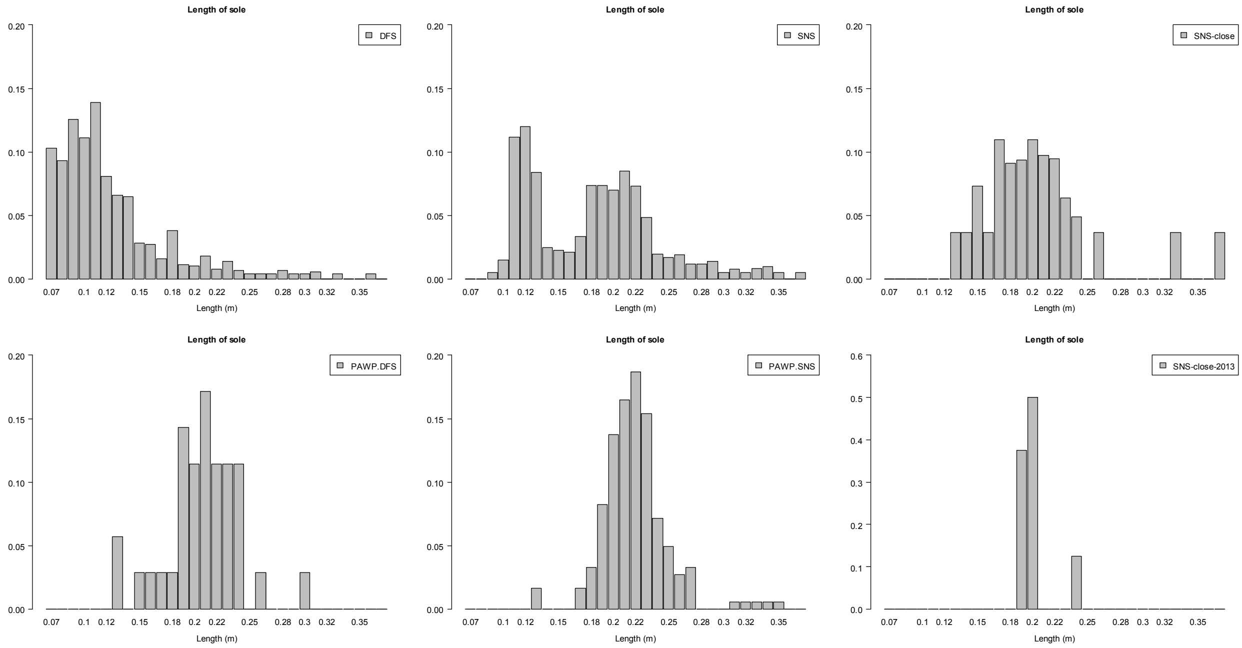

Figure 4-26: Length distributions of sole in the DFS, SNS, SNS-close, PAWP-DFS, PAWP-SNS, and SNS-close 2013. The y-axis pf SNS-close-2013 differs from the other figures.

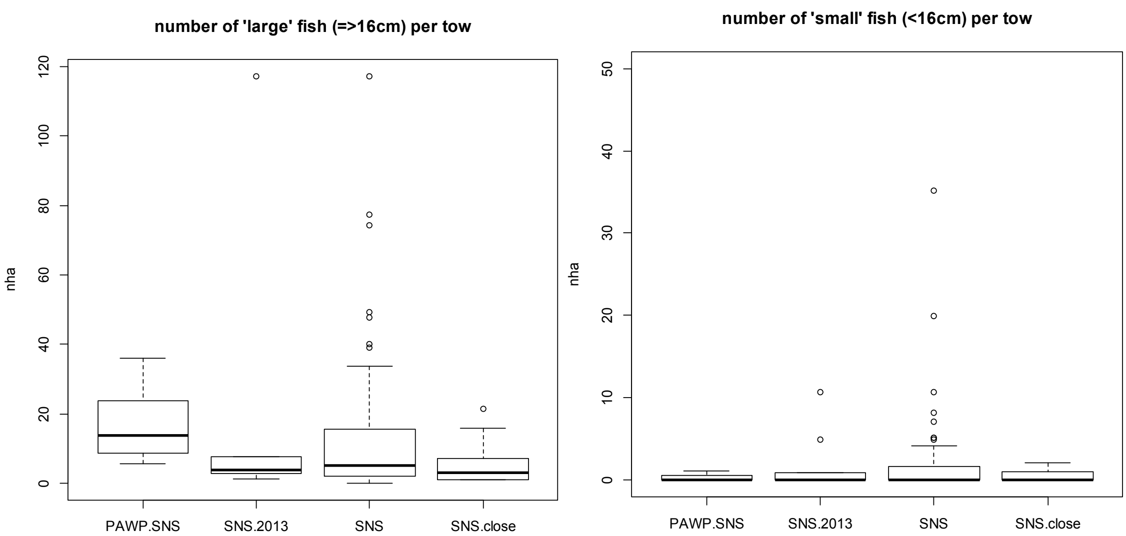

Figure 4-27: Left: large sole (=>16cm) in number per hectare; Right: small sole (<16cm) in number per hectare. The PAWP tows, the SNS in 2013, the total SNS and the SNS-close.

Pleuronectes platessa (Plaice)

The lengths of plaice in PAWP indicated a peak around 14 cm and at a slightly higher length of 20 cm (Figure 4-28). In the DFS and SNS surveys these peaks were at a lower length, most likely due to known differences in spatial distribution of the different lengths of plaice (van Keeken *et al.*, 2007). Smaller plaice occur more onshore. Compared to the SNS-close the first peak length in the PAWP SNS and DFS is similar. The second peak is slightly higher. Comparing the distribution of SNS-close and PAWP-SNS indicated a significant difference (Ds: 0.348 p< 0.01), redoing this using only the two 2013 SNS tows gave a non-significant result (Ds: 0.282, p:0.05), due to the low number of data.

Looking at the number of large (>16cm) plaice that was caught indicates that more of these were caught in PAWP than in the other sets. The number of small plaice is comparable to the other sets (*Figure 4-29*).

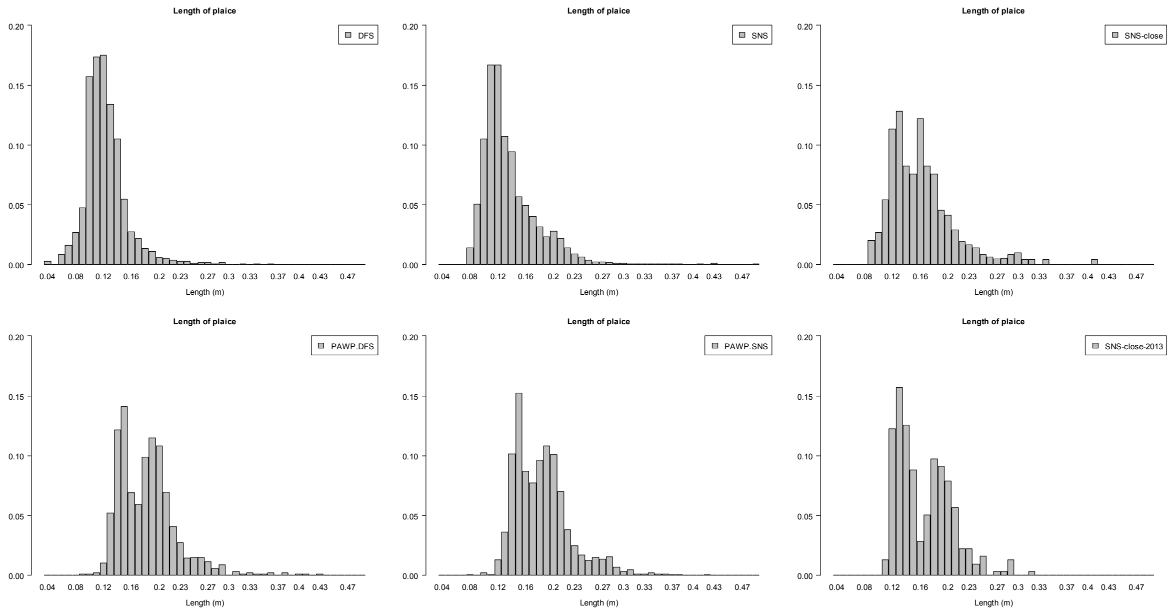

Figure 4-28: Length distributions of plaice in the DFS, SNS, SNS-close, PAWP-DFS, PAWP-SNS, and SNS-close 2013.

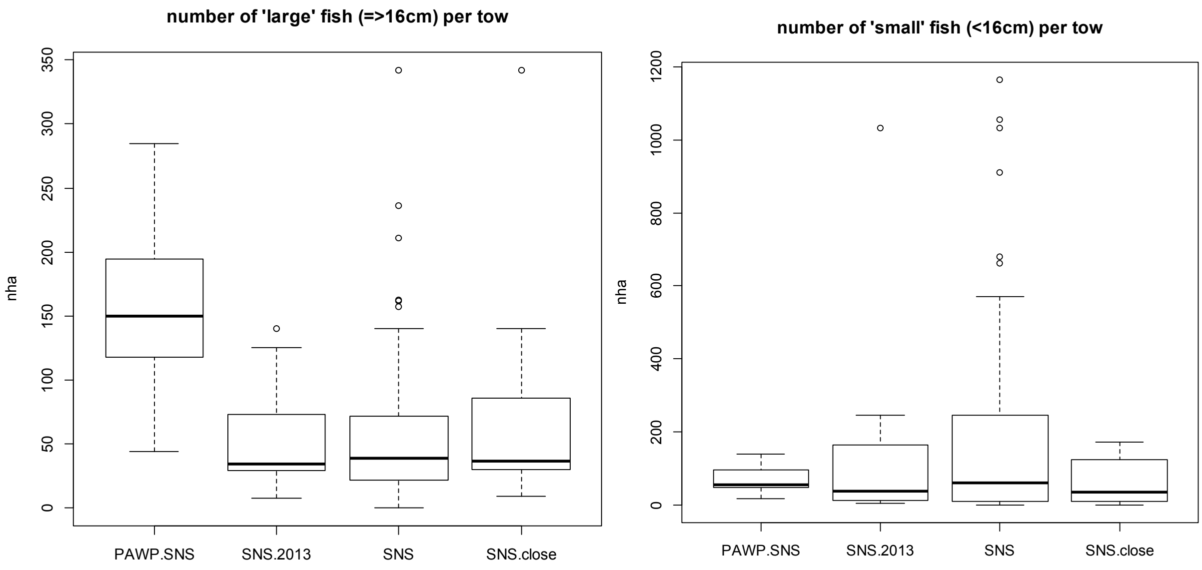

Figure 4-29: Left: large plaice (=>16cm) in number per hectare; Right: small plaice (<16cm) in number per hectare. The PAWP tows, the SNS in 2013, the total SNS and the SNS-close.

Limanda limanda (Dab)

Similar to the results of the other species, the length distribution of the DFS survey shows a higher proportion of small fish compared to the SNS and the PAWP results. The PAWP tows indicated a first peak around 6 cm, while this peak in the SNS-survey is around 8 cm. The lengths of 8-10 cm were not caught in PAWP (*Figure 4-30*). The peak of larger fish is similar around 15-17 cm. Splitting the data around this length in large and small dab shows that only a small number of small dab is caught in PAWP compared to the other sets. While the number of larger dab is slightly higher compared to the other sets.

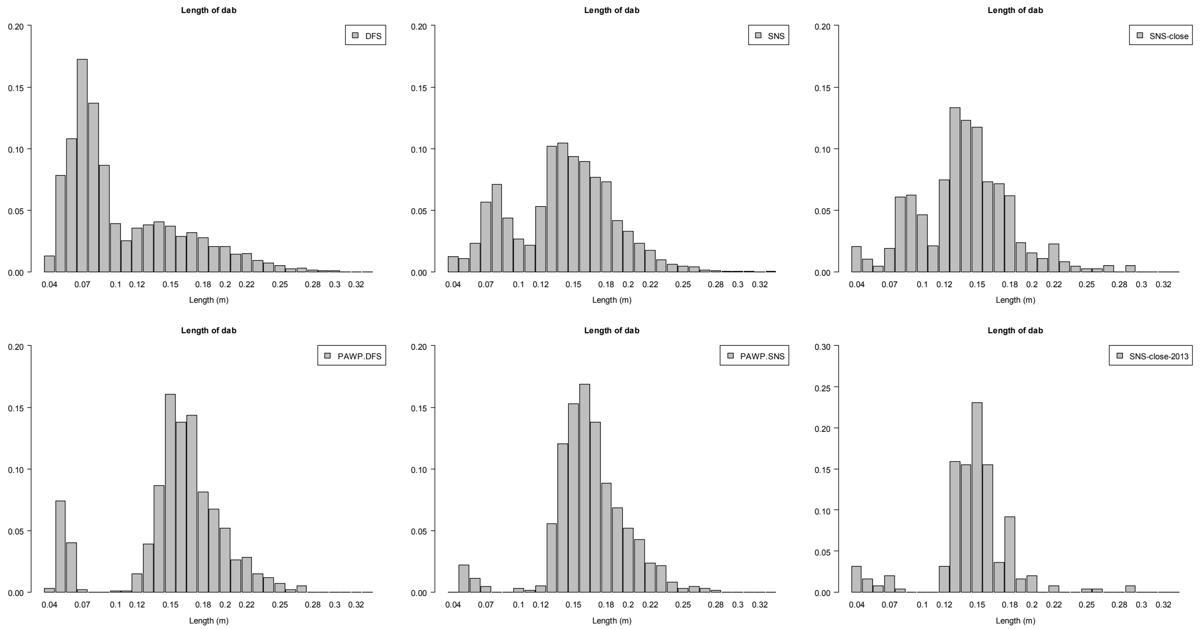

Figure 4-30: Length distributions of dab in the DFS, SNS, SNS-close, PAWP-DFS, PAWP-SNS and SNS-close 2013. The y-axis pf SNS-close-2013 differs from the other figures.

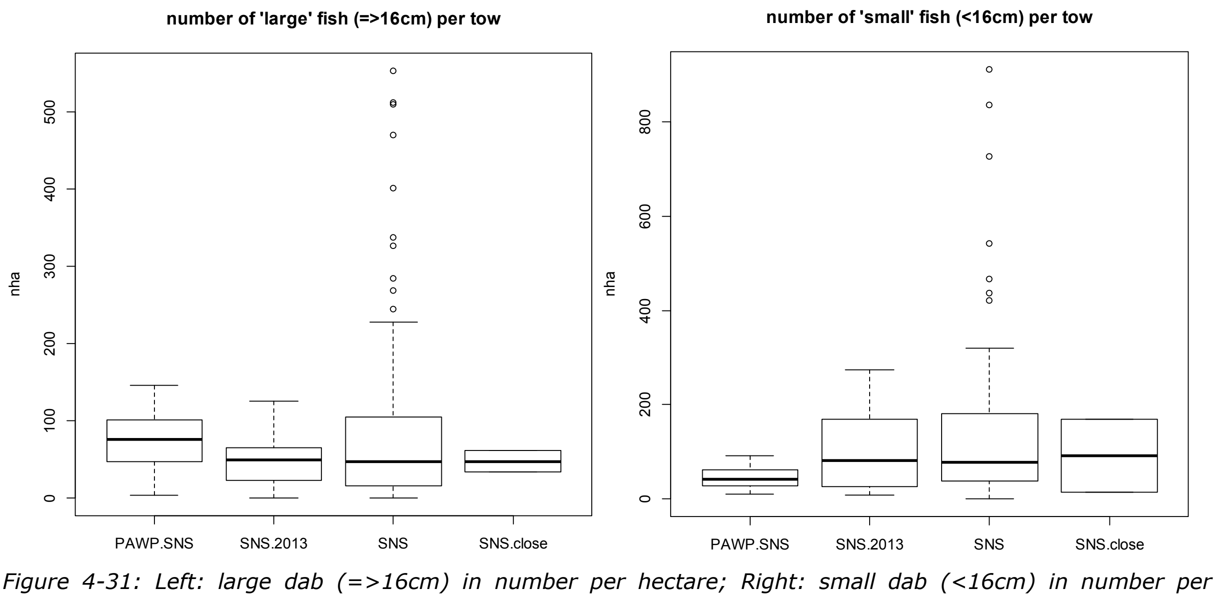

Figure 4-31: Left: large dab (=>16cm) in number per hectare; Right: small dab (<16cm) in number per hectare. The PAWP tows, the SNS in 2013, the total SNS and the SNS-close.

4.4.3 Non-target species abundance

The non-target species looked at were solenette, scaldfish, striped red mullet and greater sandeel. Comparing the catches in the SNS-net in PAWP with those in the regular SNS survey (complete set and subset) showed no significant differences, except for striped red mullet. The other three species showed in all cases that the catches in the PAWP SNS-net were within the range of the catches by year, thus also in comparison with the SNS 2013 catches.
Striped red mullet showed higher catches in PAWP compared to the SNS in earlier years. However, the catches in the SNS in 2013 were in some cases even larger than those in PAWP. It thus seems to be a good year for mullet rather than an effect of PAWP.

Comparing the catches of these non-target species in the DFS-net with the catches in the regular DFS survey showed highly significant differences for solenette, scaldfish (*Figure 4-32*) and again striped red mullet. The catches for solenette and scaldfish in PAWP were much higher than in all the years including 2013. This is most likely related to the more offshore distribution of solenette and scaldfish.

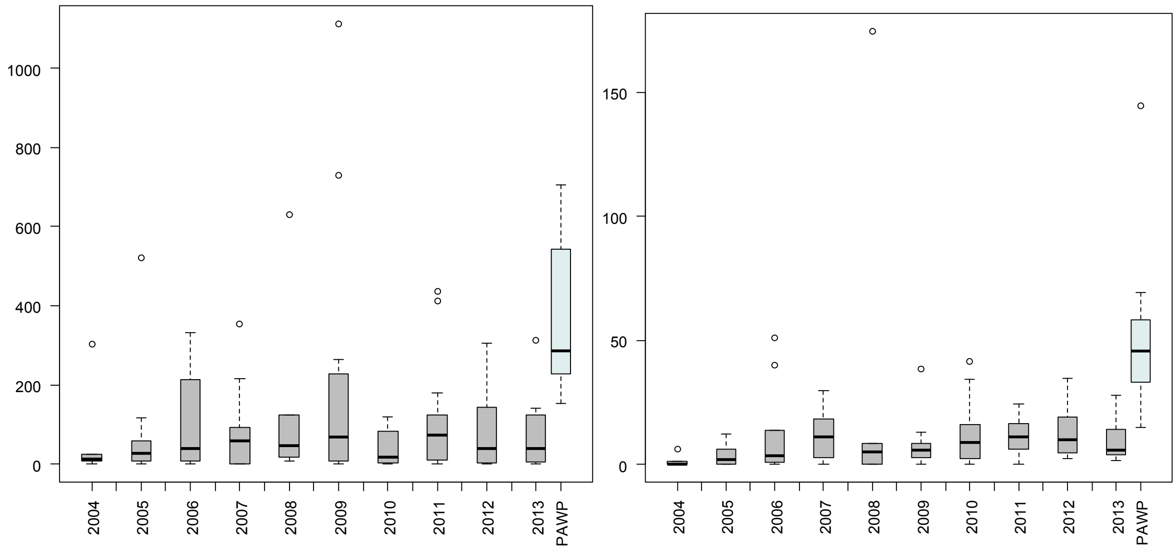

Figure 4-32: Left: Solenette in the DFS; Right: Scaldfish in the DFS. Boxplots indicating the distribution of the number of fish of each species per tow in the SNS-close by year and the 2013 PAWP-catches. The black horizontal line is the median. Number of tows by year on which the figure is based is shown in (Table 3-2).

5 Discussion

5.1 Design of the monitoring programme

Two issues regarding the design of the monitoring programme in relation to the comparison with the two annual statutory task beam trawl surveys are discussed here. The first issue is related to the equipment, the second to the spatial distribution.

The two annual statutory task beam trawl surveys differ in mesh size. The DFS has a mesh size of 20mm and the SNS a mesh size of 40mm. Both mesh sizes are used in PAWP in the same tow, which is different from the statutory surveys which fish with the same mesh size on both sides. In PAWP the DFS net with the small mesh size was attached to the SNS gear which is heavier and differs in rigging. The DFS has not been attached to its own gear, because to fish safety both gears have to have a similar weight. The heavier SNS gear has a deeper penetration than the lighter gear used in the statutory DFS. Furthermore, the SNS fishing speed is higher than the DFS fishing speed. Both aspects complicate a one-to-one comparison of the catches of the DFS-net with those in the DFS-survey. The comparison of the SNS-net with the catches from the SNS-survey can be interpreted more straightforward based on the similarities in protocol and gear design.

The second issue is the location of PAWP in comparison to the regular surveys. PAWP is further offshore than where the statutory DFS survey is performed. The fish community near shore differs from that further offshore, with smaller individuals of a number of species being in the shallower near shore waters, while larger individuals occur in the deeper waters further offshore. An effect of the difference in survey locations was shown by the comparisons in the length distribution of the catch. The statutory DFS survey clearly caught a smaller proportion of large fish compared to the same net in the PAWP area, most likely due to the near-shore distribution of the survey.

The majority of the SNS-survey tows were done closer to shore than where PAWP is located. This spatial aspect was shown in the length distribution of the total set of the statutory SNS. A subset, SNS-close, was created including the tows closest to PAWP. By doing this the number of tows for all years combined is reduced to 18. This leaves only 1 or 2 tows for the comparison by year. This is too limited to make a statistical analysis. Besides that you might even argue the validity of the subset, because a part of these tows (the eastern cloud of tows Figure 3-4) was closer to shore than PAWP.

Because of the effects described above a further discussion of the DFS results is not carried out. The SNS results are discussed. However, these have to be interpreted with care, because it is not a proper comparison as meant in a Before-After-Control-Impact (BACI) study. A BACI requires measurements with the same method before the impact, after the impact and in suitable reference areas. Before measurements and suitable reference areas are not used in the current study. The current results can therefore only be used as an indication for potential effects; no strong conclusions can be drawn from it.

5.2 Overall catches

5.2.1 Catch rates

There was limited variability in the PAWP catches, which is different from some outlying catches that were done in the demersal survey in the wind farm Egmond aan Zee (OWEZ) (van Hal *et al.*, 2012). Limited variability makes it easier to determine a potential effect of the wind farm. However, the catches in PAWP were in line with the total numbers of fish and the total numbers of fish species by tow in the catches of the SNS, and even the DFS survey. The analyses do not indicate any effect of the wind farm on the total catch or the distribution of the number of species.

On the species level all the species caught in the farm were also caught in the surrounding area. The garfish was caught in higher numbers, which is most likely related to the way the gear is handled by the SC-35. Another species that was caught only three times, but justifies a remark is the sea scorpion. This species was only caught once in all the SNS tows and 4 times in all the DFS tows in the selected period. Thus three observations in twelve PAWP tows is relatively high. This species was also caught in OWEZ, specifically on the scour-protection near the monopiles (van Hal *et al.*, 2012). It might thus be a species attracted by the new hard substrate habitat.

5.2.2 Length range

When discussing the effect of the farm on the length of fish there is one more practical aspect to mention. The DFS and SNS surveys have been designed to catch juvenile fish in the coastal zone, so the gear, the duration of a tow and the fishing speed are in line with these goals. To catch larger fish, as was the expectation in this project, this design is not ideal. The low fishing speed enables larger fish to outswim the gear and the relative short duration does not exhaust the larger fish in such way that their capacity to outswim the gear is reduced (Mous *et al.*, 2002). To actually target the larger fish a different design of the monitoring activity would have been preferred. However, that would have further reduced the comparability with regular surveys, and is probably impossible due to the safety regulations.

The analyses between the PAWP-SNS and SNS-close data set show that in PAWP more larger fish were caught compared to nearby stations of the regular SNS survey. This is also the case compared to the SNS-2013 and SNS-close-2013 sets. An effect of the vessel and, related to that, the used fishing methods cannot be excluded. However, an effect of the wind farm might be possible as well. The absence of fisheries and possibly increased food availability might have had a combined effect on the length distribution of the wind farm. In that case the wind farm might acts as a refugium.
For the farm to act as a refugium, the residence time of these fish has to be a significant part of their life cycle. As shown by the tagging experiments (Winter *et al.*, 2010), this was at least not the case for sole. The larger observed lengths in PAWP are thus contrasting the earlier results.

5.3 Target species

5.3.1 Catch rates

Only three target species were caught in reasonable numbers, sole, plaice and dab. The low catches of the other target species, flounder, brill and turbot was expected based on results of DFS and SNS. This is also indicated by the comparison with the survey numbers per hectare.

The catch rates of sole, plaice and dab indicated that the abundances in PAWP were similar to those found outside the farm. Significant effects between PAWP catches and DFS/SNS catches were only related to a single year or between years of the survey. This indicates that the annual variation is

probably larger than any effect of the wind farm. That the annual variation was larger than the farm effect was better shown in the OWEZ analyses over years (van Hal *et al.*, 2012).
Comparable abundances in and outside the farm indicate at least that the area between the monopiles is not avoided by the target species. This had been hypothesised as a potential effect of the farm (Petersen and Malm, 2006, Öhman *et al.*, 2007) due to amongst others electromagnetic fields or sound pollution by the turbines. Neither is the farm cumulating these fish species. The overall impression, similar to the OWEZ results, is that the species are indifferent to the presence of the farm, at least at the spatial scale the data are collected.

5.3.2 Length range

Length analyses on the abundant target species showed that the length range of these species in PAWP was very similar compared to the regular survey data.
Dividing the fish-data in the SNS-net at a length of 16cm in small and large fish indicates that a slightly larger number of large fish per hectare was caught in the wind farm, especially for plaice and sole. The numbers of small fish in the farm were on the low side of the catches in the regular survey.

5.4 Refugium

The hypothesis was that PAWP acts as a refugium because fisheries are excluded from the farm area which might result in larger and older individuals as well as species sensitive to fisheries as they would have a better chance to survive. If the farm functions as a refugium, a large part of the life cycle of the fish should occur within the farm. Only in this way, the fish will be protected from fishing during a significant part of the life of the fish. As a result, the residence time should be a reasonable period of their life-span. This was not shown for the target species by the data collected in tagging experiments in OWEZ. The current findings in PAWP are contrasting the results from OWEZ. The catches of larger fish in the farm compared to the surrounding area are supporting the hypothesis.

The target species in this study are demersal species of commercial interest. These are fished within the quota system, meaning that a maximum amount is allowed to be caught. When the catches are not allowed within the farm area, these catches will occur somewhere else up to the same amount. In case the residence time of the species is short in the farm, as it seemed to be based on the tagging experiments in OWEZ (only sole), there is a reasonable chance that they will be caught outside the farm. Even if they stay within the farm area for a longer period, the same amount of the population will be harvested, resulting in no to limited effect on the population.
A larger residence time and related to that a protective function of the farm can be hypothesised for some of the non-target species, as was done for greater sandeel in the report on roundfish in PAWP (van Hal, 2013). This stationary species was caught in the farm in higher numbers than in the surrounding area in March 2013. This gave the impression of a potential positive effect for this species. The numbers caught in the fieldwork for this study do not support such an effect, as they were similar to those in the SNS and DFS surveys.
Other non-target fish species for which a longer residence time might be hypothesised are those attracted by the introduced hard substrate. These include cod (Winter *et al.*, 2010, van Hal *et al.*, 2012, Reubens *et al.*, 2011a), which was not caught in the current fieldwork done with demersal tows on sandy habitat in the middle of the farm. Sea scorpion, caught in these demersal tows in PAWP, might also be attracted by the introduced hard substrate (van Hal *et al.*, 2012).

A long residence time and with that inhabiting the farm area for a large part of their life cycle is the case for a number of benthic species like the blue mussel, *Spisula* sp. and Ascidians. The data for these species were not collected consistently; however the impression of the IMARES staff in the field was that these species occurred in higher numbers than regularly encountered outside the farm area.

6 Conclusions

The field work was performed according to the programme “Operationeel plan voor het bepalen of het Prinses Amaliawindpark als refugium fungeert voor demersale vis” (Ritzen and Dam, 2011) and followed the IMARES protocols for the statutory task beam trawl surveys SNS and DFS. The gear and speed used in PAWP were the same as in the statutory SNS survey, but differ from the DFS. Therefore the results are best comparable with the SNS.

1) 27 fish species were caught in PAWP. All these species have been caught in the statutory surveys as well.
2) From experience the IMARES fishing crew noted a marked higher number of benthos species like blue mussel, *Spisula* sp. and Ascidians than they normally encounter outside the farm area.
3) Differences in protocol and spatial location between the PAWP tows and the tows of the regular SNS and DFS impeded the comparability of the catches. The following conclusions from comparing PAWP and SNS/DFS are thus indicative only.
4) The 12 PAWP tows provide a limited statistical power, therefore only a large effect of PAWP on the abundance of fish (>40-50% change) could have been detected.
5) No indication of any (positive or negative) effect of the wind farm on the total number of fish per hectare came out within those statistical limitations.
6) The number per hectare of the target species (sole, plaice, dab, turbot, flounder, and brill) in the farm area compared to the regular surveys (SNS and DFS) is not significantly different.
7) Slightly more larger fish were caught in the wind farm than in the statutory SNS survey, including target species plaice, sole and dab. However, the author expects that this is an effect of differences in protocol (different vessel and rigging) rather than an effect by PAWP.

7 Lessons learned

The current study followed the Operationeel plan (Ritzen and Dam, 2011) that meets the Wbr-permit requirements.

Two issues discussed in relation to this study limited the possibility to draw conclusions. The first is the comparability of data from the tows of the PAWP study with the statutory SNS/DFS surveys. The idea was appealing that similar tows in the farm might be compared to those from the surrounding area. However, in practice it is more complicated. A different vessel with a different rigging has an effect that cannot be excluded from the analyses. And the spatial distribution of the tows of the regular survey, especially the DFS, make that a comparison with the tows in PAWP can only be used as an indication for potential effects. No strong conclusions can be drawn from it. This issue requires a survey design that follows an experimental setup, same vessel, same rigging, dedicated reference areas, to exclude these effects. Alternatively a pre-experimental check on the comparability of data from different surveys / methods should be fulfilled.

The second issue is that the number of tows in PAWP was too small to render enough data to cope with the intrinsic variability of fish catches. The absence of designated (reducing abiotic confounding factors) reference areas added to this variability. Due to this, the statistical power of the analyses was limited and only large effects of PAWP could have been detected significantly. A power analysis on demersal catches as part of the T0 of the other wind farm Egmond aan Zee (OWEZ) (Tien *et al.*, 2004) indicated that with the current number of 12 tows only a decrease or increase of about 40-50% in total weight of the catch could had been detected. And that would only have been possible when reference areas comparable (depth, temperature, current, sediment, etc.) with the impact area would had been selected. The author expects that potential effects of the wind farm on fish are smaller than this 50% change. To detect smaller effects using this type of field work a larger number of tows in the wind farm and reference areas is needed. The OWEZ power analyses indicated that at least 100 tows were needed to detect a 20% change. To detect even smaller changes more tows are needed. This amount of tows cannot be located in the small area of the wind farm. And thus it is unrealistic to execute such a program both space, budget and time wise.

Furthermore such a large study could show potential differences between the amount of fish in and outside the farm. It will not provide however more information on the underlying processes. It remains speculative whether the differences, if any, are caused by the presence of the farm. Either by exclusion of fisheries directly, an increase in food quantity or quality, or the introduction of hard substrate or other potential causes.

The intention is to gain knowledge that is relevant for the ecological effects of wind farms. Therefore the underlying processes are required, to understand if these processes could play a role at other locations in different situations as well. To gain this type of knowledge, process oriented studies are required rather than monitoring activities as conducted here. Examples of these types of studies are the tagging and telemetry studies in the wind farm (Winter *et al.*, 2010, Reubens *et al.*, 2011a), visual observations by for example divers (Reubens *et al.*, 2011b) or camera (van Hal *et al.*, 2012, Krone *et al.*, 2013). Where monitoring studies provide information on a large part of the system, in this case a large part of the demersal fish community, process oriented studies are likely to provide only information for a small number of selected species. It will require a large number of these process studies to understand the processes driving the whole community.

8 Acknowledgments

I would like to thank the Ekofish Group for their suggestion to use the vessel SC-35 “Jakob Senior” and their support in facilitating the contact with the vessel. I would like to thank Willem Snoek and the crew of the vessel for their commitment and their support at sea. I also would like to thank Jan Dam and Huygen van Steen (Ecofys) and the RWS-reviewers for their valuable comments.

9 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Report number : C125/14
Project number : 4302505701

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

Approved: Ing. I.J. de Boois

Signature:

Date: 1 October 2014

Approved: Drs. J.H.M. Schobben
Head of department Fish

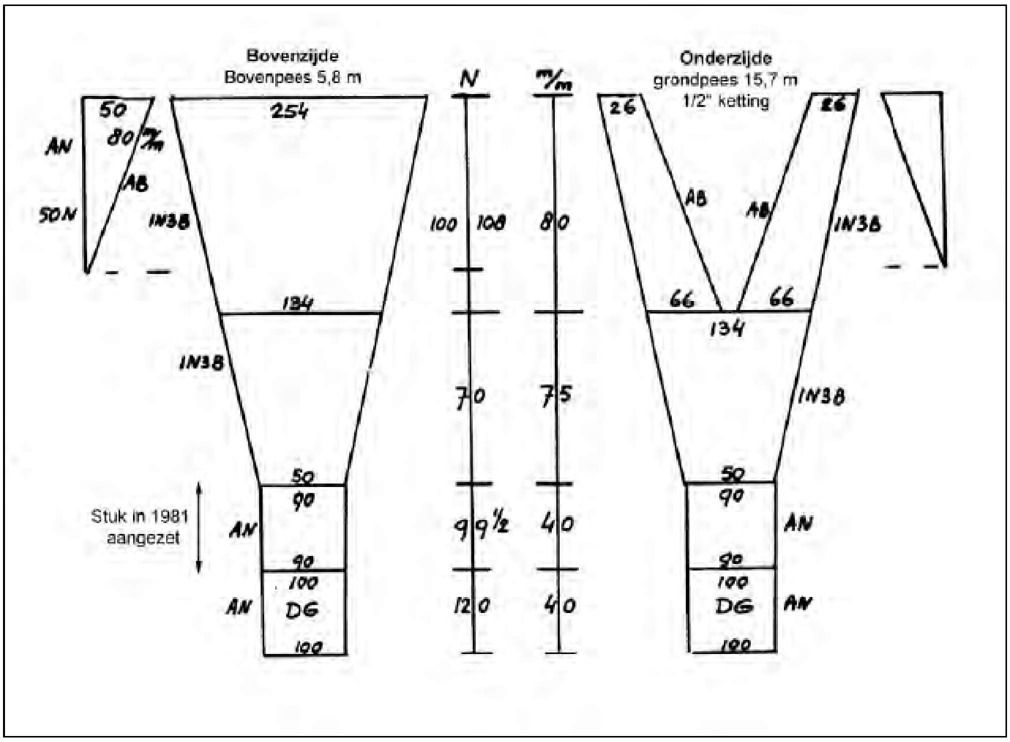
Signature:

Date: 1 October 2014

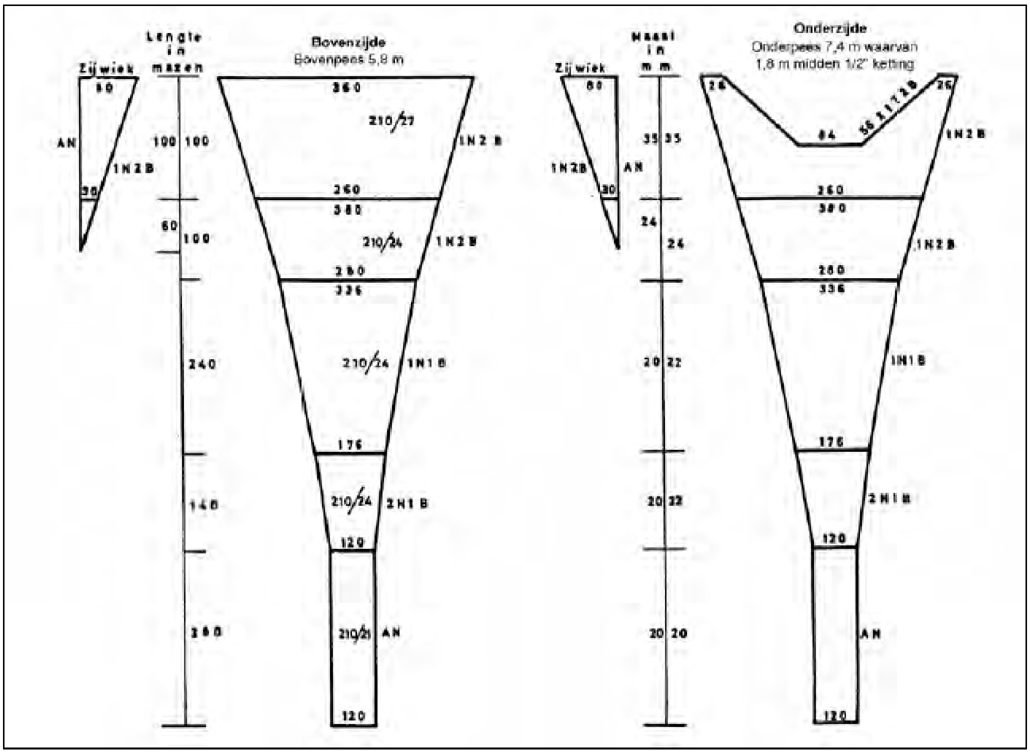
Appendix A. Construction of the SNS gear

Overview of nets used in SNS and DFS (from: Manual for the Inshore Beam Trawl Surveys, in prep.)

	SNS	DFS
Ship	Isis	Isis
ship size (m)	28m	±28m
Date started	1969	1970
Sampling Period	Sept/Oct	Sept/Oct
Usual Start date	12 Sept	26 Sept
Number of days per period	8–9 within 2 weeks	16 within 5 weeks
Beam trawl type	6m beam trawl	6m shrimp trawl
Tickler Chains	4	1
Mesh size net	80mm	35mm
Mesh size codend (stretched)	40mm	20mm
Speed fished	3.5–4knots	3knots
Time Fished	15min	15min
Approx. number of stations per year	55	100
Station positions	Fixed	Fixed
Target species	0– 4 group sole and plaice	0–1 group sole and plaice
Fish LF distribution	All	All

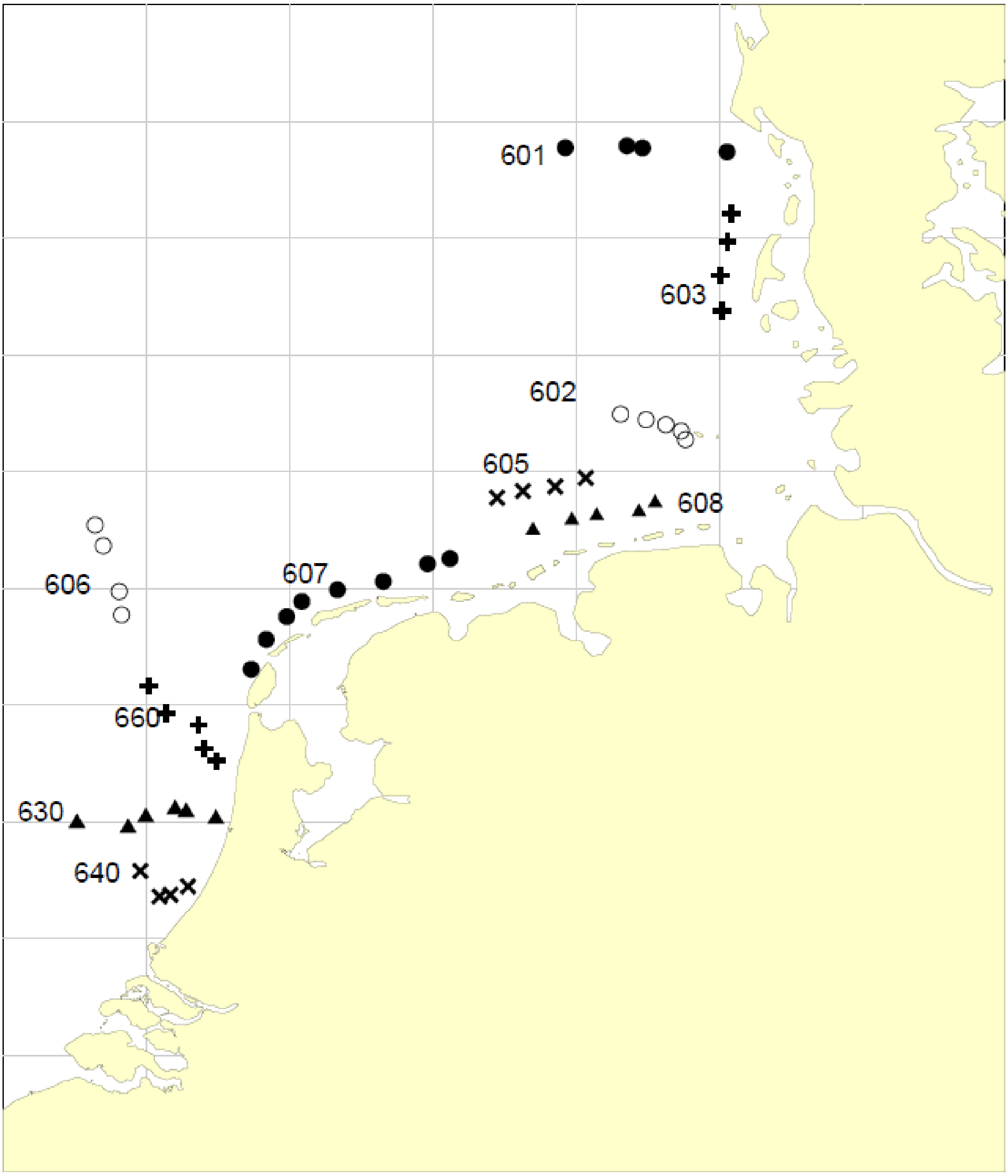


Net construction of the SNS-net

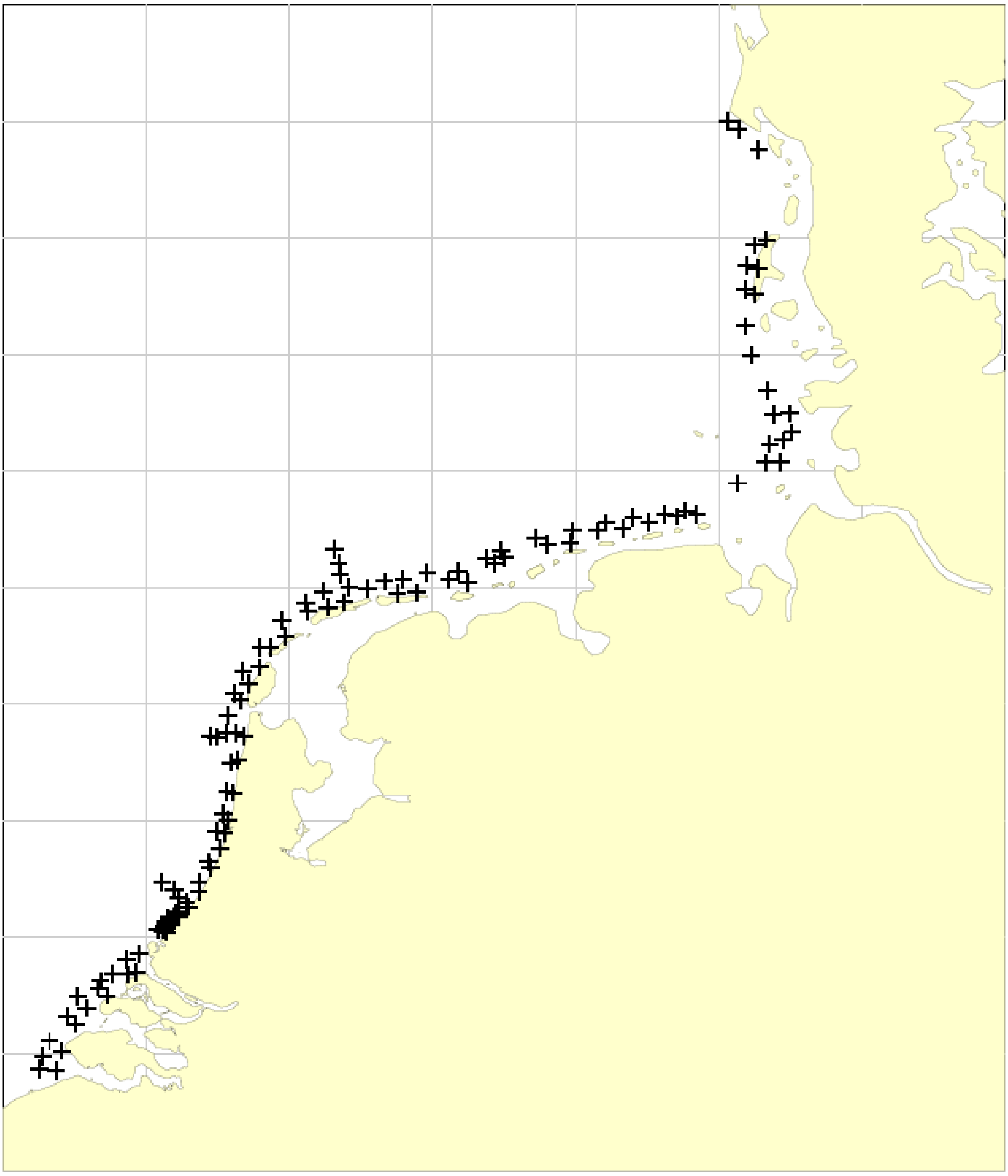


Net construction of the DFS-net

Trawl positions of the SNS (2012)



Trawl positions DFS (2012)



Appendix B. Planned tow positions in PAWP

ID	ID_start_end	X_UTM31N_WGS84	Y_UTM31N_WGS84	X_LL_WGS84	Y_LL_WGS84
DV01	DV01 start	583509	5826052	4.2323940	52.5780940
DV01	DV01 end	581927	5825895	4.2090120	52.5769230
DV02	DV02 start	580385	5826556	4.1864300	52.5830970
DV02	DV02 end	582071	5825780	4.2111180	52.5758680
DV03	DV03 start	583421	5826612	4.2312460	52.5831430
DV03	DV03 end	581971	5826470	4.2098170	52.5820850
DV04	DV04 start	580271	5827889	4.1850630	52.5950890
DV04	DV04 end	581776	5827046	4.2070750	52.5872960
DV05	DV05 start	581364	5827901	4.2012030	52.5950400
DV05	DV05 end	582984	5826995	4.2248880	52.5866510
DV06	DV06 start	581369	5829144	4.2015890	52.6062120
DV06	DV06 end	582850	5828316	4.2232460	52.5985450
DV07	DV07 start	583729	5828567	4.2362760	52.6006630
DV07	DV07 end	582336	5828653	4.2157420	52.6016520
DV08	DV08 start	583797	5828756	4.2373290	52.6023560
DV08	DV08 end	583730	5827111	4.2359330	52.5875810
DV09	DV09 start	584274	5828990	4.2444310	52.6043870
DV09	DV09 end	584207	5827346	4.2430330	52.5896130
DV10	DV10 start	580316	5827241	4.1855720	52.5892660
DV10	DV10 end	581961	5826375	4.2096380	52.5812300
DV11	DV11 start	581294	5828604	4.2003520	52.6013650
DV11	DV11 end	582898	5827650	4.2237790	52.5925480
DV12	DV12 start	584381	5826219	4.2453040	52.5794560
DV12	DV12 end	583175	5825395	4.2273090	52.5722360

Appendix C. Fish species caught in PAWP

Fish species in numbers caught by tow location, thus the sum of both nets.

Dutch name	English name	scientific_name	DV01	DV02	DV03	DV04	DV05	DV06	DV07	DV08	DV09	DV10	DV11	DV12	Grand Total
Dwergtong	**Solenette**	Buglossidium luteum	516	672	620	648	264	324	292	260	200	145	324	324	4589
Schol	**Plaice**	Pleuronectes platessa	272	314	333	421	504	306	219	218	308	328	91	257	3571
Schar	**Dab**	Limanda limanda	232	341	276	209	66	274	185	111	167	165	142	94	2262
Schurftvis	**Scaldfish**	Arnoglossus laterna	96	156	140	220	188	148	120	92	76	103	72	114	1525
Grondel	**Goby**	Pomatoschistus	17	54	85	151	75	150	38	95	8	60	19	90	842
Pitvis	**Common dragonet**	Callionymus lyra	47	147	72	44	22	71	32	19	18	27	29	19	547
Mul	**Striped red mullet**	Mullus surmuletus	25	11	25	16	32	20	24	20	8	24	11	16	232
Tong	**Sole**	Solea vulgaris	11	37	13	18	18	27	25	7	12	30	6	13	217
Zeedonderpad	**Bull rout**	Myoxocephalus scorpius	6	3	9	4	8	11	4	7	8	7	1	4	72
Harnasmannetje	**Hooknose**	Agonus cataphractus	2	3	13	4	5	4	3	2	4	1	2	6	49
Horsmakreel	**Horsmackerel**	Trachurus trachurus	3	7	9	1		16	3		3	3	2	2	49
Smelt	**Greater sandeel**	Hyperoplus lanceolatus	8	4	8	4	2		2	2	1	7	5	1	44
Grauwe poon	**Grey gurnard**	Eutrigla gurnardus	5	3	1	4	10	4	2	2	6	2	1	3	43
Wijting	**Whiting**	Merlangius merlangus	16	5	6		1	2	1	3	2	6			42
Rode poon	**Tub gurnard**	Trigla lucerna	4	6	2	4	3	3	1	3	5	4	1	1	37
Kleine pieterman	**Lesser weever**	Echiichthys vipera		1		3	5	2	2	1	4	8	4	3	33
Ammodytes	**Sandeel**	Ammodytes	1					1	5				1		8
Geep	**Garfish**	Belone belone	1		1		1		1		2		1		7
Tarbot	**Turbot**	Psetta maxima		1		1		1			1		1		5
Bot	**Flounder**	Platichthys flesus		1				1				1	1	1	5
Tongschar	**Lemon sole**	Microstomus kitt	1		2					1					4
Groene zeedonderpad	**Sea scorpion**	Taurulus bubalis	1						1			1			3
Snotolf	**Lumpsucker**	Cyclopterus lumpus	1								2				3
Griet	**Brill**	Scophthalmus rhombus			1						1				2
Rasterpitvis	**Reticulated dragonet**	Callionymus reticulatus			1		1								2
Haring	**Hering**	Clupea harengus		1											1
Kleine zeenaald	**Lesser pipefish**	Syngnathus rostellatus							1						1

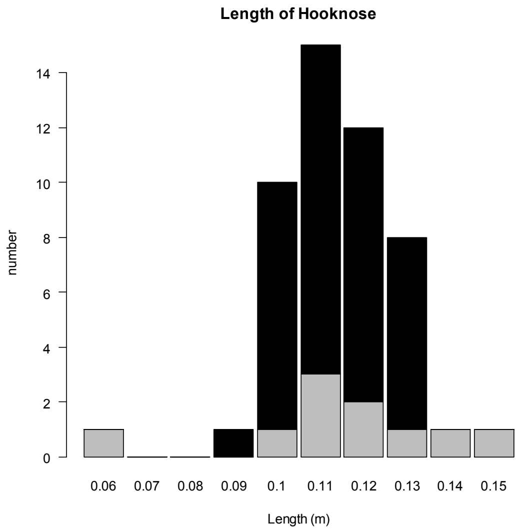
Appendix D. Benthic species caught in PAWP

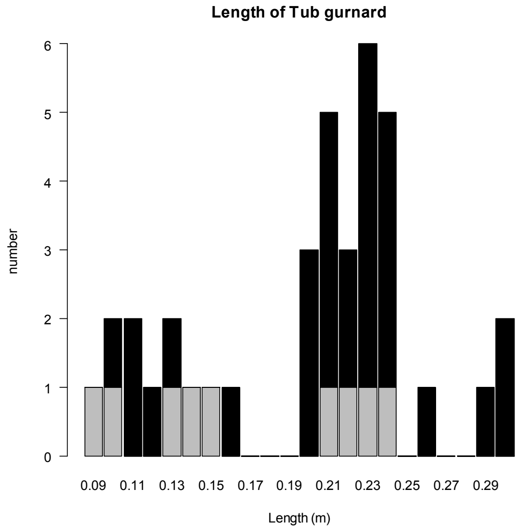
Species in numbers caught by location, thus the sum of both nets. Most of these species were registered only on the first 4 locations (DV01,DV02,DV10 and DV12). Except for *Cancer pagurus*, *Loligo* sp. and *Alloteuthis subulata*.

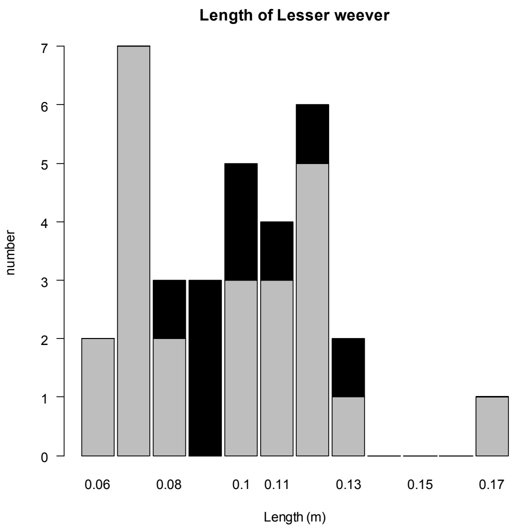
soort	scientific_name	DV01	DV02	DV03	DV04	DV05	DV06	DV07	DV08	DV09	DV10	DV11	DV12	Grand Total
Slangster	Ophiura ophiura	5632	6016								3968		5632	21248
Gewone zwemkrab	Liocarcinus holsatus	204	464								228		172	1068
Mossel	Mytilus edulis	47	60								24		900	1031
Zeester	Asterias rubens	152	516								256		92	1016
P. bernhardus	Pagurus bernhardus	208	32								104		200	544
Ovale strandschelp	Spisula elliptica										3		337	340
Zaagje	Donax vittatus												260	260
Halfgeknotte strandschelp	Spisula subtruncata	4	176								6		16	202
Venusschelp	Chamelea gallina	8	8								1		69	86
Stevige strandschelp	Spisula solida	1	72										5	78
Zeeanemonen	Anthozoa	8	48											56
Spisula	Spisula	12												12
Noordzeekrab	Cancer pagurus	1		1				2	2	1		1	2	10
Loligo	Loligo				1					1	4			6
Zakpijp	Ascidiacea												4	4
Fluwelen zwemkrab	Necora puber	2											1	3
Sepiola	Sepiola	2												2
Dwergpijlinktvis	Alloteuthis subulata				1									1
Hooiwagenkrab	Macropodia rostrata										1			1

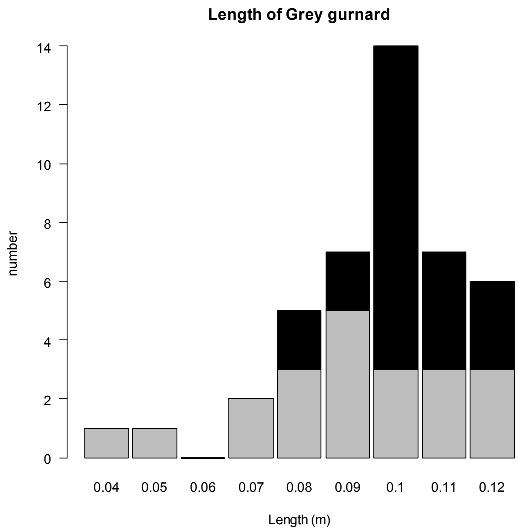
Appendix E. Length of non-target species

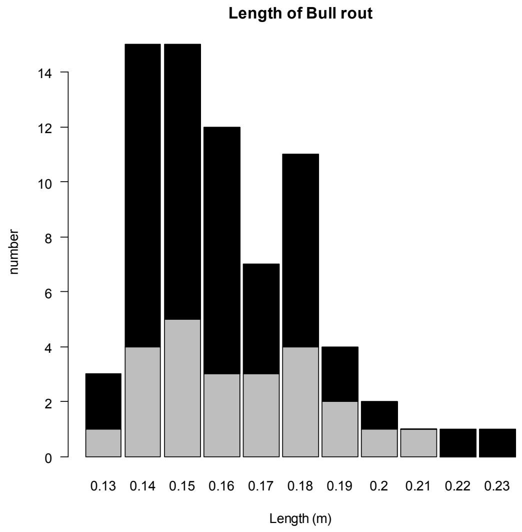
The length distribution of a number of non-target species by net-type. Hooknose, Horse mackerel, lesser weever, grey gurnard, common dragonet, bullrout, whiting and tub gurnard. Grey is the DFS-net and black the SNS-net.

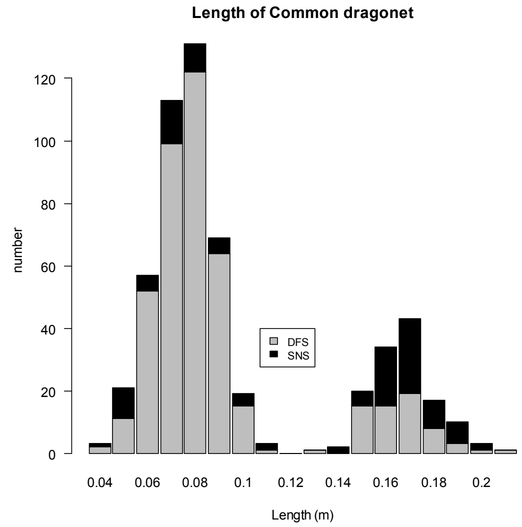


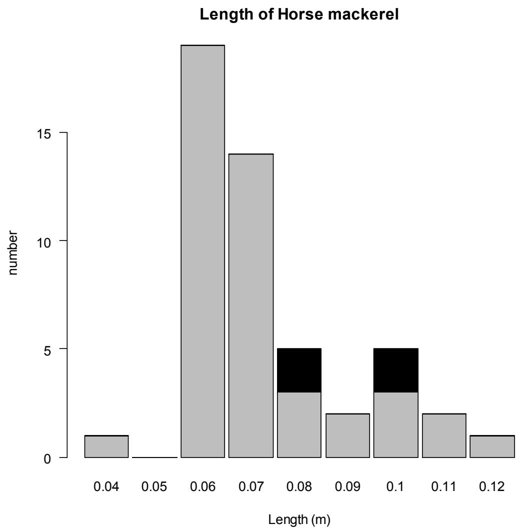


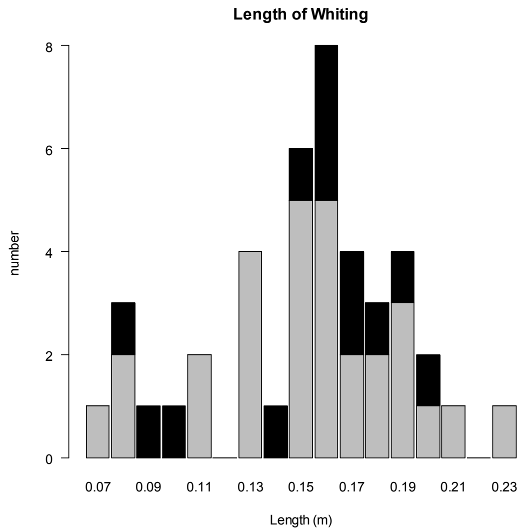





Length of Bull rout
number
Length (m)
0.13 0.14 0.15 0.16 0.17 0.18 0.19 0.2 0.21 0.22 0.23
0 2 4 6 8 10 12 14


Length of Common dragonet
DFS
SNS
number
Length (m)
0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
0 20 40 60 80 100 120


Length of Horse mackerel
number
Length (m)
0.04 0.05 0.06 0.07 0.08 0.09 0.1 0.11 0.12
0 5 10 15


Length of Whiting
number
Length (m)
0.07 0.09 0.11 0.13 0.15 0.17 0.19 0.21 0.23
0 2 4 6 8