Electromagnetic Fields benthic fish

Impact of the export cable of Net op Zee Borssele.

Author(s): Ralf van Hal, Joey Volwater, Sophie Neitzel

Wageningen University &
Research report C013/22

Electromagnetic Fields benthic fish

Impact of the export cable of Net op Zee Borssele.

Authors: Ralf van Hal, Joey Volwater, Sophie Neitzel

Wageningen Marine Research
Ijmuiden, January 2022

Wageningen Marine Research report C013/22

Keywords: Electromagnetic field, demersal fish, wind farm, OWF

Client: Witteveen + Bos Raadgevende ingenieurs B.V.
Attn.: mevrouw A. Hermans
Postbus 233
7400 AE, Deventer

This report can be downloaded for free from https://doi.org/10.18174/566390
Wageningen Marine Research provides no printed copies of reports

Wageningen Marine Research is ISO 9001:2015 certified.

Photo cover: Joey Volwater

© Wageningen Marine Research

Wageningen Marine Research, an institute within the legal entity Stichting Wageningen Research (a foundation under Dutch private law) represented by
Drs.ir. M.T. van Manen, Director Operations

Wageningen Marine Research accepts no liability for consequential damage, nor for damage resulting from applications of the results of work or other data obtained from Wageningen Marine Research. Client indemnifies Wageningen Marine Research from claims of third parties in connection with this application.
All rights reserved. No part of this publication may be reproduced and / or published, photocopied or used in any other way without the written permission of the publisher or author.

KvK nr. 09098104,
WMR BTW nr. NL 8113.83.696.B16.
Code BIC/SWIFT address: RABONL2U
IBAN code: NL 73 RABO 0373599285

A_4_3_2 V32 (2021)

Contents

Summary

This study is done as part of the permit requirements for TenneT to investigate whether and to what extent there are effects of electromagnetic fields on marine mammals and fish. In this study we assess if there are possible indications that EMFs around the cables of offshore windfarms influence the behaviour and presences of several commercial benthic fish species. In addition, it is also analyzed if there are indications of influence on the behaviour and presence of elasmobranchs and several commercial round fish species. Estimations of fish abundance are based on the catch of a beam trawl fished over the cable route and are compared to adjacent reference sites with no cables, parallel to the cable route, of the Borssele wind area. In order to ensure the catches came from the cable route being within the EMF, the beam trawls were equipped with EMF-sensors that were tested beforehand. Results of this study indicate that there was no significant difference between the catches of the target flatfish species in the vicinity of the cable and in the reference areas. For some of the assessed non-target species, it was shown that there is a difference between the cable route and the reference, specifically for dragonet and whiting. In these cases, the species showed higher abundance on the cable than in the reference area, suggesting some attraction by the cable. It remains however difficult to disentangle the impact of the EMF from other (indirect) factors.
In conclusion, the results show that under the current circumstances there is no basis for any negative impact of the cable on the abundance of the species found. Furthermore, there is no solid indication of impact of the EMF at all, which is in line with recent literature where little effect on fish behaviour in relation to EMF is found and that there is no significant effect to be expected.

1 Introduction

In the Netherlands, TenneT started in 2018 – after being designated as grid operator at sea in the Electricity Act in 2016 – the roll-out of the electricity network in the North Sea, or *Net op Zee* (NoZ). This was done to connect future wind farms in accordance with the roadmap established by the government (see letter to parliament Roadmap for offshore wind energy, reference DGETM-E2020 / 17177527). The first project within the NoZ is the connection of wind farm Borssele with the land station in the town of Borssele. The routes of the export cables of the NoZ-Borssele cross three Natura-2000 areas, namely Westerschelde & Saeftinghe, Vlakte van de Raan and Voordelta. Activities within these areas require a permit under the Nature Conservation Act (Wnb). One of the permit requirements was that a monitoring and evaluation plan (MEP) of the effects of electromagnetic fields (EMF) on marine ecology had to be developed. This plan should investigate whether and to what extent there are effects of electromagnetic fields on marine mammals and fish. Similar permit requirements were included in the Wnb permits of NoZ-Hollandse Kust (south) and NoZ-Hollandse Kust (north).

Two main components of an EMF from a subsea cable are the electric (E) and magnetic (B or H) fields (Gill et al. 2012). EMF is generated by the current passing through the cable. The size and characteristics of the field around the cable is determined, amongst other things, by the current strength and whether it involves direct current (DC) or alternating current (AC).
The natural geomagnetic field is a direct magnetic flux density with a frequency of ~0 Hz and a strength of ~ 48μT (Snoek et al. 2016)- 51.6 μT (Snyder et al. 2019). Naturally also AC fields are produced mainly by organisms (heartbeat, gill movement), these occur at frequencies less than 10 Hz with strengths up to 500 mV/m, but these reduce quickly within 10-20cm of the source (Snyder et al. 2019).
Underwater cables produce EMF that differ from the naturally occurring fields. The frequency of the AC fields of the cable are 50-60 HZ and the strength differs with their construction and the amount of current that goes through the cables. In case of Borssele the cable is an AC cable, which creates EMF with frequencies around 50 Hz and at high winds strengths of 5-6 μT were measured at 1 m of the cable near the land station (Snoek pers. comm). There are concerns about the potential impact of these cables on marine mammals and fish. These concerns not only come from nature conservation, but also from the fisheries sector that worry about the potential impact of the cables on the commercial fish populations and catches.

The concerns in relation to fish vary between species. Elasmobranchs and other species with ampullae of Lorenzini (sturgeon and catfish) use EMFs for the detection of predators and preys, for communication and for finding mates (Hutchison et al. 2020). For example, in a laboratory study it was shown that lesser spotted dogfish (*Scyliorhinus canicula*) can differentiate between types of electric fields, and might target specific types of species based on the strength or type (AC or DC) of the EMF (Kimber et al. 2011). A higher number of dogfish were found in EMF zones of an AC cable and moved less, suggesting foraging behaviour (Gill et al. 2009). Longnose skates (*Raja rhina*) were more abundant at locations where an undersea cable in Monterey Bay, California was exposed indicating a response to the EMF (Barry et al. 2008).
Other species of fish use, or are expected to use, geomagnetic fields for their long-distance migrations. Well-known examples are salmon (*Salmo sp.*) (Putman et al. 2013), and eel (*Anguilla anguilla*) (Gill et al. 2012), but potentially also plaice (*Pleuronectes platessa*) (Metcalfe et al. 1993). Eels that encountered an AC cable on their outward migration in the Baltic Sea slowed down but passed over the cable (Westerberg and Lagenfelt 2008). The migration success of Chinook salmon (*Oncorhynchus tshawytscha*) in California was found to be largely unchanged, despite some observed changes in the migration behaviour (Wyman et al. 2018; Gill and Desender 2020). Overall the results of the various studies gave mixed results (Gill and Desender 2020).

A study on the impact of the high voltage power cable of the Danish Nysted Offshore Wind Farm (buried 1 metre deep, AC) was focussed on studying the migration of eels (Hvidt et al. 2006), but also five other species were assessed. No effect was observed for eelpout (*Zoarces viviparus*) and shortspined sea scorpion (*Myoxocephalus scorpius*), while an effect was observed for eel, cod (*Gadus morhua*) and herring (*Clupea harengus*). These effects however could not be attributed to the EMF. These effects were more likely visual aspects of the cable route or in the case of cod attraction owing to additional food on the cable route. The only species for which they found a significant effect was flounder (*Platichthys flesus*), that crossed a cable more often at a small versus a large electromagnetic field (EMF). Another study exposed flounder in the lab for seven weeks to a 3.7 mT field (DC voltage) without impact on the mortality (Bochert and Zettler 2004).

The cables of the existing Dutch Wind farms were observed with underwater cameras in 2019. Various benthic organisms and some fish species were observed. No firm conclusions could be drawn from these observations (Snoek et al. 2020). Also the conclusions of the literature review done as part of the same study (Snoek et al. 2016; Snoek et al. 2020) were limited as experimental studies of EMF impact are scarce and often not directed at changes at population scale. Therefore, it is problematic to evaluate ecologically significant changes and to determine true impact (Taormina et al. 2018; Hutchison et al. 2018). Another extensive review concluded that: "based on the knowledge to date, biological or ecological impacts associated with subsea power cables may be weak or moderate at the scale that is currently being considered or planned" (Gill and Desender 2020). They however also state that it is important to acknowledge that the conclusion is based on a handful of studies and that data about impacts are scarce, so significant uncertainties concerning electromagnetic effects remain.

To add information in filling this knowledge gap, a first attempt to estimate the abundancies of demersal fish on the cable route compared to adjacent reference sites with no cables of the Borssele wind area is made in this study. The focus is on the commercial demersal (flat)fish, related to the worries of the fishing industry. The abundances are based on the catch of a beam trawl fished over the cable route. Then these abundances are compared to reference trawls parallel to the cable route. In order to ensure the catches came from the cable route being within the EMF, the beam trawls were equipped with sensors that measure the magnetic field generated by the electricity going through the cable (WaterProof), named EMF-sensors. Here, the results and analyses of this study are presented to show the practical possibilities and a first impression of the results.

2 Assignment

2.1 Research questions

The research question was:

- Are there indications that EMFs around the cables of offshore windfarms influence the behaviour and presences of the commercial benthic fish species sole (*Solea solea*), plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*)?

This question is extended with the request to also analyze if there are indications of influence on the behaviour and presence of elasmobranchs and commercial round fish species such as cod *(Gadus morhua*) and whiting (*Merlangius merlangus*).

2.2 Survey design

A part of the assignment was to design a method to determine the abundance of demersal fish on the cable.

- Develop a method to fish on the cable route and determine that the fishing gear is located on the route.
- Design a sampling protocol with which in a period of maximum four days a reasonable number of samples can be collected that enable statistical analyses of the differences in abundance on the cable and in reference areas.

3 Materials and Methods

3.1 Fishing on the cable

Various fishing techniques are used commercially and for scientific monitoring. In the research area the dominant gear is the beam trawl. This gear is also used in the regular survey along the Dutch coast (Demersal Fish Survey, DFS). Thus, fishing with this gear in a scientific design is done regularly, even in an impact and reference design.
The challenge in this case was to set the gear on the cable route and fish along the route of only a couple of meters wide. The position of the vessel compared to the expected location of the route can be determined, but the location of the gear on a long warp (about three to four times the water depth) set from a boom extending on both sides of the vessel is harder to determine. This is further complicated as the location of the cable is in an area with relatively strong tidal currents, and sampling is preferred with reasonable wind conditions (the amount of energy produced by the wind farm, preferably between 3-5bft) that affect currents and waves impacting the navigational possibilities of the vessel.

Geolocation equipment attached to the gear would not work on the seafloor, and when extending an antenna from the gear to the surface would neither be reliable as the line from the gear to the surface is impacted by the currents as well. Using the angle of the warp in relation to the vessel required a complicated setup to continuously register that and would require a more precisely geolocation of the vessel. Cameras on the gear to visually determine the route were not expected to be helpful as the cable is buried and the route most likely has merged into the environment.

As a final design it was decided to equip both beam trawls with an autonomous EMF-sensor (measuring the magnetic field generated by the electricity going through the cable) developed by WaterProof (Snoek 2021). The sensors were attached to the middle of the beam, this means they are about ~0.5 m above the seafloor (Figure 3-1). The EMF-sensor consist of tri-axial sensors, which ensures that the orientation of the sensor is not relevant in order to measure the total strength of the magnetic field above the cable. The sensors were continuously logging with a sampling frequency of 2071Hz, which enables frequency analyses up to approximately 1000Hz. The sensors were switched on and off at the beginning and end of each day. There was no possibility to get live information of the sensors to use for navigation. Thus, only after the field work it was possible to determine if specific trawls were done on or near the cable within the detection range of the EMF.

Figure 3-1 **The EMF-sensor located in the middle of the beam trawl (see green circle).** Photo: Sophie Neitzel.

3.2 Vessel and equipment

Fishing was done from the Euro cutter OD-3 “Adrianne” and with two commercially used beam trawls of the vessel. Beam trawls of 4.5m width were used equipped with a conventional beam trawl net and tickler chains. In this study cod-ends with a 40mm mesh size were used on both port and starboard side.
The decision to fish had to be made a week in advance based on the availability of the vessel and the weather conditions. Based on the weather forecast it was decided to perform the field work in the week of 6-10 September. The Monday was used as a test day for the EMF-sensors, where fishing was performed crossing the cable to test if the sensors were able to detect the presence of the cable. The results of these tests were positive.

3.3 Survey design

The goal of the survey design was to sample a reasonable amount of positions on the cable and in reference locations in the period of maximum four days in August-September 2021. More specific the fishing had to take place on the beta-cable, e.g., the most northern of the two cables following a similar route from the land station to the wind area. Thus, south of the fishing locations the alpha cable is located. The reference locations were planned 500 m away from the cable route, to make sure these did not end up on the alpha cable. All reference locations were located north of the beta cable.

In total 46 stations were planned, split in 23 pairs (Cable vs Reference). Each station exists of two samples (hauls) as fishing occurs with two beam trawls (port and starboard) resulting in two samples of each location. In total 92 samples were planned.

Cable stations		Reference stations	
Port	Starboard	Port	Starboard
23	23	23	23

The exact locations were not predefined, it was only specified that trawling had to occur outside the nature conservation areas, outside the safety zone of the wind area and outside of the zone where C-pods were located for cetacean research purposes. Also, duplication of trawls on the same day was not preferred.

First, the station (with the port and starboard net) on the cable was fished, which was followed as soon as possible by the station at the reference location. This way conditions during the trawl were kept similar as much as possible between the two paired stations. To stay within working hours, for safety reasons and to keep conditions similar, trawls only occurred during daylight.

We fished for ~5 minutes, which with a normally used commercial fishing speed would result in ~660 m distance covered. Commercial and even regular scientific fishing practice is carrying out hauls with a much longer duration and distance. The short duration was chosen to minimize deviation of the cable route, meaning that when the gear was within the EMF due to the short duration of the trawl it is likely that at least a significant part of the trawl was within the EMF. In addition, the short duration made it possible to do a larger number of hauls in the available time. These aspects were considered beneficial over the expected reduction in catchability (at least of larger fish that can outswim the trawl for some time).

3.4 Handling of the catch

After hauling the gears, the two catches were kept separate. First the starboard catch is sorted to species level (when possible). In larger catches the (larger) fish were taken out of the catch after which the rest of the catch was divided in equal parts (sub-sampling). A smaller known subsample was then sorted for further processing. Also subsampling could occur after sorting of the species, when the total number of a single species was too large to handle. In that case a known subsample of the specific species was further processed.
After sorting the benthic organisms were counted, and the fish were measured to the cm-below. These counts, measurements and the subsample factors were registered on paper and at a later stage entered in the WMR program BillieTurf 8. The port catch was handled in the same way. Following measurements the catches were released as soon as possible.

3.5 Analysis

The catches by species are handled in the analysis as pairs. A pair exists of a starboard cable and reference haul and port cable and reference haul. In most of the analyses the two starboard trawls are compared with each other, and separately the two port trawls are compared.

A non-parametric statistical approach is used to assess if the catches on the cable are significantly different from those in the reference areas.

- First the number of fish of the starboard and port sample of a pair is calculated.
- Then the mean of the number of fish in the reference area and cable area is calculated.
- The mean of REF is extracted from the mean of Cable, this is the observed difference (Xobs), where a negative value indicates on average more fish in the reference area and a positive value indicates on average more fish at cable.

- Then a randomisation was performed, where each value of a single trawl was randomly assigned to the reference area or the cable.
- For each randomisation the difference between the means of the reference and cable area was calculated (Xrand).
- The randomisation was performed 1000 times, plus Xobs gave a total of 1001 differences (X).
- These differences were ranked from low to high. A low rank indicates a preference for the reference area, while a high rank indicates a preference for cable area.
- A rank number for Xobs smaller than 26 or larger than 974 rejects at a significance level of 0.05 the null hypothesis that catches in the reference and cable area are equal.
- At a significance level of 0.1, the null hypothesis is rejected for a rank smaller than 53 or larger than 948.

Next to that a paired t-test is performed on all the starboard and port pairs together, and for only those pairs of which EMF-sensors had indicated that the trawl had been in the EMF field for at least a part of the trawl duration. For these analyses the numbers per haul were log-transformed.

4 Results

4.1 The field work

On Tuesday 7th September, 7:13h, fishing started. The first trawl was invalid due to some technical issues and is not included in any of the analysis. All the other trawls were valid, which resulted in a total of 48 valid stations fished (Annex 1), thus 96 samples collected.
Twelve valid stations were fished on Tuesday with wind SE turn to NE 2-3bft; fourteen stations on Wednesday with wind ESE 4 decreasing to 3 bft; 18 stations were fished on Thursday with winds WZW 4 decreasing to 3 bft; and four stations were fished on Friday SSW-SW 4 bft.

The visual representation of the trawls based on the GPS location of the vessel indicates that the cable trawls were on or at least near the cable (as it is in the maps) (Figure 4-1). The figure also indicates overlap between various stations, which are at least a day apart in time as every day fishing occurred from east to west alongside the cable.

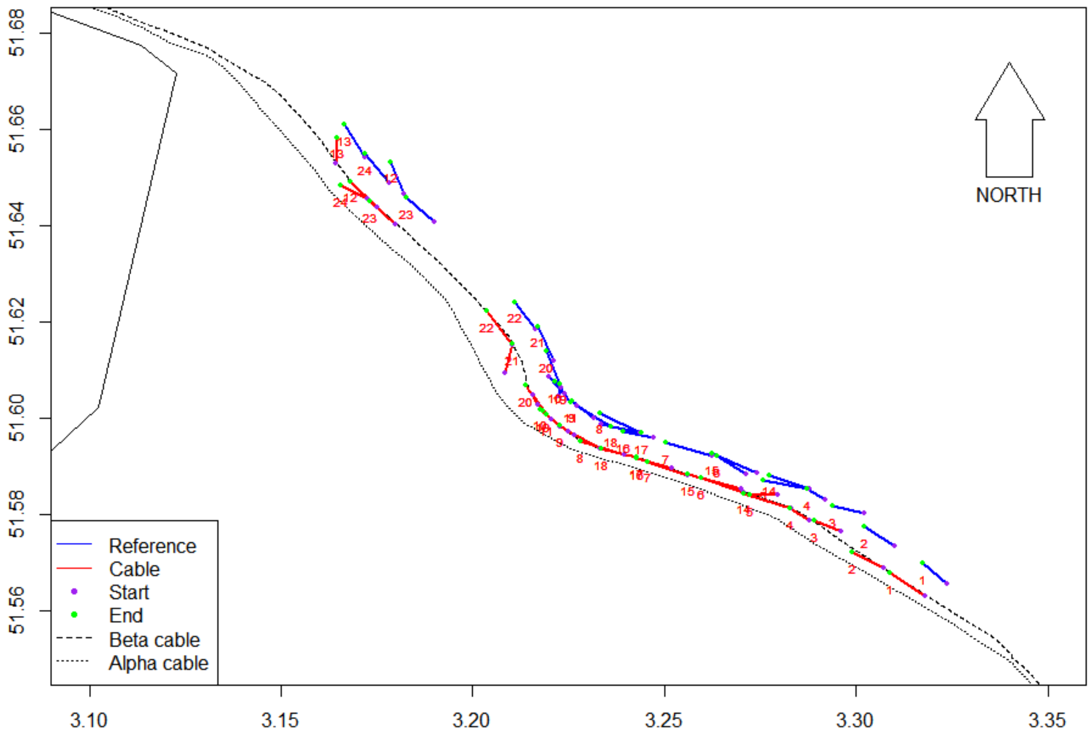


Figure 4-1 The trawled locations with in red the numbers of the paired stations (1-24).

The planned trawl duration was 5 minutes, which is the duration of the majority of the trawls (Annex 1). In three stations this duration was overshoot to a six-minute duration. In all cases this occurred only in one station of the pair. In seven stations duration was only 4 minutes, this was the case for both stations of three pairs. The sediment hampered fishing on the cable route of these three pairs, as a results fishing duration had to be reduced on the cable route. To keep the reference haul similar also the duration of this haul was shortened.
Fished distance was not recorded during fishing and could only be calculated based upon the start and end position of the hauls. As can be seen in the map created by WaterProof on the original field data (Snoek 2021) handed over directly after the fieldwork there were some issues with these positions. Correcting typos has improved the precision however some error affecting the fished distance is still expected. There are clear differences in fished distance between the trawls of the different pairs, and within pairs. As duration was more stable, fishing speed hasn't been as stable (Figure 4-2). This might have had an impact on the catchability; however, it is impossible to quantify.

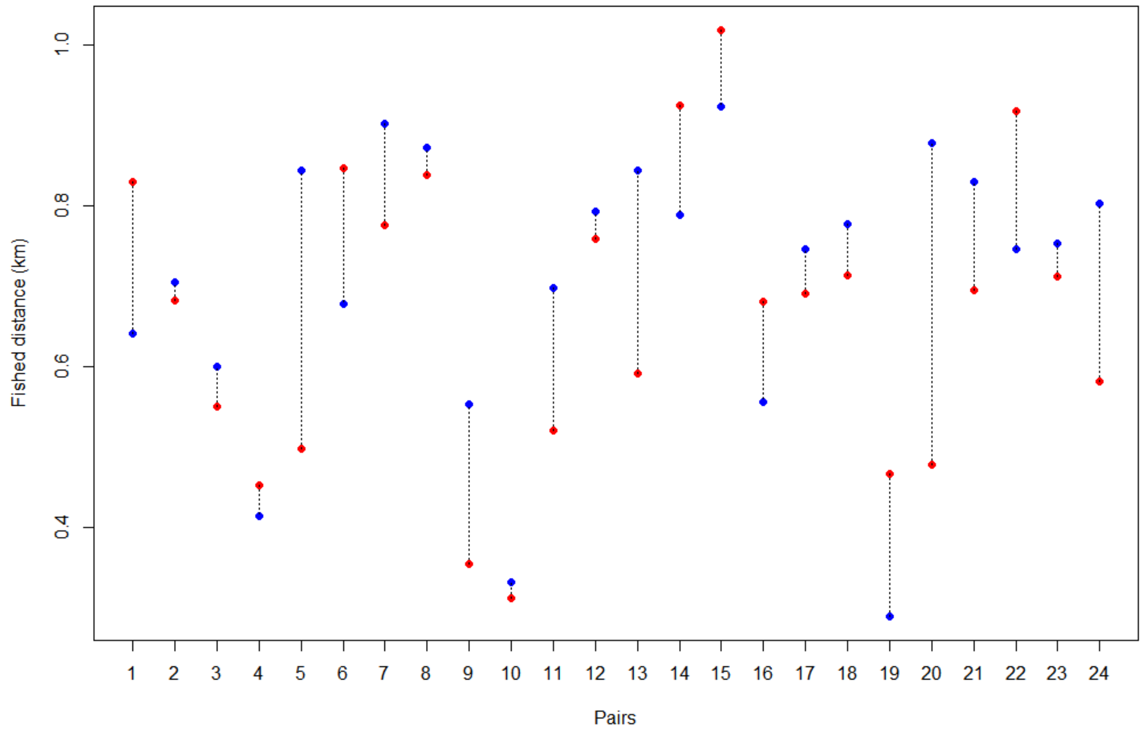


Figure 4-2 The fished distance (km) of both stations of a pair (1-24) connected for visibility with a dotted line, reference stations in blue and cable stations in red.

The fishing depths range between 10 and 30 meters (water depth at time of fishing). Most of the pairs were fished at similar depths (Annex 1).

4.2 Catch composition

The overall catches were relatively large for the short fishing duration. In many cases large parts of the catch had to be subsampled especially because of the presence of brittle stars (*Ophiura ophiura*). The most dominant fish species in the catch were the *Pomatischistus minutus* or *P. lozanoi* as these gobies can't be distinguished in the field. These were followed by plaice, dragonet (*Callionymus lyra*), dab and sole. Thus, the three target flatfish species were part of the top five. The elasmobranch species that were caught were thornback ray/roker (*Raja clavata*), lesser spotted dogfish (*Scyliorhinus canicula*) and smooth hound (*Mustelus sp.*), most likely starry smooth hound (*M. asterias*) (Table 4-1).
The most dominant benthic species were the brittle stars, and the common starfish (*Asterias rubens*). These were followed by *Liocarcinus* species and the sea urchin (*Psammechinus miliaris*) (Annex 2).

4.3 EMF detection

The EMF is linearly related to the amount of power transported through the cable, and thus in turn to the wind conditions. The wind conditions during fishing were lower than preferred, but within limits. In addition, the staff on board observed that at least the last three days the wind turbines were not in operation. Luckily, there is always a base current present that makes detection of the EMF by the sensors possible. This was seen during the test day, but also during the fishing days.
Snoek (2021) analysed and reported the sensor data by haul. The information indicated that at most cable stations at least one of the two EMF sensors recorded the EMF of the cable at the 50 Hz frequency (Snoek 2021). Based on the measurements of other cables (Snoek et al. 2020) this would mean that the trawl was at max 7.5-25 m away from the actual position of the cable.

Table 4-1 The number of fish caught in all the trawls combined.

English name	Dutch name	Scientific name	Number
Sand gobies	P. lozanoi/minutus	*Pomatoschistus lozanoi/minutus*	8827
Plaice	Schol	*Pleuronectes platessa*	5223
Dragonet	Pitvis	*Callionymus lyra*	1870
Dab	Schar	*Limanda limanda*	1682
Sole	Tong	*Solea solea*	1535
Hooknose	Harnasmannetje	*Agonus cataphractus*	1323
Scaldfish	Schurftvis	*Arnoglossus laterna*	1319
Whiting	Wijting	*Merlangius merlangus*	1217
Bib	Steenbolk	*Trisopterus luscus*	812
Lesser weever	Kleine pieterman	*Echiichthys vipera*	213
Tub gurnard	Rode poon	*Chelidonichthys lucerna*	118
Flounder	Bot	*Platichthys flesus*	90
Herring	Haring	*Clupea harengus*	60
Bull-rout	Zeedonderpad	*Myoxocephalus scorpius*	51
Thornback ray	Stekelrog	*Raja clavata*	39
Striped red mullet	Mul	*Mullus surmuletus*	38
Sea-snail	Slakdolf	*Liparis liparis liparis*	30
Sand sole	Franse tong	*Pegusa lascaris*	23
Horse mackerel	Horsmakreel	*Trachurus trachurus*	17
Greater pipefish	Grote zeenaald	*Syngnathus acus*	15
Solenette	Dwergtong	*Buglossidium luteum*	11
Lesser spotted dogfish	Hondshaai	*Scyliorhinus canicula*	10
Short-snouted sea-horse	Kortsnuitzeepaardje	*Hippocampus hippocampus*	10
Turbot	Tarbot	*Scophthalmus maximus*	8
Smooth-hound	Mustelus	*Mustelus sp.*	7
Greater sand-eel	Smelt	*Hyperoplus lanceolatus*	6
Sand eel sp.	Zandspieringen indet.	*Ammodytes sp.*	3
Five-bearded rockling	Vijfdradige meun	*Ciliata mustela*	2
Grey gurnard	Grauwe poon	*Eutrigla gurnardus*	2
Lumpsucker	Snotolf	*Cyclopterus lumpus*	2
Black goby	Zwarte grondel	*Gobius niger*	2
Three-bearded rockling	Driedradige meun	*Gaidropsarus vulgaris*	1
Lemon sole	Tongschar	*Microstomus kitt*	1

A limited number of trawls indicated having fished consistently within the EMF e.g., a clear signal at the 50 Hz frequency throughout the whole duration of the haul. Most only recorded the EMF for a part of the track. The current available data is not sufficient to determine exactly which percentage of the trawl was within the EMF. In some cable stations both sensors picked up the EMF suggesting that both nets were within the detection range of the EMF at the same time or consecutive.

According to Snoek (2021), only the cable stations 20 and 10 did not clearly show a signal of the EMF. Snoek (2021) was provided with the wrong time information for station 20, using the corrected information also during station 20 the EMF was detected (Annex 4). Station 10 did not clearly show a signal of the EMF. However, the port sensor y and the starboard sensor z seem to have picked up the EMF at least in the first minute, and the port sensor y shows a low signal throughout the whole trawl. Therefore, station 10 is included as fishing with the port net in the EMF (Table 4-2).

The EMF signals recorded at the cable stations are considered as a clear indication that the nets fished within the EMF of the cable. However, surprisingly also at 33% of the reference stations an EMF signal of the same frequency was recorded (Snoek 2021). Specifically, in reference stations 19 and 20. There seems to be no clear explanation for these observations as these stations should be too far away to detect the EMF of the beta-cable.

Table 4-2 Based on the recordings of the EMV-sensors (Snoek 2021) the P (port) and/or S (starboard) gear(s) is determined to have fished at least a part of trawl distance in the EMF.

Pairs	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
P					x	x	x				x	x	x	x				x	x	x	x	x	x	x	
S	x	x	x	x	x			x	x	x			x		x	x	x								x

The marked nets in Table 4-1 are with their counterparts in the reference area (Cable.P vs Ref.P or Cable.S vs Ref.S) included in the analyses for which it is stated that only the trawl which fished in the EMF are included. The others are excluded from those analyses. That means in the total analyses 24 pairs are included, while in the restricted analyses 26 pairs are included (2 nets for station 4 and 12).

4.4 Flatfish

The three flatfish species of commercial interest, plaice, sole and dab, are the target species of this study. These species were caught in large numbers (see Table 4-1).

4.4.1 Plaice

The catches of plaice in numbers per hectare show variation throughout the trawls (Figure 4-3), but there is no indication of a difference between catches of the port or starboard gear or between the cable and reference area.

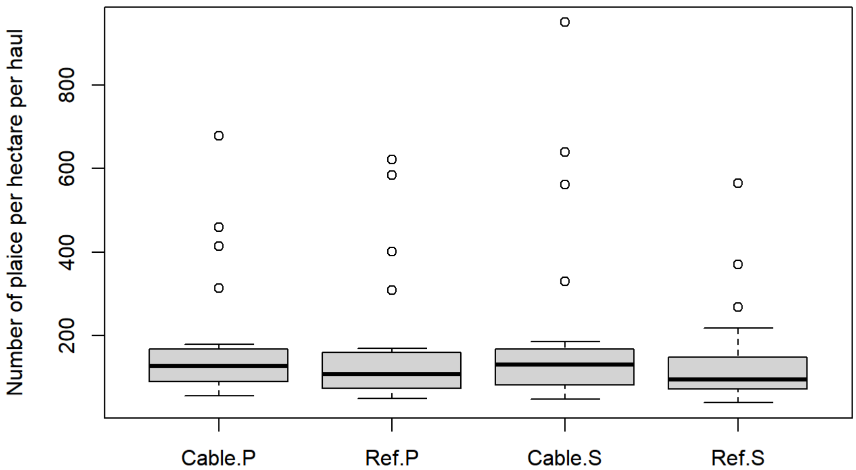


Figure 4-3 Catches of plaice in number per hectare. The boxplot represents 50% of the values (interquartile range IQR), and the black line in the box is the median. The whiskers represent the largest or smallest point that falls within the range of 1.5 * IQR. Values outside this range are represented as single points.

The majority of the plaice caught had a length between 8-12cm (mostly 0-year-old). There seems to be no difference in length distribution of plaice between the cable and reference catches (Figure 4-4).

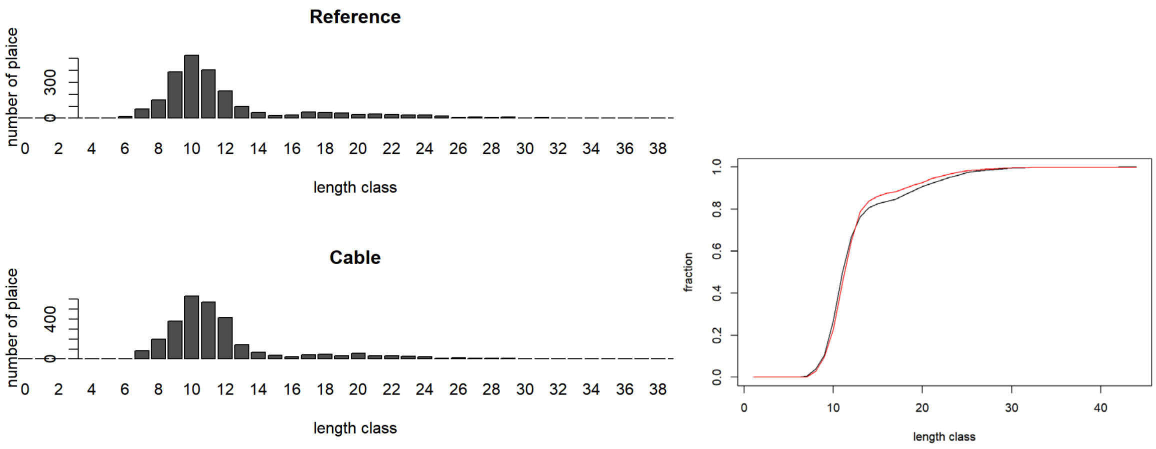


Figure 4-4 Length frequency distributions of plaice in the reference and cable catches, and the cumulative distribution function of the reference (black) and cable (red) catches by length.

Considering the issues with reliability of the GPS-locations and with that the calculation of the trawled distance, it was considered best to analyse the catches using the numbers per haul rather than the number per fished area.

Presenting the pairs against each other, indicates that most of the small catches were very similar between the pairs. However, there are some deviations with large catches on the cable and only small catches in the reference area. The two largest catches done on the cable were the port and starboard net of pair 7. The catch of both nets of this station consisted of a large number of small (<10 cm) plaice. Also, the spatially close pairs 6 and 16 indicate large catches of small plaice in the cable stations. In Annex 3 the same data are presented as barplots.

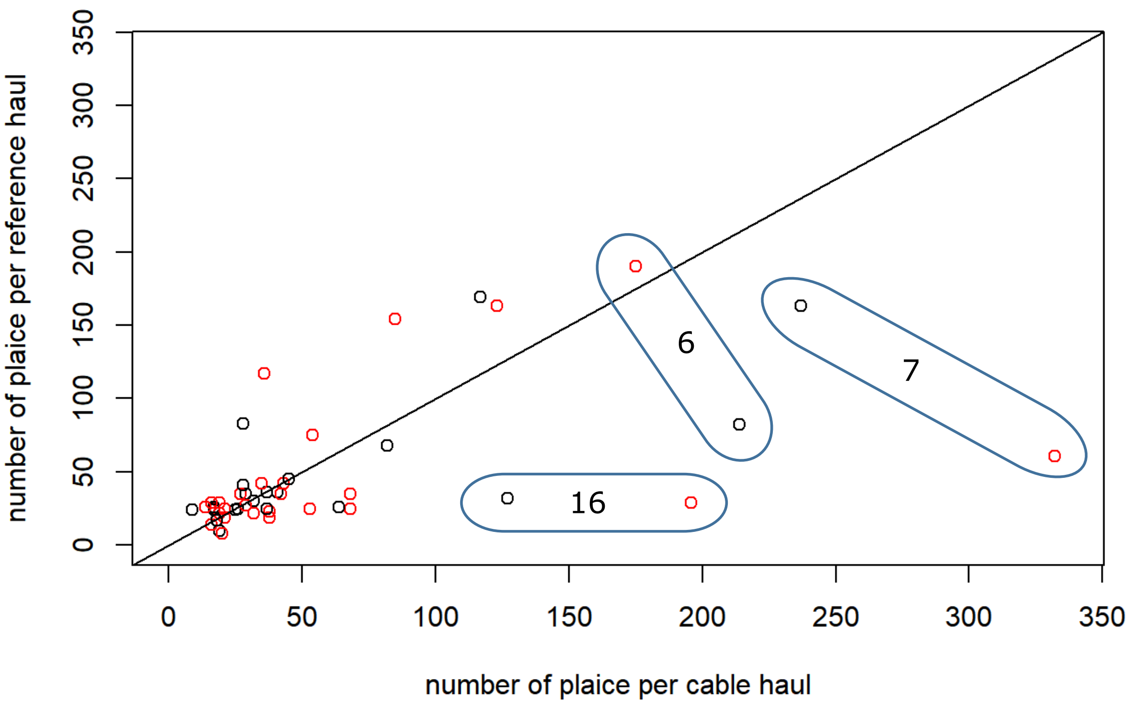


Figure 4-5 Catches of plaice in number per haul of all the paired stations (Cable.S vs Ref.S and Cable.P vs Ref.P), thus 48 points. The x-axis represents the catches of the cable stations and the y-axis represents the catches of the reference stations. The diagonal represents both catches being equal. The red dots represent the pairs of which one was fished in the EMF (**Table 4-2**). Encircled are both nets of the pairs 6, 7 and 16.

The data presented in Figure 4-3 and Figure 4-5 give the impression that there are no consistent differences between the catches on the cable or the reference area. To test this the non-parametric method was used, which results in a rank of 759 (**Figure** 4-6), indicating that the hypothesis that the catches are equal can't be rejected. The paired t-test gives a similar conclusion for all the data (t= -1.146, df =47, p=0.258), and for only the data where one of the pair fished in the EMF (t = -1.145, df =25, p= 0.26).

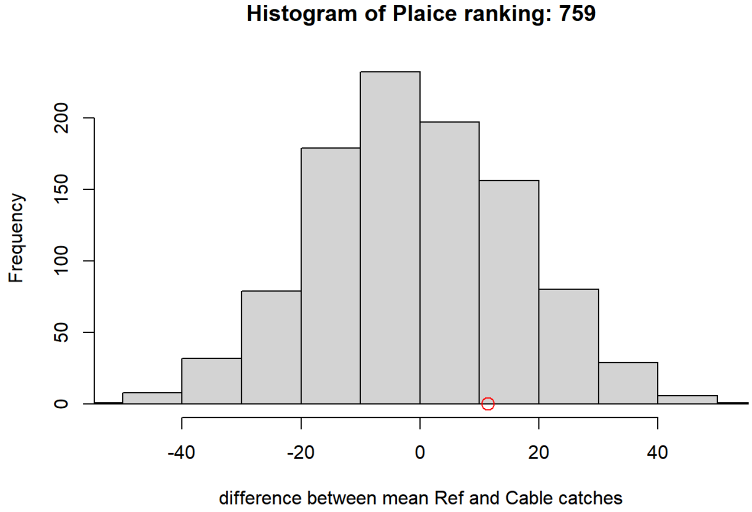


Figure 4-6 Results of the 1000 randomisations and the red circle indicating the observed value (Xobs).

4.4.2 Sole

The catches of sole in numbers per hectare show variation between the trawls (Figure 4-7) but there is no indication of a difference between catches of the port or starboard gear or between the cable and reference area.

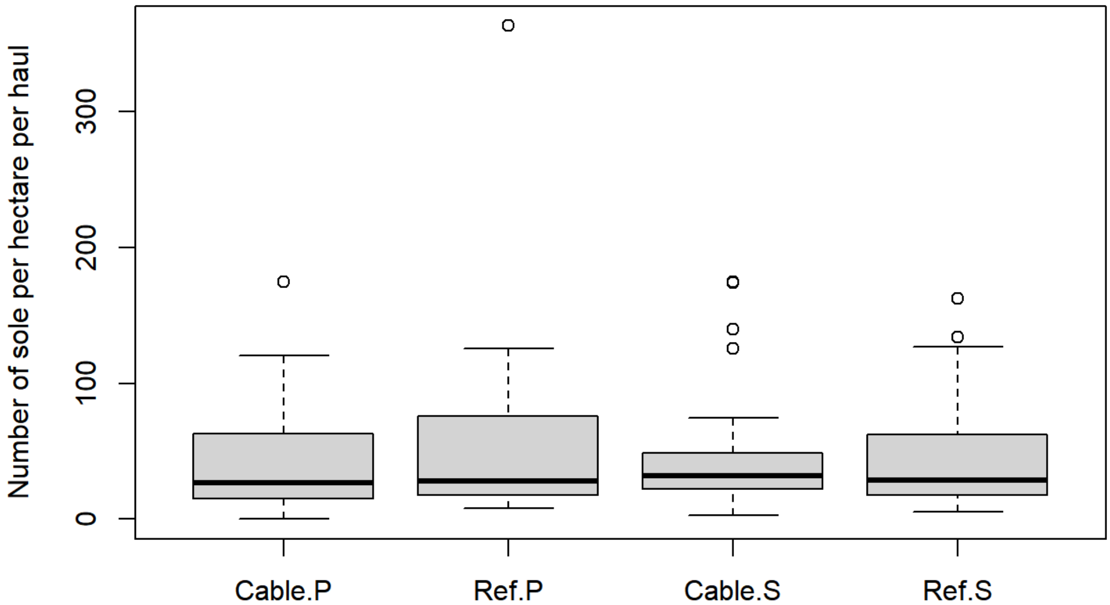


Figure 4-7 Catches of sole in number per hectare. The boxplot represents 50% of the values (interquartile range IQR), and the black line in the box is the median. The whiskers represent the largest or smallest point that falls within the range of 1.5 * IQR. Values outside this range are represented as single points.

The majority of the sole caught had a length between 18-21 cm. There seems to be no difference in length distribution of sole between the cable and reference catches (Figure 4-8).

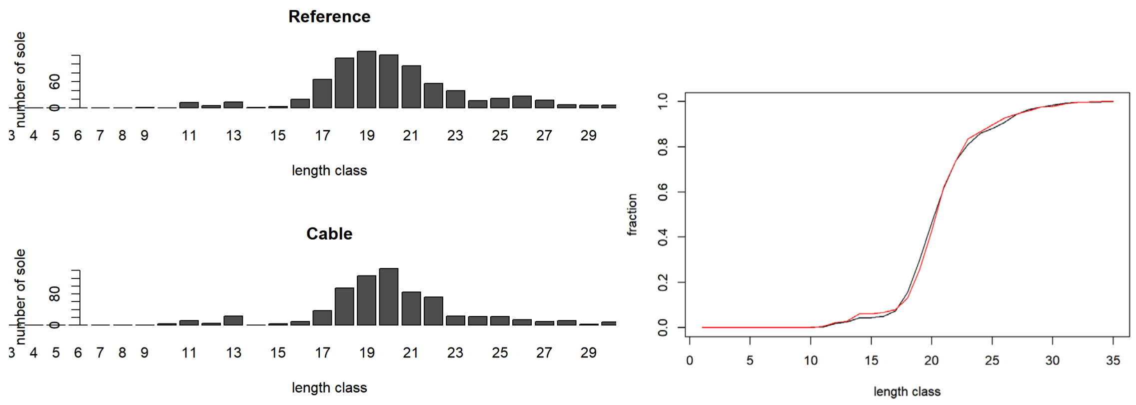


Figure 4-8 Length frequency distributions of sole in the reference and cable catches, and the cumulative distribution function of the reference (black) and cable (red) catches by length.

Presenting the pairs against each other in the same way as done for plaice, indicates that most catches were very similar between the pairs. The outlier with a large number of sole in the reference area is pair 6, while the outlier with more sole on the cable is pair 15. In Annex 3 the same data are presented as barplots.

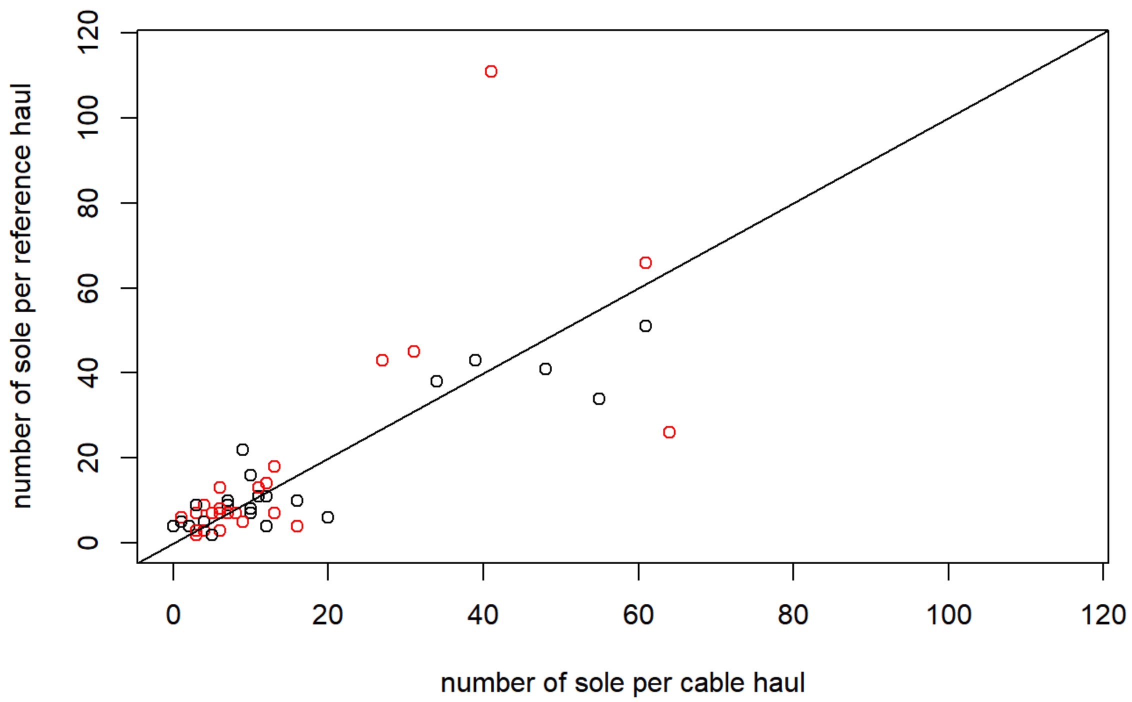


Figure 4-9 Catches of sole in number per haul of the paired values (Cable.S vs Ref.S and Cable.P vs Ref.P, thus 48 points. The x-axis represents the catches of the cable stations and the y-axis represents the catches of the reference stations. The diagonal represents both catches being equal. The red dots represent the pairs of which one was fished in the EMF (**Table 4-2**).

The data presented in Figure 4-7 and Figure 4-8 Figure 4-5 gives the impression that there are no consistent differences between the catches on the cable or the reference area. The non-parametric method confirms this and gives a rank of 451, indicating that the hypothesis that the catches are equal can't be rejected. The paired t-test gives a similar conclusion for all the data (t= 1.0405, df =47, p=0.303), and for only the data where one of the pair fished in the EMF (t = 0.5348, df =25, p= 0.597).

4.4.3 Dab

The catches of dab in numbers per hectare show variation between the trawls (Figure 4-10) but there is no indication of a difference between catches of the port or starboard gear or between the cable and reference area.

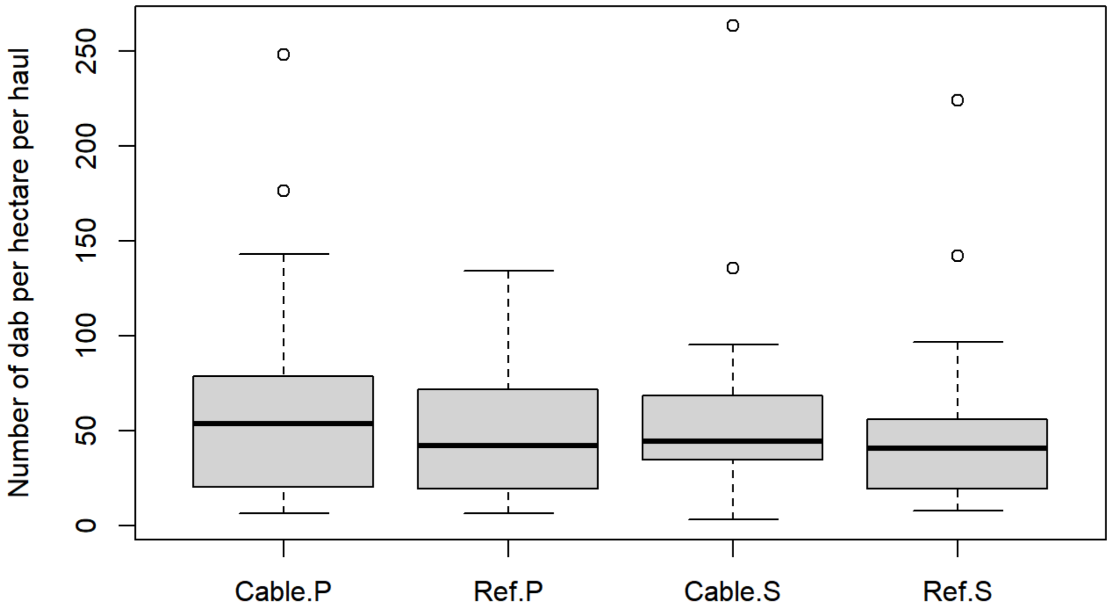


Figure 4-10 Catches of dab in number per hectare. The boxplot represents 50% of the values (interquartile range IQR), and the black line in the box is the median. The whiskers represent the largest or smallest point that falls within the range of 1.5 * IQR. Values outside this range are represented as single points.

The majority of the dab caught had a length between 12-16 cm. There seems to be no difference in length distribution of sole between the cable and reference catches (Figure 4-11).

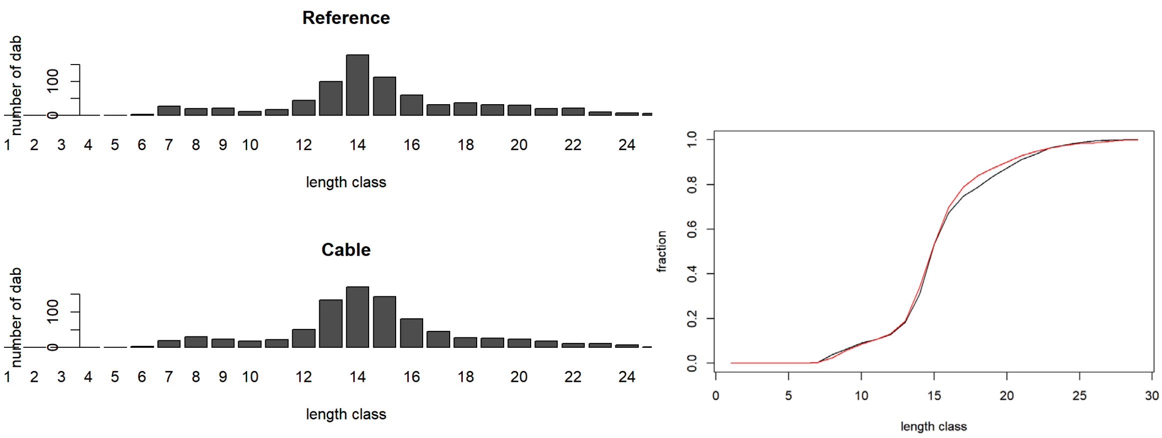


Figure 4-11 Length frequency distributions of dab in the reference and cable catches, and the cumulative distribution function of the reference (black) and cable (red) catches by length.

Presenting the pairs against each other in the same way as done for plaice, indicates that most catches were very similar between the pairs. The outlier with a large number of dab in the reference area is pair 12, while the outliers with more dab on the cable are both pairs 22 and a pair 20. In Annex 3 the same data are presented as barplots.

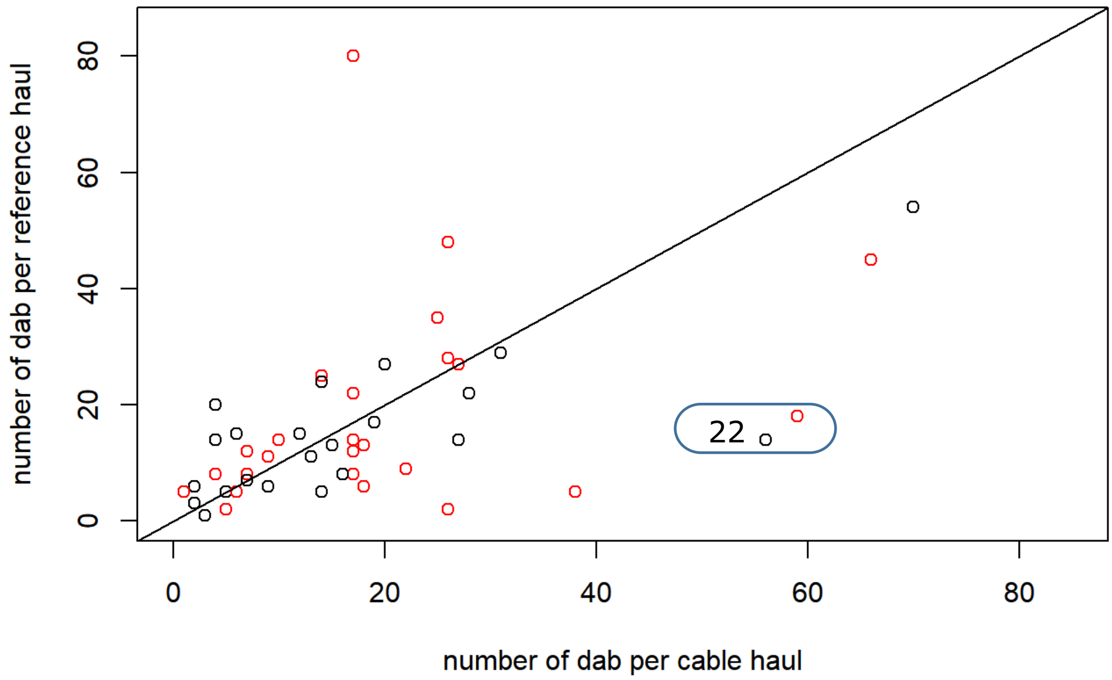


Figure 4-12 Catches of dab in number per haul of the paired values (Cable.S vs Ref.S and Cable.P vs Ref.P, thus 48 points. The x-axis represents the catches of the cable stations and the y-axis represents the catches of the reference stations. The diagonal represents both catches being equal. The red dots represent the pairs of which one was fished in the EMF (**Table 4-2**).

The data presented in Figure 4-10 and Figure 4-12 Figure 4-5 gives the impression that there are no consistent differences between the catches on the cable or the reference area. The non-parametric method confirms this and gives a rank of 653.5, indicating that the null hypothesis can't be rejected. The paired t-test gives a similar conclusion for all the data (t= -0.65725, df =47, p=0.514), and for only the data where one of the pair fished in the EMF (t = -0.83269, df =25, p= 0.413).

4.5 Elasmobranchs

Three species of elasmobranchs were caught, being the thornback ray, lesser spotted dogfish and smooth-hound sp. These species were caught in low numbers, making analysis less valuable. The thornback ray (n=39, on the cable 19 and in the reference area 20), received a rank of 439.5 indicating that the null hypothesis can't be rejected. The paired t-test gives a similar conclusion for all data (t= 0.073224, df=47, p = 0.9419). The conclusion is also similar using only the data where one of the pair fished in the EMF (t = 1.0723, df =25, p= 0.293).
The dogfish was caught seven times on the cable and three times in the reference area and got a rank of 763.5. The paired t-test gives a similar conclusion for all data (t= -0.8681, df=47, p = 0.390). The conclusion is also similar using only the data where one of the pair fished in the EMF (t = -1.1243, df =25, p= 0.272).
Smooth hound sp. were caught even less. Three were caught on the cable and 4 in the reference area. No further analyses were done. In Annex 3 the data per haul of all three species are presented as barplots.

4.6 Other species

Next to the target species several other species have been analysed.

4.6.1 Whiting

Whiting is a round fish species of commercial interest that was caught in high numbers. Like the other species there was clear variation in the number per hectare caught (Figure 4-13). All large catches of whiting were done in trawls close to the cable (Figure 4-14). In the non-parametric analysis whiting got a rank of 923; still not high enough to reject the null hypothesis. The paired t-test for all data (t= -2.9365, df=47, p= 0.005126) shows a significant larger amount of whiting in the cable catches. The t-test for only the data where one of the pair fished in the EMF was just not significant at the 0.05 level (t= -1.951, df=25, p= 0.06227).

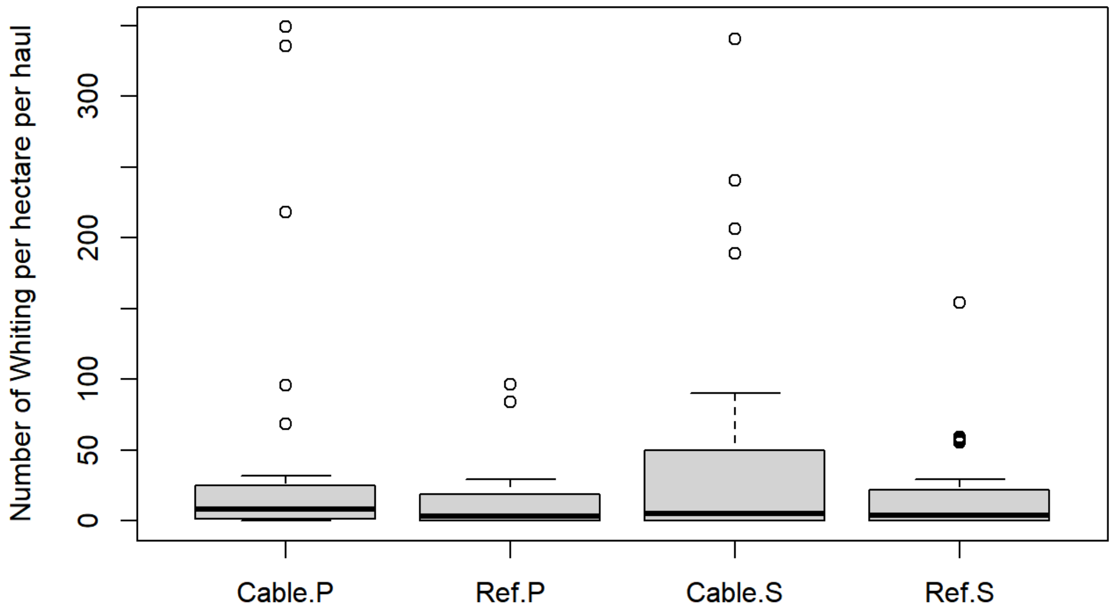


Figure 4-13 Catches of whiting in number per hectare. The boxplot represents 50% of the values (interquartile range IQR), and the black line in the box is the median. The whiskers represent the largest or smallest point that falls within the range of 1.5 * IQR. Values outside this range are represented as single points.

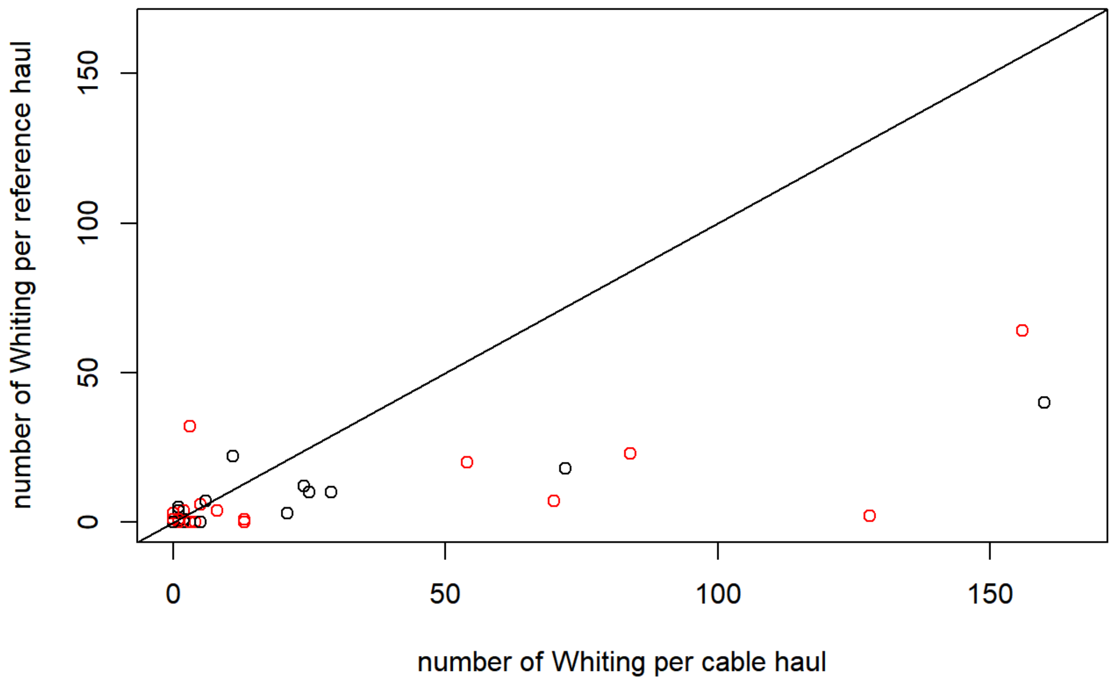


Figure 4-14 Catches of whiting in number per haul of the paired values (Cable.S vs Ref.S and Cable.P vs Ref.P), thus 48 points. The x-axis represents the catches of the cable stations and the y-axis represents the catches of the reference stations. The diagonal represents both catches being equal. The red dots represent the pairs of which one was fished in the EMF (**Table 4-2**).

4.6.2 Dragonet

Dragonet was one of the most dominant species in the catches and shows some larger variation between the cable and reference hauls (Figure 4-15). There are clearly some cable hauls with more dragonet than their pair in the reference area. However, there also are two trawls of which one of the pair fished in the EMF that showed higher catches in de reference area than in the cable trawls (Figure 4-16). The rank of dragonet is 911, so the null hypothesis is not rejected. The paired t-test of all data indicates significant more dragonet on the cable (t= -2.3262, df=47, p= 0.0244). The t-test for only the data where one of the pair fished in the EMF was not significant (t= -1.4315, df=25, 0.1647).

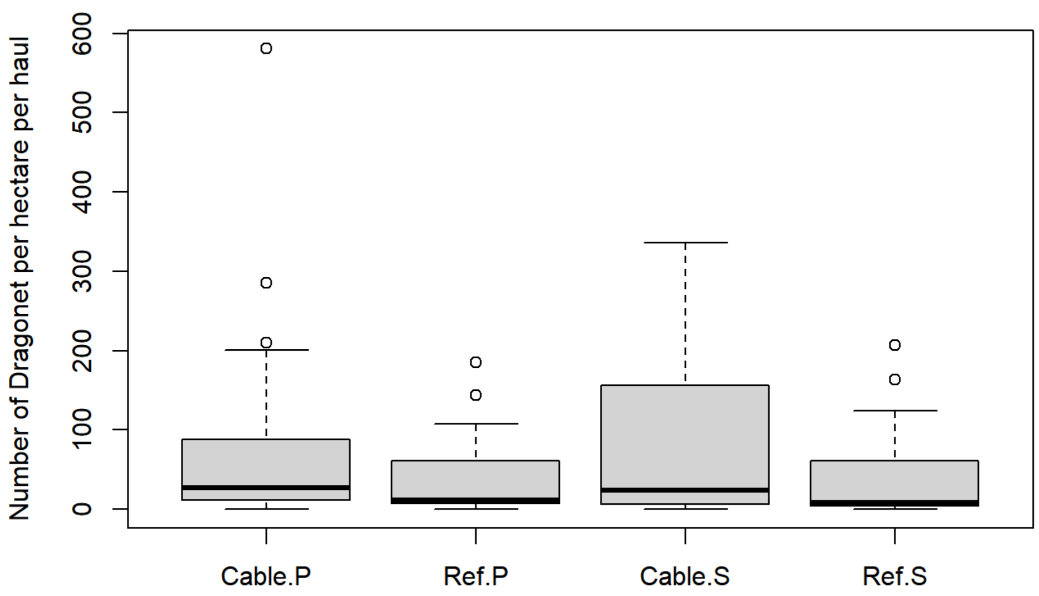


Figure 4-15 Catches of dragonet in number per hectare. The boxplot represents 50% of the values (interquartile range IQR), and the black line in the box is the median. The whiskers represent the largest or smallest point that falls within the range of 1.5 * IQR. Values outside this range are represented as single points.

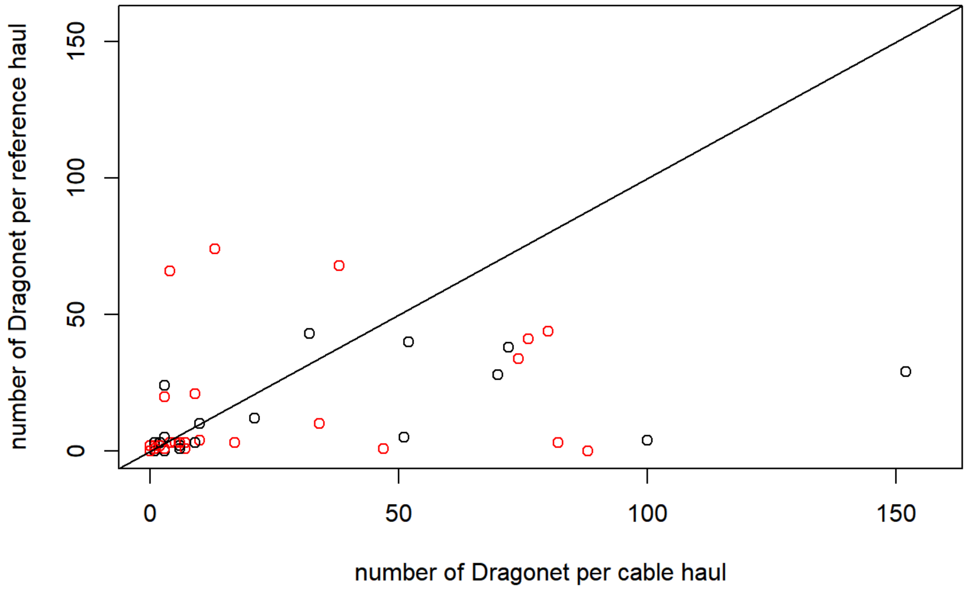


Figure 4-16 Catches of dragonet in number per haul of the paired values (Cable.S vs Ref.S and Cable.P vs Ref.P), thus 48 points. The x-axis represents the catches of the cable stations and the y-axis represents the catches of the reference stations. The diagonal represents both catches being equal. The red dots represent the pairs of which one was fished in the EMF (**Table 4-2**).

4.6.3 Brittle star

The brittle star was the most dominant species in the catches and was caught in very large numbers (Figure 4-17). There is a single reference trawl in which more brittle stars were caught then in its cable pair. While there were four trawls in which the opposite was clear. Most pairs of which one trawl fished in the EMF showed limited difference in numbers of brittle star. The statistical analyses showed no significant difference with a rank of 816, and p-values of 0.32 and 0.594.

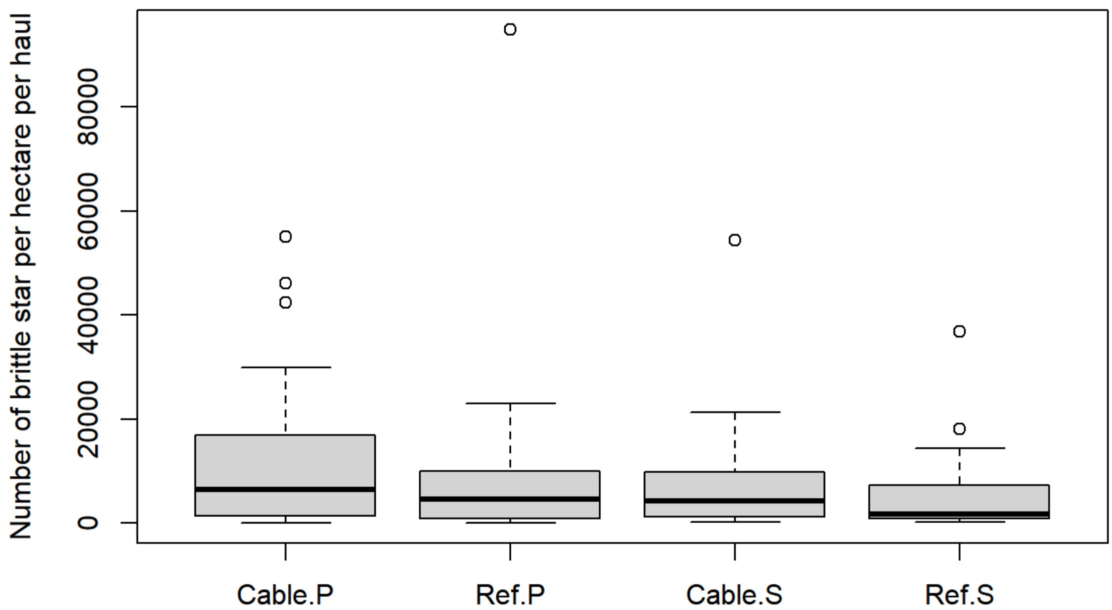


Figure 4-17 Catches of brittle star in number per hectare. The boxplot represents 50% of the values (interquartile range IQR), and the black line in the box is the median. The whiskers represent the largest or smallest point that falls within the range of 1.5 * IQR. Values outside this range are represented as single points.

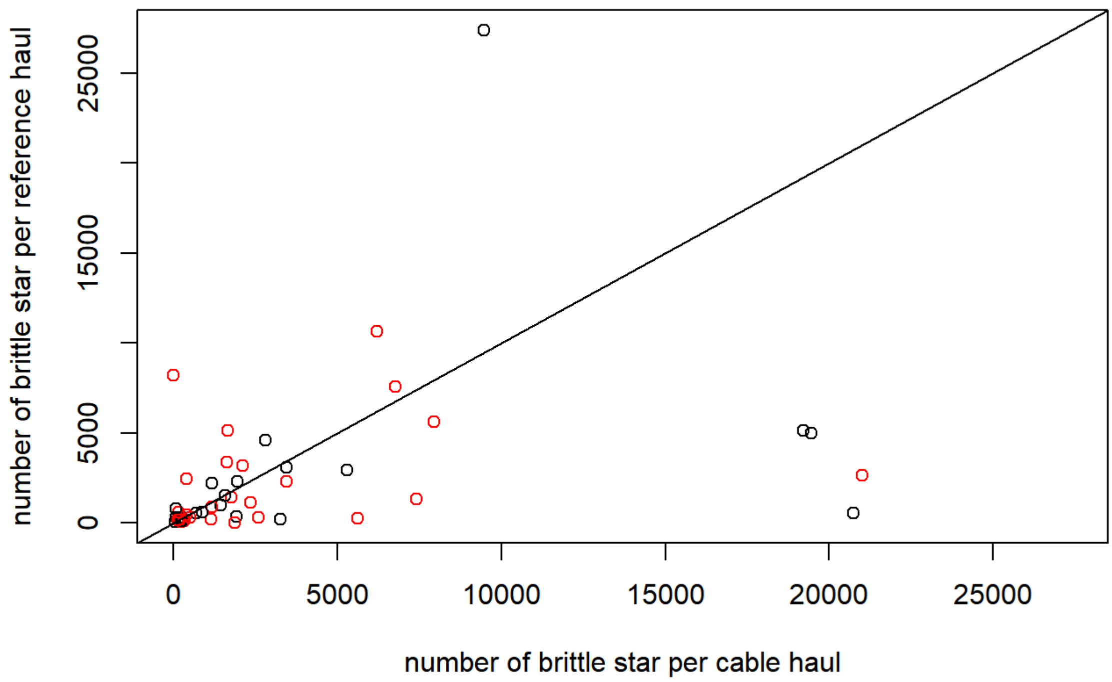


Figure 4-18 Catches of brittle star in number per haul of the paired values (Cable.S vs Ref.S and Cable.P vs Ref.P), thus 48 points. The x-axis represents the catches of the cable stations and the y-axis represents the catches of the reference stations. The diagonal represents both catches being equal. The red dots represent the pairs of which one was fished in the EMF (**Table 4-2**).

4.6.4 Sea potato

The sea potato (*Echinocardium cordatum*) occurred only in a limited number of trawls. But if they were caught, they were present in relatively high numbers. This common for catches of this species. Large catches occur on the cable route and in the reference area. The non-parametric method resulted in a rank of 817, and the statistical analyses showed no significant difference with p-values of 0.485 and 0.996.

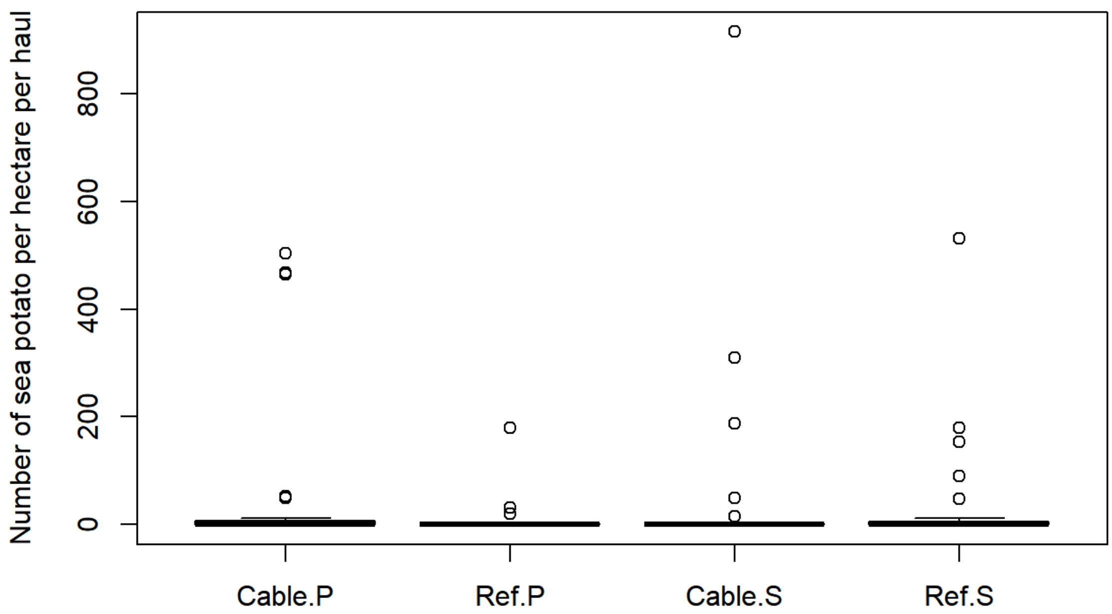


Figure 4-19 Catches of sea potato in number per hectare. The boxplot represents 50% of the values (interquartile range IQR), and the black line in the box is the median. The whiskers

represent the largest or smallest point that falls within the range of 1.5 * IQR. Values outside this range are represented as single points.

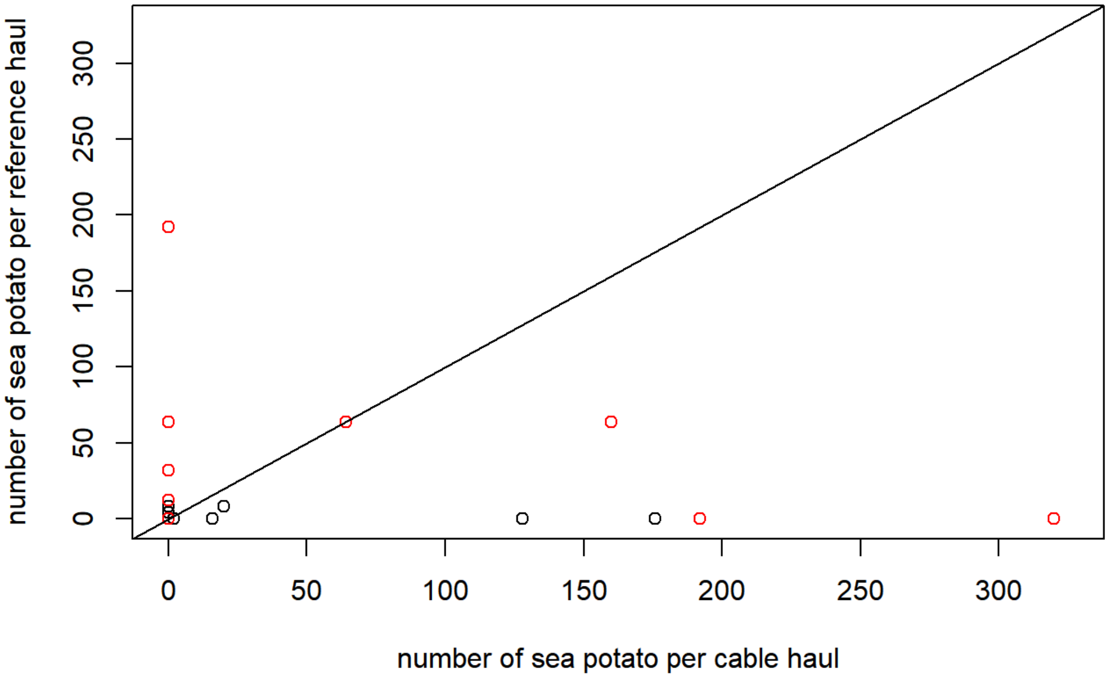


Figure 4-20 Catches of sea potato in number per haul of the paired values (Cable.S vs Ref.S and Cable.P vs Ref.P), thus 48 points. The x-axis represents the catches of the cable stations and the y-axis represents the catches of the reference stations. The diagonal represents both catches being equal. The red dots represent the pairs of which one was fished in the EMF (**Table 4-2**).

5 Conclusions and recommendations

5.1.1 Methodology

The first part of the project was to develop a method to sample fish directly on the cable. This is done with the help of WaterProof and the sensors measuring the magnetic field generated by the electricity going through the cable developed by them. The sensors attached to the beam trawl could detect the EMF and determine if a trawl was done in the EMF around a cable. Earlier measurements on other cables (Snoek et al. 2020) indicated that the sensors were able to detect the EMF at max 7.5-25 m away from the cable. The plots presented by Waterproof (Snoek 2021) show that at least a number of the trawls only fished in the EMF for a part of the track. Often this was the first part of the track, which indicates that the skipper can set the net very close to the cable, but it is more difficult to fish and stay close to the cable. The plots also show that the recorded signal was often low, in comparison with clear detections of the EMF in the same of other hauls, suggesting that the trawl was only at the outer boundary of the EMF. Real time feedback from the sensors, and possible a sensor on each side of the trawl could form an improvement to this set up. That would require additional development by Waterproof and most likely also specific fishing warps that can guide the live signal. This would make it much more difficult to arrange the fieldwork as it limits the number of available vessels, or the warp of the vessel must be changed at the start meaning it would be more costly. Waterproofs results also indicated that the sensors sometimes detected signals at the 50 Hz frequency in the reference area. It is unclear where these signals came from. As a result, the signals of the sensors at the cable sites might be affected by this unclear phenomenon as well, which might indicate that a (small) proportion of the signals indicating the presence of the cable might not directly be related to the EMF of the cable.

The decision was made to fish for a short time (4-5 minutes) to minimise the deviation of the cable route. The EMF results give the impression that even within this short duration deviation can occur, but that also makes it likely that it will occur more often with a longer haul duration. The short haul duration will result in smaller catches and likely impacts the catchability, but even with the current short haul duration the catches were often already too large to sort completely. Given the larger deviation from the planned track on top of the cable with longer haul duration, the chance that other co-factors might increase, enough catch of target species and the fact fewer hauls could be taken when longer duration was chosen, taking 5 min hauls as the base of this comparison study was a good choice.

The design in which first a trawl on the cable route was done followed immediately by a haul at about 500 m parallel to the cable in a reference area worked fine in the field. This resulted in similar pairs, at least the tide and time of day were similar, and gave the opportunity to match the duration of the second haul for duration when the first haul was different from the planned 5 min. Most pairs were also fished at similar depths, where the full depth range in the entire study area was 10-30 m, and based on anecdotal observations in most pairs also similar sediment types.

It is always difficult to plan field work considering the weather conditions. To have a vessel prepared and staff arranged to go into the fields requires some notice a couple of days in advance. Weather and with that wind predictions are often uncertain that long in advance, especially when a specific range of wind speed is preferred. This time it resulted in lower wind speeds than preferred especially on the first day. However, in the end that did not matter much, as the wind farm was not operational at that day. Thus, not only weather forecasts but for further similar studies also confirmation of operational schemes with the farm operators is required in advance of the field work.

Luckily, independent of the weather there is a base current going through the cable, also when the turbines are off. This made it possible to detect an EMF. The goal however was to do the measurements at higher currents as the impact of the EMF was expected to be larger at the wind forces during the surveys. Therefore, all the results in this report must be considered as the minimum impact of the EMF.

It was a limited study, partially designed as a first test. In the end one more pair of stations was sampled than in the original plan. Despite that, it resulted only in 24 pairs. The high variability seen in the catches, which is comparable to normal fish catches, means that with a limited number of pairs only large changes in abundance can be detected. A simple poweranalysis (pwr.t.test) for the paired-t-test indicates that with 24 pairs, a p-value of 0.05 and a power of 80%, the effect size would be ~0.60. That would mean that an increase of decrease in abundance of 60% of the mean abundance in the reference area could be detected. The outliers seen for some of the catches result in the violation of the assumptions of the t-tests presented, some of these outliers are so large that even transformation of the data used prior to the analyses isn’t sufficient to meet the assumptions. Especially with small sample sizes, these outliers might make the results of the t-tests suspicious. Non-parametric statistics are preferred in those cases, even though these are harder to understand. Therefore, the main analyses in this report are the non-parametric tests, and t-tests function as an addition in order to present similar results with a simple test.
Concluding, large effects of the cable could have been detected with this setup. Detecting smaller impact would require a large increase in number of pairs. The same poweranalysis indicates that to detect and effect size of 0.1 about 700-800 pairs are required. The length of the cable is not long enough to allow for this amount of hauls, which would result in many overlapping hauls. Furthermore, that many hauls can’t be done in a relatively short time frame which would result in larger variation in the weather and hydrological conditions. To incorporate the variation in these conditions into the analyses would require a further increase in the number of samples to be taken.
It is thus very difficult to improve on the effect size maintaining such a design. For further work it should be considered if this is the proper effect size. Else, a design with multiple reference areas could improve the effect size a bit, but even then, a larger number of pairs is required when a much lower effect size is preferred.

5.1.2 Study results

The second part of the project was to answer the research question on the potential impact of the EMF on the behaviour and presence of the target species. The chosen method is not providing any information on behaviour, as it is only a snapshot at one moment in time. Other research methods are required to make statements about behaviour. Some other studies used static gear to assess migration and different strengths of the EMF (Hvidt et al. 2006), video (Barry et al. 2008; Snoek et al. 2020) or visual surveys (Kilfoyle et al. 2018) to observe the behaviour of individual fish. Potentially also (acoustic) telemetric methods to observe the actual behaviour of the individual fish in the field could be used (Hasselman et al. 2020).
The fish monitoring used can only provide information on the presence of species and the relative abundances and length composition of these species compared to reference locations. Sampling at different EMF strengths could have made it possible to use the data of the cable route by itself to assess potential impact of different EMF strengths. In that case, sufficient sampling should have occurred at different wind speeds when the turbines are in operation, while keeping most of the other environmental conditions similar. This last part is very difficult and might only work when there is close cooperation with the wind farm operators, that should control the current strength by enabling and disabling turbines.

The current data indicate that there was no significant difference between the catches of the target flatfish species in the vicinity of the cable and in the reference areas. Reducing it to the trawls for which the EMF-sensors indicated that fishing occurred within the EMF did not make a significant difference. With the note that these are results at the minimum EMF which might change at higher EMF. Also, these results are influenced by trawls that only partially fished within the EMF, of which it is impossible to determine which part of the catch is from within the EMF.

However, for some of the assessed non-target species, it was shown that there is a difference between the cable route and the reference, specifically for dragonet and whiting. In these cases, the species showed higher abundance on the cable than in the reference area, suggesting some attraction by the cable. It is however difficult to disentangle the impact of the EMF from other (indirect) aspects. For example, are the species that occurred in higher abundance really attracted to the EMF, or was there more food available or is there a preferred temperature owing to the heat emission of the cable? These explanations have been suggested for some of the results shown in other studies (Hvidt et al. 2006).

Video observation of the PAWP cable in 2019 gave an indication that there might be some influence of the EMF on the benthic species brittle stars, sand mason worms (*Lanice conchilega*), and sea potatoes (Snoek et al. 2020). The sand mason worms are not properly sampled by the used gears. The other two species were encountered in large amounts in the current catches. The catches of brittle stars and sea potato do not support the video observations, as these were caught in similar amounts on the cable route as in the reference area.

Overall, it is possible to state that under the current circumstances there is no basis for any negative impact of the cable on the abundance of the analysed species. Furthermore, there is no solid indication of impact of the EMF at all. This is in line with recent reviews that state that little effect on fish behaviour in relation to EMF is found and that there is no significant effect to be expected (Copping et al. 2020; Copping et al. 2021).

5.1.3 Recommendations

The results indicate no basis for any negative impact on the target species. Considering this, the first recommendation is that further studies on a potential impact of the EMF on the target species should not have the highest priority.
However, if further results are preferred these should in the first-place focus on monitoring at high or maximum EMF. The current results are based on the minimum EMF. That would require the turbines to be in operation and the wind conditions to be higher than during this study. This requires more planning and flexibility of the vessel and staff. It also requires some contact with the farm operator.
A similar study at higher EMF would result in a similar power as the current study. It is necessary to consider if changes of this size are the preferred results. When smaller changes are expected and need to be detected a larger study is required. It would then be preferred to first increase the number of reference areas, for example also fishing on a reference location south of the cables.

A follow-up study can be done in the same season. As this study has shown that sufficient target fish were in the vicinity to catch them regularly enabling statistical analysis. For example, the amount of smooth hound caught is too low to do any proper analysis. For this species another area or season in which they are more abundant would be required. There seems little additional value for the target species of repeating this study in other seasons. There is no support for differences in effects at different water temperature. Furthermore, behavioural aspects, like spawning migration that differ between seasons, cannot be detected by this design. For the used design it would only mean there is more fish or less fish in the area to be caught.

To analyse effects of the EMF during migration other methods are required. Electronic tagging could indicate if the migration routes are altered in the vicinity of the cable. Or that behaviour changes at different levels of the EMF. Static gill nets could also be used to indicate differences in activity of species near the cable and in reference areas. Using gillnets would shift the focus from actually being present at the cable, to a combination of being present and the activity of fish near the cable.

Furthermore, as described it is difficult and costly to enhance the power of the analysis. If smaller effects are of interest, investments in lab studies studying the direct impact of the EMF on behaviour could help with understanding what the expected size of the effects in the field could be. Followed by a design of the fieldwork being able to detect effects of the expected size.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

References

Barry, J., L. Kuhnz, K. Buck, C. Lovera, and P. Whaling. 2008. Potential impacts of the MARS Cable on the seabed and benthic faunal assemblages. *Monterey Bay Aquarium Research Institute*.

Bochert, R., and M. Zettler. 2004. Long-term exposure of several marine benthic animals to static magnetic fields. *Bioelectromagnetics: Journal of the Bioelectromagnetics Society, The Society for Physical Regulation in Biology and Medicine, The European Bioelectromagnetics Association* 25 (7): 498-502.

Copping, A. E., L. G. Hemery, D. M. Overhus, L. Garavelli, M. C. Freeman, J. M. Whiting, A. M. Gorton, et al. 2020. Potential Environmental Effects of Marine Renewable Energy Development—The State of the Science. *Journal of Marine Science and Engineering* 8 (11): 879.

Copping, A. E., L. G. Hemery, H. Viehman, A. C. Seitz, G. J. Staines, and D. J. Hasselman. 2021. Are fish in danger? A review of environmental effects of marine renewable energy on fishes. *Biological Conservation* 262: 109297. http://dx.doi.org/https://doi.org/10.1016/j.biocon.2021.109297.

Gill, A., M. Bartlett, and F. Thomsen. 2012. Potential interactions between diadromous fishes of UK conservation importance and the electromagnetic fields and subsea noise from marine renewable energy developments. *Journal of Fish Biology* 81 (2): 664-695.

Gill, A., Y. Huang, I. Gloyne-Philips, J. Metcalfe, V. Quayle, J. Spencer, and V. Wearmouth. 2009. *COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2: EMF Sensitive Fish Response to EM Emissions from Sub-sea Electricity Cables of the Type used by the Offshore Renewable Energy Industry*, Report by Centre for Environment Fisheries and Aquaculture Science (CEFAS).Report No. COWRIE-EMF-1-06

Gill, A. B., and M. Desender. 2020. "Risk to Animals from Electromagnetic Fields Emitted by Electric Cables and Marine Renewable Energy Devices " In *OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES)*, edited by A.E. Copping and L.. G. Hemery, 86-103.

Hasselman, D. J., D. R. Barclay, R. J. Cavagnaro, C. Chandler, E. Cotter, D. M. Gillespie, G. D. Hastie, et al. 2020. "Environmental Monitoring Technologies and Techniques for Detecting interactions of Marine Animals with Turbines." In *OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES)*, edited by A.E. Copping and L.. G. Hemery, 176-212.

Hutchison, Z., P. Sigray, H. He, A. Gill, J. King, and C. Gibson. 2018. Electromagnetic Field (EMF) impacts on elasmobranch (shark, rays, and skates) and American lobster movement and migration from direct current cables. *Sterling (VA): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM* 3: 2018.

Hutchison, Z. L., A. B. Gill, P. Sigray, H. He, and J. W. King. 2020. Anthropogenic electromagnetic fields (EMF) influence the behaviour of bottom-dwelling marine species. *Scientific reports* 10 (1): 1-15.

Hvidt, C. B., M. Klaustrup, S. B. Leonhard, and J. Pedersen. 2006. *Fish along the Cable Trace Nysted Offshore Wind Farm*, Orbicon as.2508-03-002-rev10.doc

Kilfoyle, A. K., R. F. Jermain, M. R. Dhanak, J. P. Huston, and R. E. Spieler. 2018. Effects of EMF emissions from undersea electric cables on coral reef fish. *Bioelectromagnetics* 39 (1): 35-52. http://dx.doi.org/https://doi.org/10.1002/bem.22092.

Kimber, J. A., D. W. Sims, P. H. Bellamy, and A. B. Gill. 2011. The ability of a benthic elasmobranch to discriminate between biological and artificial electric fields. *Marine biology* 158 (1): 1-8.

Metcalfe, J., B. Holford, and G. Arnold. 1993. Orientation of plaice (Pleuronectes platessa) in the open sea: evidence for the use of external directional clues. *Marine Biology* 117 (4): 559-566.

Putman, N. F., K. J. Lohmann, E. M. Putman, T. P. Quinn, A. P. Klimley, and D. L. Noakes. 2013. Evidence for geomagnetic imprinting as a homing mechanism in Pacific salmon. *Current Biology* 23 (4): 312-316.

Snoek, R. 2021. *Results EMF measurements fish trawling Borssele cable*, WaterProof Marine Consultancy & Services BV.WP2020_1214

Snoek, R., C. Böhm, K. Didderen, W. Lengkeek, F. M. F. Driessen, and M. A. M. Maathuis. 2020. *Potential effects of electromagnetic fields in the Dutch North Sea Phase 2 – Pilot field Study.*, WaterProof Marine Consultancy & Services BV and Bureau Waardenburg BV.WP2018_1130_R3r3

Snoek, R., R. de Swart, K. Didderen, W. Lengkeek, and M. Teunis. 2016. *Potential effects of electromagnetic fields in the Dutch North Sea Phase 1 – Desk Study.*, WaterProof Marine Consultancy & Research BV and Bureau Waardenburg BV.WP2016_1031

Snyder, D., W. Bailey, K. Palmquist, B. Cotts, and K. Olsen. 2019. *Evaluation of Potential EMF Effects on Fish Species of Commercial or Recreational Fishing Importance in Southern New England*, US Department of the Interior (DOI).BOEM 2019-049

Taormina, B., J. Bald, A. Want, G. Thouzeau, M. Lejart, N. Desroy, and A. Carlier. 2018. A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. *Renewable and Sustainable Energy Reviews* 96: 380-391.

Westerberg, H., and I. Lagenfelt. 2008. Sub-sea power cables and the migration behaviour of the European eel. *Fisheries Management and Ecology* 15 (5-6): 369-375.

Wyman, M. T., A. P. Klimley, R. D. Battleson, T. V. Agosta, E. D. Chapman, P. J. Haverkamp, M. D. Pagel, and R. Kavet. 2018. Behavioral responses by migrating juvenile salmonids to a subsea high-voltage DC power cable. *Marine Biology* 165 (8): 1-15.

Justification

Report C013/22
Project Number: 4316100264

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved:	Dr. Erwin Winter Researcher
Signature:	
Date:	11 March 2022

Approved:	Drs. Jakob Asjes MT Member
Signature:	
Date:	14 March 2022

Annex 1 Trawl information

Code	Valid	Month	Day	Time	latitude_s	latitude_h	longitude_s	longitude_h	water depth	Duration	Pairs	Wind direction	Wind force	Tidal phas
01_C	n	9	7	613	51.55798	51.55798	3.32852	3.31912	8	5	0	138	2	5.8
02_C	y	9	7	631	51.56323	51.568	3.31797	3.30873	10	6	1	138	2	6.2
03_R	y	9	7	745	51.56567	51.56997	3.32367	3.31747	10	5	1	131	2	7
04_C	y	9	7	841	51.56888	51.57228	3.30708	3.29885	10	5	2	133	2	8
05_R	y	9	7	909	51.5736	51.5775	3.31017	3.30212	12	5	2	131	2	8.5
06_C	y	9	7	941	51.5765	51.5788	3.29623	3.28917	12	5	3	117	2	9
07_R	y	9	7	1010	51.5803	51.5818	3.30222	3.29388	13	5	3	105	4	9.5
08_C	y	9	7	1116	51.57892	51.58138	3.28788	3.28267	18	4	4	102	2	10.5
09_R	y	9	7	1139	51.58313	51.58527	3.29205	3.28713	18	4	4	102	2	11
10_C	y	9	7	1204	51.5841	51.5842	3.27952	3.27232	23	5	5	100	2	11.5
11_R	y	9	7	1241	51.58537	51.58728	3.28758	3.27575	24	5	5	52	2	12
12_C	y	9	7	1359	51.58462	51.58765	3.27083	3.25958	30	6	6	52	2	1.1
13_R	y	9	7	1513	51.58838	51.59217	3.27133	3.26363	30	5	6	41	4	2.3
14_C	y	9	8	546	51.58825	51.59105	3.256	3.2457	27	5	7	120	7	4.5
15_R	y	9	8	649	51.5922	51.59503	3.2625	3.25025	25	5	7	120	7	5.6
16_C	y	9	8	741	51.59238	51.59523	3.23945	3.22822	20	5	8	120	7	6.4
17_R	y	9	8	812	51.59697	51.60115	3.2438	3.2331	17	5	8	114	7	7
18_C	y	9	8	902	51.59647	51.59855	3.22655	3.22265	20	5	9	112	7	7.8
19_R	y	9	8	925	51.60012	51.60355	3.23157	3.22575	20	5	9	110	7	8.2
20_C	y	9	8	951	51.59977	51.60193	3.2206	3.2177	21	4	10	110	4	8.6
21_R	y	9	8	1009	51.60512	51.60765	3.22402	3.22147	20	6	10	110	4	8.9
22_C	y	9	8	1022	51.60487	51.60073	3.21562	3.21917	23	4	11	110	2	9.1
23_R	y	9	8	1054	51.60867	51.60345	3.2199	3.22553	23	4	11	110	4	9.6
24_C	y	9	8	1252	51.64392	51.64922	3.17492	3.16797	24	5	12	108	2	11.6
25_R	y	9	8	1337	51.64647	51.65327	3.182	3.1785	23	5	12	110	4	0.1
26_C	y	9	8	1436	51.65302	51.65833	3.16423	3.16468	30	5	13	90	4	1.1
27_R	y	9	8	1511	51.65418	51.66103	3.17185	3.16655	24	5	13	95	4	1.7
28_C	y	9	9	553	51.58142	51.58448	3.28322	3.27078	22	5	14	220	7	4.1
29_R	y	9	9	633	51.5853	51.5883	3.28783	3.27748	22	5	14	220	7	4.7
30_C	y	9	9	717	51.58543	51.58835	3.27	3.25602	18	5	15	220	7	5.5
31_R	y	9	9	817	51.5887	51.59273	3.2741	3.2624	18	5	15	230	7	6.5
32_C	y	9	9	934	51.58965	51.59172	3.25205	3.24277	26	5	16	240	7	7.8
33_R	y	9	9	1003	51.59598	51.59725	3.24705	3.23925	17	5	16	240	7	8.3
34_C	y	9	9	1040	51.59385	51.59198	3.23333	3.24288	19.5	5	17	240	7	8.9
35_R	y	9	9	1101	51.59888	51.59697	3.23353	3.24388	17.5	5	17	240	7	9.2
36_C	y	9	9	1215	51.59728	51.59365	3.22508	3.2336	20	5	18	240	4	10.5
37_R	y	9	9	1238	51.60265	51.59838	3.2272	3.23612	22	5	18	240	4	10.8
38_C	y	9	9	1308	51.5984	51.60145	3.22282	3.21817	23	4	19	240	4	11.3
39_R	y	9	9	1325	51.60463	51.60722	3.22227	3.22273	23	4	19	240	4	11.7
40_C	y	9	9	1344	51.60295	51.60682	3.21698	3.21395	25	5	20	240	2	11.9
41_R	y	9	9	1402	51.6063	51.61388	3.22288	3.21928	21	5	20	240	4	12.2
42_C	y	9	9	1447	51.60935	51.6155	3.20845	3.21022	24	5	21	240	4	0.7
43_R	y	9	9	1508	51.61205	51.6191	3.22098	3.217	22	5	21	240	4	1
44_C	y	9	9	1528	51.6152	51.62227	3.21043	3.20358	24	5	22	240	4	1.4
45_R	y	9	9	1610	51.6184	51.62418	3.21645	3.21095	23	5	22	240	4	2.1
46_C	y	9	10	520	51.640183	51.64508	3.17988	3.17322	23	5	23	211	7	2.9
47_R	y	9	10	549	51.64075	51.64573	3.19003	3.18262	23	5	23	211	7	3.4
48_C	y	9	10	614	51.6456	51.64835	3.17255	3.16538	23	5	24	210	7	3.8
49_R	y	9	10	645	51.6489	51.65488	3.17832	3.17178	23	5	24	210	7	4.3

Trawl duration of the pairs compared.

Pair	4	5	6
1		1	1
2		2	
3		2	
4	2		
5		2	
6		1	1
7		2	
8		2	
9		2	
10	1		1
11	2		
12		2	
13		2	
14		2	
15		2	
16		2	
17		2	
18		2	
19	2		
20		2	
21		2	
22		2	
23		2	
24		2	

Fishing depth (water depth at the time of fishing) in meters of the pairs (1-24)

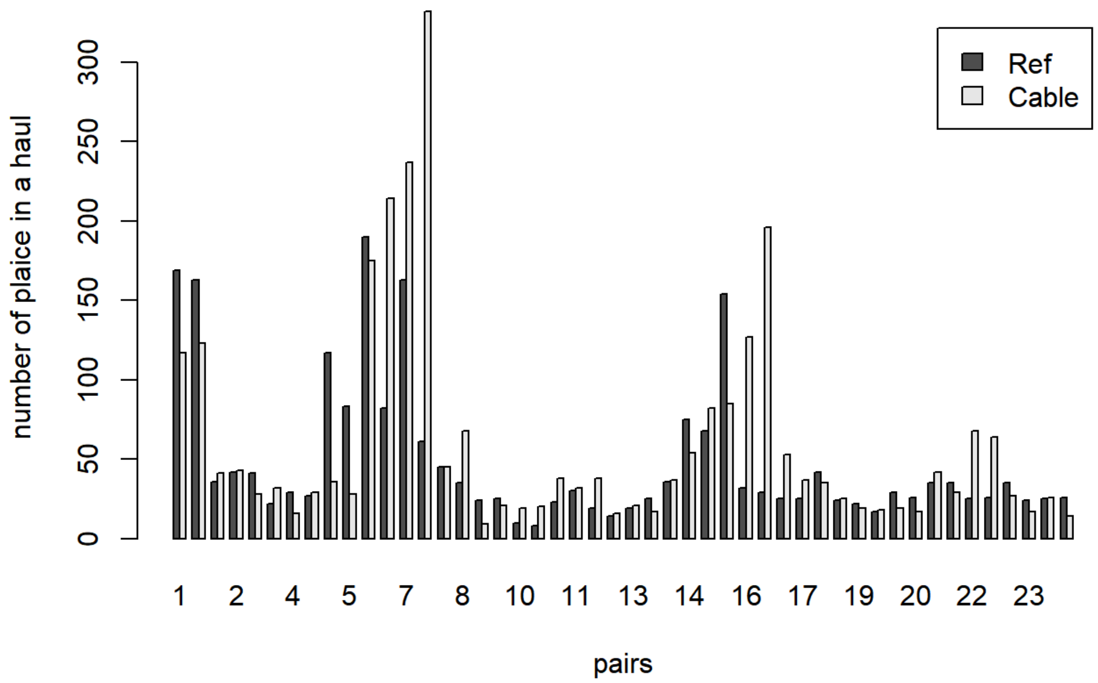
Pair	10	12	13	17	17.5	18	19.5	20	21	22	23	24	25	26	27	30
1	2															
2	1	1														
3		1	1													
4						2										
5											1	1				
6																2
7													1		1	
8				1				1								
9								2								
10								1	1							
11											2					
12											1	1				
13												1				1
14										2						
15						2										
16				1										1		
17					1		1									
18								1		1						
19											2					
20									1				1			
21										1		1				
22											1	1				
23											2					
24											2					

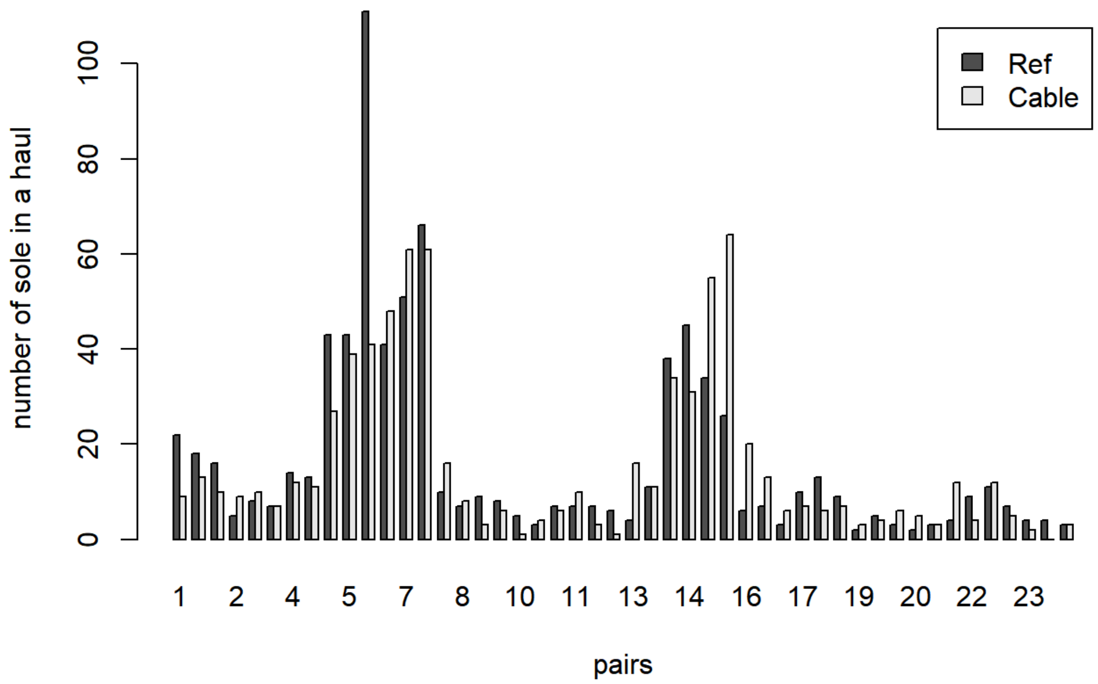
Annex 2 Benthic species composition

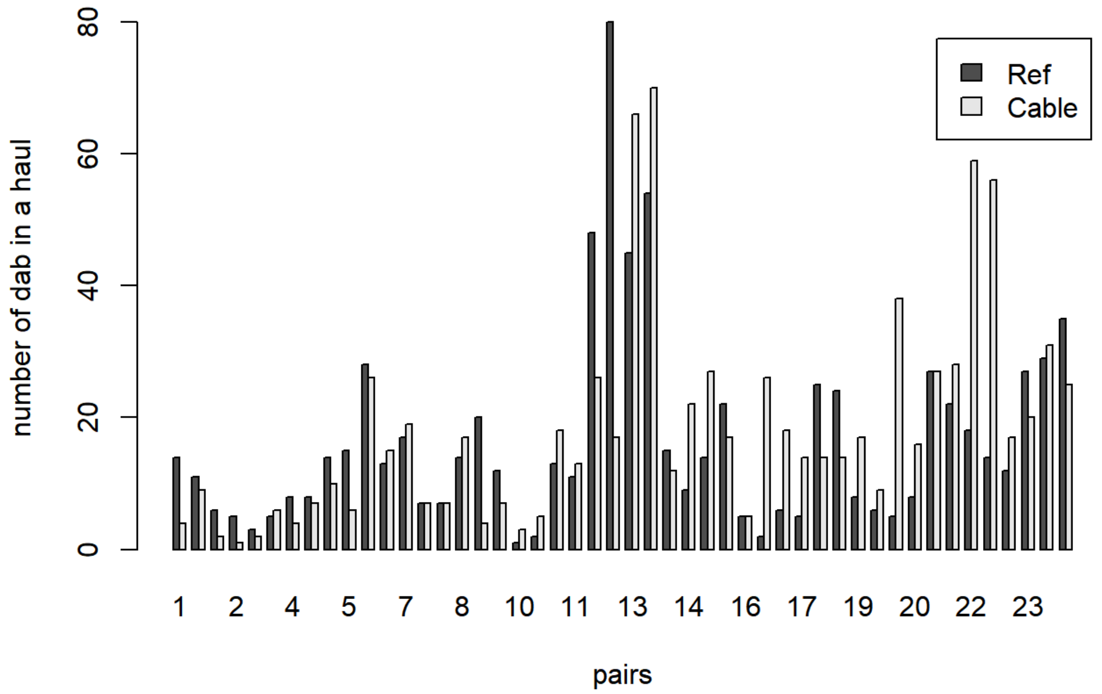
Scientific name	**Number**
Ophiura ophiura	290162
Asterias rubens	71311
Liocarcinus sp.	65570
Psammechinus miliaris	9816
Spisula sp.	5788
Nassarius reticulatus	5110
Pagurus bernhardus	3260
Crepidula fornicata	2960
Alcyonium digitatum	2288
Crangon crangon	2002
Natica sp.	1952
Macropodia rostrata	1694
Echinocardium cordatum	1544
Diogenes pugilator	854
Loligo sp.	661
Mytilus edulis	520
Liocarcinus marmoreus	490
Necora puber	256
Anthozoa	241
Buccinum undatum	81
Ensis sp.	77
Maja squinado	57
Pagurus sp.	36
Sepia sp.	34
Neptunea antiqua	32
Sepiola sp.	15
Cancer pagurus	14
Thia scutellata	8
Portumnus latipes	3
Modiolus modiolus	2
Homarus gammarus	1
Liocarcinus vernalis	1
Holothuroidea	1

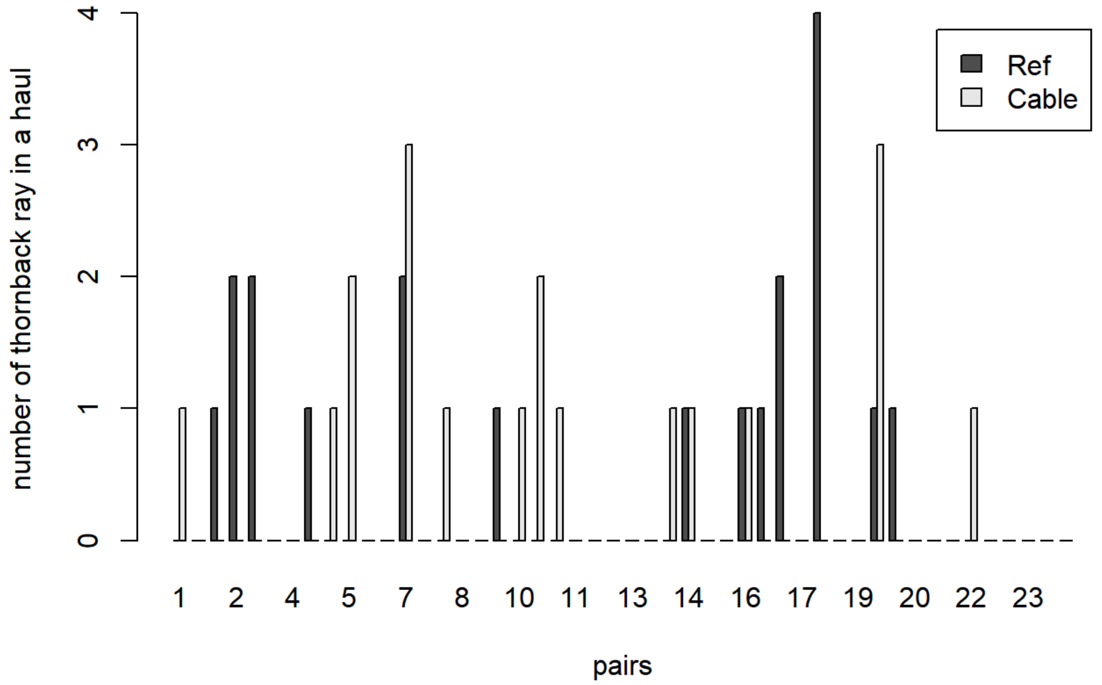
Annex 3 Catches by species

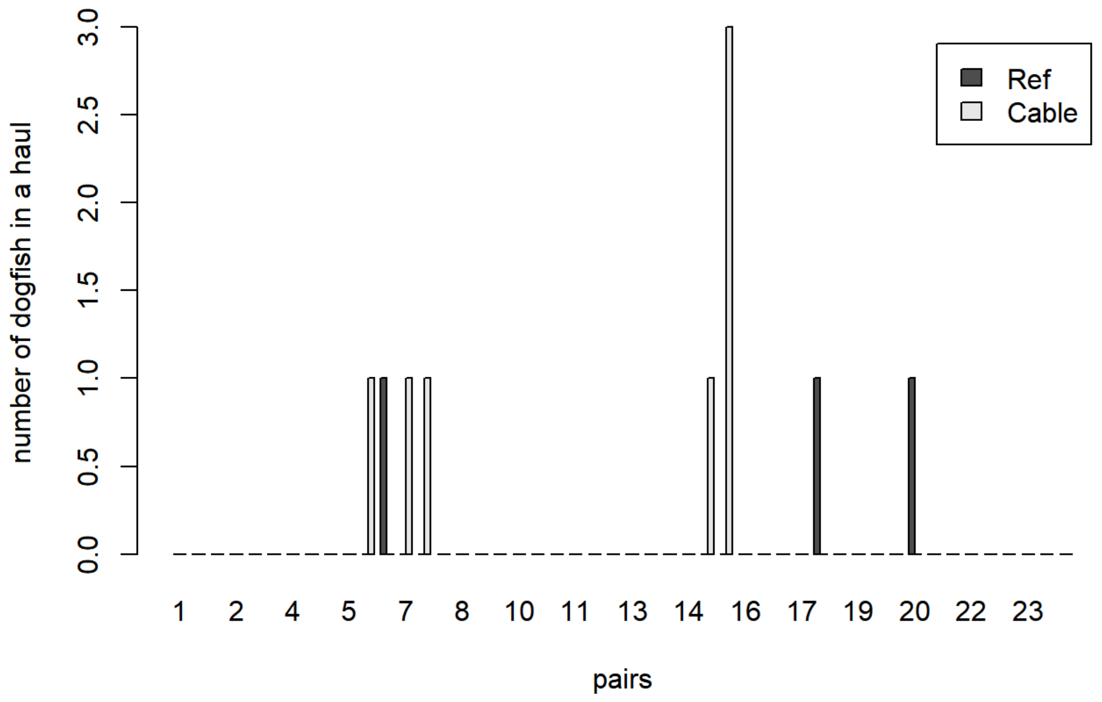
The catches in number of the species per haul for both gear separately presented by pair.

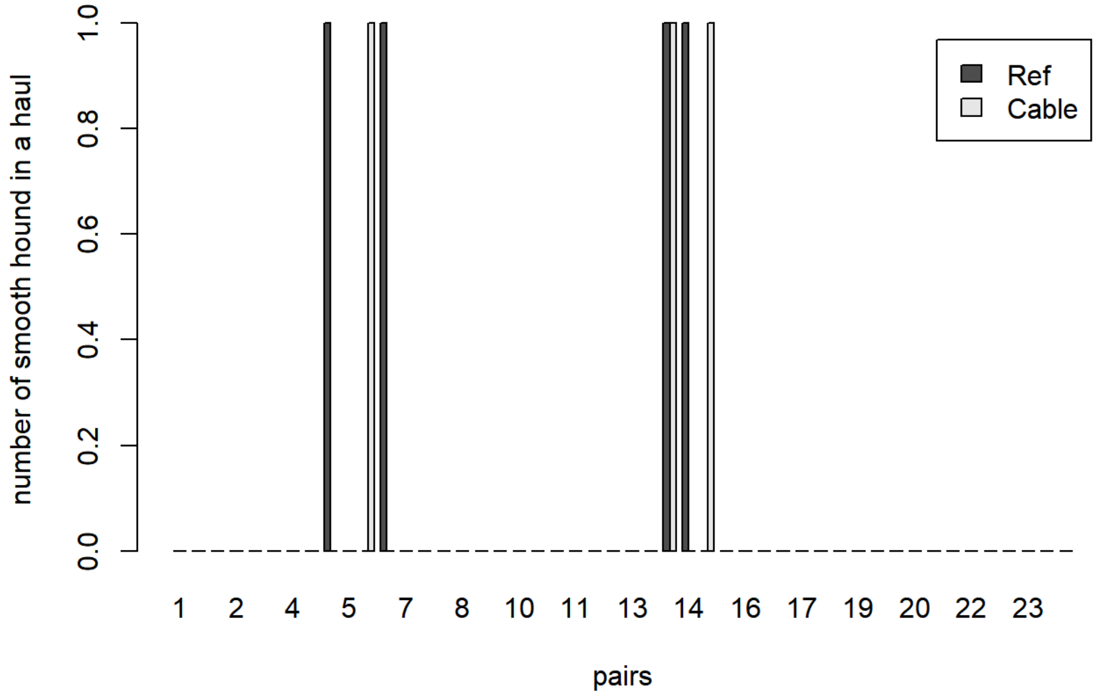


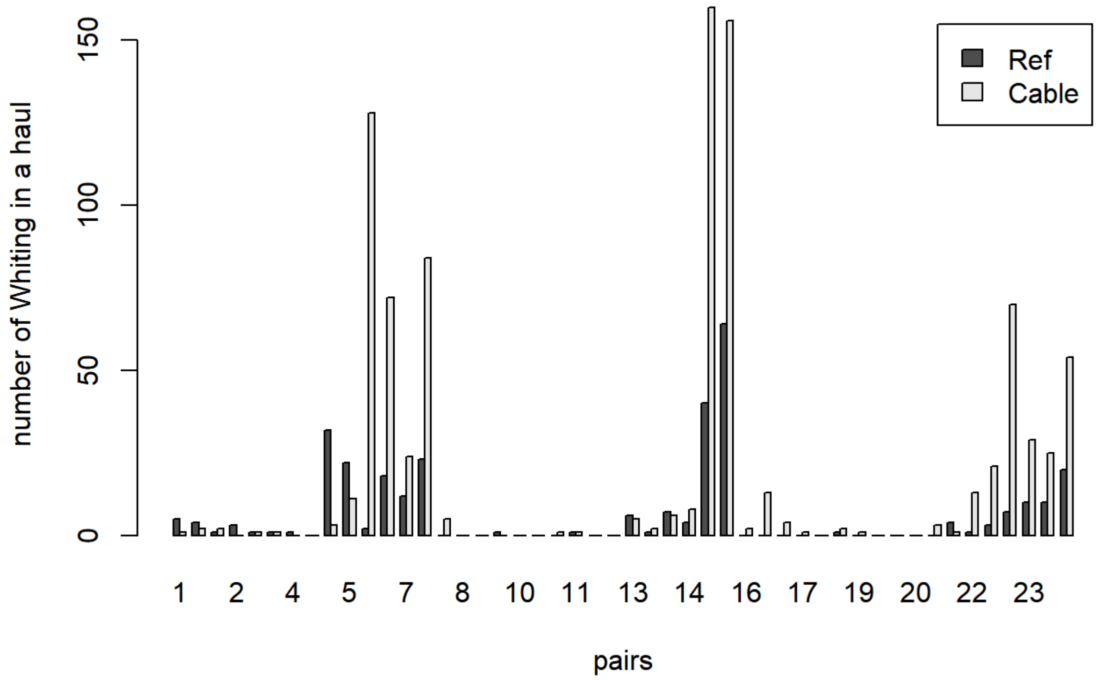


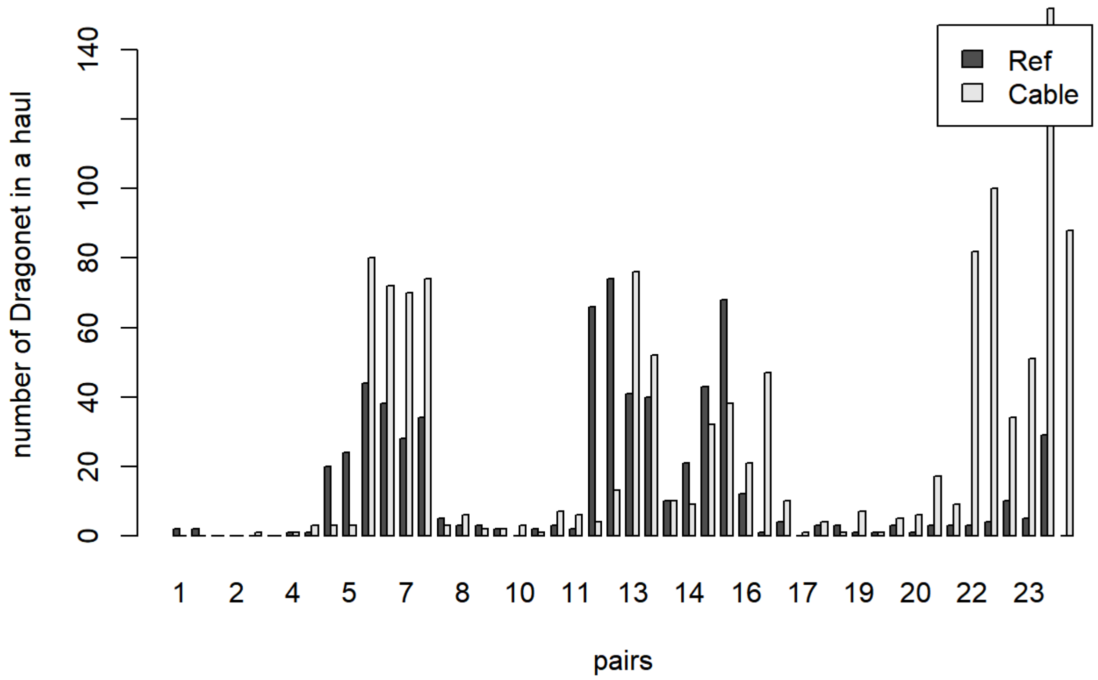

number of dab in a haul
0
20
40
60
80
Ref
Cable
1
2
4
5
7
8
10
11
13
14
16
17
19
20
22
23
pairs


number of thornback ray in a haul
0
1
2
3
4
Ref
Cable
1
2
4
5
7
8
10
11
13
14
16
17
19
20
22
23
pairs


number of dogfish in a haul
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Ref
Cable
1 2 4 5 7 8 10 11 13 14 16 17 19 20 22 23
pairs


number of smooth hound in a haul
0.0
0.2
0.4
0.6
0.8
1.0
Ref
Cable
1 2 4 5 7 8 10 11 13 14 16 17 19 20 22 23
pairs


number of Whiting in a haul
0
50
100
150
Ref
Cable
1
2
4
5
7
8
10
11
13
14
16
17
19
20
22
23
pairs


number of Dragonet in a haul
0
20
40
60
80
100
140
Ref
Cable
1
2
4
5
7
8
10
11
13
14
16
17
19
20
22
23
pairs

Annex 4 Updated EMF-figure

For trawl 20, Waterproof was provided the wrong start time of the haul. After their memo (Snoek 2021) this was corrected, which resulted in a corrected figure. The x and y sensor indicate in the figures on the right that for a part of the trawl the EMF was detected.