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The first passive fishing effort as a form of co-use in an offshore windfarm in the Netherlands

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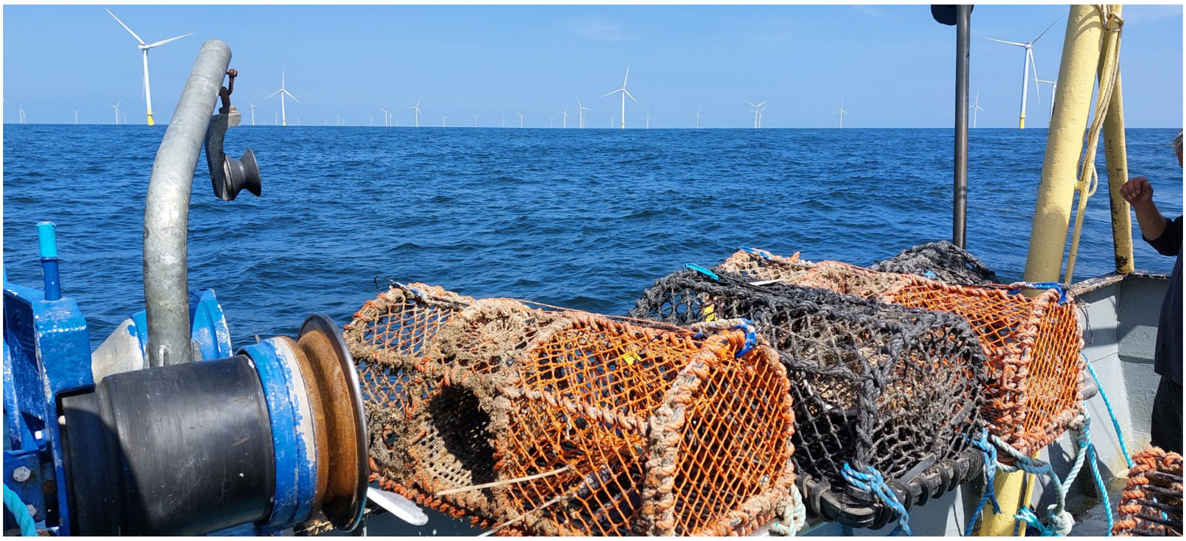

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Summary

Introduction

Upscaling offshore wind, decreasing space for fisheries

Offshore wind farms (OWFs) are a source of renewable energy, providing a sustainable alternative to fossil fuels. In the Dutch North Sea OWFs are rapidly expanding and will expand more, taking up space traditionally used for fishing. To address this concern, the concept of co-use of passive fisheries in offshore wind farms could emerge as an alternative for part of the fishers.

To enable co-use, an area passport guide has been published for Borssele OWF, indicating which forms of co-use are preferred in different zones of the offshore wind farm[1]. The south-eastern area of Borssele (OWF Borssele II) has been indicated as the most promising for passive fishing, due to its relatively shallow seabed and relatively short distance from the coast.

To determine the potential of passive fisheries in OWFs in the future, several research projects have been established that are an experimental form of co-use fisheries. This study investigated the potential of brown crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*) pot fisheries (gear code FPO) in Borssele II and the risks thereof to the OWF and the fisheries. During the research, velvet swimming crab (*Necora puber*) also appeared of interest as a target species. The goal was to compare the catch statistics such as Catch Per Unit Effort (CPUE) and Landable Catch per Unit Effort (LPUE) in Borssele II (referred to as Borssele II 2022 experiment) with those of results of experiments in OWF Prinses Amalia Windpark (referred to as PAWP 2023 experiment), to get an idea of the influence of the maturity of the anti-scouring associated communities in the longer existing PAWP (officially opened in 2008, last monopile installed in 2007) compared to the recently built OWF Borssele II (officially opened in 2021, last monopile installed in 2020). It was also attempted to estimate the population sizes of brown crab and European lobster.

The potential risk of damage to the OWF infrastructure from crab-pot-strings and their anchors is important and therefore also the subject of research. The potential mobilization of crab-pot strings was studied under different sea conditions.

Results

Displacement of the crab-pot-strings

The use of dahns (buoys with marker flags) can lead to safety issues. It is mandatory by EU fishing legislation to use dahns as the end markers of a crab-pot-string. However, these make a crab-pot-string unstable because waves and currents have a lot of grip on the dahn. The haul out indicator serves as an early warning signal to take out crab-pot-strings when conditions are not suitable for crab-pot-string fisheries in an OWF. It has been proposed as a safety measure to prevent that crab-pot-strings are mobilised in the OWF.

Based on our measurements it seems that the anchorsand crab-pot-strings were stable even under 9 Bft winds (from the south east) and a haul out indicator[2] level of 684 cm, where 445 cm was considered to be the threshold level. This seems to suggest the threshold can be increased. However, given the high uncertainties of the measurements, more experience, more data of higher accuracy and evaluation are needed to interpret the results.

Comparing catch statistics (CPUE, LPUE) and population size

The catches of brown crab, European lobster and velvet swimming crab were determined in the form of CPUE and LPUE. Also bycatch of other species was determined.

[1] https://windopzee.nl/onderwerpen/wind-zee/landingspagina-0/meervoudig-gebruik/ (read 19-10-2023)

[2] Haul out indicator: an early warning signal based on predictions of extra water level to NAP, significant wave height and swell. At a certain threshold level is predicted, the crab-pot-strings need to be removed keeping good seamanship in mind.

Brown crab: with a CPUE of 0.08 to 0.2 and a LPUE from 0.01 to 0.05 brown crab per pot per day the results of present study are on the very low side as compared to (international) literature. The CPUE and LPUE of this Borssele II 2022 experiment were much lower than those of the PAWP 2023 experiment. The CPUE and LPUE of brown crab were influenced by different factors. E.g. the LPUE of brown crab in the Borssele II 2022 experiment were influenced by soaking time and location (ridge or valley) and not by pot type (Medley, Parlour) or pot order (south to north). In PAWP 2023 experiment the LPUE of brown crab was influenced by soaking time and by pot type (Medley, Parlour) but not by pot order. The location was not a relevant variable for PAWP (all flat seabed of more or less the same depth).

The recaptures from the Catch : Mark : Recapture experiment were too low to estimate population size.

European lobster: In total, eight European lobsters were caught during the Borssele II 2022 experiment, of which at least seven were landable, one undetermined. This number was too small for determining CPUE, LPUE or population size. In the PAWP 2023 experiment five European lobsters were caught, all larger than the MLS (minimum landing size), four males and one undetermined. These results were alike.

Velvet swimming crab: Relatively high catches of velvet swimming crab were found. With a short soak time a CPUE 0.7 – 1.5 velvet swimming crab was measured which decreased exponentially to a ~0.02 – 0.04 velvet swimming crab with increasing soak time. The CPUE of the PAWP 2023 experiment started high at 4.66 crab per pot per day and lowered to 0.18 The CPUEs for the Borssele II 2022 experiment were clearly lower. In both cases the CPUEs reduced in time. In the Borssele II 2022 experiment soaking time, pot type and location were significant variables, pot order not. In the PAWP 2023 experiment soaking time and pot type were significant variables.

The LPUE in the Borssele II 2022 started at ~0.75 lowering to 0.1 landable velvet swimming crab per day. In the PAWP 20123 experiment started at 3.48 lowering to 0.16 landable velvet swimming crab per day.

In summary, in the Borssele II 2022 experiment, the CPUE and LPUE for both brown crab and velvet swimming crab were much lower than the CPUE and LPUE for both brown crab and velvet swimming crab found in PAWP in 2023. This difference could be caused by the age of the OWF and maturity of the sessile and mobile benthos communities on the scour protection layer. In time more benthic flora and fauna can colonize the hard substrate and other species including crab species, could be attracted. The long period PAWP has been closed for fisheries also provided more time without disturbance for development of benthic communities in the soft sediment and for the population of brown crabs. However, there are also alternative explanations not related to the age of the OWFs such as differences in area and particular circumstances during the year of performing the experiment. A spill over[3] impact for the higher brown crab densities in PAWP may have occurred which was less likely for the Borssele II experiment, due to the larger distance from the crab-pot-strings to the anti-scouring.

Bycatch
Bycatch was low in general, mostly velvet swimming crab and brown crab were caught. Next to these two species and European lobster a total of 18 other species were caught in low numbers (in total 21 species). Other species caught were striped red mullet *(Mullus surmuletus*, 15 in total), pouting (*Trisopterus luscus*), common cuttlefish (*Sepia officinalis*, seven in total), Atlantic cod (*Gadus morhua*) and bull rout (*Myoxocephalus scorpius*). In PAWP only 11 species were caught but in higher numbers , e.g. 39 sepias were caught.

Weather
The weather conditions give the basic data in order to evaluate the safety measures for the mobilisation of the crab-pot strings. The weather conditions were rather rough in the summer of 2022.

[3] Spill over mechanism: individuals of a certain species migrate from a specific area with higher production of that species to neighbouring areas. The production of that specific species could be higher e.g. due to reduced fisheries or enlarged opportunities for shelter and increased food availability.

With 6 out of 9 periods in between expedition days with 7Bft or higher, the sea was rough with high waves. The used vessel, YE152 with its length of 9.95 m, appeared sensitive to the resulting waves and swell leading to substantial down time.

Concluding

This experiment was the first experiment of co-use passive fisheries with crab-pots in an OWF, thereby it has obtained valuable data on what can be caught in an OWF. It has also generated more experience on working and performing passive fisheries in an OWF. The experience can be used for evaluations on the policy of passive fisheries of brown crab and other species in OWFs.

Recommendations have been made to improve the catches and to improve risk mitigation. The main recommendations are:

- The executing fisher is responsible for minimizing the loss of fishing gear. It is mandatory to use dahns (buoys with marker flags) as the end markers of a crab-pot-string. However, these make a crab-pot-string unstable because waves and currents have a lot of grip on the dahn. Especially if the weather conditions are bad for long periods, there is a risk of the dahn disappearing or the material being pulled underwater. Safety can potentially be improved by exploring whether stability of the dahn can be increased. This is an alternative measure for the haul out indicator combined with the translocation of the crab-pot strings when storms and high waves are anticipated.
- Two experiments have now been conducted of each ten days on crab-pot-fisheries. A more representative experiment representing complete fishing season can provide more insight in the economic considerations of a realistic fishing season. In addition, more tests give a better insight in the annual variability. To reduce costs for crab fishing, the frequency of emptying pots could possibly be reduced. It would be favourable to have bait that lasts longer. The crab pots will keep on catching, increase number of crabs and European lobster.
- Crab-pot strings are placed parallel to the current for safety reasons (higher location certainty during release of the crab-pot strings and less surface area in the mobilising current). However, the crab-attracting bait plumes are much wider when the crab-pot-strings are placed perpendicular to the current. Thus, higher catches are expected. Both risks and catches associated with placing the crab-pot-strings in this way need to be assessed.
- From south to north up to the German Bight, brown crab densities increase. The question arises whether this is also the case in the OWFs. It is worth doing an exploration to the northern areas (west of Gemini and Doordewind) to explore the market potential.
- The measurement method for determining the position of the Bruce anchors needs improvement.
- It seemed that the crab-pot-strings are quite stable even with a level of haul out indicator ~50% higher than the agreed threshold. This raises the suggestion that the threshold of the haul out indicator could be higher.

1 Introduction

1.1 Decreasing space for fisheries

Fisheries on the North Sea experience serious problems (e.g. high fuel prices, Brexit, loss of fishing grounds). One of the causes is the progressing need for space by offshore wind farms (OWFs). OWFs are a source of renewable energy, providing a sustainable alternative to fossil fuels. In the Dutch North Sea OWFs are rapidly expanding and will expand more[4]. The ambition is to have realised 21 GW (4.5% of the area of the North Sea) by 2030 and between 38 GW to 72 GW in 2050[4]. However, they also have the potential to impact marine ecosystems and the fishing industry, which traditionally occur in these areas. To address these concerns, the concept of co-use and co-location of passive fisheries in offshore wind farms has emerged as an opportunity for a number of the fishers (Cramer et al., 2015). This approach of co-use also involves other activities such as aquaculture, recreation and nature conservation[5] (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). To enable co-use it is necessary to explore the potential and implications for co-location of passive fisheries (and the other activities). Cramer et al. (2015) made a first inventory and concluded that passive pot-fisheries (gear code FPO[6]) on brown crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*) would have the highest potential for fishing in OWFs. The velvet swimming crab (*Necora puber*) could also be a commercial species of interest (Rozemeijer et al., 2021).

4 https://windopzee.nl/onderwerpen/wind-zee/wanneer-hoeveel/ (read 19-10-2023)
5 https://windopzee.nl/onderwerpen/wind-zee/landingspagina-0/meervoudig-gebruik/ (read 19-10-2023)
6 https://fish-commercial-names.ec.europa.eu/fish-names/fishing-gears_nl (read 23-10-2023)

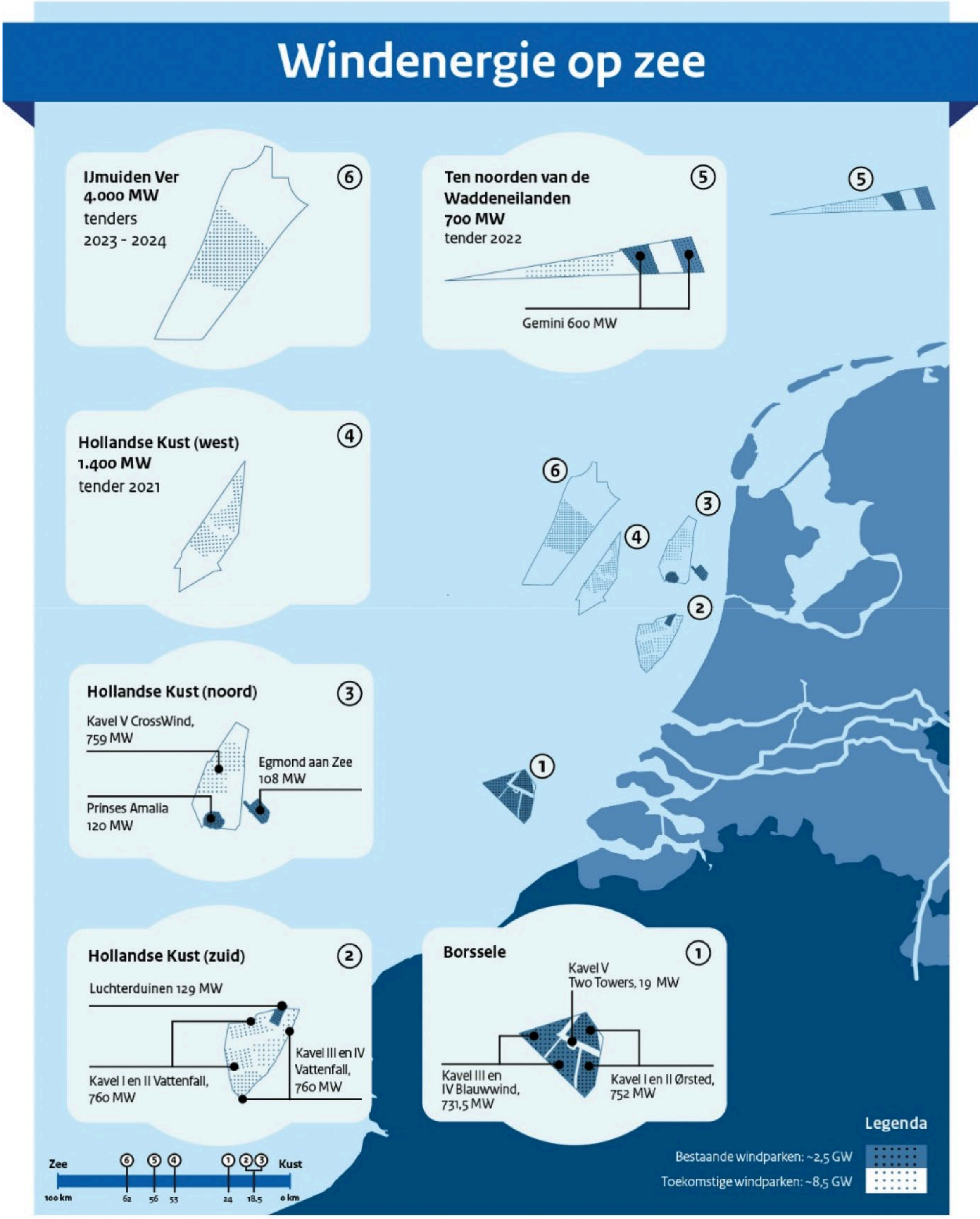

Figure 1. The position of Borssele II Wind park along the Dutch coastline[7]. It is integrated in the larger wind park Borssele. The south east park is Borssele II. The multi coloured picture right below gives the co-use zones. The dark blue zone is the passive fisheries experiment zone. (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020).

7 Windenergie op zee | Duurzame energie | Rijksoverheid.nl (read 19-12-2023)

1.2 Co-use of OWF Borssele

To enable co-use (co-location[8]), an ‘Area Passport’ guide has been published for Borssele OWF (*Figure 2*), indicating which forms of shared use are preferred in different zones of the park. Besides mariculture, sustainable energy generation and storage, and nature-promoting projects, passive fishing in Borssele has also been designated a specific area (*Figure 3*, Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). The south-eastern area of Borssele (OWF Borssele II) has been indicated as the most promising for passive fishing, due to its relatively shallow seabed and relatively shorter distance from the coast.

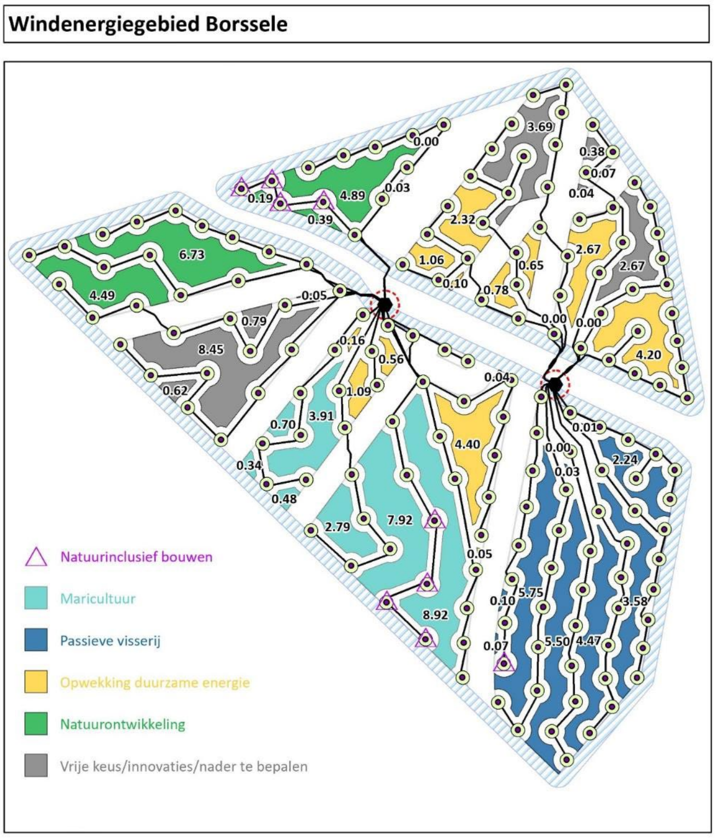

Figure 2. Co-use of Borssele Wind park. Natuurinclusief bouwen = Nature-inclusive construction (Δ violet). Maricultuur = Marine aquacultuur (light blue); Passieve visserij = Passive fishing (dark blue); Opwekking duurzame energie = Generation of renewable energy (yellow); Natuurontwikkeling = Nature development (green); Vrije keus/innovaties/nader te bepalen = Free choice/innovation/to be determined (grey) (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020).

1.2.1 Research projects on passive fisheries within OWFs

To determine the potential of passive fisheries in offshore windfarms in the future, preliminary studies have been performed (see e.g. Cramer et al., 2015). In addition several research projects have been established that are an experimental form of co-use fisheries. The following experimental fisheries projects are running in parallel:

1. The project “Win-Wind” (financed by TKI Wind op Zee) investigated the possibilities of crab and European lobster pot fisheries in Prinses Amalia Wind Park (PAWP). This project ran from 1-1-2019 till 1-12-2023. It focusses on safety, catch statistics of brown crab and European lobster in PAWP, ecology, economics and transition. A major topic was safe fishing in an OWF

[8] Schupp et al. (2019) define categories of multi-use. Passive fisheries share Space and Time with an OWF, but not Provisioning or Functional services more thereby qualifying it as co-location.

(risk evaluation and mitigation). An overview of the results and downloads (reports etc.) of Win-wind can be found at the WUR website[9]. The results of this project are referred to as ‘PAWP 2023’ (Rozemeijer et al., 2023).

2. The study ‘Damage by anchors’ (Rozemeijer et al., 2022a) was financed by the Ministry of Agriculture, Nature and Food quality. This was initiated parallel to Win-Wind in order obtain extra data on safety and risk. In this study it was investigated what the potential damage could be when the used Bruce anchors hit an infield cable, and concluded that the Bruce anchor only caused a superficial bruising of the outer layer, no real damage. In addition, adapted Bruce anchors with anti-hook-in-devices were tested but these proved not to be useful, preventing the actual anchoring.
3. Chance of crab-pot-string mobilisation (*Figure 3*, Scheveningen study, Rozemeijer et al., 2021, financed by Ministry of Agriculture, Nature and Food quality). This was initiated parallel to Win-Wind in order to obtain extra data on safety and risk. Here the chance that crab-pot-strings are mobilised and move under different weather and sea conditions was investigated. In addition the Catch per Unit Effort (CPUE) and the Landable Catch per Unit Effort (LPUE) were determined for brown crab and velvet swimming crab.
4. The project called “Passive fisheries” investigates other forms of passive fisheries in Borssele II like gill nets, pots for other target species than crab, mechanical jigging and rod and line fisheries. This project consists of a desk study (Neitzel et al., 2023a) and experimental testing with different gears (Neitzel et al., 2023b). Both parts are financed by Ministry of Agriculture, Nature and Food quality. The testing phase started in April 2023.

1.3 Knowledge gap

There is a lack of knowledge on the catch of brown crab and European lobster in OWFs and the risks thereof to the OWF and the fisheries.

Fishing, working and manoeuvring inside OWFs are different from outside on the North Sea. There are additional conditions and requirements to allow activities in OWFs. Knowledge is needed of the risks that can occur, for example, how to prevent crab pot-strings mobilization in areas with wind turbines and high-voltage cables in the seabed. Describing and reducing operational risks to fishing activities in OWFs is a priority from a safety and liability perspective. It is mandatory to use dahns (buoys with marker flags) as the end markers of a crab-pot-string (*Figure 3*). However, these make a crab-pot-string unstable because waves and currents have a lot of grip on the dahn. In Rozemeijer et al. (2021, 2022a) it was established crab-pot-strings could be deployed with a risk of 1 (on a scale 1-25) with Bruce anchors up to 8 Bft and wind direction 222° (South West) in combination with dahns. More experience is needed to support this finding. The PAWP 2023 experiments yielded experience with the safety measures (Rozemeijer et al., 2023). More practical experience is needed to generate knowledge on passive fisheries in OWFs. For the Ministry of LNV and Rijkswaterstaat, this knowledge is relevant in the light of developing future policy for co-use of OWFs.

In addition, an understanding of how many crabs and lobsters could be caught in OWFs is needed to estimate whether fishing can be profitable. The age of the OWF and thereby maturity of the hard and soft substrate communities may influence the CPUE and LPUE. To take this into account CPUEs and LPUEs of Borssele II (a new OWF with initiating hard substrate benthic communities) will be compared to the CPUEs and LPUEs that were determined in PAWP which was opened in 2008 (Rozemeijer et al., 2023).

[9] Win-Wind - WUR (Seen at 20-10-2023)

1.3.1 Research questions

The Ministry of Agriculture, Nature and Food Quality has requested this research project in OWF Borssele II to obtain more knowledge on passive fishing as a form of multi-use and to learn about the influence of the age of the OWF on the fisheries activities. The research questions of this project with experimental passive fisheries are:

1. Are the crab-pot-strings in a set-up of five pots mobilised under summer weather and hydrological conditions when anchored with two Bruce anchors of 15 kg each?
2. How do these mobilisation results compare with the 2023 PAWP results and with the results obtained in 2021 in the vicinity of Scheveningen (Rozemeijer et al., 2021)?
3. Do the results lead to adjusting safety measures for PAWP or Borssele II?
4. Is it possible to catch brown crab and European lobster in Borssele II?
5. What are CPUE, LPUE of brown crab and European lobster and what percentage of tagged animals was recaptured in Borssele II?
6. How do these results (CPUE, LPUE and recatch percentage) compare to the results found in PAWP in 2023 (keeping in mind there are differences in time, location and fishing practices) ?
7. What is the estimated population size of brown crab and European lobster at Borssele II?
8. What is the bycatch in Borssele II when using crab-pot-strings with Medley pots and Parlour pots?

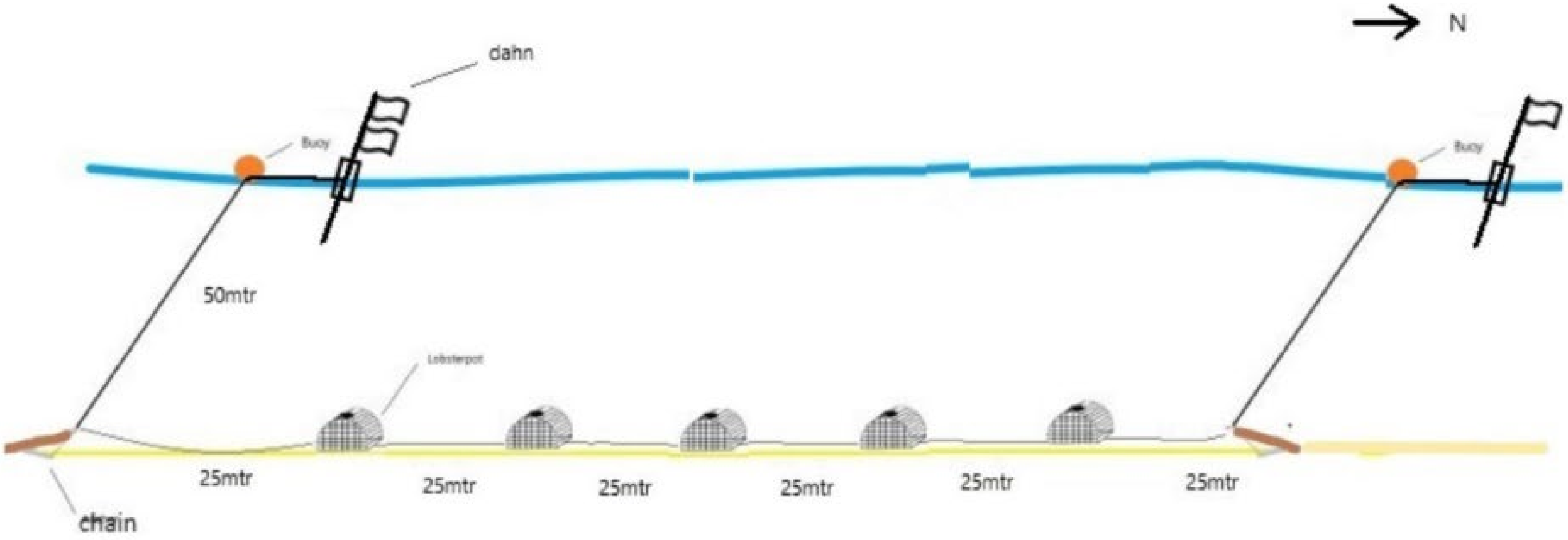

Figure 3 Crab-pot-strings with five pots and two chains (serving as anchoring). A dahn is attached (buoy with flag(s), counterweight, flashlight and radar reflector) next to the buoy. The double flag means the most southern buoy of the string. A single flag signs the most northern buoy. In this set up mutual distance between the pots is 25m. The buoy anchor line is 2 to 3 times the local water depth (Rozemeijer et al., 2020, Rozemeijer, 2023).

1.4 Reading guide

Materials and methods are described in chapter 2. In chapter 3 The weather conditions during the experiments are described. These results were basic data to answer the research questions 1 to 3. The potential mobilisation of the crab-pot-strings under different weather conditions is described in chapter 4 answering research questions 1 to 3. The catches of brown crab, European lobster, velvet swimming crab and other species are given in chapter 5 answering research questions 4 to 8. The discussion is given in chapter 6. Chapter 7 gives the conclusions and recommendations.

1.4.1 The interconnectivity between the Borssele II 2022 experiment and the PAWP 2023 project.

As a result of the Beleidsnota (policy memorandum) Noordzee 2016-2021 it was decided to open the existing wind farms OWEZ, PAWP and Luchterduinen (except Gemini) for vessels smaller than 24 meters and the use of a fishing rod was also allowed (Staatscourant 2018, 22588[11]). Furthermore it was agreed on that an experiment with passive fishing would take place in either PAWP, OWEZ or Luchterduinen in cooperation with the wind farm owner. To enable this form of co-use, Topconsortium voor Kennis en Innovatie Wind op Zee (TKI) issued a grant programme on co-use and financed the Win-Wind project proposal[10]. Eneco was willing to participate in this Win-Wind proposal to come such a co-use experiment. As a result a document with conditions for such an experiment was drawn up in cooperation with Eneco, the coastguard, the Ministry of LNV and Rijkswaterstaat Zee en Delta. The document was published in the Staatscourant (2019, 42365[11]). The Win wind project got elected to carry out the experiment in PAWP (Staatscourant 2019, 50033[12]). The Win-Wind project was the first implementation in the field of co-use passive fishing.

OWFs offer amounts of hard substrate like the wind turbines and anti-scouring. Hard substrate is very interesting for brown crab because the epibenthic and benthic communities (potential prey items) on hard substrates have a higher biomass and higher biodiversity (Kerckhof et al., 2019, Coolen et al., 2020, Degraer et al., 2020, Ter Hofstede et al., 2022). In addition the crevices and rocks offer shelter for the brown crab (Tonk & Rozemeijer, 2019). PAWP represents an older OWF. The construction started in 2006 and PAWP opened in 2008. The installation of Borssele II was finished in 2021. It can be expected that the communities on the hard substrates in PAWP will be in a climax community[13] with more species and higher biomass as compared to Borssele II. Two years after installation in Borssele II, these hard and soft substrate communities are still starting to develop (Kerckhof et al., 2019, Coolen et al., 2020, Degraer et al., 2020). Also the directly surrounding soft seabed around the wind turbine is anticipated to have more biomass (Degraer et al., 2019, 2020, Mavraki et al., 2020, 2021). This would offer more prey (both in numbers and species) for brown crab. It is therefore also anticipated that the densities of brown crab will be higher (Bouma & Lengkeek, 2012, 2013, Krone et al., 2017, Stelzenmüller et al., 2021, Ter Hofstede et al., 2022). The anti-scouring offers a preferred habitat for the brown crab (Krone et al., 2017, Tonk & Rozemeijer, 2019, Ter Hofstede et al., 2022). It would add in practical experience and knowledge on passive fisheries in OWFs to compare catches of PAWP with Borssele II to yield more information on catch potential in relation to circumstances. In the original set up it was the intention to start the PAWP catch experiment in 2022, parallel to the Borssele II 2022 experiment. However practical issues caused that the PAWP catch experiment was delayed till 2023 and reported in 2023 (Rozemeijer et al., 2023).

10 The consortium Win-Wind exists oft Stichting Wageningen Research (Wageningen Marine Research and Wageningen Economic Research) and a fisheries cluster of Cramer Noordwijk Beheer BV (Rems Cramer), Noordzee Charters (Arjan Korving) and Rederij W. van der Zwan & Zn BV.

11 Staatscourant 2019, 22588 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)

12 Staatscourant 2019, 50033 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl) and the later contract

13 A climax community is the “endpoint” of succession within the context of a particular climate and geography.

2 Materials and Methods

In an abbreviated overview (to be detailed in later sections), the set-up was that nine crab-pot-strings were placed in Borssele II OWF (*Figure 3*, *Figure 4*). Four strings were placed on the ridges of the sandbanks and five strings in the valleys between the sandbanks. The positions were registered at deployment and at set times strings were lifted and positions registered again to determine displacement. The pots were emptied, baited and deployed. The caught brown crab and European lobsters were tagged and released upstream for recapture. Bycatch was registered as well.

Data on water and weather conditions were obtained from Rijkswaterstaat and where needed related to the displacement of the crab-pot-strings. Data on water and weather are also valuable data to estimate the workable days for a small fisheries vessel.

The catch data were used for increase in catch number versus soaking time (time the crab-pot-strings were submerged in the water) and catch per unit effort (CPUE, is number of crabs per pot per day) determination. Catch: Mark: Recapture data on European lobsters and brown crab were obtained to statistically estimate population size in case of sufficient recaptures (Chen & Rozemeijer, 2023, internal memo).

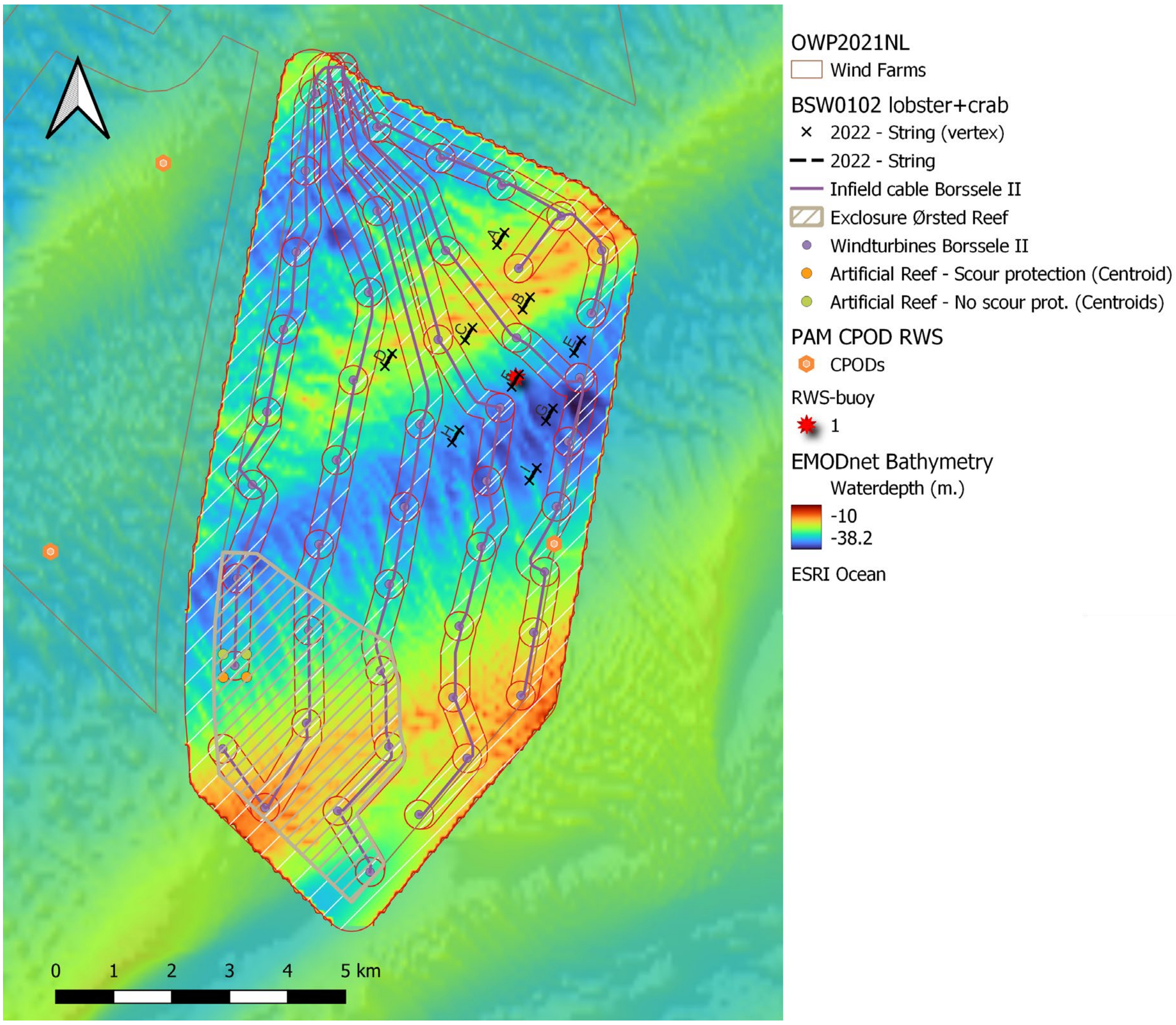

Figure 4. Sampling area in OWF Borssele II with the locations of the nine strings (four on ridges of the Rabsbank/Thorthonbank and five in the valleys). In the south eastern corner of OWF Borssele II an area excluded from fishing was established because of four artificial reefs from Ørsted. See legend at the right side for further explanation.

2.1 Borssele II OWF

Borssele I + II is a 752MW offshore wind power project owned and operated by Ørsted. It is located in the Dutch North Sea, nearby the province of Zeeland, Netherlands. It occupies an area of 122 km^2, containing 94 Siemens Gamesa 8 MW turbines (39 in Borssele II), at a depth ranging from 14-36 m, 22 km to coast (*Figure 1*, *Figure 4*, *Figure 5*). The 8 MW turbines of the project are installed on monopile foundations. Each wind turbine has a tip height of 200 m and a rotor diameter of 167 m. Turbine blade length is 81.4 m while the swept area of each turbine is 21,900 m^2. Generated electricity is transmitted to Tennet's Borssele Alpha offshore substation via 190 km of 66 kV inter-array cables. The general distance between the turbines in Borssele II is one km. The construction works on the wind farm commenced in January 2020. In June 2020 the last monopile was installed with its anti-scouring. It was officially opened in September 2021[14].

[14] https://nl.wikipedia.org/wiki/Windpark_Borssele, Windpark Borssele 1&2 in Nederland | Ørsted (orsted.nl) (read 18-10-2023). All Borssele 1&2 Foundations Installed | Offshore Wind (read 20-12-2023).

The first foundation of PAWP were laid in October 2006. The installation of the last anti-scouring layer was March 2007, the last wind turbine was installed December 2007. PAWP was opened officially in 2008. The turbines were installed at a depth of 19-24m. A distance of 550m is maintained between the turbines.

2.1.1 Policy environment of Borssele OWF

Borssele OWF is the first OWF in the new situation of using an area passport as described in Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2020). Borssele II was assigned for passive fisheries. To this extent the possibility of passive fisheries was concretized by the call "Request for experiments with passive fishing in wind energy area Borssele, lot II, Ministry of Agriculture, Nature and Food Quality" (Staatscourant 2021, 37376)[15]. Safety preconditions were defined such as having Automatic Identification System (AIS) and VHF radio installation on board and a maintenance zone around OWF operator's assets of 250 m any side. Rijkswaterstaat is the competent authority for the entire Borssele OWF. To do an fishery experiment a permission had to be obtained from both Rijkswaterstaat and Ministry of Agriculture, Nature and Food Quality.

At the moment only experiments with passive fisheries are allowed (Beleidsregel instelling veiligheidszone windparken op zee, article 4). The policy framework for commercial activities with passive fisheries is still in development.

2.2 Natural system

A concise description of the natural system in and around Borssele Windpark is given in order to have a first context to be able position the biological results of research questions 4 to 8 (when needed).

Borssele Windpark is located in a complex of Flemish and Zeeland banks: tens of kilometres long and kilometers wide sandbanks (*Figure 5*). The combination of a stable megastructure (sandbanks) and a dynamic microstructure (sand waves and mega ridges) within a coherent set of sandbanks and troughs as present on the Zeeland Banks can only be found here in the Dutch EEZ.

Buitenbank 3, Schaar and the complex of Thortonbank, Westpit and Rabsbank are the sandbanks present in the Borssele area. The peaks of the Zeeland banks are down to -15 metres where the valleys go down to -40. The banks and valleys are largely parallel to the tidal current. There are sand waves of 2 to 8 m height almost transverse to the Zeeland banks, from valley to peak, perpendicular to the prevailing tidal currents. This indicates regular dynamics otherwise the sand waves would be smoothed out.

15 https://zoek.officielebekendmakingen.nl/stcrt-2021-37376-n1.html

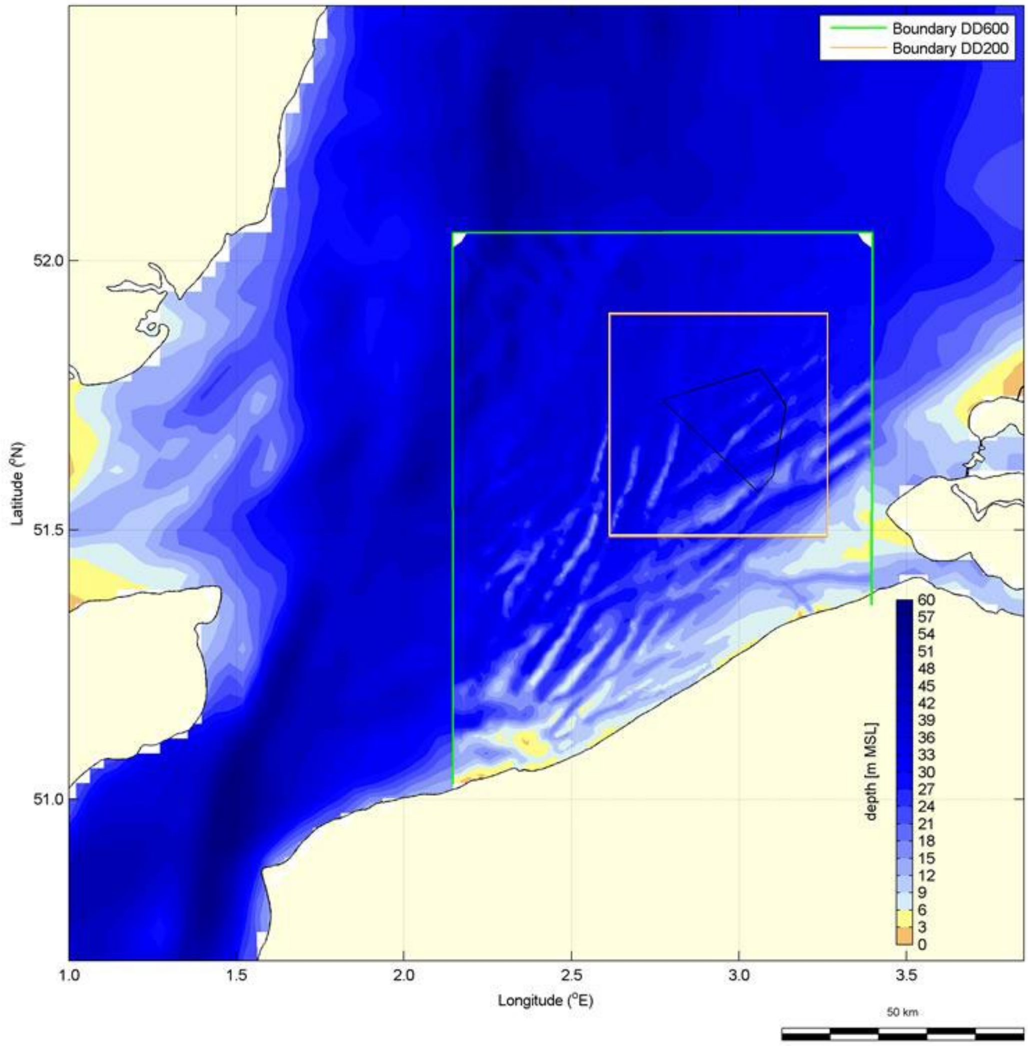

Figure 5. Bathymetry of the Zeeland and Belgian sea areas (Deltares 2016, FOD Volksgezondheid 2020). Depth profile is given in different colours, see legend underside of the map. The contour Borssele Offshore Wind farm is drawn in the smallest square.

Soil composition (average sand grain size) is an important factor for the benthos. Three zones in terms of soil sand density can be identified within the wind energy area which corresponds to the flow velocities of the water at the site (Fugro, 2016):

- Zone 1 roughly follows the contours of the tops of the large sandbanks and is characterised by a relatively high sand density.
- Zone 2 roughly corresponds to the deeper parts located between the sandbanks and is characterised by relatively low to medium sand densities.
- Zone 3 is widespread across the Borssele wind energy area and lies between zones 1 and 2. The relative sand density in situ is highly variable.

Grain sizes range between 125 - 250 µm: medium to coarse sand. Locally, there may also be some gravel (Cleveringa et al., 2012).

The larger Banks region is low in biodiversity on the sandy sediments of the seabed (soft sediments), also the Borssele II area before the construction of the OWF (Herman et al., 2014). The benthic fauna community on the Zeeland Banks show patterns related to sediment grain size and depth: from the white furrow shell *Abra alba* - *Mysella bidentata* community; fine-sanded with little silt, in the valleys) through *Nephtys cirrosa* (sand sawyer spec; fine-sanded on the slopes) to *Ophelia limacina* - *Glycera lapidum*, (two bristle worm species; coarse-sanded, on the slopes, very low species richness and density). The distribution patterns of the benthic animal communities indicate very heterogeneous living conditions along a transect across the banks between valley, summit and flank but also due to sediment characteristics.

The Zeeland Banks appear to be relatively rich in fish (Cleveringa et al., 2012, Herman et al., 2014). Based on Cleveringa et al. (2012), the ten most abundant fish species seaward of the Zeeland Banks are: goby (*Gobiidae spec.*), plaice (*Pleuronectes platessa*), dwarf sole (*Aseraggodes xenicus*), dab (*Limanda limanda*), common dragonet (*Callionymus lyra*), lesser weever (*Echiichthys vipera*), sole (*Solea solea*), sand eel-like fish and reticulated dragonet (*Callionymus reticulatus*).

2.2.1 Brown crab

The brown crab is carnivorous. It is a specialist on hard-shelled prey. With its large powerful claws it crushes the shells. Their diet includes molluscs, crustaceans and echinoderms as well as dead organisms. Brown crabs display a wide range of feeding behaviours including picking up molluscs such as mussels and oysters, digging large pits to reach buried molluscs such as razor clams (Ensis sp.), chasing, ambushing, grabbing and pouncing for respectively smaller and larger decapod crustaceans (Tonk & Rozemeijer, 2019). Juvenile brown crabs have also been shown to selectively choose prey with a preference for smaller bivalves.

Brown crab can be found on the soft sediments of the seabed. They have a preference to be close to hard structures where they find shelter (Tonk & Rozemeijer, 2019, Ter Hofstede et al., 2022)

Brown crab was present at low densities at the Zeeuwse Banken area before the construction of the OWFs (see section 5.7).

2.2.2 Hard substrates

The hard substrates (anti-scouring and monopile) at Borssele II were not measured yet. It is a recently build OWF maximum two years old in 2022. It is anticipated that the communities are in an early stage of colonisation (Kerckhof et al., 2019, Degraer et al., 2020). In older OWFs an increase in biodiversity, a different biodiversity and higher biomasses was encountered on the hard substrates, higher than found associated with soft substrates (Vanagt & Faasse, 2014, Kerckhof et al., 2019, Degraer et al., 2020, Ter Hofstede et al., 2022). The hard substrate communities on OWFs showed large overlap with the communities on oil wrecks and rocky substrate (Coolen et al., 2020). Common species encountered on hard substrates of OWFs were anemones (*Metridium senile* and *Sagartia* spec.), brown crab (*C. pagurus*), swimming crabs (*Liocarcinus spec*., *Necora puber*), the common starfish (*Asterias rubens*), gobies (*Gobius* spec.), and cod-like fish (*Trisopterus spec.*, *Gadus morhua*). Species like *Metridim dianthus* and *M. senile* can reduce biodiversity by predation and overgrowing. The mussel *M. edulis* and Tubulariidae can increase biodiversity by offering structures. The green sea urchin (*Psammechinus miliaris*) can increase biodiversity by clearing substrates by grazing, offering thereby new surface for settlement (Coolen et al., 2020).

2.3 Catch experiment

2.3.1 Planning and weather

The Borssele II catch experiment consisted of ten expeditions (days at sea). A planning was made with an even spread of expeditions in periods of soaking time (time between deployment and retrieval of pots) to establish a curve of numbers of brown crab caught versus soaking time over the total range. Weather conditions (wave height, wind), however, determined the final expeditions-dates (see Table 2). Workable conditions were defined at an anticipated summed significant wave height and swell of 1.0 m maximally, usually between wind force 0-3 Bft. The weather and conditions predictions of OWF Borssele (issued by Ørsted) and the website https://www.windfinder.com/ were used to determine workable conditions. On expedition day 1 the strings were placed and expedition day 10 the strings were removed. Every expedition day in between, the strings were hauled, emptied, rebaited and placed back.

2.3.2 Vessel

The Meru (YE152, 9.95 m, mono hull, single engine) was used, departing from the harbour of Neeltje Jans. The Meru was built in Scotland, in 1987. The GPS system used was a Furuno USA GP31[16] without differential global positioning system (DGPS) and an accuracy of approximately 50 m. The AIS transponder was class B. AIS stands for Automatic Identification System. This transponder or transceiver displays, for example, the position, identification, type of ship, speed, cargo, course, etc. of each ship using a built in GPS receiver. Vessels > 20 m have an obligatory AIS class A transponder which is transmitting real time. Vessels < 20 are allowed to use a AIS class B which is not transmitting realtime but can have a delay of 10 to 15 minutes[17].

Figure 6. The Meru (YE152) in full action, photo from Ronald Ribbe, Breskens, www.rorifocus.nl.

16 https://www.furunousa.com/-/media/sites/furuno/document_library/documents/brochures/brochures/gp31_brochure.pdf (seen 06-08-2023).

17 AIS class A of B werking en uitleg - Marifoonhalen.nl (seen 21-11-2023)

2.3.3 Location and Measurements

Together with a group of fishermen (experienced in crab pot fishery, gill netting and hand lining) the locations were chosen using the following considerations: shortest shipping distance and largest distance to the nature reservation (leading to the north west corner). Ørsted had no direct influence on this selection of locations and had no issues with the positions on coordinating the Borssele II 2022 experiment. Strings were evenly distributed over the ridges (four) and valleys (five) (*Figure 4*). In Table 1 the positions are given in several systems.

At each expedition day the position of the strings was determined on hauling and deploying. The moment the buoy line was hauled tight (straight line to the bottom) a signal was given and the position was registered from the GPS system of the vessel.

When hauling, the strings were checked for integrity of the string and for excessive accumulation of sediment. Heavy sediments can prevent any mobilisation by currents or waves. A heavily sedimented string is not representative to crab pot fisheries where the strings are hauled on a regular basis. In addition, cages were emptied from caught animals.

Sex and carapace width (CW) were registered for brown crabs and velvet swimming crab. Sex and carapace length (CL) were registered for European lobsters. Brown crabs and European lobsters were tagged and registered. Next, all animals were released at the site of catch (*Figure 4*). Pots were baited with horse mackerel. Subsequently the crab-pot-strings were placed back on the seabed.

Table 1 Chosen positions of the strings as determined in the process with the fishermen. The coordinates are given in three annotation systems									
				ETRS89 UTM31 (meters)		WGS84 geogr. Decim. degrees		WGS84 geogr. degrees min. decimaal	
String ID	Position	Average Depth	Orientation of the point	Easting25831	Northing25831	LonWGS84dec	LatWGS84dec	Longitude4326DDmm	Latitude4326DDmm
A	Ridge	21.5	northwards	506549.0	5724593.3	3.0947069	51.6722778	3°05.6824′E	51°40.3367′N
A	Ridge	21.5	southwards	506678.0	5724807.6	3.0965763	51.6742032	3°05.7946′E	51°40.4522′N
B	Ridge	20.5	northwards	506990.5	5723479.7	3.1010684	51.6622600	3°06.0641′E	51°39.7356′N
B	Ridge	20.5	southwards	507119.5	5723694.0	3.1029382	51.6641851	3°06.1763′E	51°39.8511′N
C	Ridge	20	northwards	505997.5	5722950.4	3.0867023	51.6575118	3°05.2021′E	51°39.4507′N
C	Ridge	20	southwards	506125.9	5723165.0	3.0885632	51.6594401	3°05.3138′E	51°39.5664′N
D	Ridge	22.5	northwards	504614.9	5722501.5	3.0667099	51.6534890	3°04.0026′E	51°39.2093′N
D	Ridge	22.5	southwards	504739.2	5722718.6	3.0685094	51.6554398	3°04.1106′E	51°39.3264′N
E	Valley	31.5	northwards	507877.6	5722731.8	3.1138775	51.6555235	3°06.8327′E	51°39.3314′N
E	Valley	31.5	southwards	508003.9	5722947.7	3.1157083	51.6574630	3°06.9425′E	51°39.4478′N
F	Valley	31	northwards	506801.4	5722146.5	3.0983089	51.6502748	3°05.8985′E	51°39.0165′N
F	Valley	31	southwards	506929.4	5722361.4	3.1001627	51.6522057	3°06.0098′E	51°39.1323′N
G	Valley	31.5	northwards	507393.0	5721556.2	3.1068473	51.6449594	3°06.4108′E	51°38.6976′N
G	Valley	31.5	southwards	507515.0	5721774.5	3.1086156	51.6469210	3°06.5169′E	51°38.8153′N
H	Valley	31.5	northwards	505771.7	5721184.1	3.0834097	51.6416329	3°05.0046′E	51°38.4980′N
H	Valley	31.5	southwards	505898.9	5721399.5	3.0852511	51.6435683	3°05.1151′E	51°38.6141′N
I	Valley	31.5	northwards	507106.9	5720527.9	3.1026920	51.6357171	3°06.1615′E	51°38.1430′N
I	Valley	31.5	southwards	507235.1	5720742.7	3.1045487	51.6376467	3°06.2729′E	51°38.2588′N

2.4 Fishing materials used

2.4.1 Cages

Two types of cages were used in order to obtain experience on crab catching in general: Medley and Parlour pots. Medley pot sizes used were 60 x 22 cm, 28-32kgs. They are 5 mm netted – with soft or hard eyes – bait bag – roped and rubbered base – hook and elastic (*Figure 7*). The parlour pots were 92 x 45 x 40 cm and 13 kg, 3,5mm orange polyethylene net. Cages are prone to scour. This will be tested by determining effort of haul-out (in time, secs or mins). These cages are round on the top of the pot and have weight added at the bottom. This will ensure that a pot always tumbles when upside down and stays secured on the sand in the right way. Lobster cages have a rigid conical entrance, crab cages have a flexible conical entrance. Bait was inserted, fatty type fish like horse mackerel were used in the beginning and it was switched to fish cutting waste of mostly sea wrass (*Dicentrarchus labrax*) and flathead grey mullet (*Mugil cephalus*) when the stocks of horse mackerel had run out.

Figure 7 Medley pot for crustacea fishing

2.4.2 Strings

Cages were set in strings. A string consisted of:

1. a pick-up buoy
2. 3 m rope
3. a A1 type buoy
4. 6 meter rope
5. a dahn
6. anchor lines (105 m; three time water depth))
7. Bruce anchor @ 15kgs on a
8. 25 meter rope
9. Starting the cages on in total 160 m of rope with 5 pots @ 13-32kgs, starting with a cage, 40 in between to the next cage, ending with a cage (160 m from cage to cage).
   Order: Parlour : Medley : Parlour : Medley : Parlour.
10. And the reversed order of 1-9 starting with 9. Length from anchor to anchor: 210 m

The order of dahn and A1 buoy was reversed as compared to *Figure 3*. The strings were deployed parallel to the current (*Figure 4*, differently from the Wadden area where currents are less strong, Tonk & Rozemeijer, 2022). Next to the buoy a dahn is attached with flag(s) and radar reflector reducing the risk of accidental collisions and according to legal requirements. An example is given in *Figure 3*. Nb the order of the dahn and A1 buoy were reversed in this set up.

Buoy lines were 14mm, potlines were 20mm. Each pot was attached to the headrope with a spinner. All lines are spliced together, except for the buoy/dahn connection and pots. These were connected with a spinner. There were no rotating parts which are subject to wear. This method of connecting has been used successfully for decades within FPO fishery.

The dahns are made from Bamboo or GRP, with a foam float in the middle and a contra weight at the bottom, keeping the pole up. Reflective tapes, a radar reflector and flashlights were mounted. A fluorescent flag was on top (*Figure 8*).

Figure 8 A group of dahns on the deck of the YE152 (photo: M.J.C. Rozemeijer).

2.5 Tagging of animals

A Catch : Mark: Recapture approach was chosen to estimate population size (Skerrit 2014, Bell et al., 2003, Spencer, 2013, Skerrit et al., 2023). With a statistical model the recapture percentages of animals with a tag can be converted into population estimates (Bell et al., 2001, Chen & Rozemeijer, 2023). All brown crab and European lobster were tagged with Hallprint T-bar tags: TBA Standard anchor T-bar tags for lobsters and double bar TBA LEVO tags for brown crab, all with a Hallprint VP-S Tagging Tool (for type TBA standard anchor T-Bar tags) (Hallprint Pty. Ltd, Holden Hill, South Australia). Previous studies (Smith et al., 2001, Moland et al. 2011a,b, Skerrit, 2014) show that the T-bar tags are sufficiently durable to enable identification of recaptured animals after periods of up to several years, without appearing to affect survival or behaviour within the first year of tagging. Linnane & Mercer (1998) showed a survival rate of 97% and proves that the tags does not affect the lobsters' burrowing behaviour. When losing the tag it leads to a non-lethal flesh wound (Van Stralen & Smeur, 2008). Each tag has a unique five digit identification number, making it possible to construct accurate capture and movement records for each marked animal. In addition contact details were added to register recapture.

For lobsters, the tag was placed between carapace and first tail somite (tail harness segment). To that extend the lobsters abdomen was bent carefully till the bare flesh of the tail muscle was visible. Then the tagging tool was directed tailwards (distal) at least one cm sideways from the middle track (preventing damage of critical organs, Skerrit at el., 2023) and inserted in the abdominal muscle. The tag was inserted, and only after making a quarter turn the tagging tool was retracted, enhancing the retention of the tag in the flesh.

For brown crab a 3 mm Ø incision was pierced with an awl in the posterior margin of the carapace at the line of division of the moult. The location was approximately 1cm medial from the most lateral point. The awl was blocked with a rubber cork after 5 mm to prevent excessive penetration and consecutive damage of the gills and body cavity. Next the tagging tool was inserted in the branchial cavity and the TBA LEVO tag was inserted. When the tag was placed closer towards the broadest part of the carapace (relative to the tail), only limited damage of the gills was observed. When the tag was placed more towards the tail substantial areas of gill could be affected after two week incubation (Rozemeijer, unpublished data).

Van Stralen & Smeur (2008) cited that lobsters lose 10-20% of a slightly different type of tag (Floy-Tags similar to Hallprint T-bar tags). They measured 1.2% tag loss over one year field experiment (including molt and casual damage). Jurrius & Rozemeijer (unpublished data) measured spontaneous 0.166 tag loss/year/ind. for an individual non-moulting brown crab in laboratory conditions.

Figure 9 Upper: A brown crab with an inserted tag in the gill cavity during the 'PAWP 2023' expedition (Photo by M.J.C. Rozemeijer).

Lower: Brown crab with tag encountered on the HMS Adder during a diving expedition during the 'Scheveningen 2021' experiment (Rozemeijer et al., 2021) (Photo by Renate Olie)

2.6 Meteorological and hydrodynamic data

The meteorological and hydrodynamic data were used to calculate e.g. the Haul out indicator and to correlate with potential crab-pot-string displacement (research questions 1 to 3). The data were retrieved from https://waterinfo.rws.nl/ and and https://dataplatform.knmi.nl/ at several dates.. The weather and water data also reflect the potential workable days for a fisher to sail out and harvest the caught animals (and bait the pots again). Conform Rozemeijer et al. (2021, 2022a,b) conditions were taken from Hoek Van Holland, Maasmond, E13 buoy. The assessed conditions were, Significant wave height (m), swell (m) and maximum extra water level as compared to Normaal Amsterdams Peil (NAP, indicative of wind surge and thereby currents). The station Lage Licht (Nieuwe Waterweg) was no longer available for wind speed (m/s) and wind direction. Two stations nearby were selected for replacement and compared: Hoek van Holland and Lichteiland Goeree. The two stations exhibited the same windspeeds (with some interval towards each other so the same pattern, see *Figure 11*).

2.6.1 Haul out indicator

It is mandatory to use dahns (buoys with marker flags) as the end markers of crab-pot-strings[18] (ref). However, these can make a crab-pot-string unstable because waves and currents have a lot of grip on the dahn (Rozemeijer et al., 2022a,b). The haul out indicator serves as an early warning signal to take out crab-pot-strings when conditions are not suitable for crab-pot-string fisheries in an OWF. It has been proposed as a safety measure to prevent that crab-pot-strings are mobilised in the OWF (Rozemeijer et al., 2022a,b). Mobilised crab-pot-strings can get entangled in wind turbines and the (dragging) Bruce anchors can potentially damage infield cables. It is the sum of predictions of extra water level compared to NAP, significant wave height and swell (all in cms). It was intended to sail and place the crab-pot-strings outside the OWF when the threshold is predicted. However, when the weather and waves change to fast, and it becomes unsafe to sail out, the principle of good seamanship applies and safety for crew and vessel have priority of crab-pot-strings and material damage.

Evaluation of the haul out indicator is part of the research question of evaluating the WMS (Rozemeijer, 2023).

2.6.2 Workable days

As mentioned in section 2.3, workable conditions were defined at an anticipated summed significant wave height (Hs) and swell of 1.0 m max. After the expeditions the amount of workable days was determined using the retrieved Rijkswaterstaat data (the actually measured results). However in the assessment leading up to the expeditions the local data, which is a forecast, as close as possible to PAWP were used. For the evaluation the actual results were considered rather than forecasts. To this extent the data from buoy 'E13' were used to conform to the haul out indicator approach (Rozemeijer et al., 2022a,b).

For the workable day indicator, workable hours per day were set from 07:00 until 21:00. In this timeframe the number of days were assessed with values of ≤100 cm (sum Hs and swell). With this approach the potential of workable days was determined for the period 29-07-2023 to 29-09-2023.

2.7 Statistical methods

The number of animals caught (catch number) per pot is registered each expedition Since soaking times are different each time and to compare with other literature, catch numbers were normalised to CPUE and LPUE. The CPUE and LPUE were determined for brown crab and velvet swimming crab by analysing the number of animals caught after a given soaking time. The catch curve was calculated using Generalized Additive Models (GAM)[19]. For brown crab a landing seize of ≥14cm was used, for velvet swimming crab ≥6.5 cm conform the UK (except Scotland: MLS of 7.0, Barreto & Bailey, 2015). (NB: the Netherlands have not set a MLS yet). For European lobsters catches were too low to determine CPUE and LPUE.

The catch number per pot contained a high percentage of hauls without any lobster or crabs ("zeros", *Figure 10*), therefore, it was modelled as a negative binomial distribution. A total of for covariates were tested for their effects on catch number:

1) Soaking time (hour).
2) Pot type: Medley or Parlour.
3) Normalized pot position: 1-5, 1 being the most southward pot.

[18] Implementing regulation of the control regulation 404/2011: https://eur-lex.europa.eu/legal-content/NL/TXT/HTML/?uri=CELEX:02011R0404-20200714. Regulations regarding buoys are contained in Articles 13 and 15.

[19] A GAM is a multivariate linear model with a key difference when compared to Generalised Linear Models such as Linear Regression. A GAM is allowed to learn non-linear features.

4) Location type: ridge or valley.
GAM modelling was applied with response catch number modelled as negative binomial distribution. All four covariates and their possible interactions were tested. The best model was selected based minimum Akaike information criterion (AIC) [20]. Models were tested using likelihood ratio tests. Model fitting diagnosis was also conducted.

The statistical modelling was conducted under R4.0.2 using package glmmTMB, the illustration of model effect was done using the package effects.

Other variables were tested with Wilcoxon rank sum test (R4.0.2) or ANOVA (XLSTAT).

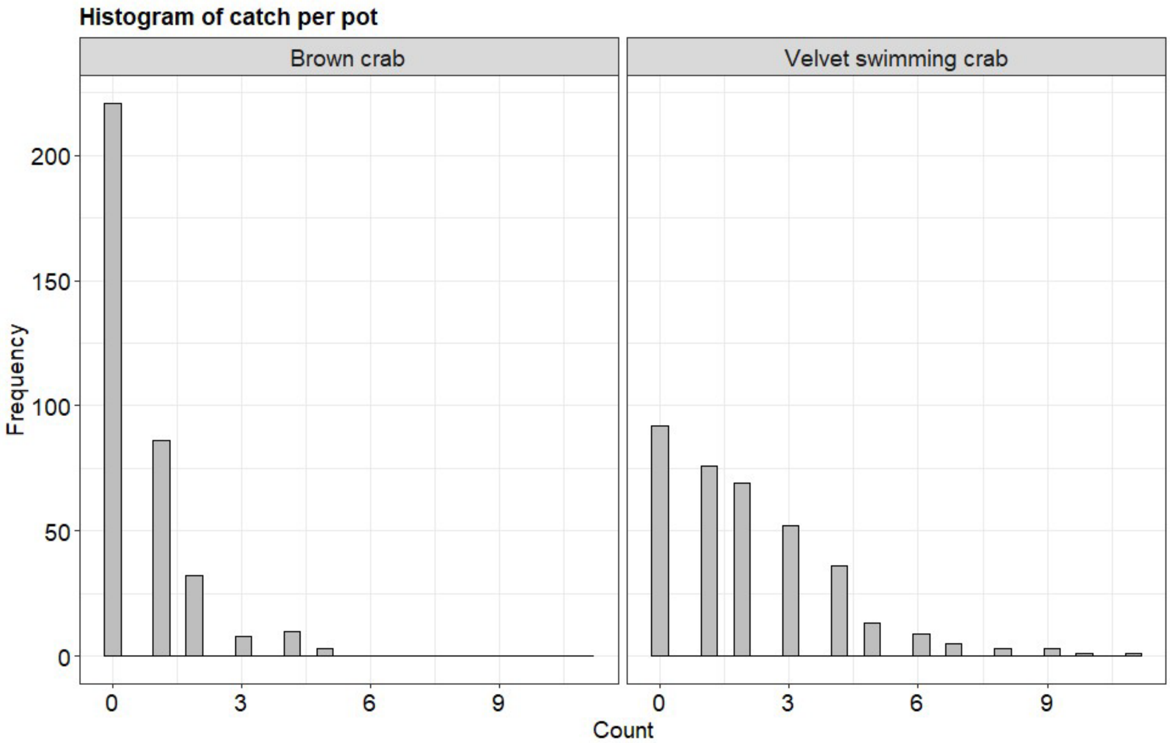

Figure 10 Histogram of the caught crabs per pot. Especially for the brown crab a high number of cages were empty. X axis: number of crabs per pot; Y-axis, number of occurrences.

2.7.1 Comparing catches between Borssele II and PAWP

The OWFs Borssele II and PAWP differed 13 years in age and thereby development of the epi- and benthic communities on the hard substrate of the anti-scouring and the soft sediments of the directly surrounding seabed. In PAWP both hard and soft substrates have had a longer development time.in PAWP the food availability is most likely higher and hence higher densities of brown crab. The hypothesis is that the catches in Borssele II 2022 will be lower than the catches in PAWP 2023 due to the lower food availability (developing communities on hard and soft substrates versus climax situation ate PAWP).

The catch results of Borssele II and PAWP were compared on the basis of CPUE and LPUE. Since the circumstances had forced a year delay in between the expeditions, an indication of the year to year

[20] The Akaike information criterion (AIC) is a mathematical method for evaluating how well a model fits the data it was generated from. In statistics, AIC is used to compare different possible models and determine which one is the best fit for the data. AIC is calculated from: i) the number of independent variables used to build the model, and ii) the maximum likelihood estimate of the model (how well the model reproduces the data). The best-fit model according to AIC is the one that explains the greatest amount of variation using the fewest possible independent variables.

variability was derived by comparing the Beam Trawl Survey (BTS)[21], Sole Net Survey (SNS)[22] and Demersal Young Fish Survey (DYFS)[23] data over a number of years between the quadrants in which Borssele II and PAWP are situated. The sampling in BTS and SNS is done by trawling, which is quite a different method compared to fishing with pots that attract through bait scent. Therefore this comparison is an indication for year to year differences, not a hard figure. In addition, the fishery in the OWFs is expected to have bigger catches of species that prefer hard substrate (such as brown crab, European lobster, Atlantic cod) due a spill over impact from the anticipated higher densities from the hard substrate (anti-scouring) (Krone & Schröder, 2011, Krone et al., 2013, 2015, 2017, Reubens et al., 2014, Stelzenmüller et al., 2021). This complicates the comparison with BTS, SNS and DYFS data.

Fisheries data could yield the same indications of the local ecology. Fisheries intensities and CPUEs reflect the local densities and thereby suitability of the habitat and local densities. Fisheries data were obtained from the official logbook data.

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21 Every summer, Wageningen Marine Research carries out a Beam Trawl Survey in the North Sea on the Tridens research vessel. The primary aim of the Beam Trawl Survey (BTS) is to supply fisheries with independent stock indices and estimates of the age-structure of North Sea plaice (*Pleuronectes platessa*) and sole (*Solea solea, Solea vulgaris*). The BTS indices are used by the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) for stock assessments and recruitment estimation. Both are important data sources for the catch predictions and hence for management advice. (Surveys in de Noordzee - WUR)

22 The Sole Net Survey is carried out in September and is designed to determine the annual class strength of 1-, 2- and 3-year-old sole and plaice. Fishing is carried out with a 6-metre sole trawl off the North Sea coast from the Netherlands to Denmark, including in rays at right angles to the coast covering various depth zones. During the survey, numbers (all species) and length distributions (fish species, brown crab, Norway lobster) of the entire catch are recorded. In addition, biological data (individual length, weight, sex, maturity stage, age reading material) of plaice, sole, flounder, brill, dab, turbot and lemon sole are collected on a regular basis. The data are used by ICES in catch forecasts for plaice and sole. As data from the entire catch are recorded, the survey also provides useful information on changes in the demersal (fish) fauna of the sampled areas. . (Surveys in de Noordzee - WUR)

23 Primairy target of the DFYS are: abundance indices of sole, plaice, brown shrimp., Length–frequency data are gathered for all fish species, brown shrimp and edible crab, sexratio and length–frequency for elasmobranchs, counts of macrozoobenthos (optional: temperature and salinity).

3 Weather results

The weather conditions were assessed in order to be able to evaluate research questions 1 to 3. The weather data are essential data to construct the Haul out indicator and workable days.

3.1 Expeditions and conditions

The expeditions of the Borssele II 2022 experiment were performed from 29/7/2022 (baiting and first deployment of the strings) to 23/9/2022 (final haul out, Table 2). The soaking time (deployment duration) ranged from 1 day to maximum 12 days (average 6.2 days). Usually the increase in caught animals follows a Holling Type II functional response (which a curve coming to a plateau, saturation, demonstrating the decreasing attraction because the bait disappears (ICES, 2005, Tully et al., 2006, Spencer, 2013, Skerrit 2014, Rozemeijer et al., 2021)). Expeditions were ideally planned to include a range of soaking times (that differed in length) but weather conditions had to be taken into considerations resulting in the actual implementation. The YE152 had its limits in sailing due to mostly wave height and swell. Limiting conditions were determined by a Sum of significant wave height and swell of ~1 m. A workable day is a day with a Sum of significant wave height and swell < 1 m

3.1.1 Windspeed

The development of the windspeed is given in *Figure 11*. Wind speed and direction are important determining factors for wave height, swell and extra water level to NAP (wind set-up). In general the windspeed was not higher than 16 m/s (Bft 7). Only the period between the ninth and tenth expedition a windspeed of 24m/s was reached (Bft 9, South East). Several periods high winds followed each other making it difficult to sail.

3.1.2 Conditions from expedition tot expedition

De averaged and maximum data for water and weather conditions are given in Table 2.The maximum extra water level to NAP (set-up) ranged from 95 to 193 cm per period (Table 2). The 10 min averaged windspeed ranged from 2.8 to 6.9 m/s. The maximum windspeed ranged from 6.0 to 24.0 m/s (Bft 9) at 140° which is approximately South-East on the compass rose. One period with 9 Bft has occurred, five periods with 7 Bft, two periods with 6 Bft, and one period with 4 Bft. The wind periods with 7 and 9 Bft ranged from East (90°) to South-East (140°). The average E13 10 min. averaged Significant Wave height ranged from 34.8 cm to 128.1 cm. The E13 maximal Wave height ranged from 53 cm to 369cm. The E13 10 min averaged Swell height ranged from 2.2 cm to 30.2 cm.

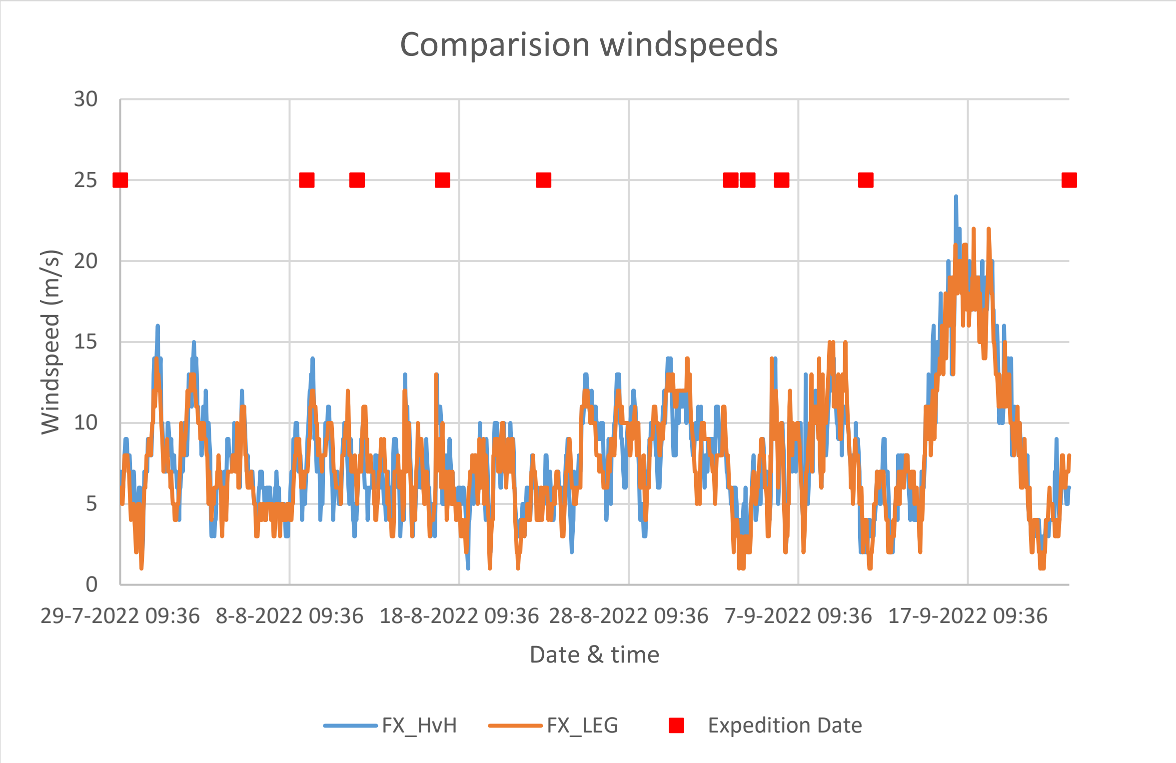

Figure 11 Windspeeds (in m/s) during the experimental period from 29/7/2022 (09:36) till 23/9/2022, (09:00). When comparing windspeeds at Hoek van Holland dune station (FX_HvH, blue line) with Lichteiland Goeree (FX_LEG, orange line) during the expeditions. The red squares represent the days of expedition.

Table 2 Overview of the expeditions performed, purpose, soaking time (rounded up to days), time of the first string out of the water (except * which is the first string deployed on the first expedition) and different weather and water conditions measured at Hoek van Holland (Maximum Water level to NAP, set up , a measure for current), E13 (Eurogeul13, wave and swell) and Hoek van Holland (dunes (wind). The maximal extra set-up compared to the astronomical tide was calculated by Rijkswaterstaat. Average and maximal wind speed (in itself 10 min. average) in the period between the dates; direction of the maximal wind force in degrees; average and maximal significant wave height (in itself 10 min. average) in the period between the dates; average and maximal significant swell (in itself 10 min. average) in the period between the dates. For 29/7/2022 the values at the moment of the first deployment are given

Dates of expeditions	**Purpose**	**Soaking time**	**First string out of the water**	**Maximum Water level to NAP Hoek van Holland**	**Hoek van Holland Average windspeed**	**Hoek van Holland Maximum windspeed**	**Hoek van Holland Wind direction of maximum wind force**	**E13 Average Sign. Wave height**	**E13 maximum Sign. Wave height**	**E13 Average Sign. Swell**	**E13 maximum Sign. Swell**	**Maximum Haul out Indicator Σ(WL, Wave, Swell)**
dd/m/yyyy		(days)	hh:mm	cm	m/s	m/s	degrees	cm	cm	cm	cm	cm
29/7/2022	Bait, deploy	*	10:00	116	5.0	6.0	50	92.2	115	6.0	8	48
9/8/2022	Bait, measure, tag	11	10:30	145	5.4	16.0	100	66.6	163	4.6	14	277
12/8/2022	Bait, measure, tag	3	8:50	136	5.9	14.0	120	55.6	96	3.7	6	182
17/8/2022	Bait, measure, tag	5	9:56	164	4.6	13.0	80	37.4	88	3.8	11	232
23/8/2022	Bait, measure, tag	6	9:07	127	4.2	10.0	50	59.8	116	7.5	5	267
3/9/2022	Bait, measure, tag	11	10:08	127	6.4	14.0	120	85.3	169	6.1	16	276

4/9/2022	Bait, measure, tag	1	9:59	105	2.8	6.0	40	34.8	53	2.2	4	141
6/9/2022	Bait, measure, tag	2	9:25	95	4.8	14.0	90	37.7	67	2.4	4	142
11/9/2022	Bait, measure, tag	5	8:52	167	5.6	14.0	100	82.8	167	6.5	24	304
23/9/2022	Measure, tag, final haul out	12	8:53	193.0	6.9	24.0	140	128.1	369	30.2	192	684
	Average	6.2										
	Standard Deviation	4.1										

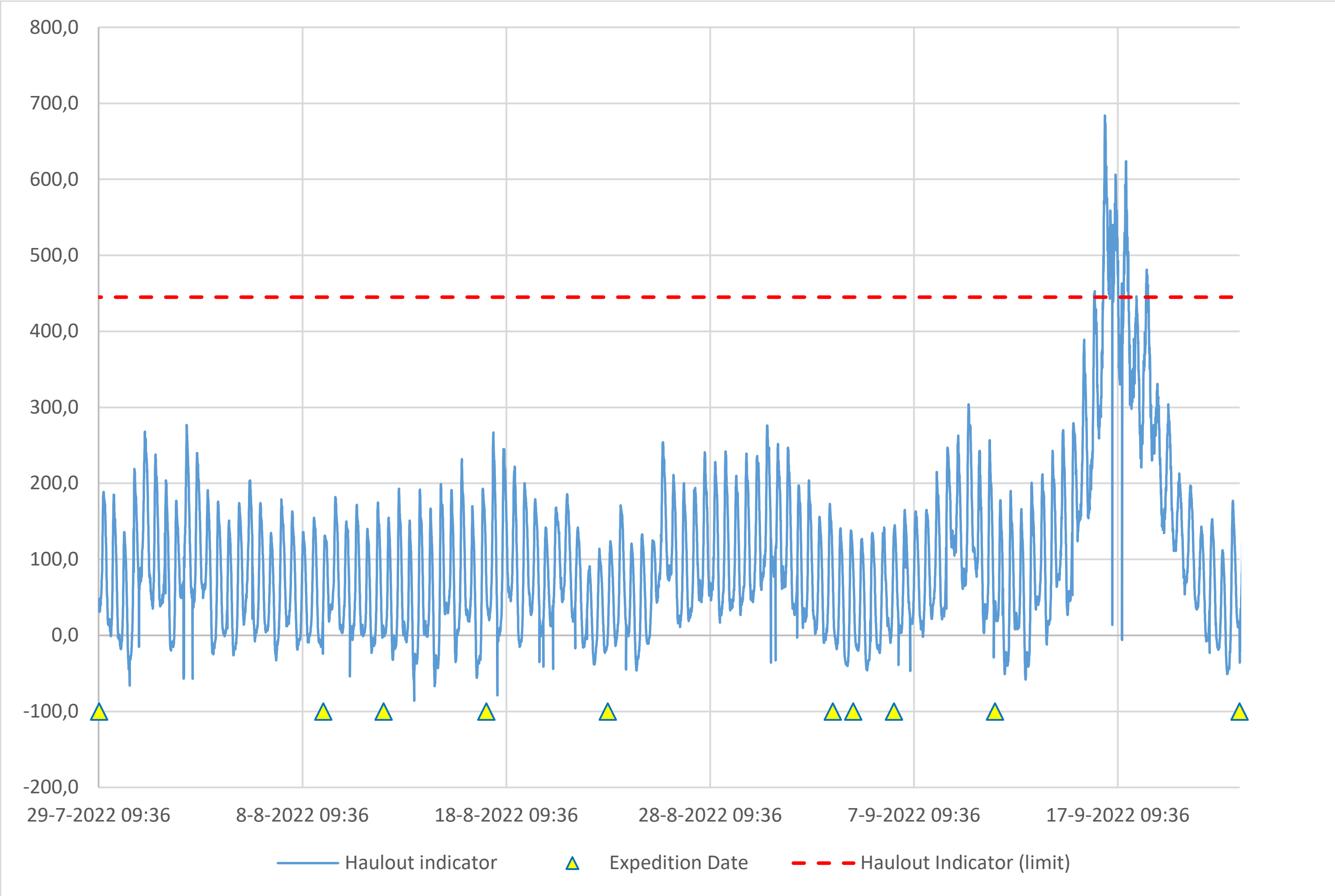

Figure 12 The evolution of the haul out indicator in time. X-axis: time in days, indicated by date. Y-axis: level of the haul out indicator (in cms). The red dashed line represents the threshold. When this level is predicted the crab-pot-strings have to be taken out. The yellow triangles represent the days of expedition. They do not represent a value of the haul out indicator.

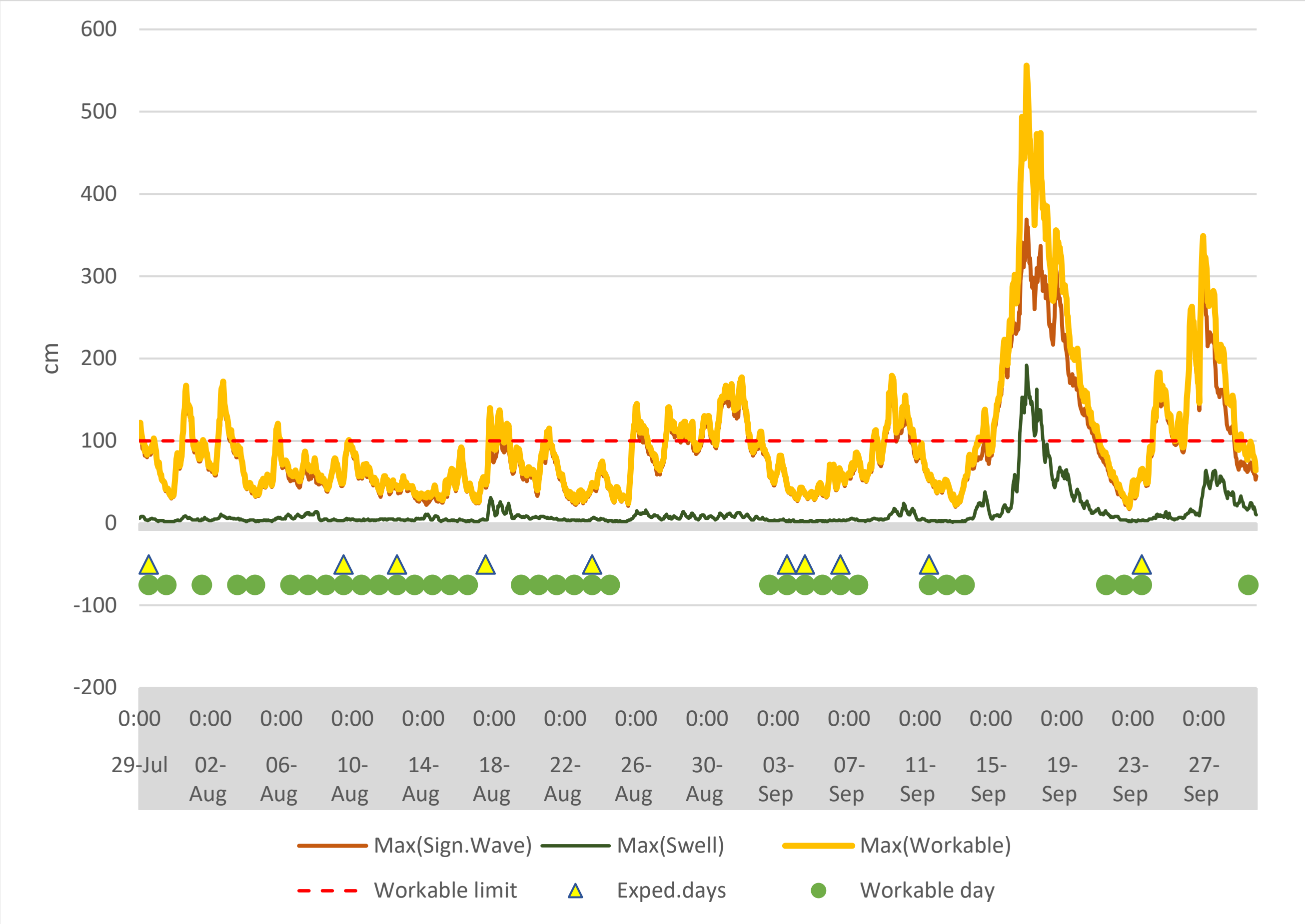

Figure 13 Registration of the Sum (yellow line) of the significant wave height (orange line) with swell (green lines) (all in cms). The actual expedition days are given with yellow triangles. The potential workable days are given in green dots. The workable days were determined according to section 2.6.2. The limit for the workable days is given with the red dashed line.

3.2 Haul out indicator

The Haul out indicator was developed as an early warning indicator to be able to haul the crab-pot-strings before the crab-pot-strings would be able to mobilise due to adverse circumstances (Rozemeijer et al., 2022a,b). This indicator uses significant wave height (Hs_sea), swell (Hs_swell) and set up (extra water level as compared to Normaal Amsterdams Peil, WL). When a certain threshold is passed (445 cm), predicted weather and water conditions are adverse, there is a threat of currents mobilising crab-pot-strings (Rozemeijer et al., 2022a,b). The course of the haul out indicator during the Borssele 2022 experiment is given in *Figure 12*. A clear tidal pattern can be distinguished. With windspeeds up to 7 Bft the haul out indicator had a maximum of 304 cm. Only at windspeeds of 24m/s (Bft 9) the haul out indicator increased to 684 cm. The maximum haul out indicator over the soaking period is given in Table 3. Note that the maximum haul out indicator (Sum(WL + Hs_swell + Hs_sea)) does not necessarily occur at the moment of individual maximum WL, Hs_swell and Hs_sea (Table 2).

3.3 Workable days

The amount of workable days is an important factor in determining whether fishing in an OWF can be performed profitable (evaluation of operations). As a workable days threshold an anticipated summed significant wave height (Hs) and swell of 100 cm max was used during the expedition periods. The workable days threshold is applicable for vessels <20 m. Both the captains of the WR143 and YE152 did not want to sail out at a sum (Hs + swell) of ~100 cm. The results for the workable days are given in *Figure 13*. Applying a strict implementation of the workable days threshold of 100 cm resulted in 34 workable days of which nine were used and one expedition day was performed on a non-workable day. An amount of 34 workable days is ~60% of the 56 days the Borssele II 2022 experiment lasted.

4 Mobilization of crab-pot-strings

To determine the risk occurring of mobilization of crab-pot-strings anchored with regular Bruce anchors, we assessed the mobilisation of crab-pot-strings under the occurring circumstances. The evaluation yielded more experience with the crab-pot-strings and the Haul out indicator. To assess the potential mobilization of the crab-pot-strings, the following steps were taken:

1. The positions and averaged crab-pot-string lengths were determined as essential information.
2. Next to assess the reliability of the measurement method was performed in section 4.1. This assessment was of the experimental error was based on the positive (surplus) length difference of a crab-pot-string longer than the theoretical length of 210 m.
3. To get a first impression of the accuracy of the actions and potential difficulties and causes the actual positions of the first and second Bruce anchor were compared to the planned positions (section 4.2)
4. The potential displacement of the anchors and strings was assessed through the deviation in position between deployment and haul out for the first and second Bruce anchors separately. The deviation in Bruce anchor position was compared with the measurement error.

4.1 Averaged string length and measurement error

The deviation of the theoretical crab-pot-string length was assumed to be the measurement error. The average string length measured is given per string in *Figure 13* and Table 3. The averages ranged from 219.7 to 260.9 m. The average length was larger than the theoretical length of 210 m for all crab-pot-strings. The theoretical length of the crab-pot-string is 210 m (section 2.4, *Figure 3*) The surplus length to 210 m was assumed to be the measurement error (Table 3). In section 6.2 we make an elaborate analysis of potential sources of these errors.

This longer-than-theoretical length illustrated the difficulties of this measurement of positions. The average surplus length differed between the 40 m (± Standard deviation (StDev) of 15 m) and 80 m (± 60 m StDev) per crab-pot-string. The percentage of measurements of crab-pot-strings longer than 210 m ranged between 57 to 89%. The average positive length difference was 59.3 m (± 45.7 m) (all crab-pot-strings). The negative length differences were not considered because that error could also be produced by not fully stretching of the crab-pot-string due to e.g. currents or late hooking of the Bruce anchor into the seabed. In the discussion more elaborate considerations were described on the experimental error of determining the position (of the Bruce anchors) of crab-pot-strings.

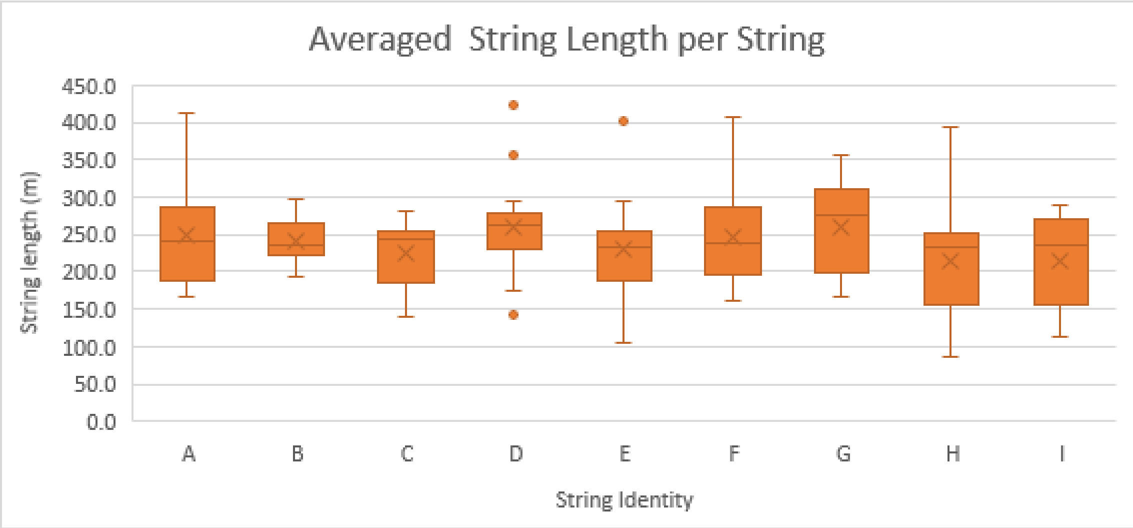

Figure 14 Box and Whisker Plots of the average length of each string as measured in the expeditions. String stands for crab-pot-string. The letters correspond to string Ids in Figure 4

Table 3 The average crab-pot-string length per string, with standard deviation (St Dev), number of observations (N), the % of successful measurements. Next the average length difference of strings longer than the maximum length of 210 m is given with its St Dev, number of observations longer than 210 m. Next the length difference was averaged over the strings (with the St Dev and N).

Length of the string	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Average Length	249	242	222	261	231	248	260	220	220
St Dev Length	69	29	40	60	65	59	61	74	61
N	15	15	18	18	14	16	14	15	14
% successful measurement	83	83	100	100	78	89	78	83	78
Positive length difference									
Average length difference of strings >210 m	80.1	42.0	40.4	64.0	61.4	63.6	88.5	48.0	54.0
St Dev difference	60.3	23.3	14.7	50.4	53.1	50.8	39.6	48.9	19.7
N	9	12	12	16	8	11	9	10	8
% strings >210 m	60	80	67	89	57	69	64	67	57
Average Length difference of too long strings		**Average + StD**	**Average + 2 STD**						
Average Length difference >210 m	59.3	105.0	150.7						
St Dev average	45.7								
N	95								
Deviation actual vs planned	**First Anchor**	**Second anchor**							
Average deviation	50.8	263.0							
St Dev	56.3	65.0							
N	70	73							
Deviation subsequent anchor$_{Deployment}$ to anchor$_{Haul\ out}$ combinations									
Average deviation	73.2								
St Dev	49.8								
N	133								

4.2 Actual positions as compared to the planned

In order to get a grip on the mechanisms of what can cause deviations in the positions of the anchors of the crab-pot-strings, the measured positions of the Bruce anchors were compared to the planned positions of the Bruce anchors. Beforehand theoretical positions were planned (*Figure 4*). Under the influence of currents, movement and precision of the vessel, the actual deployments differed from the planned deployment. The deviation between actual positions and planned is a measure for these difficulties and the accuracy that is possible.

In Table 3, the averaged deviations of planned versus actual anchor positions are given (50.8 m for the first anchor and 263 m for the second anchor). In *Figure 15* the averaged deviations of planned versus actual anchor positions are given per string. It became obvious that the first anchor is placed closer to the planned position (51 m deviation) than the second anchor (263 m deviation), both deployment and haul out combined in one graph. This difference in deviation is most likely caused by the fact that the vessel followed a certain course but was deviated from that course by currents, waves and wind. This happened especially during haul out when the vessel is on autopilot. Personal observations acknowledged this phenomena and confirmed a more zigzag course than a straight line. Imagine the heavy ship hauling in and pulling the light crab-pot-string and anchor, pulling the anchor from its original position.

NB string F also has a very high deviation of the first anchor but that is due to the fact the F-string had to be moved since a Rijkswaterstaat measurement buoy was deployed too close to the planned location.

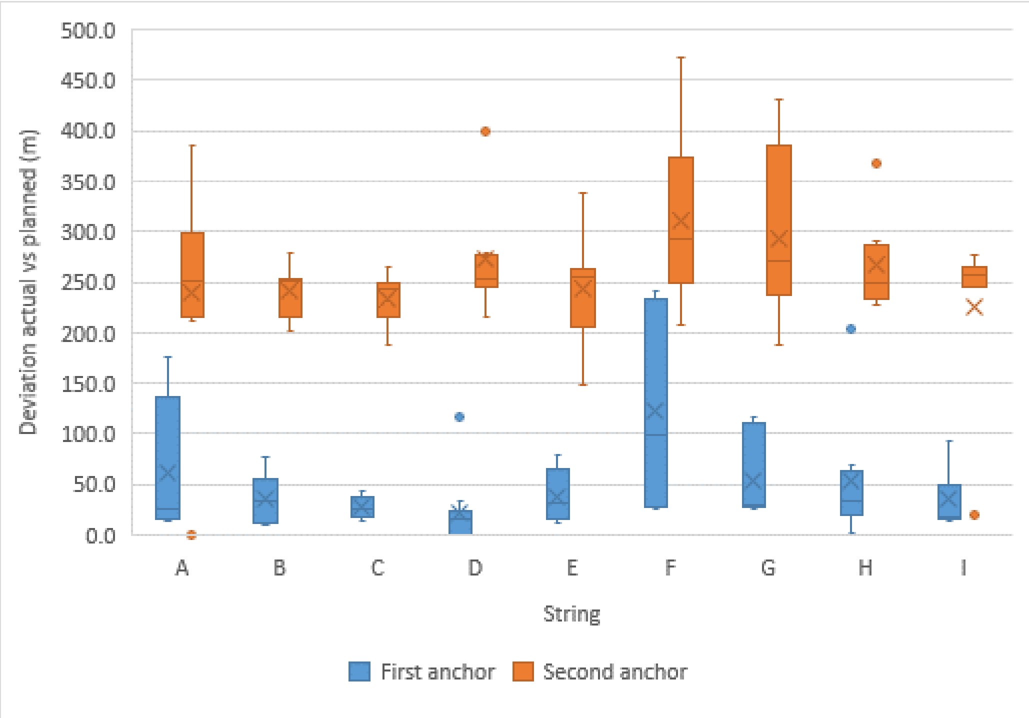

Figure 15 Box and Whisker Plots of the averaged deviations of planned versus actual anchor positions are given per string.

4.3 Displacement of the anchors and strings

4.3.1 Overview

For each string the positions of the anchors were determined at deployment and haul out in order to assess deviations in position potentially caused by currents and waves (answering research questions 1 to 3). This resulted in a number of crab-pot-string positions. *Figure 16* gives the overview of all crab-pot-strings. *Figure 17* gives an overview of crab-pot-string A. All figures of the other crab-pot-strings are given in Annex 1 (*Figure 33* to *Figure 40*). Most crab-pot-strings appeared neatly clustered around the planned positions. Some exceptions can be noted like crab-pot-strings E and G2. Take e.g. string A3 (*Figure 10*) string C3 (*Figure 20*) and string D10 (*Figure 21*) as examples of crab-pot-strings with an abnormal orientation. In addition some strings were too long like string A5 which was recorded as 413 m long. String F seemed to have major deviations. However, due to the fact a measurement buoy of Rijkswaterstaat was deployed nearby the original crab-pot-string F positions, String F was actively moved to the South-East. Below the results are described in more detail (section 4.3.2).

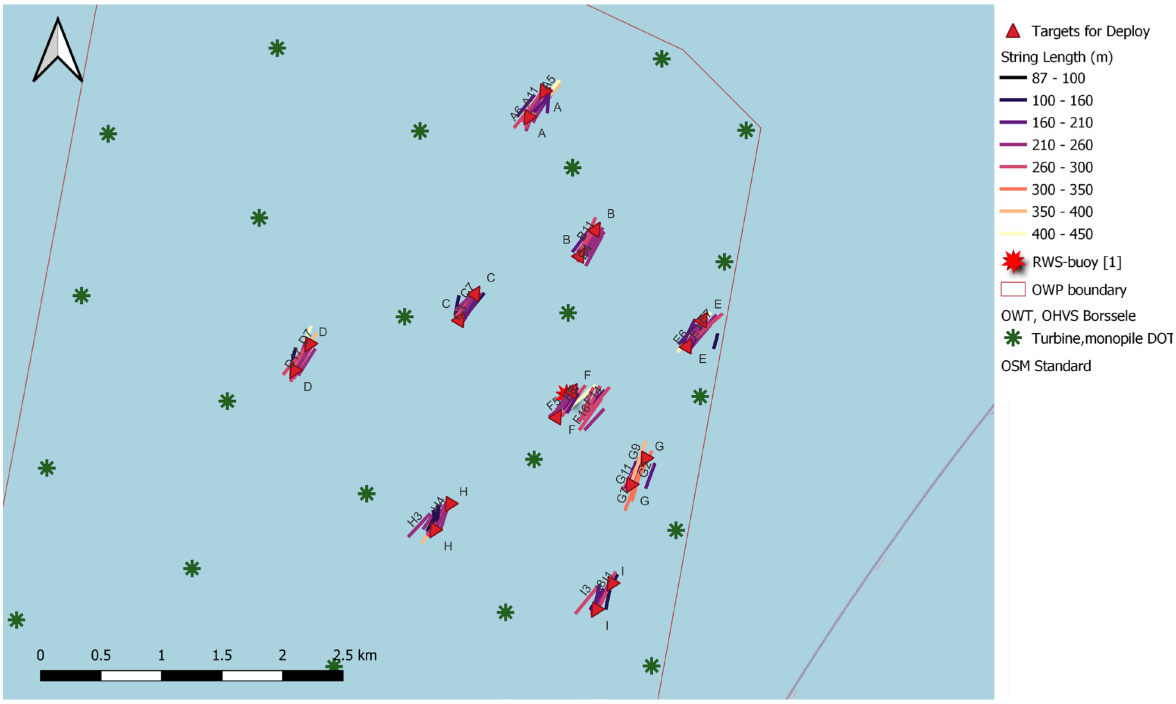

Figure 16 Overview of all established crab-pot-string positions. Green stars represent the turbines. The red star represents a measurement buoy of Rijkswaterstaat that was deployed nearby the original crab-pot-string F (more clear in). Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted (either haul out or deployment, not necessarily consecutive in time). Zoomed in figures for each location can be found in Annex 1 and the figures there (Figure 33 to Figure 40).

4.3.2 Detailed analysis of the crab-pot-string positions in time

For all subsequent $anchor_{Deployment}$ to $anchor_{haul\ out}$ combinations the deviation of the positions was determined. The average deviation was 73.2 m (± 49.8 m, N= 133). It was analysed which strings had more deviation than 150.7 m, which is the averaged measurement error added up with twice its St.Dev (Section 4.1, Table 3). All strings with a deviation larger than the measurement error were strings that were too long. The first five highest observations directly < 150.7 m were 4 strings with an abnormal orientation (more perpendicular to the currents rather than parallel to the currents): A3-S A4-S (*Figure 17*), D9-N D10-N (*Figure 35*), E12-N E13-N (*Figure 36*), H8-N H9-N (*Figure 39*), suggesting a wrong measurement. Only the fifth had a normal orientation: C1-S C2-S (*Figure 34*); but C2 was quit short 156.1 m instead of 210 m, suggesting either a measurement error or a late grabbing in the seabed of the first anchor and dragged by the ship, shortening the string length thereby resulting in a larger deviation.

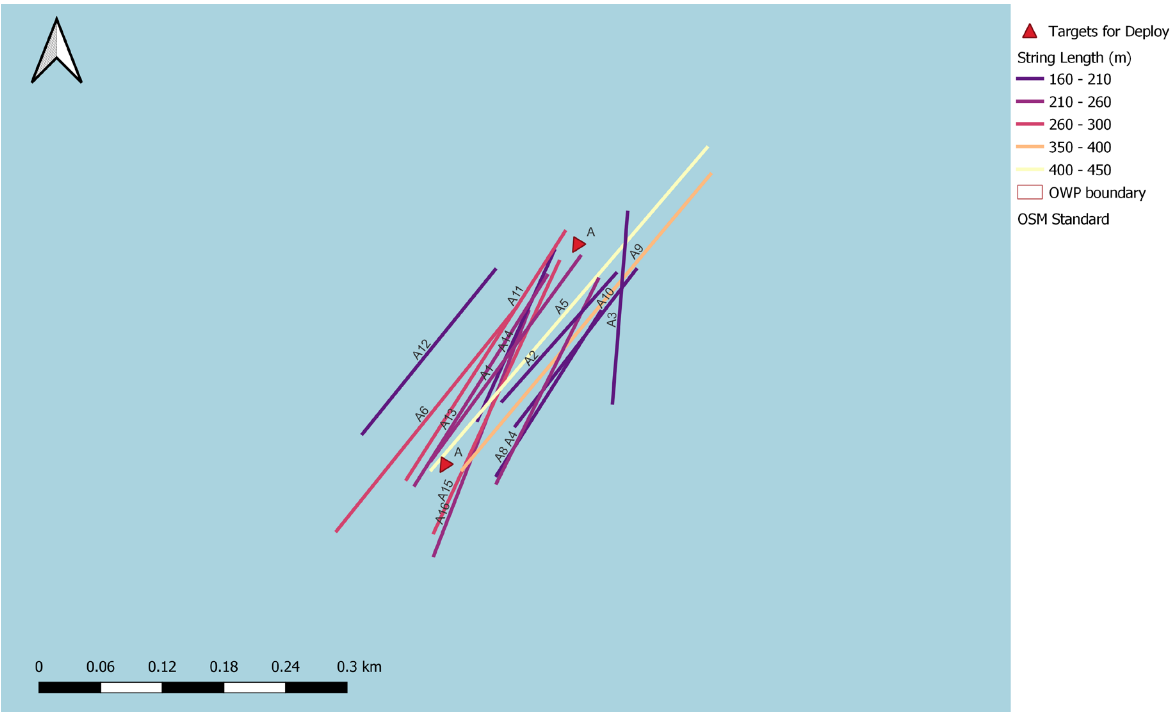

Figure 17 Overview of the established crab-pot-string positions of crab-pot-string A. Red triangles represented the planned positions. The different colours represent different lengths (see legend). The numbers represented the subsequent accepted (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

4.3.3 Mobilisation during 9 Bft

Special attention was given to the potential mobilisation of the crab-pot-strings from 11-9-2022 to 23-9-2022 when it was 9 Bft from the South East with with a Hs of 3,69 m. Table 4 gives an overview of all measurements (five strings). NB four strings had already been taken out to prevent overloading of the vessel. In the last column the delta (Δ: difference) of the measured deviation with Measurement error + 1 Standard Deviation is given to determine whether the measured deviation in position is large enough to be assumed a realistic deviation. As it appeared all deviations between deployment and haul out were well within the cloud of observations of the measurement error (within one Standard Deviation of the average). Also some deviations were smaller than the accuracy of the used GPS (50 m).

Table 4 The individual deviation measured from deployment on 11-09-2022 to haul out at 23-09-2022. In the columns Deployment ID and Haul out ID, the assigned IDs of the Bruce anchors are given. Letter: String ID, number sequence number; S or N stands for South or North. The deviation between the position of the deployed anchor and the same anchor at haul out is given in m. Difference (Δ)with Measurement error + 1 Standard Deviation stands for the fit of the measurement with the measurement error.			
Deployment ID	**Haul out ID**	**Deviation (m)**	**Δ with Measurement error + 1 St Dev**
C17-S	C18-S	39.0	-66.0
C17-N	C18-N	75.3	-29.7
D17-S	D18-S	26.0	-79.0
D17-N	D18-S	88.9	-16.1
F16-S	F17-S	45.0	-60.0
F16-N	F17-N	87.3	-17.7
H16-S	H17-S	40.6	-64.4
H16-N	H17-N	102.3	-2.7
I16-S	I17-S	41.6	-63.4
I16-N	I17-N	76.6	-28.4

5 Catches

The results below give answer to the research questions 4 to 8 on species caught, CPUE, LPUE and population size.

5.1 Detailing experimental design

Table 5 Experimental set-up. First deployment date was 29-07-2022. Each date received a sequence number. The sequence number kept increasing with date even if a sampling had not succeeded. *: hauls with extended soaking time due to the unmeasurable hauls on the previous date

29-07-22	09-08-22	12-08-22	17-08-22	23-08-22	03-09-22	04-09-22	06-09-22	11-09-22	23-09-22
A (5 pots)	1	2	3	4	5	6	7	8	Allready taken out
B (5 pots)	1	2	3	4	5	6	7	8	Allready taken out
C (5 pots)	1	2	3	4	5	6	7	8	9
D (5 pots)	1	2	3	4	5	6	7	8	9
E (5 pots)	not measure able	2*	3	4	5	6	7	8	Allready taken out
F (5 pots)	First deployme nt	2	3	4	5	6	7	8	9
G (5 pots)	1	not measure able	3*	4	5	6	7	8	Allready taken out
H (5 pots)	not measure able	2*	3	4	5	6	7	8	9
I (5 pots)	not measure able	2*	3	4	5	6	7	8	9
Total number of zero catch pots	**2**	**6**	**1**	**2**	**1**	**18**	**21**	**4**	**2**
Total number of non-zero catch pots	**23**	**34**	**44**	**43**	**44**	**27**	**24**	**41**	**23**

A total of 9 strings (A-I) and 5 pots (location 1-5) per string were used in the study (Table 5). For most strings the first deployment was 29-07-2023. There are several hauls that were not measurable (due to weather conditions, upcoming swell) as illustrated in Table 5, resulting in varying time intervals. Additionally, string A, B, E, G were taken out earlier (11-09-2022) than the last haul date (23-09-2022) and thus considered as missing data. In principle the crab-pot-strings had the configuration of Parlour : Medley : Parlour : Medley : Parlour. Only string F had five Medley pots and string G five Parlour pots.

A total of 360 pot catches were collected over the time. There were a total of 57 pots of zero catches of all species (see Table 5). Most of the zero catches appeared on 4th and 6th September 2022.

The pots were individually numbered. The pot position was normalized for analyses i.e. (pot order switched when strings were reversely deployed from haul out). Note that all count plots or analysis done below were on pot level, not string.

5.2 Species caught

The total number caught per species in Borssele II were summarized in *Figure 18*A. Mostly velvet swimming crab and brown crab were caught (left panel *Figure 18*A). Other species caught in some amounts were striped red mullet (*Mullus surmuletus*), pouting (*Trisopterus luscus*), common cuttlefish (*Sepia officinalis*), Atlantic cod (*Gadus morhua*) and bull rout (*Myoxocephalus scorpius*) (right panel *Figure 18*A). See in *Figure 18*A for the incidentally caught species.

European lobsters were caught in comparable numbers in both OWFs (Figure 18A,B). In the Borssele II 2022 experiment eight European lobsters were caught, all larger than the MLS (minimum landing size), six, females, one male and one undetermined (Table *6*). In the PAWP 2023 experiment five European lobsters were caught, all larger than the MLS (minimum landing size), four males and one undetermined (Rozemeijer et al., 2023). Given the small numbers of European lobsters caught, no further analysis were applied.

In PAWP less species were caught as bycatch in the 2023 expedition (*Figure 18*B) as compared to the Borssele II 2022). Stripped mullet was caught more during the Borssele II 2022 expedition. Cuttlefish was caught more during the PAWP 2023 experiment as compared to the Borssele II 2022 expedition, as well as starfish.

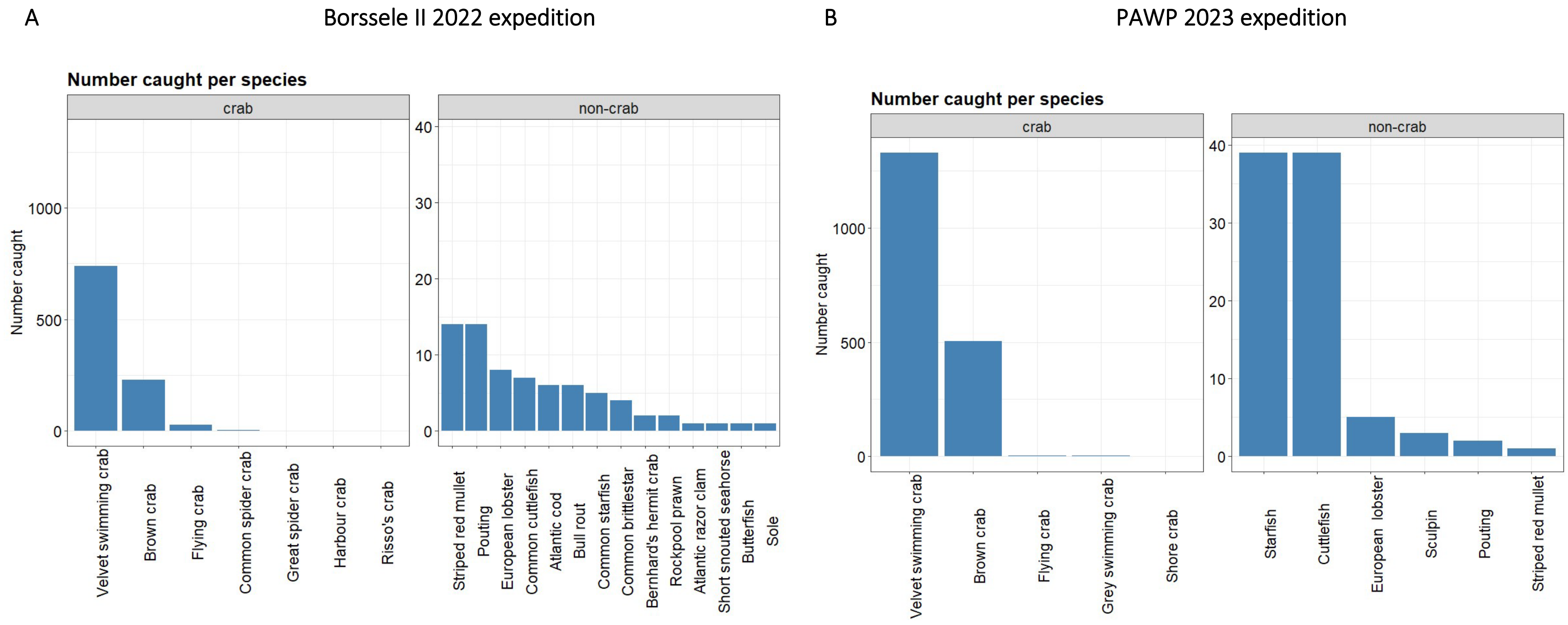

Figure 18 overview of all species caught during the ten experimental days in Borssele II in 2022 (A) and PAWP 2023 (B).

5.3 Sex distribution over species of direct interest

The caught number and percentage by sex are listed in Table 6. Of the main species of interest, only eight European lobsters were caught: six females (all landable size, average carapace length 11.3 ±1.4 cm), one male (carapace length 11.5), one undetermined. For both crab species a majority males was caught. A total of 229 brown crab were caught: 35 females and 194 males. A 42 out of 229 brown crab were above the minimum landing size. Large numbers of velvet swimming crab were caught: 740 of which 110 were females and 625 males. The female brown crab number of individuals increased from 9.1% in below 14cm group to 42.9% in above 14cm group, while the velvet swimming crab female decreased from 23.8% (<6.5cm) to 8.2% (≥6.5cm). For velvet swimming crab a minimum conservation reference size (MCRS) of 65 mm CW was taken (Wallace & Rae, 2018). This is the general UK MCRS whereas in colder region like Scotland a MCRS of 70 mm CW is used. [24]

Table 6 number of animals by sex, brown crab and velvet swimming crab are also separated by their MCRS size

Species	**Female**	**Male**	**unknown**	**total**
Brown crab (all)	35 (15.3%)	194 (84.7%)	0	229
Brown crab (≥14cm)	18 (42.9%)	24 (57.1%)	0	42
Brown crab (<14cm)	17 (9.1%)	170 (90.9%)	0	187
Velvet swimming crab (all)	110 (14.9%)	625 (83.1%)	5	740
≥6.5cm	34 (8.2%)	379 (91.1%)	3	416
<6.5cm	76 (23.8%)	244 (76.3%)	0	320
Flying crab	5 (19.2%)	19 (73.1%)	2	26
European lobster	6 (75%)	1 (12.5%)	1	8

5.4 Carapace width distribution by sex

The carapace width distribution by sex is given in Table 7, *Figure 19* and *Figure 20*. The mean CW of both female and male brown crab is below MCRS of 14 cm[25] . For velvet swimming crab the males are just at MCRS and the females below.

Table 7 Mean and median carapace width of brown crab and

Species	**Female Mean (median)**	**Male Mean (median)**	**Wilcoxon rank sum test on median**
Brown crab	13.9 (14.1)	11.8 (11.40)	Significant (p<0.001)
Velvet swimming crab	6.1 (6.1)	6.5 (6.7)	Significant (p<0.001)

24 Velvet swimming crabs are recommended Cornwall Good Seafood Guide and Velvet swimming crab - Rating ID: 901 | Good Fish Guide (mcsuk.org); both visited 31-07-2023.

25 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1241&rid=4 (visited 13-12-2023)

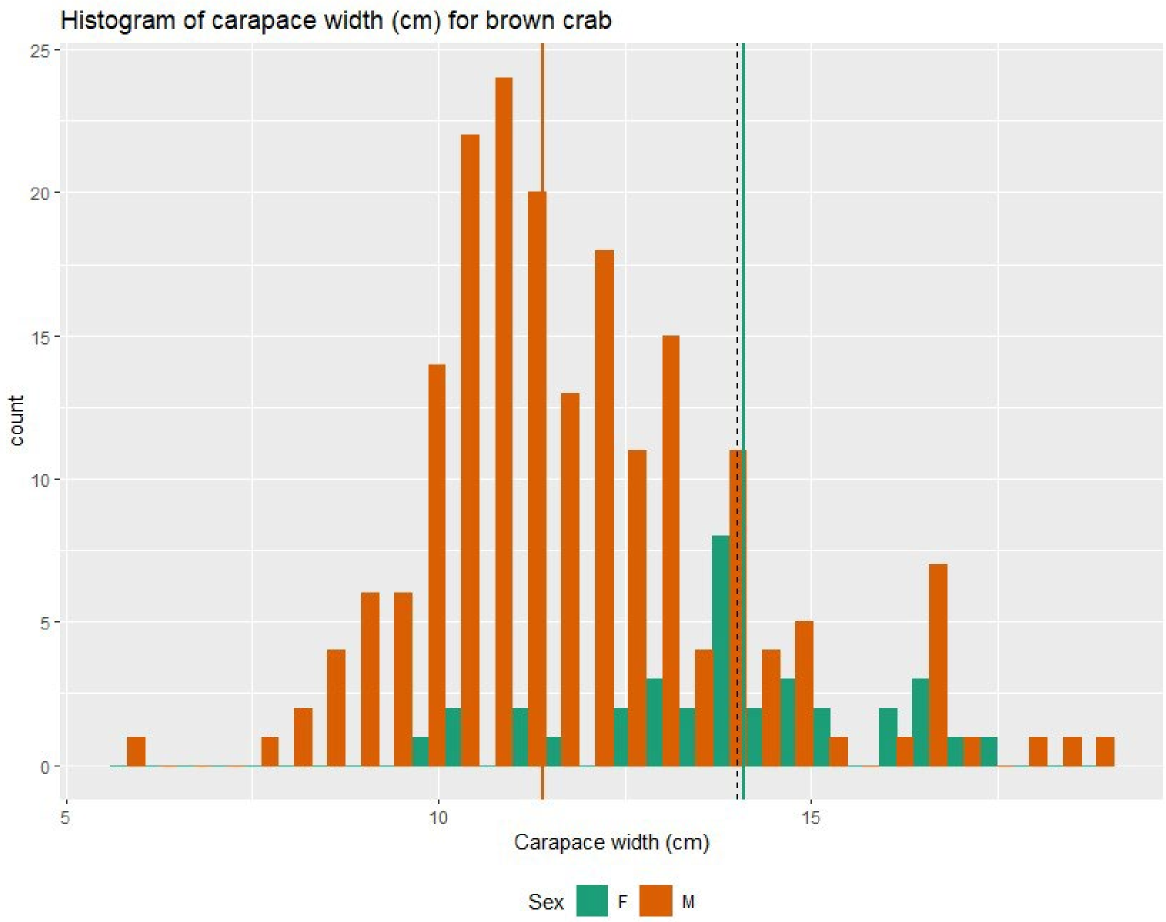

Figure 19 Brown crab: length distribution by sex (orange: male, green: female,). The median length is plotted as solid line, and MCRS length is plotted as dashed line.

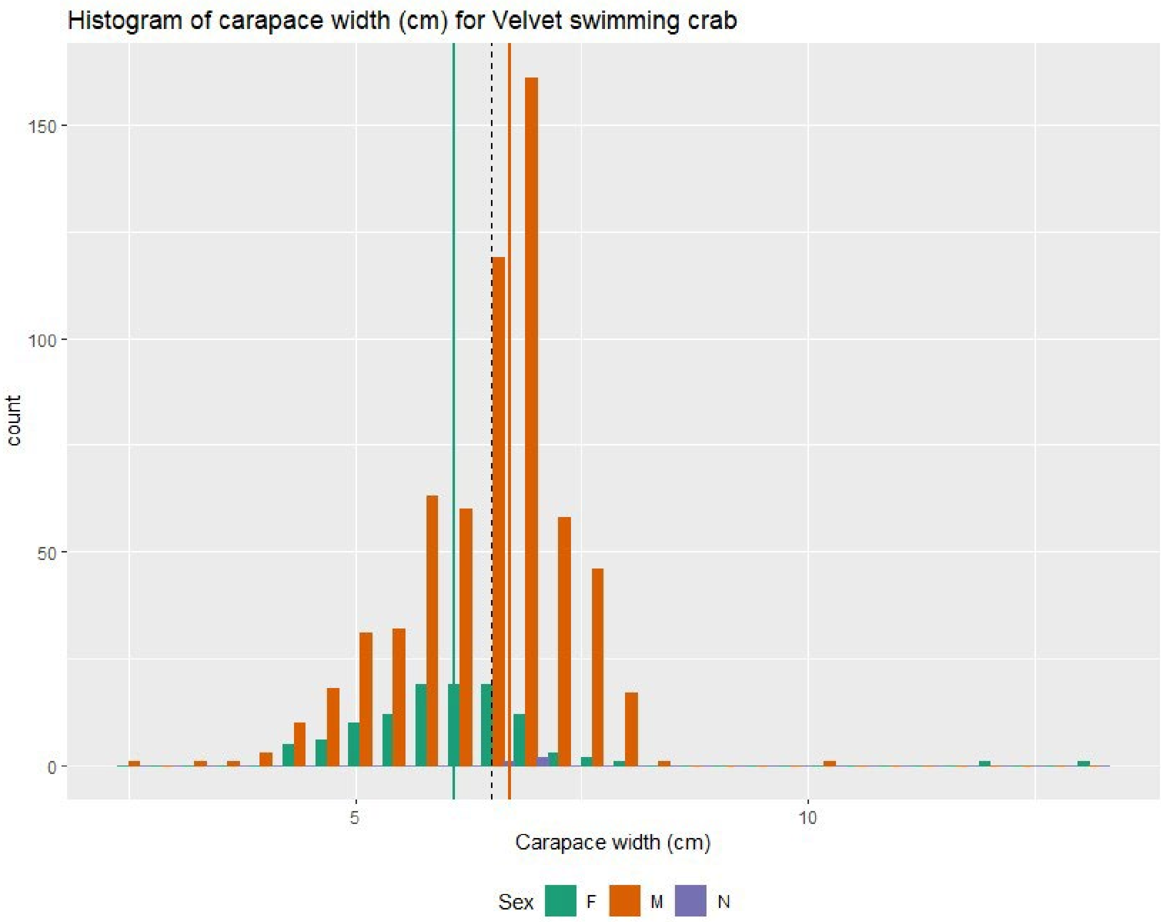

Figure 20 Velvet swimming crab: length distribution by sex (orange male, green female, purple: not determined). The median length is also plotted as solid line, and MCR length is plotted as dashed line.

5.5 Catch numbers of animals

Results are presented on brown crab and velvet swimming crab. The catches of European lobster were too small for statistical analysis.

5.5.1 Brown crab

The number of caught brown crab increased steadily up to 12 days/288 hours of soaking time (*Figure 21*). The best fitted model for the catch numbers of brown crab in time included soaking time, type of pot and type of location. The tested p-values of these covariates are given in Table 8 (see also *Figure 21*). The strongest factor that determined catch numbers is soaking time, while pot type and location showed only borderline significance[26] in the statistical tests. The estimated marginal effect for each variable is illustrated in *Figure 21*. The number of brown crab increased with soaking time (up to around 12.5 days/300 h). Additionally, Parlour pot gave higher catches compared to medley pots and ridge conditions higher compared to valleys.

[26] Borderline significance: sometimes an effect does not have a p-value <0.05, but around the statistical significance level of 0.05. this could be that the results do fit our hypothesis (have a valid effect size), but just due to small sample size, it does not show statistical significance. The term borderline significance draws the attention.

Table 8 Covariates tested with their significance for the catch numbers of brown crab

covariates	**p-value (from likelihood ratio test)**
Soaking time	<0.001
Type of pot (Medley, Parlour)	0.043
Pot order (1~5)	N.S. (not significant)
Type of location (ridge, valley)	0.055

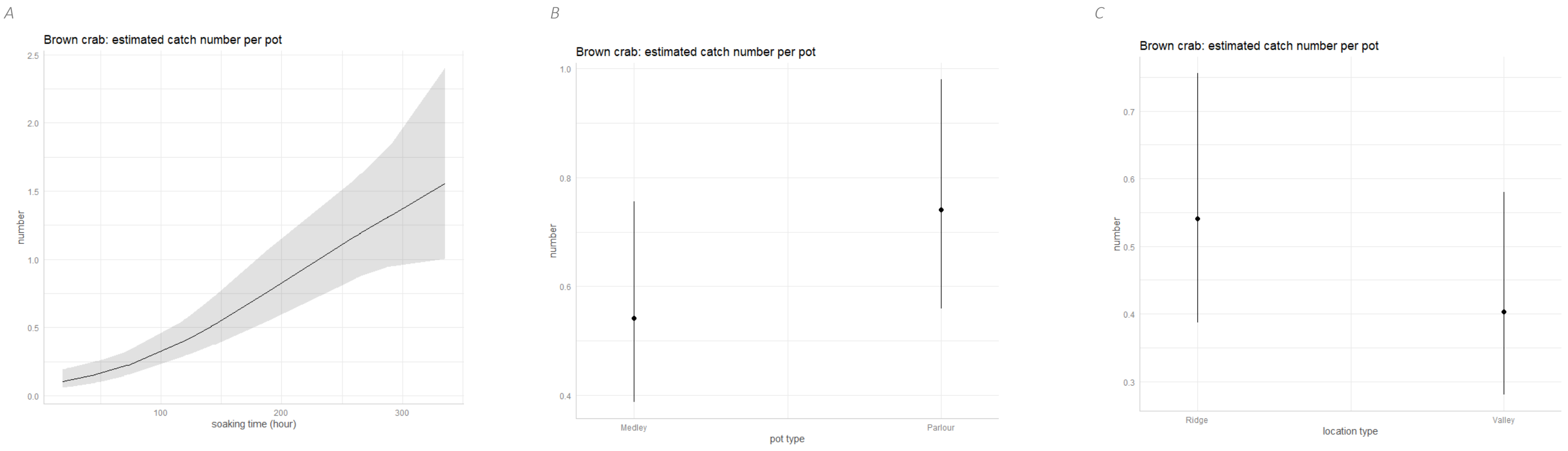

Figure 21 Estimated marginal effect on the catch number for soaking time (A, p<0.001), pot type (Parlour or Medley, B, p= 0.043) and location type (Ridge or Valley, C, p = 0.055) for brown crab.

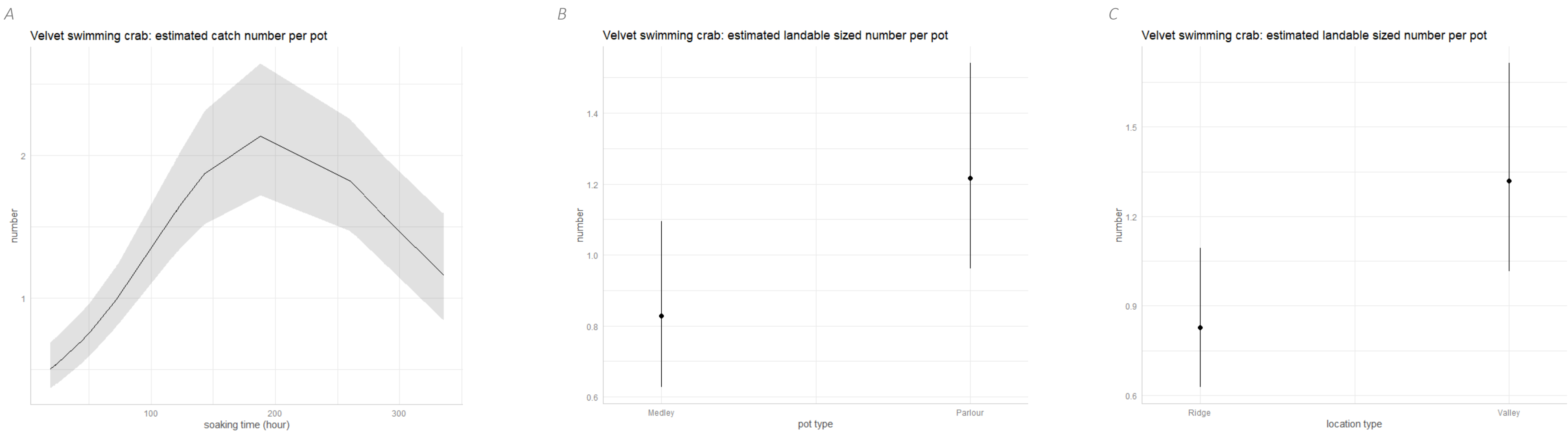

Figure 22 Estimated marginal effect on the catch number for soaking time (A, $p<0.001$), pot type (Parlour or Medley, B, $p= 0.001$) and location type (Ridge or Valley, C, $p = 0.001$) for velvet swimming crab.

5.5.2 Velvet swimming crab

The number of caught velvet swimming crab showed an optimum curve with a peak at ~8 days (*Figure 22*). The best fitted model for the catch numbers of velvet swimming crab included soaking time, type of pot and type of location for velvet swimming crab. The tested p-values of these covariates are given in Table 9. The strongest factor that determines catch numbers is soaking time. Also pot type and location also showed a significant effect in catch number. Pot order was not significant The estimated marginal effect for each variable is illustrated in *Figure 22*. The catch rate of velvet swimming crab peaks within soaking time ranges of 150-250 hour (~8 days). However, there are few samples within this range to provide more certain estimates. After a soaking time of ~260 hrs, the catch number decreased. This reduction could imply escape from the pots or predation by the brown crab. Additionally, Parlour pot and valley conditions clearly resulted in higher catch numbers ($p \leq 0.001$, Table 9). The valley being better catch grounds for velvet swimming crab was contrary to what was found for brown crab.

It should be noted that for the peak point in *Figure 22* the collected sample size within this time period was very low, yielding a gap of knowledge. Additionally, samples collected within this gap (around 190 hrs) are all from one string G, and this string has only Parlour pots and it is located in the Valley area. This means it is difficult to estimate the catch number and rate within this soaking time range around 190 hrs. It seems likely that the peak is part of a plateau which lowers after ~260 hrs and not a maximum.

Table 9 Covariates tested with their significance for the catch numbers of velvet swimming crab

covariates	p-value (from likelihood ratio test)
Soaking time	<0.001
Type of pot (Medley, Parlour)	0.001
Pot order (1~5)	N.S. (not significant)
Type of location (ridge, valley)	<0.001

5.6 CPUE and LPUE

The catch numbers in time were converted to CPUE and LPUE for brown crab and velvet crab.

5.6.1 CPUE and LPUE for brown crab

CPUE

The CPUE was determined based on catch number of brown crab and soaking time. The CPUE of brown crab started at 0.1 - 0.2 brown crab per pot per day and levelled off to a more or less constant 0.08 – 0.16 brown crab per pot per day (*Figure 23*). Even after 12 days, brown crabs kept on being caught in the pots.

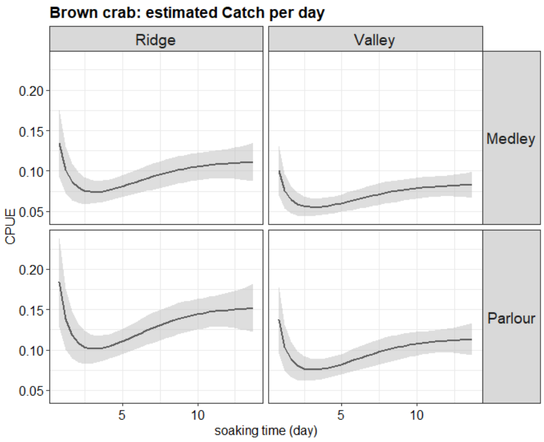

Figure 23 Estimated marginal effect on the CPUE for soaking time (bottom X-axis), pot type (Parlour or Medley, Y-axis) and location type (Ridge or Valey, top X-axis) for brown crab.

LPUE

Only 42 out of 229 brown crab were at MCRS (≥14.0 cm). The best fitted model includes soaking time and type of location with interaction, implying that the soaking time effect differs between ridge and valley. Type of pot or normalised pot order appeared not significant (Table 9). The LPUE of brown crab seemed to increase with soaking time at the ridges from 0.01 to a maximum of ~0.05 landable crab per pot per day (*Figure 24*). Given the high uncertainty and low sample size (in total only 42 landable sizes) these results are tentative.

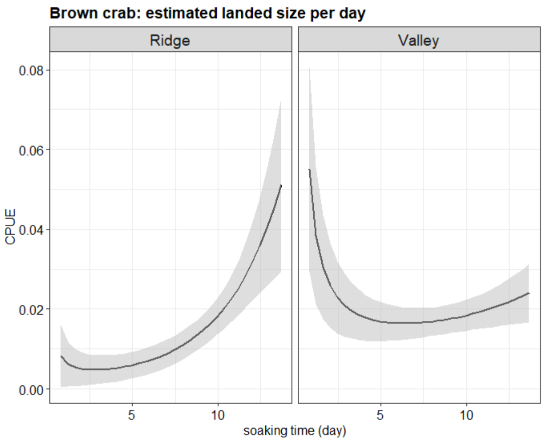

Figure 24 Estimated marginal effect on the LPUE for soaking time (bottom X-axis) and location type (Ridge or Valley, top X-axis) for brown crab.

Table 10 Covariates tested with their significance for the landable catch numbers of brown crab

Covariates	**p-value (from likelihood ratio test)**
Soaking time*type of location(ridge, valley)	<0.001
Type of pot (Medley, Parlour)	N.S. (not significant)
Pot order (1~5)	N.S. (not significant)

5.6.2 CPUE and LPUE for velvet swimming crab

CPUE

The CPUE was determined based on catch number of velvet swimming crab and soaking time. The CPUE of velvet swimming crab started at 0.7 – 1.5 velvet swimming crab per pot per day and decreased exponentially to a ~0.02 – 0.04 velvet swimming crab per pot per day (*Figure 25*). Even after 12 days, velvet swimming crabs kept on being caught in the pots.

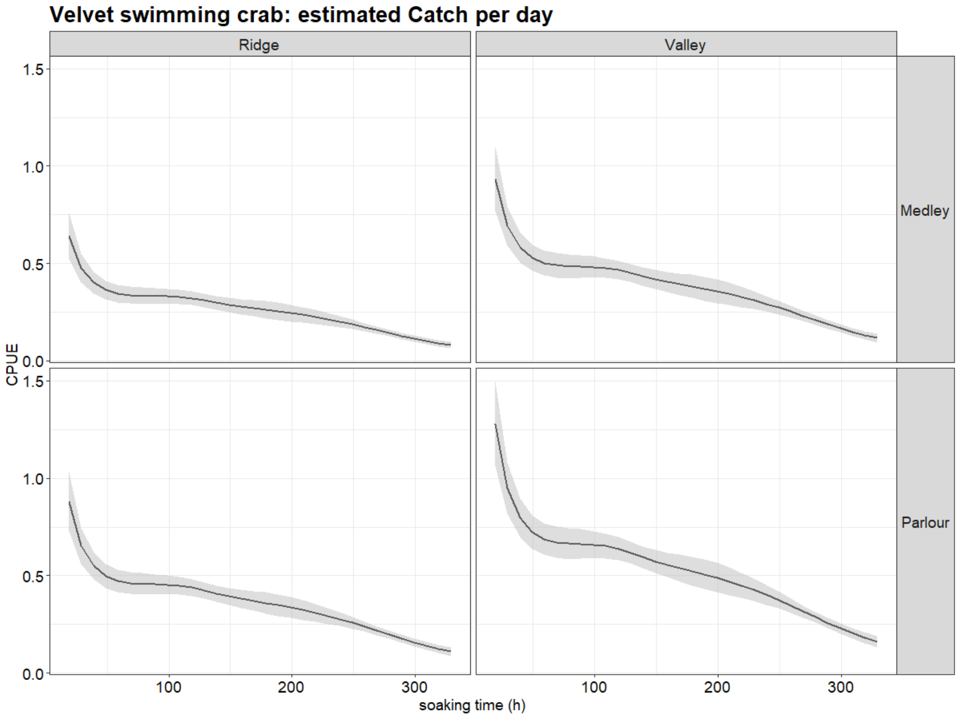

Figure 25 Estimated marginal effect on the CPUE for soaking time (bottom X-axis), pot type (Parlour or Medley, Y-axis) and location type (Ridge or Valley, top X-axis) for velvet swimming crab.

LPUE

From a total of 740 velvet swimming crab 416 were ≥ MCRS (6.5 cm). The LPUE was influenced by type of pot (Parlour higher than Medleys) and location (valleys higher than ridges) (Table 11, *Figure 26*). For the valleys it started at ~0.75 lowering to 0.1 landable velvet swimming crab per day.

Table 11 Covariates tested with their significance for the landable catch numbers of velvet swimming crab.

Covariates	**p-value (from likelihood ratio test)**
Soaking time	<0.001
Type of pot (Medley, Parlour)	0.002
Pot order (1~5)	N.S. (not significant)
Type of location (ridge, valley)	<0.001

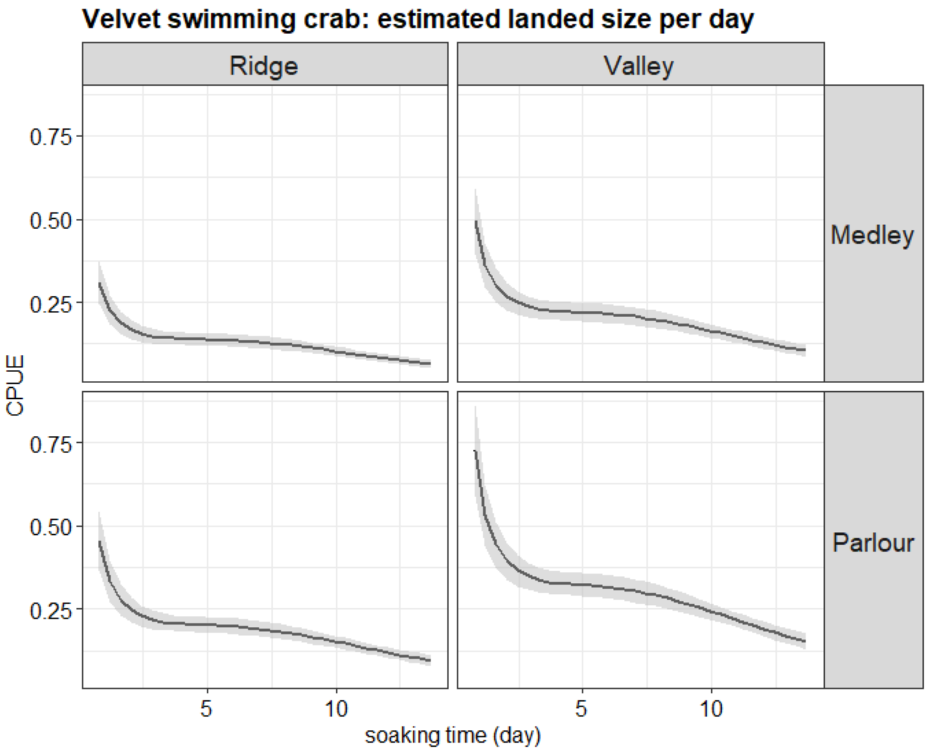

Figure 26 Estimated marginal effect on the LPUE for soaking time (bottom X-axis), pot type (Parlour or Medley, Y-axis) and location type (Ridge or Valey, top X-axis) for velvet swimming crab.

5.6.3 Comparing CPUE and LPUE of Borssele II with PAWP

In PAWP 2023 a second experiment on catching crab and European lobster was conducted. In the Borssele II 2022 experiment the weather allowed an even distribution of the soaking time enabling GAM analysis. In the PAWP 2023 experiment the weather caused delays in hauling resulting in a discrete and skewed distribution of soaking time. Therefore the data were grouped into a categorical variable soaking time with 4 groups: 19~25 hour, 38~48 hour, 92~ 139 hour and 582~629 hour (Rozemeijer et al., 2023).

The data of the Borssele II 2022 experiment and the PAWP 2023 experiment were fused into figures for CPUE and LPUE of brown crab and velvet swimming crab. NB the environmental setting of the Borssele II 2022 experiment was the Zeeuwse Banken with ridges and valleys (*Figure 4*). the environmental setting of the PAWP 2023 experiment was a flat seabed (Rozemeijer, 2023, Rozemeijer et al., 2023). In the figures the categories ridge and valley were made with the same values for the PAWP 2023 experiment.

Brown crab CPUE

A CPUE of 0.08 to 0.2 were estimated for Borssele II 2022. In PAWP a CPUE for brown crab was estimated of 0.2 to 1.2 (2 to 2.5 * higher) (*Figure 27*, Rozemeijer et al., 2023). That is at least 4 times higher. In the Borssele II 2022 experiment soaking time, pot type and location (ridge or valley) were significant for the CPUE (and not pot order). In the PAWP 2023 experiment only soaking time was significant and pot order or pot type were not.

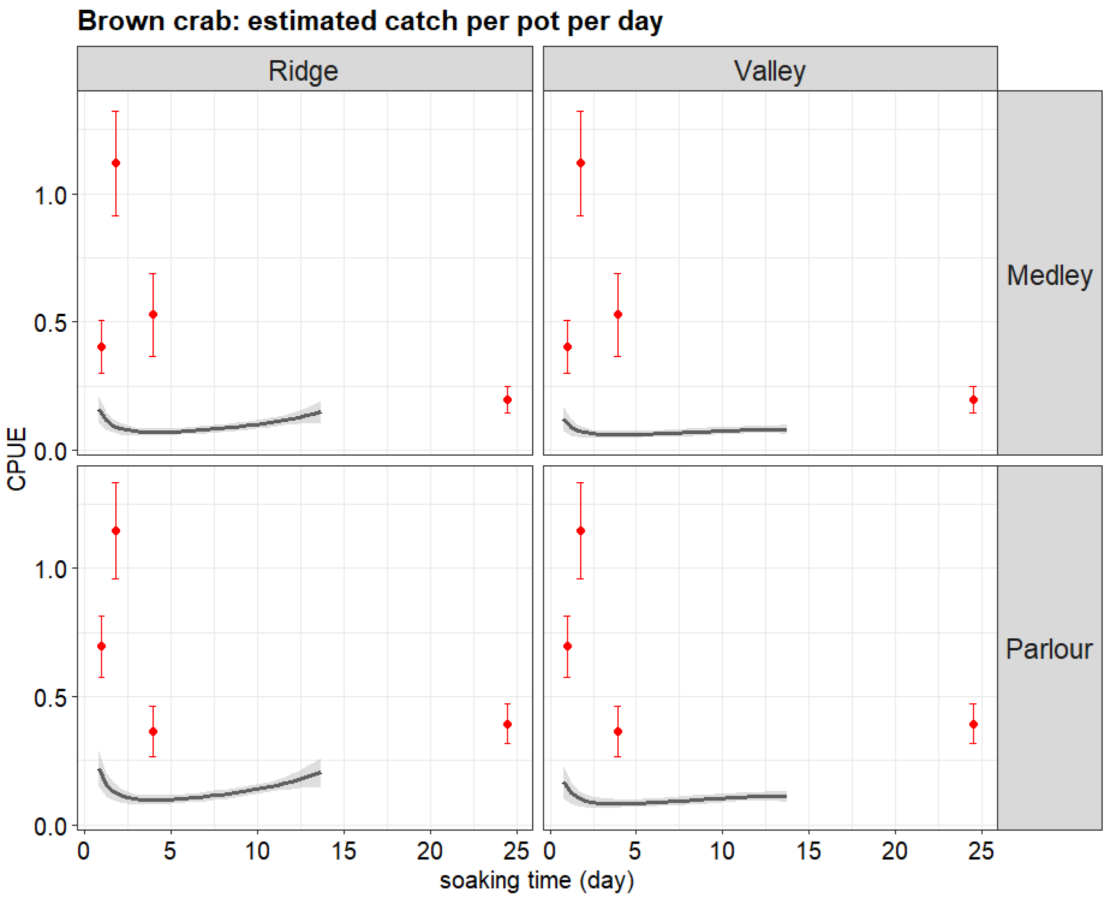

Figure 27 CPUEs of brown crab for the Borssele II 2022 experiment (black line: average with grey band +/- standard deviation) and the PAWP 2023 experiment given as averages (red dots) +/- standard deviation (red error bars). PAWP 2023 experiment values differed between pot type but not between ridge and valley.

Brown crab LPUE

The Borssele II 2022 experiment a LPUE from 0.01 to 0.05 crab per pot per day was estimated where as in the PAWP 2023 experiment a LPUE of 0.1 – 1 was estimated. The highest LPUE in PAWP was after approximately 2 days soaking time. The LPUE lowered after this peak. This is contrary to the results of the Borssele II experiments where the LPUE increased after five days soaking time (*Figure 28*). Pot order and pot type were not significant for the Borssele II 2022 experiment. Soaking time and location were significant (Table 10). In the PAWP 2023 experiment soaking time and pot type were significant and pot order not (*Figure 28*, Rozemeijer et a., 2023). So on pot type both experiments differed. In both experiments the pots kept catching landable brown crab for prolonged time, even after the bait was gone.

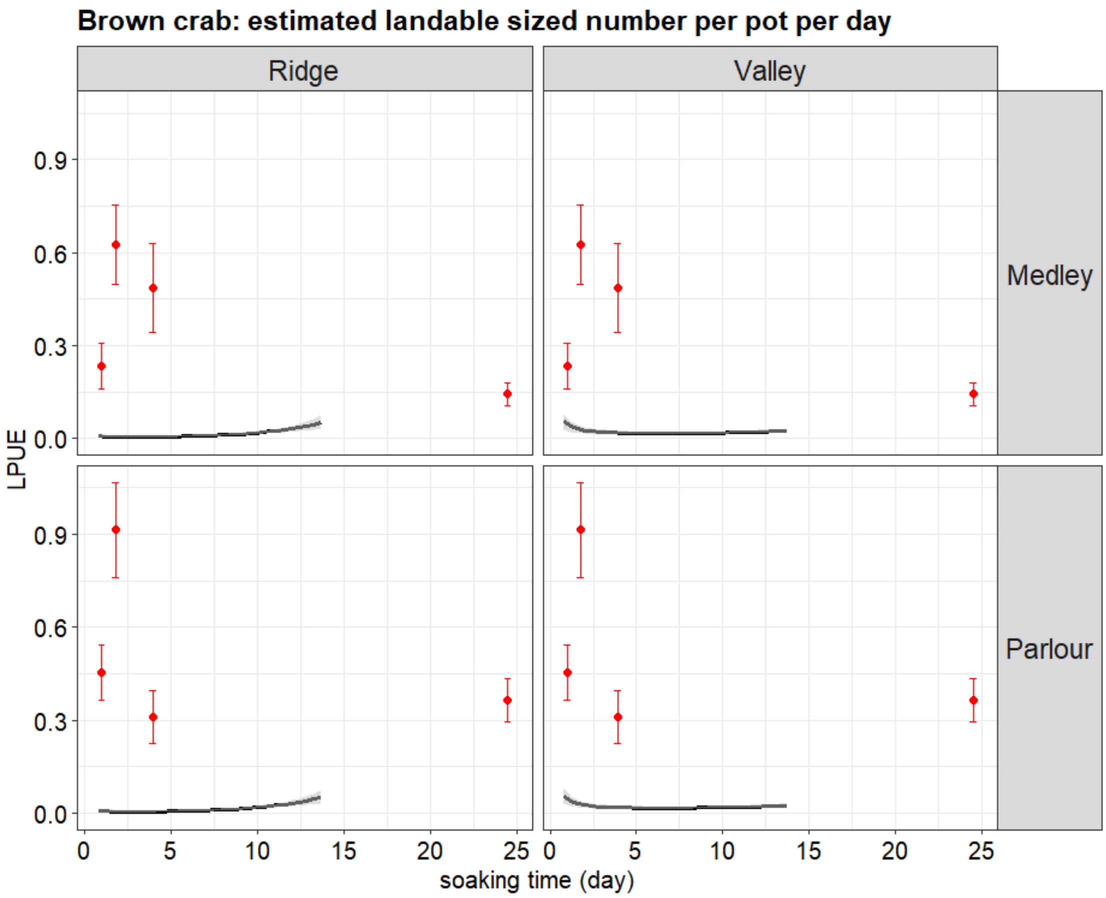

Figure 28 LPUEs of brown crab for the Borssele II 2022 experiment (black line: average with gray band +/- standard deviation) and the PAWP 2023 experiment given as averages (red dots) +/- standard deviation (red error bars). PAWP 2023 experiment values differ between pot type but not between ridge and valley.

Velvet swimming crab CPUE

In *Figure 29* the CPUEs for both experiments are given for velvet swimming crab. The CPUEs for the Borssele II experiment were clearly lower. In both cases the CPUEs reduced in time. In the Borssele II 2022 experiment soaking time, pot type and location were significant variables, pot order not. In the PAWP experiment soaking time and pot type were significant variables, pot order not. So the forcing variables were alike.

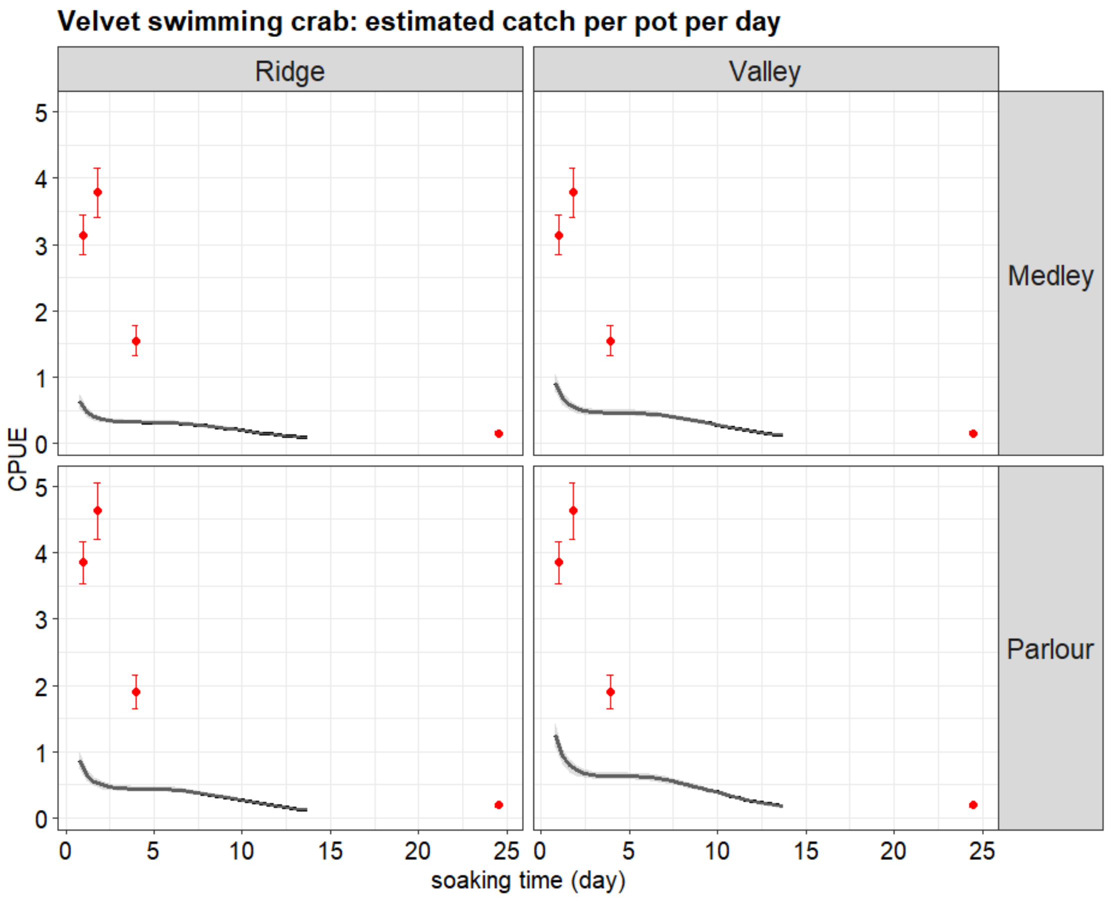

Figure 29 CPUEs of velvet swimming crab for the Borssele II 2022 experiment (black line: average with gray band +/- standard deviation) and the PAWP 2023 experiment given as averages (red dots) +/- standard deviation (red error bars). PAWP 2023 experiment values differ between pot type but not between ridge and valley.

Velvet swimming crab LPUE

In *Figure 29* the CPUEs for both experiments are given for velvet swimming crab. The CPUEs for the Borssele II 2022 experiment were clearly lower. In both cases the CPUEs reduced in time. In the Borssele II 2022 experiment soaking time, pot type and location were significant variables, pot order not. In the PAWP 2023 experiment soaking time and pot type were significant variables, pot order not. So the forcing variables were alike between the Borssele II 2022 experiment and the PAWP 2023 experiment.

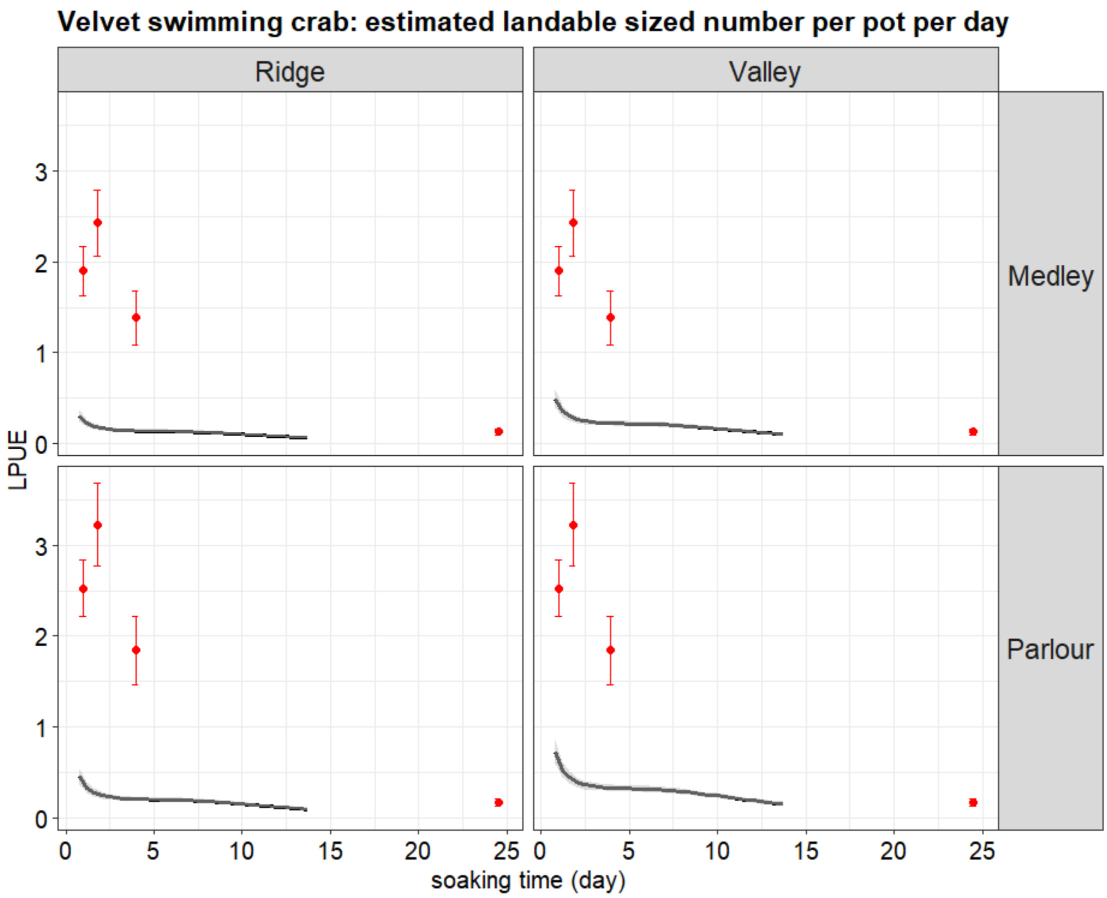

Figure 30 LPUEs of velvet swimming crab for the Borssele II 2022 experiment (black line: average with gray band +/- standard deviation) and the PAWP 2023 experiment given as averages (red dots) +/- standard deviation (red error bars). PAWP 2023 experiment values differ between pot type but not between ridge and valley.

5.7 Comparing spatial aspects in time

The catch results of Borssele II and PAWP were compared on the basis of CPUE and LPUE. Since the circumstances had forced a year delay in between the expeditions, an indication of the year to year variability was derived by comparing the BTS, SNS and DYFS) data over a number of years between the quadrants in which Borssele II and PAWP are situated. These data also yield a rough approximation of the suitability of the soft sediment areas for brown crab (NB, not for the OWF area). Fisheries data were also analysed to obtain the same indications.

5.7.1 Spatial distribution of the brown crab population

The spatial distribution data from BTS[21], SNS[22] and DYFS[23] (section 2.7) for brown crab were collected from 2010 to 2022. Two examples (2010, 2022) were given in *Figure 31* and *Figure 32*. Spatial distribution showed important areas in the German Bight, above the Wadden islands (Texelse Stenen) and Yorkshire, Lincon, Norfolk area at the UK side (*Figure 32*). The overview showed the increase of brown crab in the southern North Sea as was shown by Tonk & Rozemeijer (2019). Density of the measuring pints and amounts caught were too low (too many zero-values) to make actual quantitative comparisons between the two locations (see Annex 2).

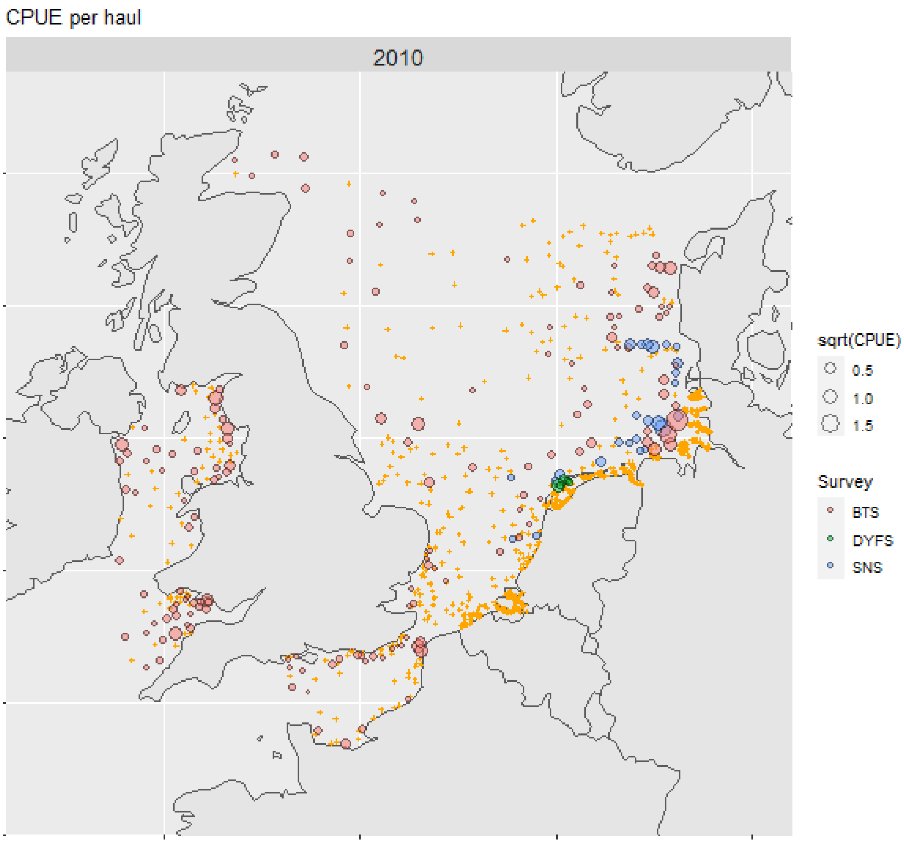

Figure 31 CPUE of brown crab in 2010 by the monitoring programmes BTS, SNS and DYFS.

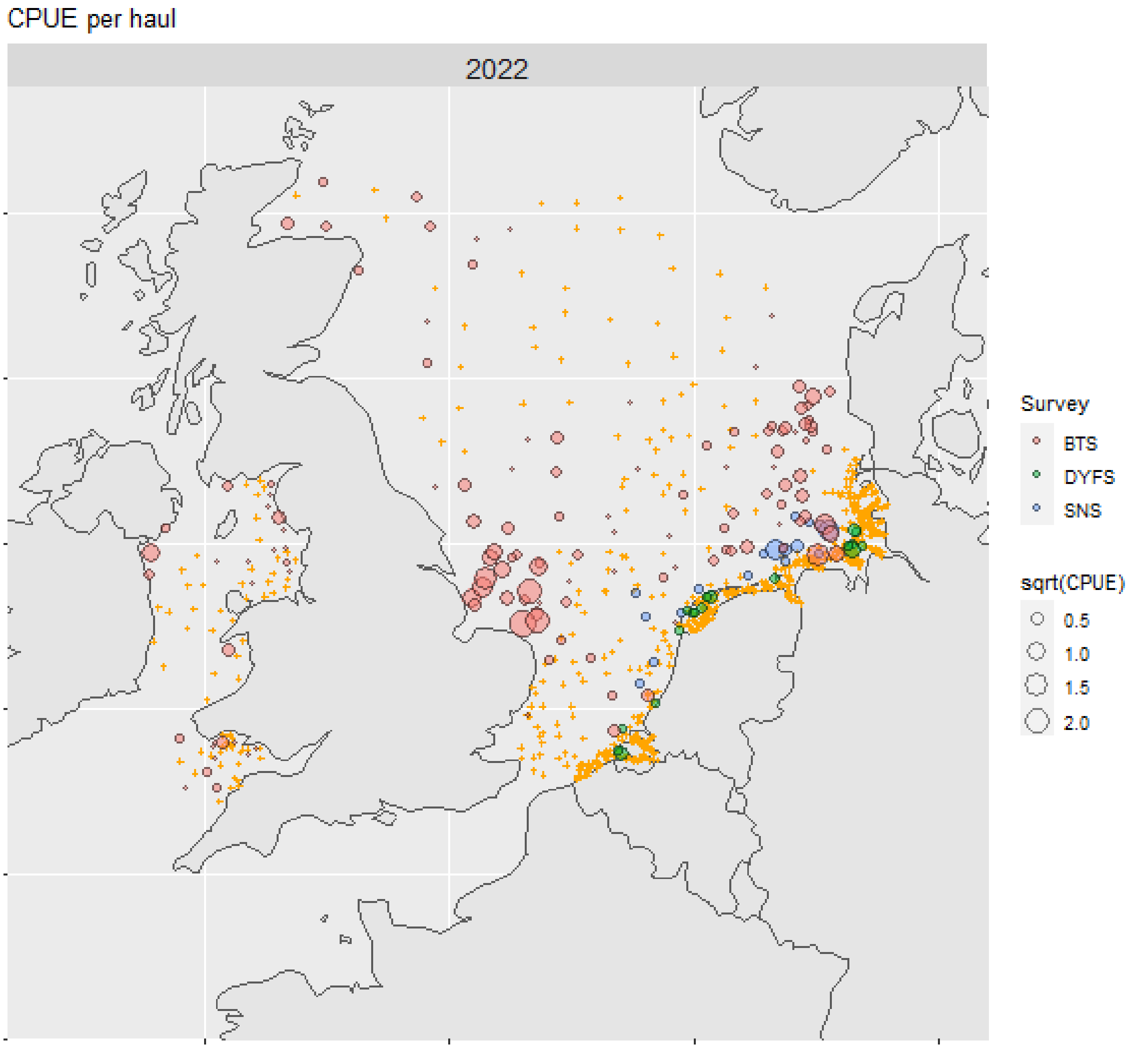

Figure 32 CPUE of brown crab in 2022 by the monitoring programmes BTS, SNS and DYFS.

5.7.2 Fisheries data

Beam trawl of several mesh sizes (TBB_all_70-99, TBB_all_>=100[6]), and otter trawl of several mesh sizes (OTB_OTT_all_<100 and OTB_OTT_all_>=100) showed low catches along the Hollandse Coastal Arch. For FPO for crustaceans (CRU), it seems there is a tendency that the PAWP quadrant (IJmuiden) had higher catches than the Borssele quadrant (*Figure 33*). The question is raised whether the available data are fisheries. No crab-pot fisher is known is this area. It could also be the number are just landings, brought to the fish auction of IJmuiden, caught elsewhere (S. Verver, pers. Comm.). Anyhow, decisive comparison was not realistic since the Borssele quadrant lacks sufficient data for a true comparison (eight out of ten years have no data on Borssele II area).

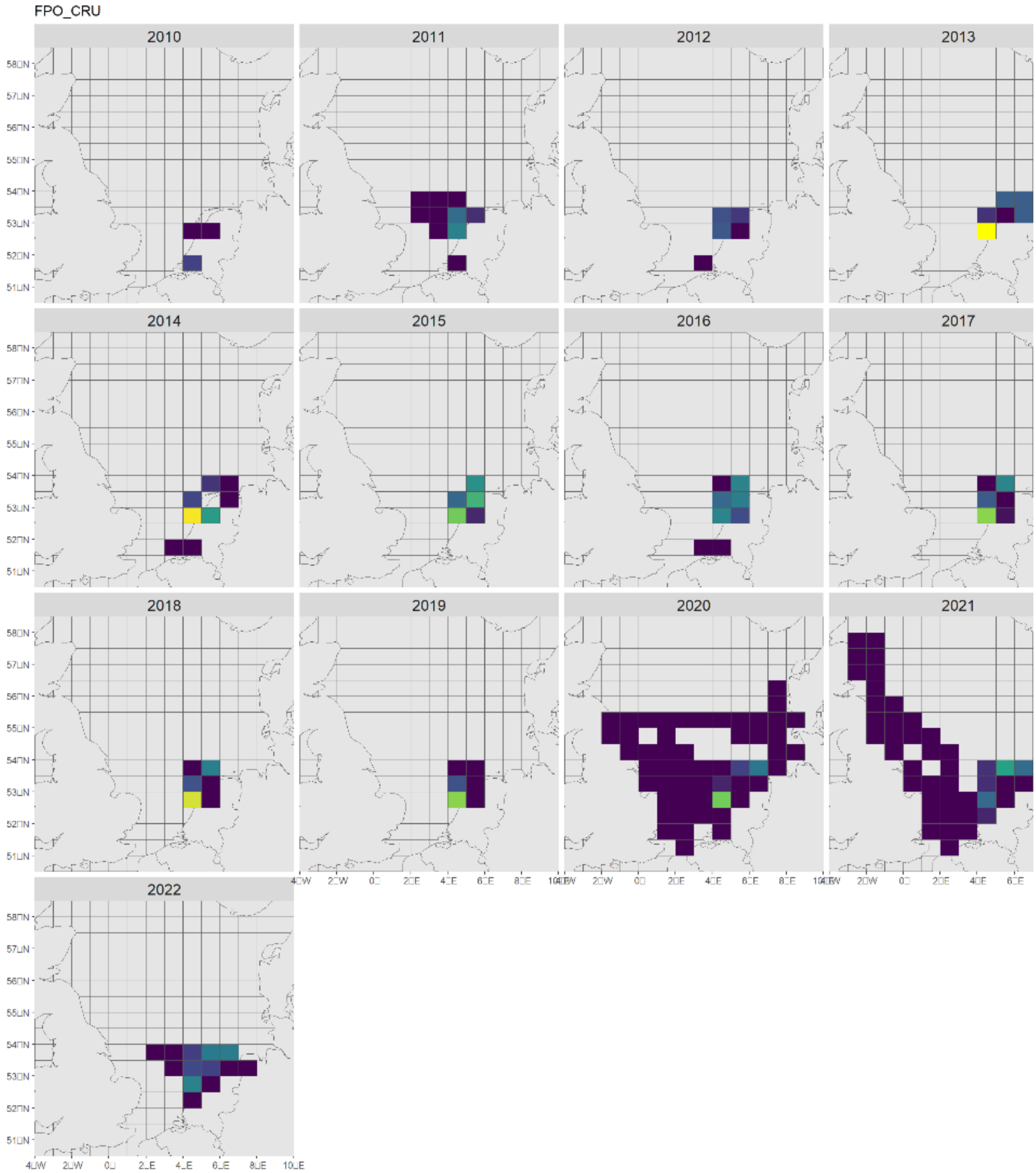

Figure 33 CPUE of brown crab 2010 : 2022 by pots for crustaceans (FPO_CRU)

5.8 Tags and population estimates

A total of 233 brown crab were tagged: 189 males and 44 females. Only four tagged animals were caught, all males (1.7% of total, 2.1% of number of males) were recaptured, on four different dates three on crab-pot-string E and one in crab-pot-string G. This is unfortunately not enough to do reliable estimate of the population size.

6 Discussion

6.1 Weather

The weather is an important aspect in evaluating operational aspects and risks involved with passive fisheries in OWFs. It determines whether a crab-pot-string should be temporarily removed from the OWF. It also determines whether it is possible to sail and harvest the crab-pots. This aspect helped in answering the research questions 1 to 3.

The conditions were rather rough in the summer of 2022. With 6 out of 9 periods in between expedition days with 7Bft or higher, the sea has been rough with high waves. The YE152, with its length of 9.95 m, appeared sensitive to the resulting waves and swell. Due to this weather the second expedition had to be stopped after five hauled and measured crab-pot-strings; crab-pot-string G could not be found due to the waves on the third expedition and there were extended periods of waiting in between the expeditions.

In total 12 days were counted with ≥7 Bft between July and September. Long time series analyses (1971-2022) of data of IJmuiden revealed that July has on average 0.29 (±0.82) days ≥7 Bft, August 0.67 (±2.20) and September 1.31 (±4.19), amounting to an expected 2.27 days ≥7 Bft in total. This illustrates again the windiness of the summer of 2022.

Translating this weather to normal exploitation implies several opposing interests. One the one hand, given the low CPUE, longer soaking times are welcome because of a commercial preference to have full crab-pots. On the other hand, after long soaking times, the bait was completely gone, that could be a disadvantage for the CPUE and LPUE like e.g. the observed loss for the velvet swimming crab. The brown crab kept on entering at a low CPUE despite the fact the bait had disappeared. Artificial bait might extend the period of active fishing and increase catch.

Also important, waves and swell can become too high to sail out and still not reach the haul out indicator threshold. Then these high levels will prevent the precautionary haul out of crab-pot strings when the weather becomes even more extreme (see below).

6.1.1 Haul out indicator

The haul out indicator serves as a warning to take out crab-pot-strings when conditions are not suitable for crab-pot-string fisheries in an OWF. It has been proposed as a safety measure to prevent that crab-pot-strings are mobilised in the OWF (WMS, Rozemeijer 2023, Rozemeijer et al., 2022a,b). Mobilised crab-pot-strings can get entangled in wind turbines and the (dragging) Bruce anchors can potentially damage infield cables. In Rozemeijer et al. (2022a,b) the haul out indicator threshold was set at 445 cm with a wind speed of 18 m/s (8Bft) and a direction of 222° (~South West, Rozemeijer et al., 2021). During the Borssele II 2022 expedition period the haul out indicator threshold was exceeded from 16 to 18-9-2023 (*Figure 12*). The haul out indicator reached 684 cm at wind speed of 24 m/s (9Bft) coming from 140° (~South East). During the PAWP 2023 expeditions haul out indicator was 542 cm with a windspeed of 17 m/s (7 Bft) and with a wind direction of ~North West (276°, Rozemeijer et al., 2023).

The haul out indicator has some disadvantages in its current set up. The prediction of the extra water level as compared to NAP is only available in a prediction of two days in advance. This is a very short period for the fishers to react. But even with an adapted haul out indicator the time of reaction remains short. Conditions can change rapidly and within a few hours. It happens often that the waves and swell build up to above the workable and safe working threshold while the haul out indicator is still well below its threshold (see e.g. *Figure 13* on workable days). On the other hand it seems that the threshold of haul out indicator can be raised reducing the chance and urgence to sail out and translocate the crab-pot-strings outside the OWF.

6.1.2 Workable days

An important aspect is the amount of workable days in evaluating operations and exploitation. In daily practice significant wave height and swell are added and used as an indication whether it is safe to sail with a This workable days threshold of 100 cm. This workable days threshold is below the threshold set in the WMS (>150 cm significant wave height, Rozemeijer et al., 2020, Rozemeijer, 2023). This approach was used both captains of the vessels in both the Borssele II 2022 experiment (sections 2.3, 3.3) and the PAWP 2023 experiment (Rozemeijer et al., 2023). Applying the threshold, 60% of the days were workable. This is lower as compared to the average percentage of workable days. Neitzel et al. (2023b) compiled an historical overview of the workable days at Borssele II. This resulted in 79% workable days in July and 71% workable days in August. They only used significant wave height, so a direct comparison is not possible, although significant wave height is the major component of the workable days threshold (*Figure 13*).

An important aspect was the perception of the risks by the captain. If higher winds are predicted for the next day and / or the arrival of higher winds is unpredictable in the summer of 2023, the captain can be unwilling to take the risk to be caught by earlier arriving wind and associated waves (Rozemeijer et al., 2023). Smaller vessels like the YE152 are more influenced by waves and swell. Bigger vessels are less influenced but with size, expenses increase as well, e.g. because more crew is needed (salaries) and the vessel is more expansive (purchase, fuel costs). So the personal risk perception, the anticipated weather and vessel size are factors of influence that should be taken into account when estimating the amount of workable days (Rozemeijer et al, 2023).

6.2 String length and measurement error

In order to answer research questions 1 to 3 and to assess if crab-pot-strings have been displaced, it is necessary to know the measurement error. The measurement error was assessed by determining the measured surplus string length as compared to the theoretical string length.

It appeared that the strings varied in length, see e.g. the overview in Table 3, *Figure 16*. All strings were recorded as longer on average than the theoretical 210 m from anchor to anchor. Also shorter crab-pot-strings were measured. These differences in actual length as compared to theoretical length can be caused either by the anchoring itself or by the way of measuring.

6.2.1 Anchoring: drift

On release the anchor drops down to the sea bed. Here it can be taken by the currents and drift for a short while. Since the depth ranged between 20 and 34 m, the descend time will be 2 to 3 seconds. With an horizontal current speed of 1.1 m/s, this impact of drifting seems negligible (2-4 m).

More impact can be expected in the non-grabbing of the anchor into the seabed. It is not assured that an anchor grabs in the seabed immediately. When the anchor is attached to the string by an unrolling line under tension that is connected to a ship slowly moving with the currents, as a result the anchor could be dragged along with the ship. This will continue most likely until the first crab-pot touches the seabed.

6.2.2 The measuring of location

Too early release of the anchor
In the measuring itself there are several sources causing deviations and there is room and need for improvement. Firstly the moment of calling anchor has been dropped can be improved. A better timed call improves the precision of the measurement. In principle conform Rozemeijer et al. (2021) the position was called when the buoy line is tensioned and going straight down, before the lift is felt. With

the vessel 'SCH61' (double hull, double waterjet engine) it was fairly easy to remain above the anchor position. With the YE152, a low speed had to be attained, hampering the precision in the call of anchor position. It can also happen that the anchor has already released the seabed and shifted from its original position.

Calling of position
In addition the skipper did the call but he was sometimes so busy the call came too late, resulting in distance covered by the moving vessel. The latter can be solved by having two persons determining the moment of call. The issue with moment of call can be solved by choosing a better moment of the call. For the first anchor, it seems better to have the moment of hauling the first buoy into the vessel. Then there is still the length of the anchor line out in the water, but that length is known and therefore correctable. For the second anchor the moment of the fourth crab-pot might be a good moment. That has a fixed distance of 65 m towards the anchor position. And one can expect the anchor still fixed in its original position since the string line is not yet in a steep angle and not yet pulling hard. Calling at the fifth pot has been tested in PAWP and yielded less reliable results.

Uncertain vessel position
For both positions of the anchors one has to be aware the vessel does not necessarily has to be aligned in a straight line with the crab-pot string, or deviated from its course, introducing uncertainties.

GPS
Also the GPS has its uncertainty of ~50 m, adding to the uncertainty. It is possible that the wind turbines caused disturbances by e.g. physical or electromagnetic disturbance of the GPS signals (Spirent Communications, 2022, Kocewiak et al., 2012). The vessel GPS can then be more vulnerable because of the open cables that are susceptible to disturbance (Kocewiak et al., 2012). Rozemeijer et al. (2023) observed that a handheld Garmin was more reliable than the vessel GPS in PAWP.

Human factor
Another cause was the writing down of the position on the registration form. That appeared in the data quality procedure a major source of error. Both Latitude and Longitude are each five numbers. Writing them down appeared less easy than one would expect upfront. In the data quality procedure, some positions could be corrected but a large part could not. For the Borssele II 2023 Passive Fishing experiment this step in the procedure has been improved by taking pictures of the vessel GPS. In the PAWP 2023 experiment a variant was tested using the vessel GPS and its MaxSea output and a handheld Garmin GPS.

Another source lays in the reaction times and distances to be covered to use all devices. E.g. to be on the deck to observe progress and next to read out a GPS in the cabin takes time to cover the distance. An observation for the PAWP is that it can account for a 15 m difference in position. This urges to use both a handheld Garmin which can register on the spot (standing on the deck), at the very moment of action and the vessel GPS that will be later in registering the action (in the bridge). The Garmin is probably more accurate than the much older vessel GPS which has more accuracy. In Addition the AIS should be class A.

Evaluating
In essence, this measurement of anchor position needs to be considered as uncertain. There is no fixed point towards which the measurement was directed. The vessel was moving, with its course not fixed due to weather and water conditions. The anchor could be moving over the sea bed either while searching holdfast in the seafloor or while hauling (too early dragged by the vessel). These were potentially major sources of error.

Rozemeijer et al. (2023) suggested to lay still next to both dahns before hauling. The human error factor can be reduced by using other GPS equipment and by having more persons alert on calling the signs for the anchor position. Rozemeijer et al. (2023) suggested to use both an AIS class A and a handheld multiband GPS

6.3 Displacement of the crab-pot-strings

Overall, the figures (*Figure 16*, *Figure 17*, *Figure 33 - Figure 40*) show clusters of crab-pot-strings close together with an alignment as planned (~South-West to North-East). There are differences between the positions of a deployed anchor and a subsequently hauled anchor. We see crab-pot—strings with a different orientation than ~South-West to North-East. Take e.g. string A3 (*Figure 17*) string C3 (*Figure 34*) and string D10 (*Figure 35*) as examples of crab-pot-strings with an abnormal orientation. In addition, some strings were too long, like string A5 which was 413 m long (indicating something went wrong in the measurement). But it is unsure how significant these differences are. As shown the uncertainty in the measurement procedure is large (see previous sections, Table 3, Table 4) making a potential displacement questionable. In addition the displacements estimated from a deployed anchor to a subsequently hauled anchor are within the average measuring error per string plus one standard deviation.

Also for all the estimates between 9-8-2022 till 11-09-2022 there is no reason to assume the strings could be mobilised by currents and waves. Referring to *Figure 12* in this period the Haul out indicator is well below the agreed threshold of 445 cm (Rozemeijer et al., 2022). At this threshold level, crab-pot-strings were not mobilised at 8 Bft, using Bruce anchors of 10 kg. In the current test Bruce anchors of 15 kg were used. A major difference was the sequence of dahn and A1 buoy. In 2021 (Rozemeijer et al., 2021) the A1 buoy was connected to the anchor with a buoy line. Subsequently followed 6 m line and the dahn. This should prevent the bouncing and dragging of the dahn. In the Borssele II tests the dahn was connected to the anchor with the buoy line and subsequently 6 m of line and then the A1 buoy. In principle this should increase the bouncing of the anchor and thereby enhance the chances for mobilisation. However it was observed that the 6 m line was normally wrapped around the dahn, pulling the A1 Buoy close to the dahn and thereby adding extra buoyancy to the dahn (Rozemeijer, personal observation).

Taking the measurement error and the small deviations of the anchor positions and the low haul out indicator during most of the experiment into account, it is probable the anchors have not moved during the tests in Borssele II 2022. More experience and evaluation is needed to interpret the results.

6.3.1 Adapting the procedure?

The combination of haul out indicator and obligation to translocate the crab-pot-strings was was intended as an interpretation of the condition "The executing party is responsible for minimizing the loss of fishing gear."[15]. Other means of minimising gear can be thought of like e.g. combing the dahn directly with an A1 buoy or more A1 buoys in line between the anchor and the dahn.

It might be better to chance the name from haul out indicator to e.g. drift indicator which is more alike its current functioning. It gives an indication that the crab-pot-strings might become instable.

6.3.2 No displacement during 9 Bft

In the period from 11-09-2022 to 23-09-2022 the estimated displacement was low, with the range of the measurement error and its Standard deviation (section 4.3.3, Table 4) while the conditions were clearly adverse: extra water level to NAP was at most 193 cm, H_s was 369 cm as a maximum, the swell was maximally 192 cm and the haul out indicator 684 cm. The indication that the crab-pot-strings have not moved is still strong: five out of ten measurements were below the average measurement error, 5 within the average measurement + one standard deviation. The indication they have not moved is stronger than for the crab-pot-strings during the less harsh conditions.

This opens the discussion if the threshold of the haul out indicator can be increased. A higher threshold would increase the workability for exploitation by fishers. It would reduce administrative burden and increase the potential for profitable exploitation by reducing the potential costs and increasing harvest time.

6.4 CPUE and LPUE

The set up used nine crab-pot-strings with each five cages is different from usual cage fishing with strings of 50 cages or more on a crab-pot-string. In addition fishing is usually year round where these tests were performed end of July to end of September. The commercially important period of October to December with higher catches (Steenbergen et al., 2012) could not be used because of the reduction in workable days due to bad weather conditions and associated risks in an OWF. Also the months from January to June were not harvested which are usually low in catches (section 6.1). In it set-up wat is comparable to the approach of Lovewell et al. (1988) and Stelzenmüller et a. (2021). The calculated numbers will also be a measure for the period of which one anticipates the exploitation period (valid scientific approach). Calculated CPUE and LPUE of this study will differ (but most likely approach) from the estimated CPUEs and LPUEs from commercial fisheries (like Bennet 1974 and Öndes et al., 2017).

6.4.1 CPUE and LPUE brown crab

CPUEs are subject to uncertainties due to additional factors, such as state of the individual animal, escapements, gear design selectivity, trap spacing, density and saturation effects, species interactions, bait, changing area of bait influence or attractiveness and environmental factors (Bennet, 1974, Miller 1979, 1990, Sundberg, 1985, Lovewell et al., 1988, Fogarty & Addison 1997; Bell et al. 2001; Ziegler et al. 2003, Montgomery 2005, Reidenbach & Koehl, 2011, Öndes et al., 2019, Skerrit et al., 2020).

A CPUE of 0.08 to 0.2 and a LPUE from 0.01 to 0.05 crab per pot per day were estimated for Borssele II 2022. In PAWP a CPUE for brown crab was estimated of 0.2 to 1.2 and a LPUE of 0.1 – 1 (Rozemeijer et al., 2023). Steenbergen et al. (2012) measured a CPUE of 0.1 to 1.15 at the Texelse Stenen near Texel and Vlieland, also in August, September (no LPUE given). A fisher using crab pots estimated he caught 1.7 crab maximally per pot per day at the Texelse Stenen above Vlieland and Terschelling in summertime (pers. comm., no LPUE estimate possible).

Bennet (1974) measured a LPUE of approximately 0.3 to 1.6 crabs for males and 0.5 to 5.7 females in Devon, England (depending on season, assuming a crab to weigh 0.454 kg to recalculate weight to number of individuals). Lovewell et al. (1988) had CPUEs ranging from 0.28 to 2.81 crabs and a LPUE of 0.08 to 0.8 brown crab per pot per day (Table 12), depending on pot type and soaking time, at Yorkshire, UK. Bell et al. (2003) calculated a CPUE of 2.74 per tide (one low and high-water period) which is roughly 5.5 brown crabs per pot per day at the Race Bank, north Norfolk also in the months August, September. Using a recalculation factor based on density, LPUE would approach 4.4. Spencer (2013) had an average CPUE of 1.79 per tide which is roughly 3-4 crabs per pot per day near Seaton Sluice (UK). Woll et al. (2006) found various CPUEs ranging from 3.6 to 13.4 and a LPUE ranging from 2.5 to 6.2 at various locations in the Mid Norway region with habitats ranging from exposed (ocean) to sheltered (fjords and protected grounds leeward of large islands). Öndes et al. (2019) calculated an average CPUE of ranging from <1 to 8 brown crabs per pot, and an LPUE ranging from 0.92 to 2.03 kg/pot/trip depending on type of pot, type of bait and boat, moment of the year (Isle of Man, northern Irish Sea). In an approximation the LPUE was estimated ~1 to 2.2 crab per pot per day. Stelzenmüller et al. (2021) found an average CPUE of 14.5 brown crabs and an LPUE of ~10.5 (June and August) in transects an OWF located near the island of Helgoland (German Bight, the better area for brown crab, Tonk & Rozemeijer, 2019)

Concluding, with a CPUE of 0.08 to 0.2 and a LPUE from 0.01 to 0.05 crab per pot per day the results of present study are on the very low side.

Table 12 overview of the Catch Per Unit Effort (CPUE) and Landing/Landable Catch Per Unit Effort (LPUE) for some areas and authors.					
	CPUE	LPUE	Area	MLS	Remarks
Lovewell et al. (1988)	0.28 - 2.81	0.08 - 0.8	Yorkshire, England	11.5	
Bell et al. (2003)	~5.5	~4.4	Race Bank, north Norfolk , England	11.5	LPUE estimated by CPUE * legal dens/total dens
Spencer (2013)	4		Seaton Sluice, England	13	
Woll et al. (2006)	3.6 - 13.4	2.5 - 6.2	Mid Norway	13	
Steenbergen et al. (2012)	0.1 - 1.15		Texelse Stenen		
Öndes et al. (2019)	7 - 8	~1 - 2.2	Isle of Man, northern Irish Sea	13	
Stelzenmüller et al. (2021)	14.5	10.5	island of Helgoland (German Bight)	13	
Rozemeijer et al. (2021)	0.3-1		Wrecks near Scheveningen	14	
Rozemeijer et al. (2023)	0.2 -1.2	0.14 – 0.96	PAWP	14	
Rozemeijer et al. (this study)	0.08 - 0.2	0.01 -0.05	Borssele II	14	

6.4.2 CPUE and LPUE velvet swimming crab

The velvet swimming crab *N. puber* (L.) is thought to be a main by-catch species for OWF multi use cases (van de Boogaard et al., 2019). In the present study, a CPUE 0.7 – 1.5 velvet swimming crab per pot per day and decreased exponentially to a ~0.02 – 0.04 velvet swimming crab per pot per day (*Figure 25*). The LPUE started at ~0.75 lowering to 0.1 landable velvet swimming crab per day (*Figure 26*). Rozemeijer et al. (2023) estimated a CPUE range from 0.2 to maximally 4.7 and an LPUE range from 0.1 to 3.5, also decreasing in time. Skerrit et al. (2020) encountered similar results for the inshore potting area off Northumberland, UK, velvet swimming crab being a potential resource, like Roach (2019) for the Westermost Rough OWF, UK, near the Humber estuary (before and after placement of the OWF). Velvet swimming crab are cautious to enter a trap when European lobsters or brown crab are already present in a pot (Skerrit et al., 2020). Roach et al. (2018, 2022), Roach & Cohen (2020) argued velvet swimming crab occupies the same ecological niche as brown crab and could replace brown crab if the latter is caught in excessive amounts.

The most conspicuous aspect of the soak curve of the velvet swimming crab is the drop after 9-10 days (*Figure 22*). This is similar to the results of 2021 in which a drop in velvet swimming crabs was observed as well after prolonged soaking time (Rozemeijer et al., 2021). This could be either due to escape by the smaller velvet swimming crab or predation of this species by the larger brown crab.

Wallace & Rae (2018) measured a CPUE of 0.24 for pots without an escape gate and CPUE of 0.06 for pots with an escape gate. For the Westermost Rough OWF and control area a range 0.5 to 3 velvet swimming crabs per pot per day (CPUE) were measured (over several years and areas, Roach, 2019, Roach & Cohen, 2020). These results are comparable to the CPUEs of present studies (0.39 to 0.6).

Concluding, the CPUE and LPUE were within the ranges of (international) literature. Velvet swimming crab could be an important exploitable by-catch. If targeted, it is important to use pots without escape gates and to reduce soaking time. On the other hand, increasing soaking time seems to increase the LPUE of brown crab, so there is a trade-off.

6.4.3 Pot-position

Table 8 and Table 10 showed pot position is not significant: upstream northward pots were not favoured, alike the results of PAWP (Rozemeijer et al., 2023). This is contrary to findings of

Rozemeijer et al. (2021) where a significant impact of pot position was measured. Probably this has to do with the differences in tidal currents at the two locations. In Borssele II the high tide and low tide current are more or less equal in force. The low tide current is about 97% of the high tide current whereas for Scheveningen bigger differences occur. Here the low tide current is about 74% of the high tide current (Duik de Noordzee schoon App, Ministerie van Binnenlandse zaken, 2020). With these differences it can be anticipated that in Borssele II the bait plume[27] is evenly distributed along the crab-pot-string, whereas in Scheveningen the bait plume was more concentrated around the northern pots.

6.5 Comparing Borssele II catches with PAWP catches

The CPUE and especially LPUE were low in Borssele II 2022. PAWP had a larger CPUE and especially larger LPUE than Borssele II. This could be due to:

- different areas;
- different year;
- differences in development history of the OWF;
- reduction of fisheries;
- differences in obligatory distance to maintenance zones in Borssele II (250 m to any asset of the OWF operator) of and in PAWP zones you are 100-150m away from erosion protection.

6.5.1 Different areas

Differences in soft seabed habitat quality (soft seabed characteristics, water quality) of the two locations could cause differences in density of brown crab. It was attempted to derive indications for differences in habitat quality with two approaches: fisheries data and monitoring data (BTS, DYFS, and SNS surveys). Comparing the fisheries in both areas was not possible due to the low number of observations (and doubts on the interpretation, section 5.7.2). Low number of observations is also true for the data of the BTS, DYFS, and SNS surveys. Both comparisons are hampered by the fact that the Borssele area is not frequently sampled and fished. In addition the BTS, DYFS, and SNS surveys are done by trawling which not specifically suitable for brown crab. In addition the BTS, DYFS, and SNS surveys could not have been done in PAWP since 2006 (start construction). Based on these impressions and with inadequate data it is not possible to state that PAWP is an area better suited for brown crab than Borssele II (for whatever ecological reason).

6.5.2 Different years

The impact of the different years (2022 versus 2023) could not be investigated because the 2023 data are not available yet. Year to year differences can be important, given the year to year variability in measured densities during the surveys (Annex 2). The potential difference between 2022 and 2023 cannot be assessed however due to the fact that these data are gathered in the last quarter of the year.

6.5.3 Differences in development history of the OWFs

Various habitats

In addition differences in CPUE and LPUE between Borssele II and PAWP could be due to the differences in development history of the OWFs. In general monopiles offer various types of habitat (Bouma & Lengkeek, 2012, 2013, Vanagt & Faasse, 2014, Kerckhof et al., 2019, Degraer et al., 2020, Coolen et al., 2020, Ter Hofstede et al., 2022):

- An intertidal zone on the turbine: with typical species like green algae, different species of barnacles, oysters (*Ostrea edulis*), mussels (*Mytilus edulis*) and small amphipods like *Jassa herdmani*.

[27] Baited fishing gears attract animals from a distance. The bait dissolves in the water and is dispersed by currents and diffusion into a plume. The animals (crabs, European lobsters) react to and are attracted by the odour of the decaying bait.

- A shallow subtidal zone (from the intertidal zone to circa 3 m depth) mostly covered with mussels and some common starfish (*Asterias rubens*).
- The remainder of the turbine with mussels, small crustaceans, the orange anemone (*Diadumene cincta*), polychaetes, Pacific oysters (*Magallana gigas*), brown crab, plumose anemones (like *Metridium senile*), *Sargartia* spp. anemones and sea urchins. With increasing depth mussels decrease and sea anemones increase.
- The anti-scouring with anemones (*D. cincta, Sagartia sp., M. senile*), small crustaceans like *J. herdmani*, common starfish, various crustaceans (velvet swimming crab, hermit crab), polychaetes and hydroids. Bryozoans like *Conopeum reticulum* could have a high coverage (alike sponges as e.g. *Halichondria panicea* breadcrumb sponge). is present
- The enriched soft substrates in the direct surroundings of the wind turbines which have received organic enrichment from the detritus and faeces falling from the monopiles.
- And the larger surrounding seabed at larger distances with the typical soft sediment communities with polychaeta and bivalves. The main bivalves of this community are *A. alba*, *Spisula subtruncata* (cut through shell) and *Ensis leei* (Atlantic jackknife clam, formerly known as *Ensis directus*).

The associated communities can either be sessile like the mussel or sea anemones of live on or just above the bottom (epibenthic communities). The variation in species presence at the hard structures depends on various drivers, such as age, materials used, and complexity of the structures (Kerckhof et al., 2020, Coolen et al., 2020, Ter Hofstede et al., 2022).

Succession in communities
With time both biomass and biodiversity increase on both turbine and anti-scouring evolving into a highly biodiverse community (Bouma & Lengkeek, 2012, 2013, Kerckhof et al., 2019, Coolen et al.,2020, Degraer et al., 2020). Three stages can be discerned so far. In the first period (~2 years) after installation of the turbine and anti-scouring rapid colonisation followed with opportunistic species like the colonial bryozoan *Electra pilosa*, least skeleton shrimp (*Phtisica marina*), scale worm (*Lepidonotus squamatus*, polychaete worm) and the amphipod *J. herdmani* and a relatively short pioneer stage.

The second stage was a diverse intermediate stage characterised by large numbers of suspension feeders (like the slender tube amphipod *Corophium acherusicum*, sea anemones and *Pomatoceros triqueter*, a tube-building annelid).

A third stage was dominated by *M. senile* and *M. edulis*. -dominated stage, was reached after 10 years *M. senile* is a strong competitor for space by rapidly colonising new substrata leaving no space for others, consuming potentially settling larvae and smothering new recruits (Kerckhof et al., 2019). The biomass and biodiversity on hard substrates of the OWFs was high and increased with time (Bouma & Lengkeek, 2012, 2013, Rumes et al., 2013, Vanagt & Faasse, 2014).

OWF anti-scouring already attracted large quantities of brown crab after two years in the German Bight (Krone et al., 2017). However, this is an area with high densities of brown crab so one can expect brown crabs to migrate towards the OWF to profit from the protection of the anti-scouring (*Figure 31*, *Figure 32*, Tonk & Rozemeijer, 2019).

The construction of Borssele II started in 2020, finishing in 2021. So, in 2022 the hard structures were one, maximally two years old and hence in the first stage of colonisation: a community with low biodiversity low biomass and patchy coverage of the substratum (Kerckhof et al., 2012). For PAWP the most recent measurements were 2013 (Vanagt & Faasse, 2014) and Ter Hofstede et al. (2022). The hard substrate communities of PAWP showed large overlap with the older communities on oil wrecks and rocky substrate (Coolen et al., 2020). Most important species encountered on the hard substrates of PAWP were anemones (*M. senile* and *Sagartia* spec.), brown crab, velvet swimming crabs, the common starfish, *Lanice conchilega*, (sand mason worm). gobies, and cod-like fish (*Trisopterus spec.*, *Gadus morhua*). NB no measurements on (epi)fauna on the anti-scouring have been done in either of the OWFs in 2022 and 2023. The lower CPUE and LPUE in the Borssele II could be the result of lower brown crab densities due to the lack of prey items as compared to the assumed to be more developed hard substrate communities on the anti-scouring of PAWP (Vanagt & Faasse, 2014, Kerkhove et al, 2019, Ter Hofstede et al., 2022) with potentially higher numbers of brown crab.

6.5.4 Reduction of fisheries

In addition, fisheries pressures have been annihilated in PAWP which could result in larger crab populations, especially the larger crabs resulting in a higher LPUEs for brown crab and velvet swimming crab in PAWP.

6.5.5 Distance to the anti-scouring

Another aspect is the distance to the anti-scouring. These were not alike: in Borssele II the minimum distance was at minimally 500 m to 1000 m maximally. In PAWP it was at minimally 100 m to 360 m maximally to the nearest pot. This is a likely factor influencing the CPUE and LPUE. Stelzenmüller et al. (2021) showed local spill-over up to distances of 300 to 500 m to the nearest turbines. Spill-over is explained as follows: due to the higher population of crabs on the anti-scouring the immediate vicinity also has higher densities. These higher densities on and near anti scouring result in higher densities in the larger surroundings as well.

Comparing CPUEs and LPUEs of Borssele II and PAWP in relation to results of other studies showed CPUE and LPUE in Borssle II were low in 2022. Comparison of spatial data (Annex 2) showed also high annual variability in brown crab densities. More data is needed to improve the insights and to be able to advice fishers to invest in crab and European lobster fisheries in OWFs or not. (In addition emotional considerations were also important for fishers (Baan & Leemans, 2023)).

6.6 Mark and recapture

Only 2.1% of the tagged number of males were recaptured (4 individuals). In a test on population calculations with the capture: mark: recapture test of 2021, 1.6% females (5 individuals) and 5.0% males (19 individuals) were recaptured. From the test calculations it became apparent that sufficient absolute numbers in an even distribution over the expeditions need to be caught and that current recaptures were too low (Chen & Rozemeijer, 2023, internal memo).

As compared to others the current recapture percentages were low. Bell et al. (2003) used the technique for a similar purpose but did not give recapture percentages. Spencer (2013, Blyth UK in November, comparable small scale set up lasting 6 weeks), calculated a 3.8% recapture percentage of 3,718 brown crab. This number is low but sufficient for estimating populations due to the high absolute numbers and even distribution over the expeditions. That number is comparable to the 3.4% of present study. Hunter et al. (2013) had a 17% to 40% recapture percentage of 128 testing animals for a migration research, large time scale (lasting almost one year) and space (Chichester to Falmouth, south coast of the UK). They also offered a substantial reward to commercial fishers. Ungfors et al. (2007) also measure an 8.0 – 8.7% recapture percentage for large scale migration research (3,749 crabs tagged, 7 years and Skagerrak and Kattegat, mark and recapture experiment). Coleman & Rodrigues (2017) had a recapture percentage between 0.6 to 22.4% for a 4-year, large scale migration experiment (6,954 brown crab tagged) at the Orkneys with dedicated fishers.

6.6.1 More measurements needed

Comparison of spatial data (Annex 2), results of other years and results of other studies show that the CPUEs and LPUEs of Borssele II and other OWFs can differ from year to year. This is the first experiment fishing on crabs and European lobster and the PAWP 2023 the second experiment with target species crabs and European lobster. Normally population estimates and harvest and earning potential are determined based on long-term time series(Rozemeijer & Van de Wolfshaar, 2019, Tonk & Rozemeijer, 2019, Hoekstra, 2021, Strietman et al., 2023). More data are needed to make an better evaluation of the potential of OWFs for passive fisheries on crabs and European lobster in OWFs.

7 Conclusions and recommendations

7.1 Conclusions

Can the crab-pot-strings in a set-up of five pots be mobilised under summer weather and sea current conditions when anchored with two Bruce anchors of 15 kg each?
In the WMS (Rozemeijer et al., 2020, Rozemeijer, 2023) the mobilisation of crab pot-strings was defined as an risk to damage infield electricity cables, although earlier research demonstrated that Bruce anchors did not damage the infield cables (Rozemeijer et al., 2022a,b). Also the chance of mobilisation was low. Despite the uncertainties of measurement procedures, it seems probable that the anchors have not moved during the experiments, not even at 9 Bft from the South East. This wind speed has not been tested before. This opens the potential to increase the threshold level of the haul out indicator.

The measurement of the position of the anchors proved very difficult. Nothing was fixed: the vessel moves, the anchors may move. The measurement procedure can be optimised by using better gear (newer vessel GPS or even better an AIS class A in combination with a hand held Garmin GPS), an adapted procedure (laying still next to the dahns, moment of calling) and better human resource utilization (when and where to call, two persons involved). Most uncertainty should be reduced by lay still next to each dahn before starting any hauling. More experience is needed to evaluate results obtained in the experiments described.

How do these mobilisation results compare with the 2023 PAWP results and with the 2021 results in Scheveningen (Rozemeijer et al., 2021)?
In the Scheveningen study the crab-pot-strings have not been mobilised. In the PAWP study the crab-pot-strings seemed not to have been mobilised alike this study. As compared to the Scheveningen study the observed windspeed was higher during the Borssele II 2022 expeditions: 24 m/s (9 Bft, South East) as compared to the 18 m/s (8 Bft, ~South West) in 2021. Also the maximum haul out indicator attained a higher level: 684 cm as compared to the 445 cm in 2021 and 542 cm 17 m/s (7 Bft, ~North West) in PAWP. In both the expeditions in Borssele II 2022 and PAWP the measurements on the positions of the Bruce anchors and thereby potential mobilisation were uncertain.

Do the results lead to adjusting safety measures for PAWP or Borssele II?
The results could lead to safety measures adjustments for the threshold level of the Haul out indicator and the set-up of the anchor buoy line. Apparently the crab-pot-strings are quite stable even at a haul out indicator level of 684 cm. However, the measurements were too uncertain to justify raising the threshold responsibly. More data is needed.

The question is raised which set up should be used. In the current study, the Polyform A1 buoy was placed after the dahn (in relation to the Bruce anchor). In practice the Polyform A1 buoy curled up around the dahn resulting in a double buoy. This opens an interesting option to have both dahn and Polyform A1 buoy linked next to each other (and with one or two Polyform A1 buoys 6 m more towards the anchor).

Is it possible to catch brown crab and European lobster in Borssele II?
Yes, during the project we have caught brown crab and European lobster. In addition another commercially interesting species, velvet swimming crab, was caught and some sepias and red mullets as well. For velvet swimming crab it would be necessary to develop trading routes to e.g. Spain.

What are CPUE, LPUE of brown crab and European lobster and recatch% of tagged animals in Borssele II?
The CPUE and LPUE are low as compared to other locations. This can be due to the fact that OWF Borssele II is recently build and therefore the anti-scouring has a low biomass and food availability

and brown crab populations have not been build up yet. The monitoring and fishery data had too many zero values for the locations at stack to give additional indications.

How do CPUE, LPUE and recatch-% compare to PAWP?
The Borssele II 2022 experiment showed a smaller CPUE and especially smaller LPUE thanPAWP 2023 experiment . This could be due to a number of reasons. There could be differences in the habitat quality of the surrounding soft substrate around the OWFs. However, the data on the monitoring and fisheries were not adequate to derive indications for such differences. The Borssele II experiment was in 2022, the PAWP experiment in 2023. The impact of difference in year of the experiment could not be investigated because the 2023 monitoring data are not available yet. Year to year differences can be important, given the year to year variability in measured densities in Annex 2.

In addition the differences in CPUE and LPUE could be due to the differences in development history of the OWFs. OWFs that have been deployed earlier have more developed hard substrate communities on the anti-scouring with higher biomasses of sessile benthos and epibenthos. Also it is anticipated that the directly surrounding soft seabed will be enriched. Higher prey availability could lead to higher densities of predating brown crab. Since no direct measurements were done on benthos communities on hard substrates and soft seabed, this cannot be concluded. However it is plausible.

Differences may also be related to the fact that fisheries pressures reduced dramatically and crab populations are large. Especially the fact that in PAWP larger crabs were caught with higher LPUEs for brown crab and velvet swimming crab make this explanation also plausible.

Another aspect is the distances to the anti-scouring. These differ between the two OWFs: in Borssele II the minimum distance from anti-scouring to closest was at least 500 m to 1000 m. In PAWP the distances could be 100 to 360m. In Germain OWFs local spill-over mechanisms occurred up to distances of 300 to 500 m. So the spill-over effect could apply to PAWP (crabs coming from the anti-scouring to the pots). It seems unlikely for Borssele II.

The weather in the season of expeditions (summer 2022) was more windy than average summers which resulted in more waves than usual and less workable days than average. This reduced possibilities to perform expeditions. This is also an indication for potential profitable exploitation in the future. The presence of the wind turbines and OWF related vessels pose additional risk, especially during high waves and strong currents thereby reducing the possibilities more.

The CPUE and LPUE of brown crab and velvet swimming crab were influenced by different factors. E.g. the LPUE of brown crab in the Borssele II 2022 experiment were influenced by soaking time and location (ridge or valley) and not by pot type (Medley, Parlour) or pot order (south to north). In PAWP 2023 experiment the LPUE of brown crab was influenced by soaking time and by pot type (Medley, Parlour) but not by pot order. The location was not a relevant variable for PAWP (all flat seabed of more or less the same depth).

What is the population of brown crab and European lobster at Borssele II?
Due to the low recaptures of tagged animals it was impossible to estimate the population sizes of both brown crab and European lobster.

What is the bycatch in Borssele II when using crab-pot-strings with Medley pots and Parlour pots?
An interesting bycatch were velvet swimming crabs. The LPUE was ~0.75 with a short soaking time, lowering to ~0.1 with longer soaking times. That makes this species an interesting target when weather dictates short soaking times. When soaking times increase the number of velvet crabs decrease but brown crab numbers still increase. Other bycatch species are given in *Figure 18*. The total amount of bycatch is low, with the usual species. Next to velvet swimming crab, red mullet could be commercially interesting but specific bait seems required for this species. Also sepia (common cuttlefish) could be a commercial target species.

7.2 Recommendations

7.2.1 Increasing catch

Long-term fishing in PAWP
Two experiments have now been conducted and a third experiment is ongoing. The results provide a view on the financial feasibility of crab-pot fishing OWFs based on ten boat trips maximum. It is recommended to verify these results with a more representative experiment in which crab-pot-string fishing is performed during a complete fishing season in PAWP or a similar OWF. This can provide more insight in the economic considerations of a realistic fishing season. In addition, more tests give a better insight in the annual variability.

Artificial, long-term bait
The new OWFs with co-use options are at larger distances from ports (Strietman et al., 2023). Travel distances (expenses) are therefore larger. Less frequent haul outs could reduce the costs and thereby the chance of profitability. It would be favourable to have bait that lasts longer. To reduce costs for crab fishing, the frequency of emptying pots could possibly be reduced. In such a situation it is important that the crab-pots remain to fish. Fish bait generally dissolves and is eaten within a week. Artificial bait and light have the potential to last longer. By offering several types of artificial bait and light, including bait that gives off odour for long periods, catching success can be measured. These results can help achieve profitable catching in OWFs. Nb: light was also found to be a potential attraction source for brown crabs in Belgian research (Jasper Van Vlasselaer, ILVO).

Placing crab-pot-strings perpendicular to the current
Crab-pot strings are placed parallel to the current for safety reasons (higher location certainty during release of the crab-pot strings and less surface area in the mobilising current). The crab-attracting bait plumes are however, much wider when the crab-pot-strings are placed perpendicular to the current. Thus, higher catches are expected. In addition, given the direction of the infield cables in Borssele II and PAWP (perpendicular to the current, also expected in other new OWFs), it would increase deployment possibilities and allow longer crab-pot-strings and thus significantly increase the earning potential for fishers. However, it is not yet known how to place crab-pot strings in practice from a safety perspective.

Additional species on the earning model
In PAWP, some quantities of cuttlefish were caught in crab pots. Also, the European lobsters caught were large in size. It is worth using targeted techniques to explore whether catch of these high yielding species and other squid can be optimised.

Earning model for velvet swimming crab
The quantities of velvet swimming crab were caught in PAWP were high. This might be a species of interest for exploitation. To get a better insight the market potential and the revenue model of this species needs to be investigated.

Potential of modifications to the ‘throats’ of the pots
The entrance to the pot is called a ‘throat’. Shape and material of the throat determine the species and sizes of species caught. Although fishermen have gained knowledge through experience there is limited scientific evidence on this topic. As the throat is an important determinant of catch and therefore profitability, it is important to look into this with more detail and be able to advise fishers in a target-specific way.

Stocks
In some parts of UK and Irish waters, brown crab catches are collapsing. In France, brown crab populations are threatened by disease (Joint NWWAC/NSAC/MAC advice 2021). As issues with brown crab populations are increasing at European level, the urgency and pressure on Dutch and German Bight stocks is increasing an international fisher started fishing in Dutch waters with 4-5 times more pots than local fishers (Tonk & Rozemeijer, 2022). In the Germain Bight EUK and Irish fishers were increasingly active (Stelzenmüller et al., 2021). This is a threat to this unquoted species. What are the

brown crab stocks in the Dutch part of the North Sea and what is the maximum sustainable yield (MSY)? The same question applies to e.g. velvet swimming crab and European lobster.

Opportunities in the North of the Wadden ?
Brown crab densities are lower in the southern waters (the Delta region) and higher to the north (region above the Wadden islands) all the way up to the German Bight. The question arises whether brown crab densities are also higher in the more northern situated OWFs. In Borssele II, CPUE and LPUE assessments have been performed and the results are relatively poor compared to the results of others in the Netherlands (Table 12). At some wrecks near Scheveningen results are better but still not adequate for a profitable earning model for fishers. CPUE and LPUE assessment results in OWF PAWP were higher than Borssele II. It is worth doing an exploration to the areas above the Wadden Islands (west of OWF Gemini and Doordewind) to explore the market potential.

7.2.2 Safety

Dahns and Polyform A1 buoys set up
The executing fisher is responsible for minimizing the loss of fishing gear. It is mandatory to use dahns (buoys with marker flags) as the end markers of a crab-pot-string. However, these make a crab-pot-string unstable because waves and currents have a lot of grip on the dahn. Especially if the weather conditions are bad for long periods, there is a risk of the dahn disappearing or the material being pulled underwater. Safety can potentially be improved by exploring whether stability of the dahn can be increased. E.g. the set-up of the crab-pot-string offer a potential for improvement. Crab-pot-strings can be deployed with different set-ups of dahns and Polyform A1 buoys. For example a set-up of two A1 buoys as front runners for the dahn (anchor : buoy line : A1 buoy : line : A1 buoy : line : dahn) or an A1 buoy connected to the dahn to enhance buoyancy (anchor : buoy line : A1 buoy : line : dahn connected to an A1 buoy). More experience (data) is needed to evaluate the behaviour of the anchors and crab-pot-strings under adverse circumstances. GSM devices could be attached to the dahns for online tracking.

Measurement method for determining position
The measurement method for determining the position needs improvement. One approach is to determine the position laying still just beside the dahns before hauling any of the two. This will ensure that the Bruce anchors do not move. In addition two means of determining position are advised: a modern vessel GPS / AIS class A together with a multiband handheld GPS. In addition an elaboration of the output of the handheld Garmin has the potential to improve the position estimates afterwards. This approach needs to be tested.

Haul out indicator and threshold
It seemed that the crab-pot-strings are quite stable even with a level of haul out indicator 684 cm (~50% higher than agreed threshold of 445 cm of the haul out indicator, Rozemeijer et al., 2023). This raises the suggestion the threshold indicator could be higher. Increasing the threshold would achieve better workable conditions for fishers and increase the potential for profitable exploitation. Performing more tests also yields more and more reliable data on the haul out indicator and a better basis for evaluation.

In addition it is necessary to redesign the haul out indicator based on variables that have a longer prediction time then the prediction time associated to extra water level to NAP. A variable is needed that predicts/represents current. Current is measured at e.g. measuring points "Schouwenbank Stroomgat" "Buitenbanken West" and "IJgeul stroommeetpaal". The first two are near and in Borsseel OWF. But it is not clear how representative these locations are for other locationsRozemeijer et al. (2023) showed current velocity is site specific. So finding a measurement site that can representative might be difficult. An alternative approach might be needed and developed. Furthermore a definition and testing phase with available data could assist in choosing the most appropriate formula.

8 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.

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Justification

Report C052/23
Project Number: 4316100149

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. L. Tonk
Researcher

Signature: 

Date: 20 december 2023

Approved: Dr. A.M. Mouissie
Business Manager

Signature: 

Date: 20 december 2023

Annex 1 Maps with the crab-pot-string positions

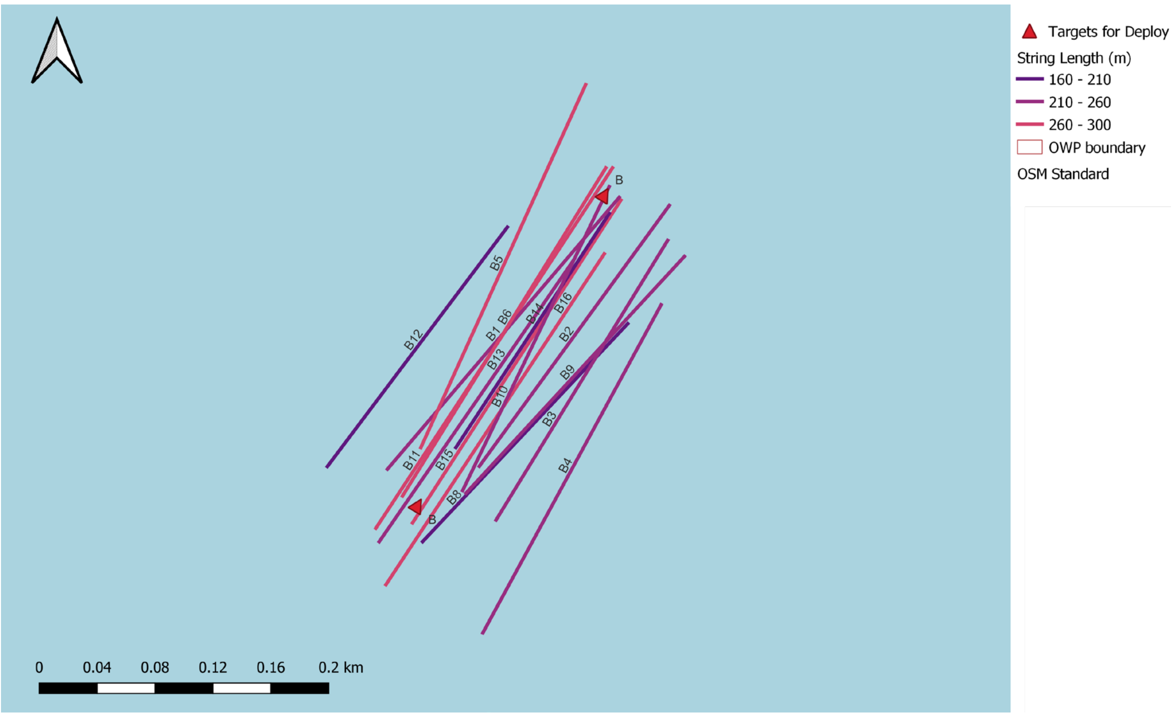

Figure 34 Overview of the established crab-pot-string positions of crab-pot-string B. Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted measurement (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

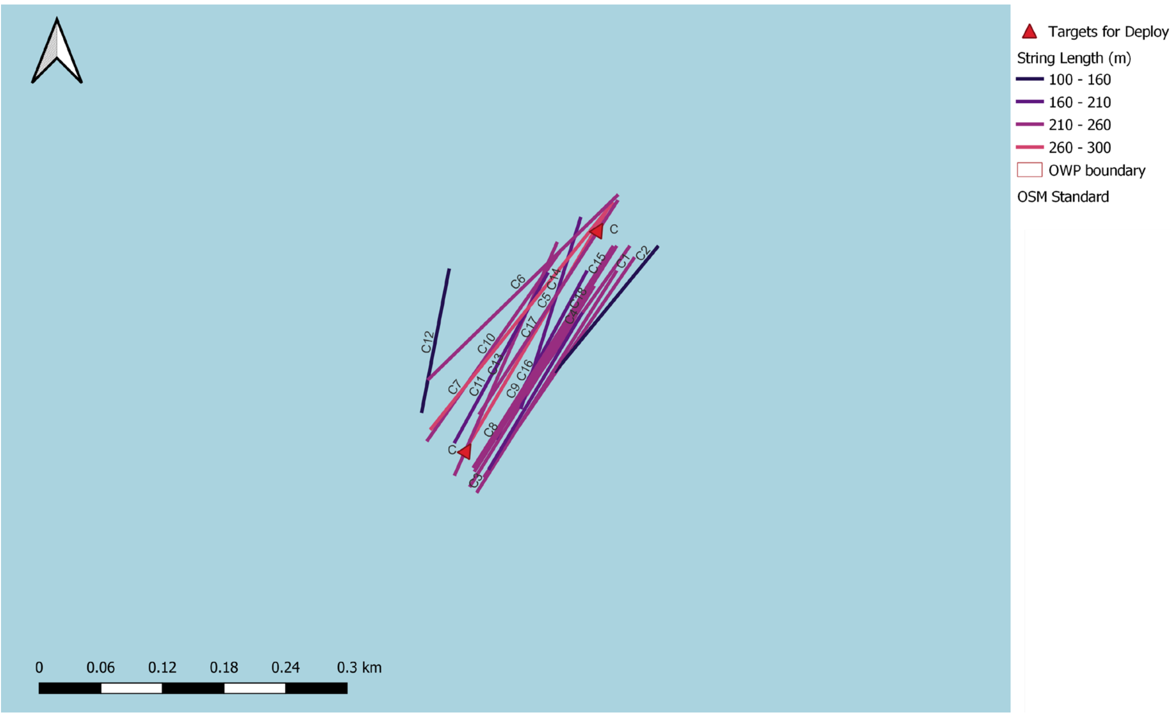

Figure 35 Overview of the established crab-pot-string positions of crab-pot-string C. Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted measurement (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

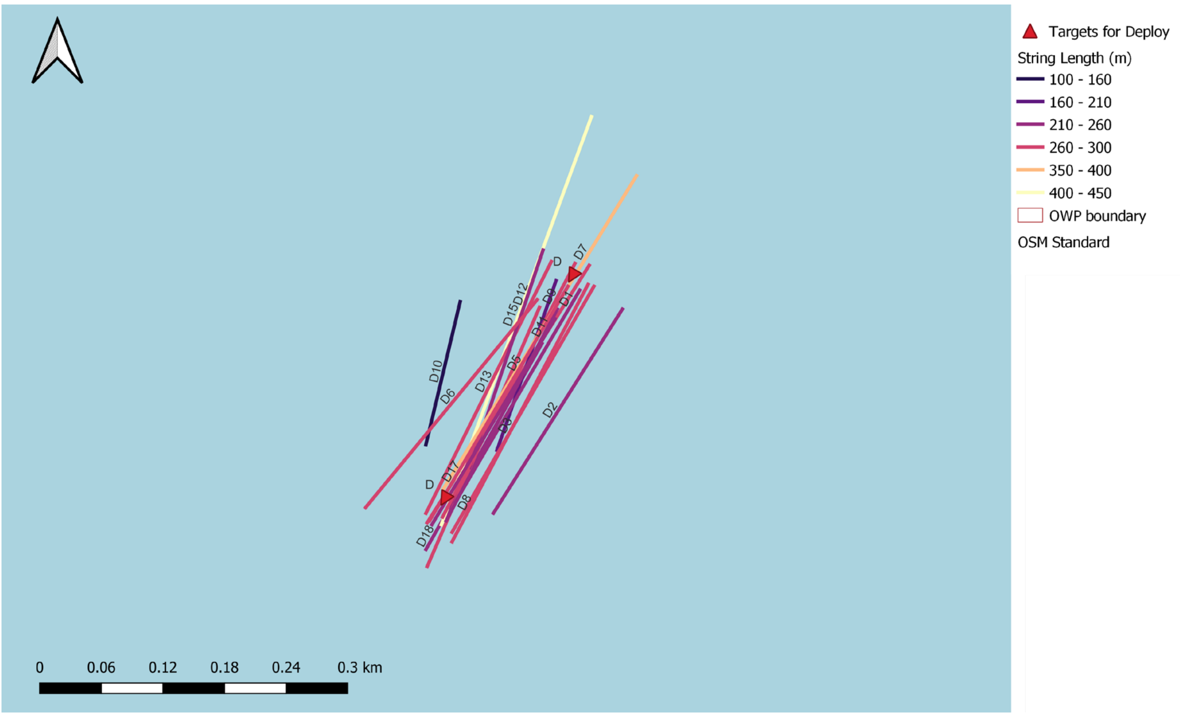

Figure 36 Overview of the established crab-pot-string positions of crab-pot-string D. Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted measurement (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

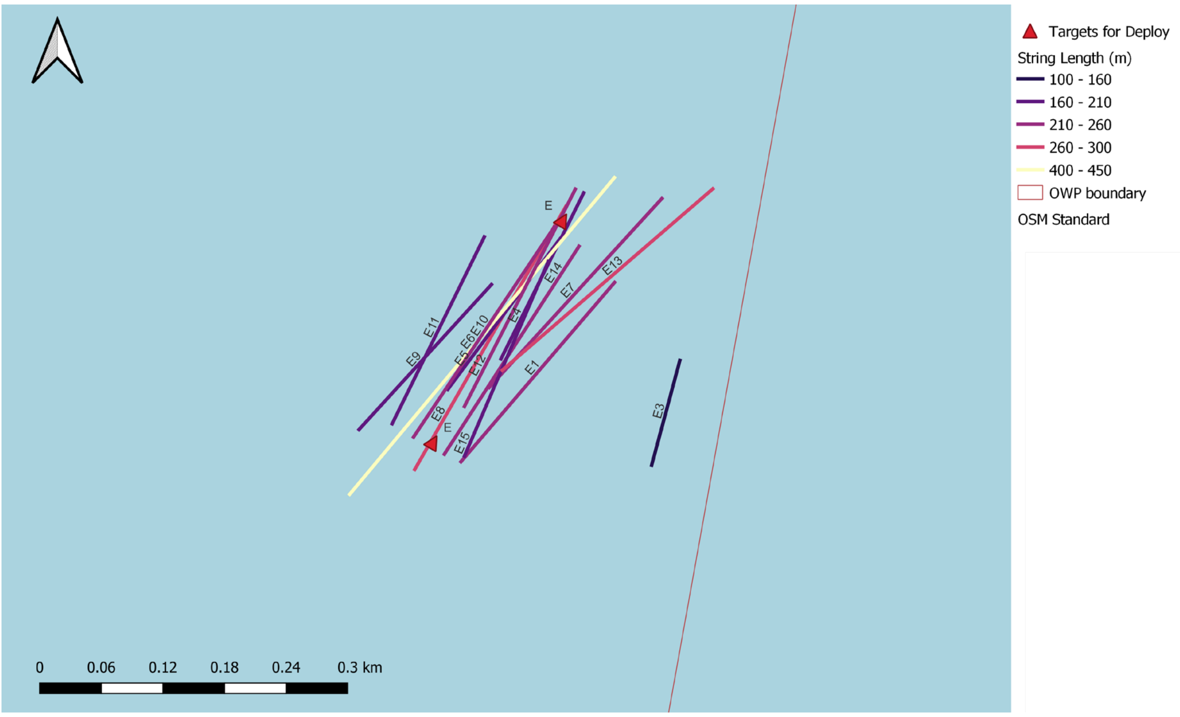

Figure 37 Overview of the established crab-pot-string positions of crab-pot-string E. Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted measurement (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

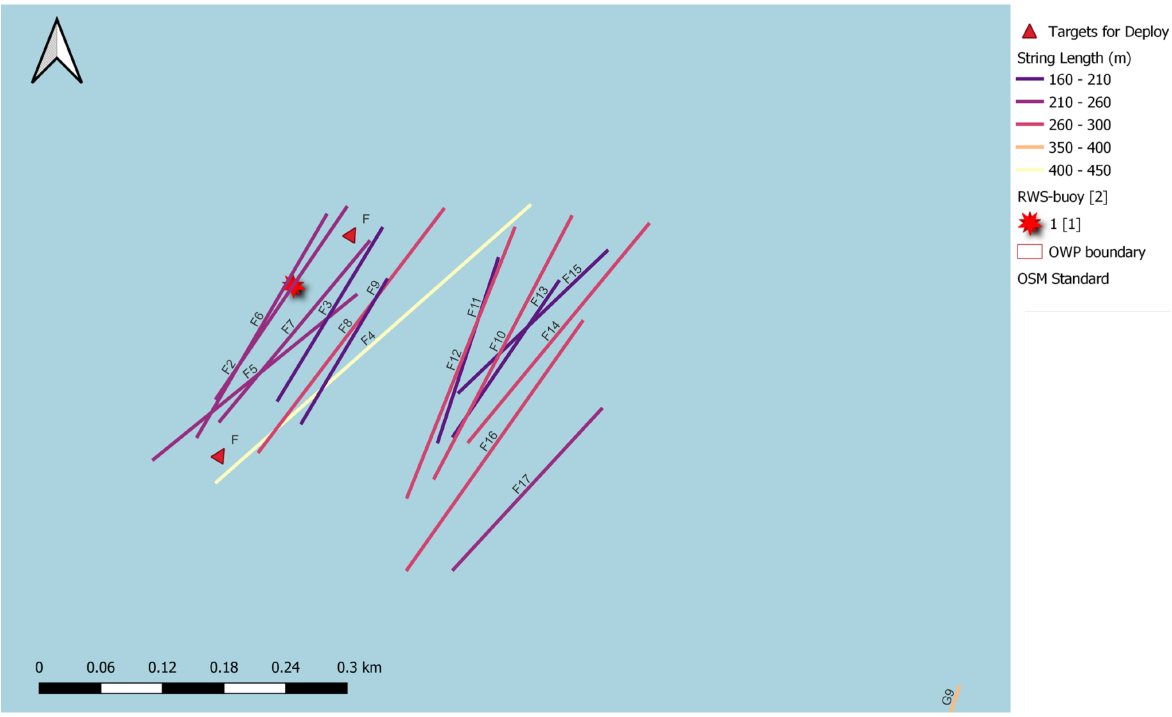

Figure 38 Overview of the established crab-pot-string positions of crab-pot-string F. Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted measurement (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

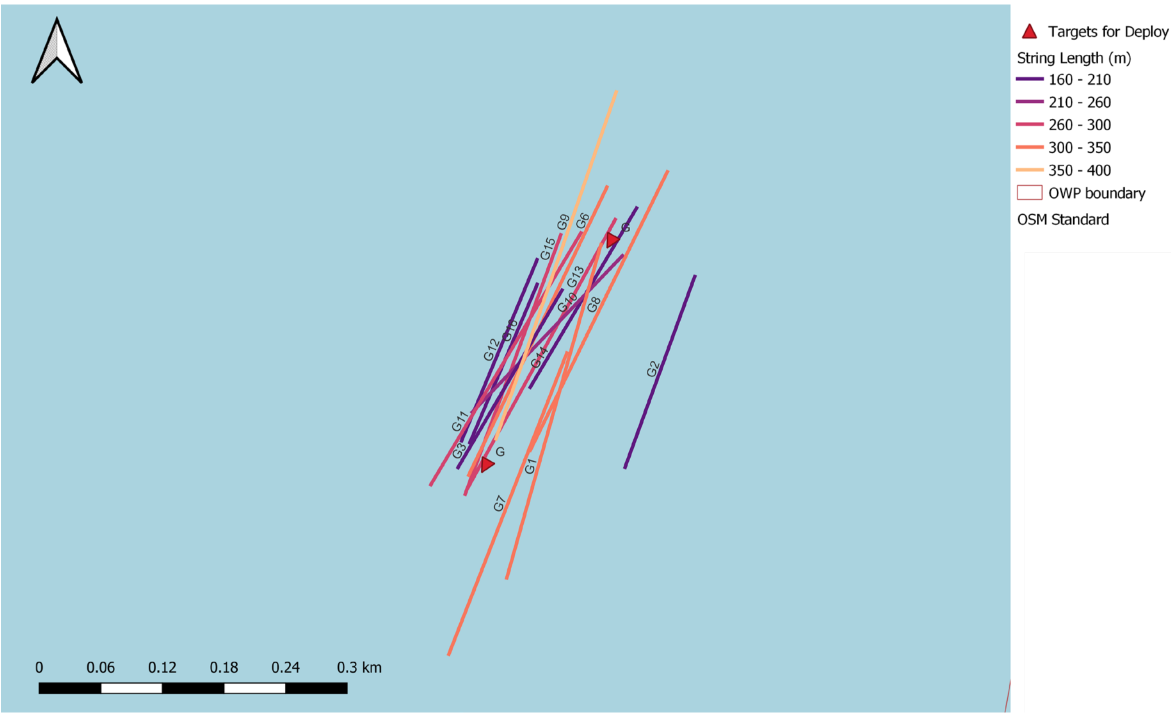

Figure 39 Overview of the established crab-pot-string positions of crab-pot-string G. Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted measurement (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

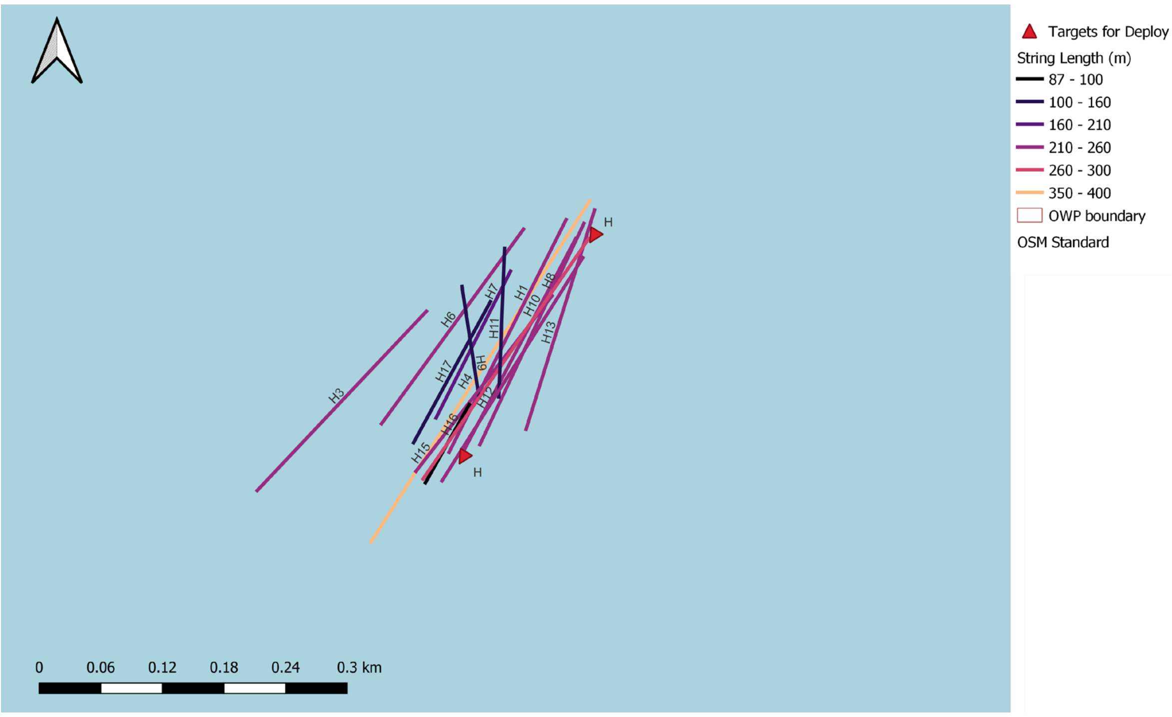

Figure 40 Overview of the established crab-pot-string positions of crab-pot-string H. Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted measurement (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

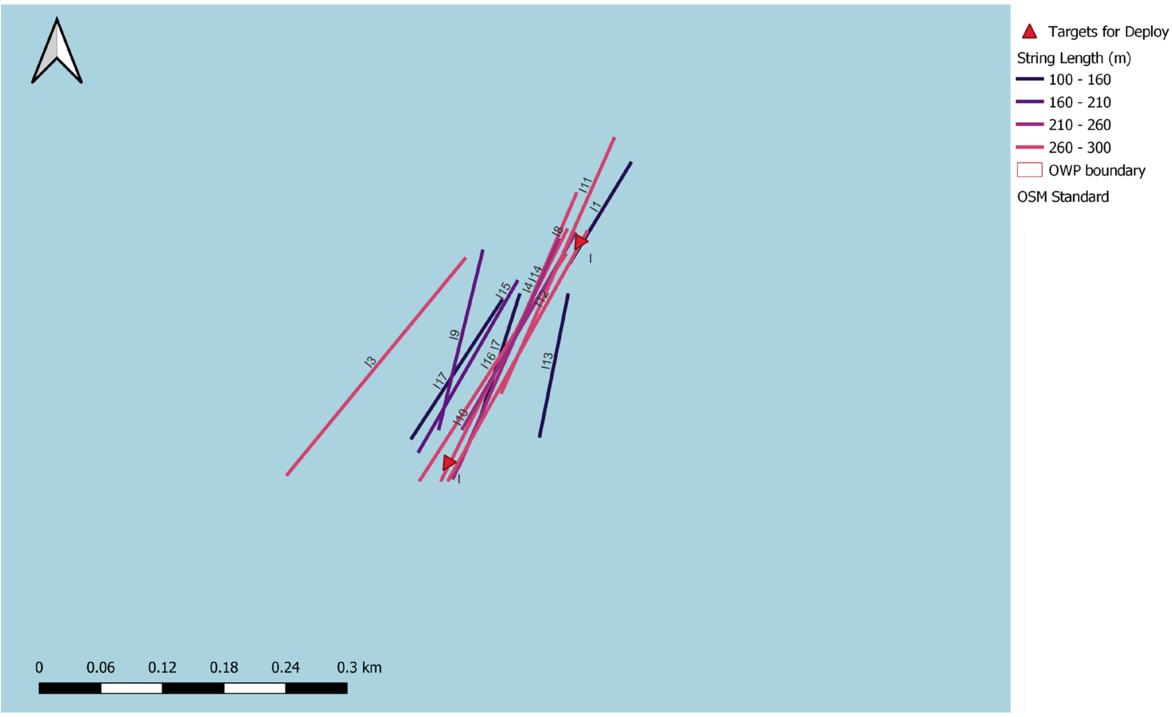

Figure 41 Overview of the established crab-pot-string positions of crab-pot-string I. Red triangles represented the planned positions. The different colours represent different lengths (see legenda). The numbers represented the subsequent accepted measurement (either haul out or deployment, not necessarily consecutive in time). Note the scale bar for the spatial scale.

Annex 2 Spatial distribution of brown crab through the years

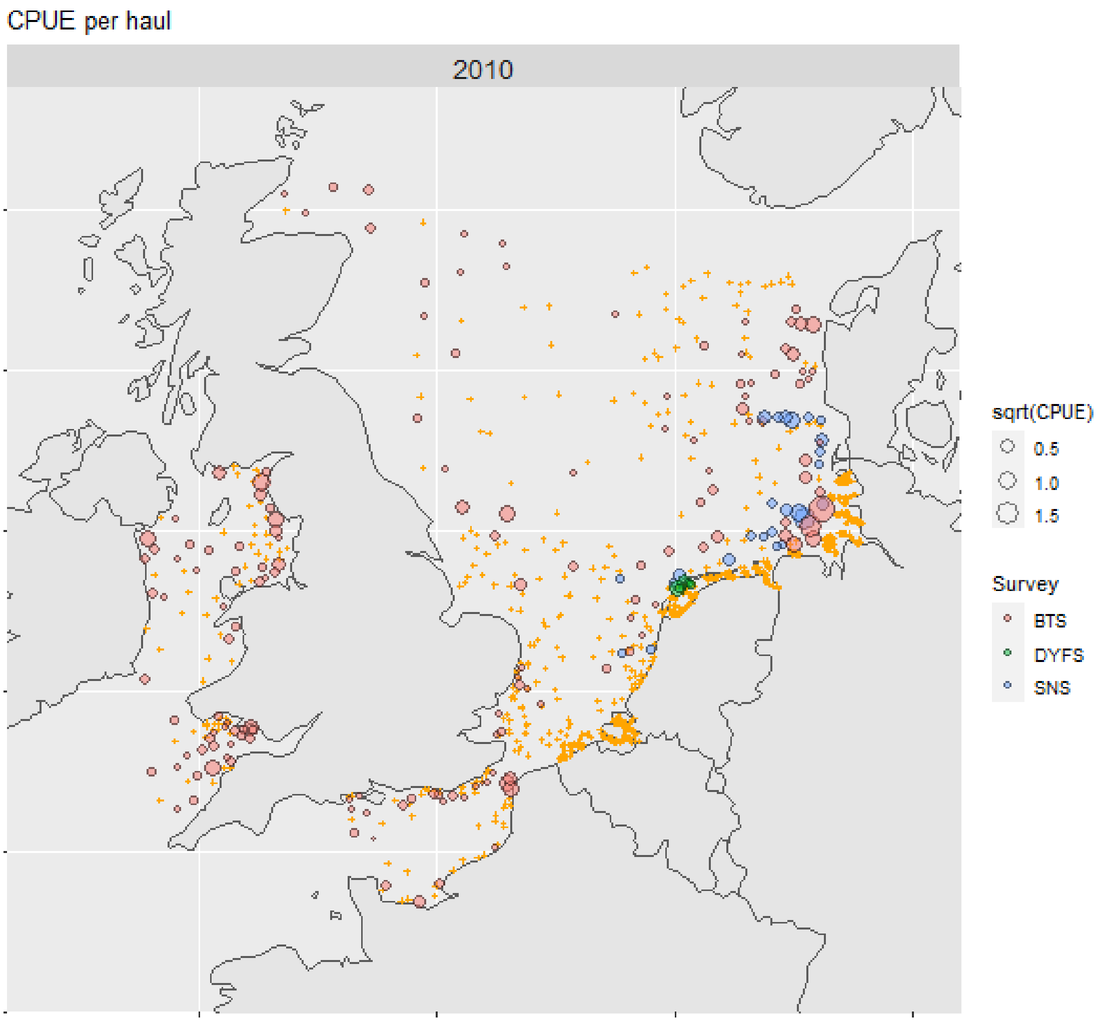

Figure 42 CPUE of brown crab in 2010 by the monitoring programmes BTS, SNS and DYFS.

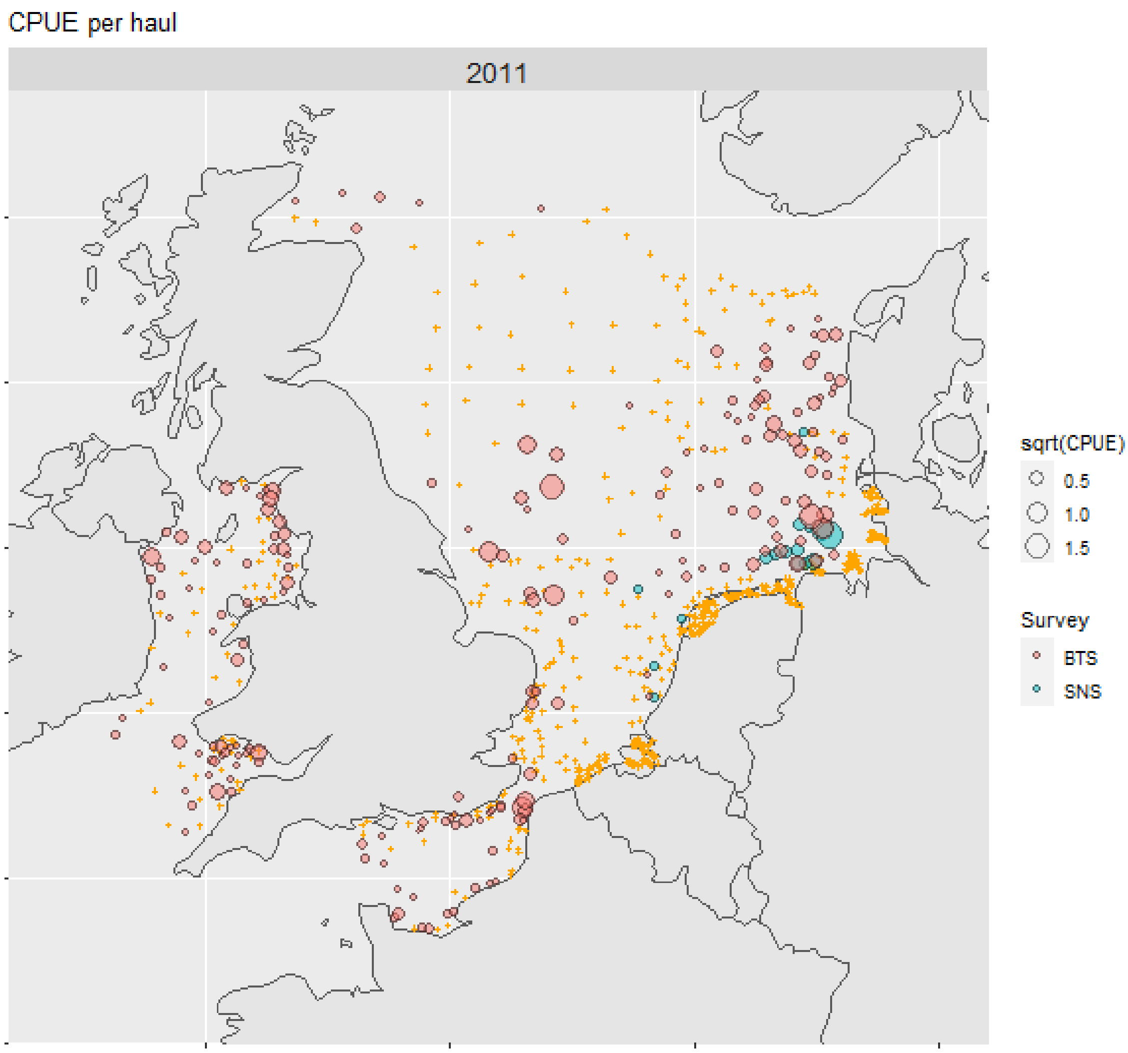

Figure 43 CPUE of brown crab in 2011 by the monitoring programmes BTS, SNS and DYFS.

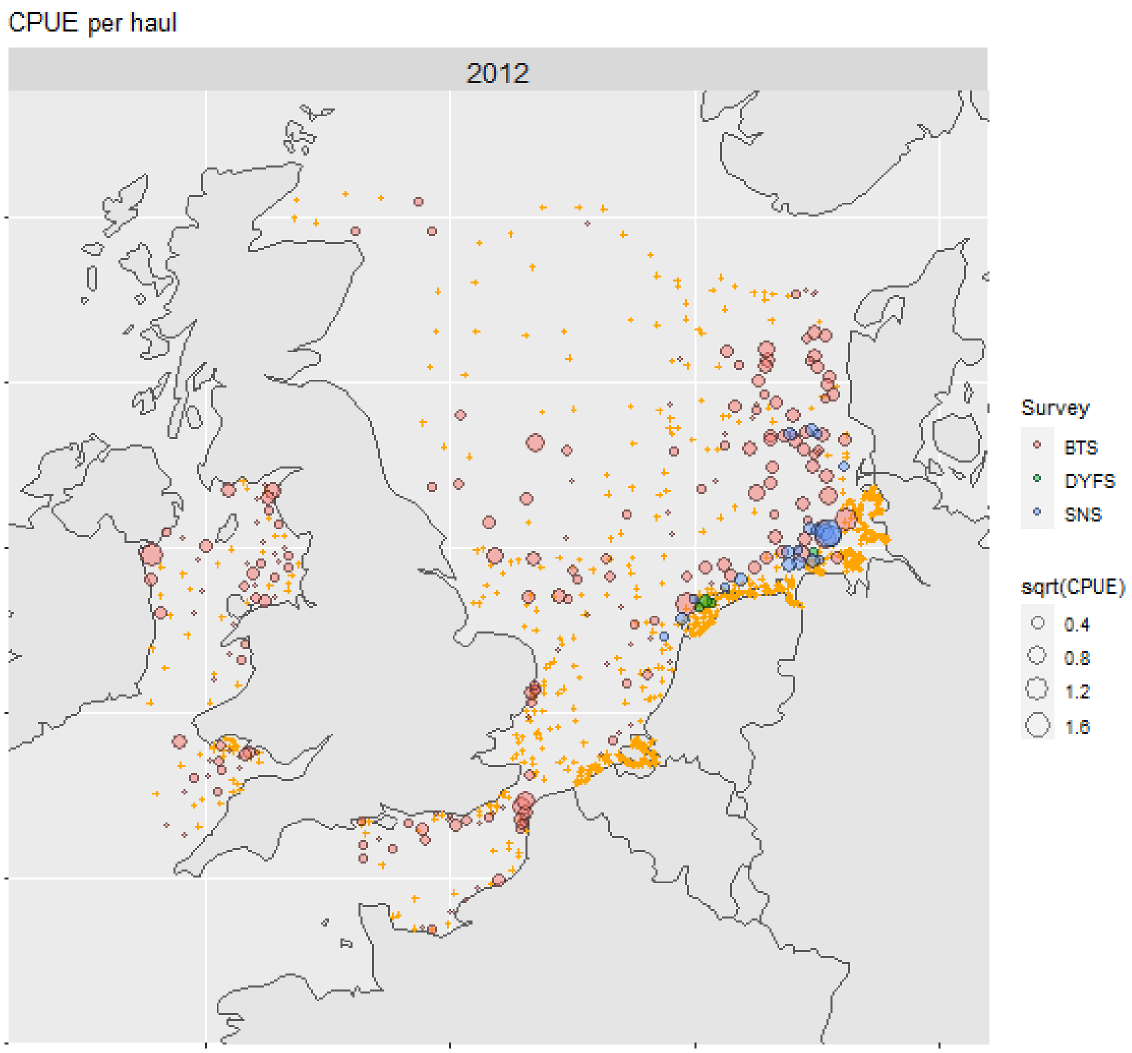

Figure 44 CPUE of brown crab in 2012 by the monitoring programmes BTS, SNS and DYFS.

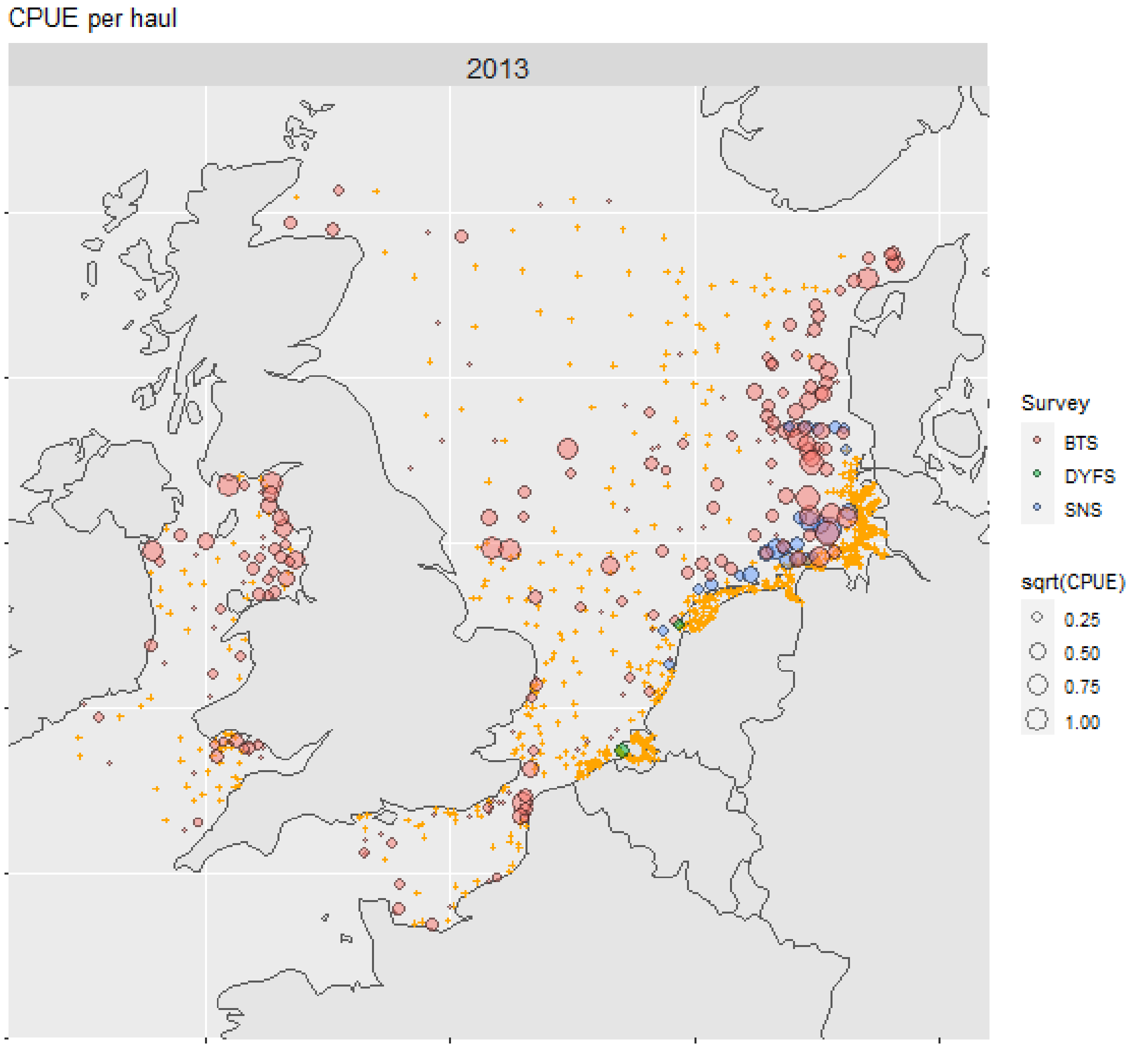

Figure 45 CPUE of brown crab in 2013 by the monitoring programmes BTS, SNS and DYFS.

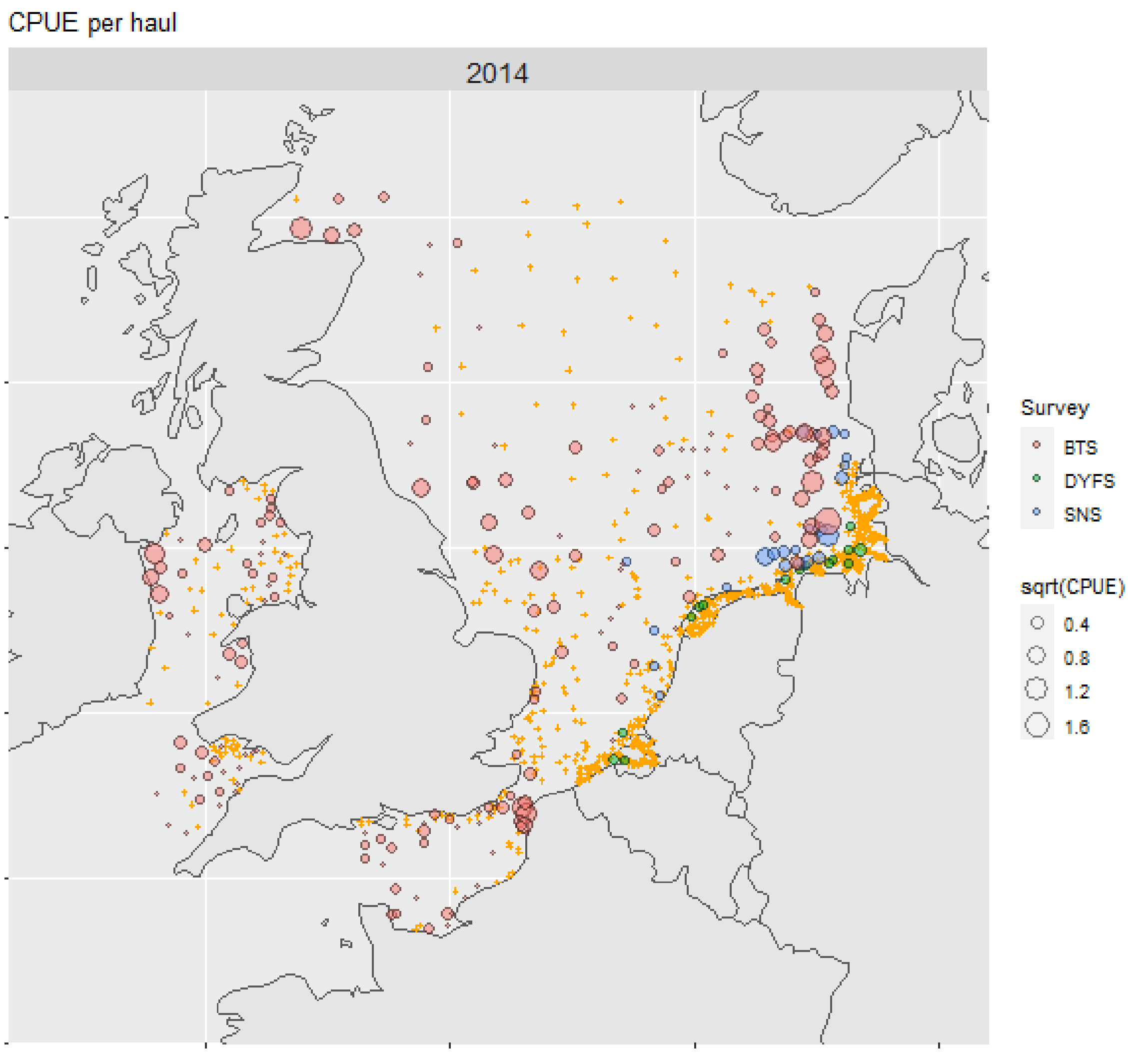

Figure 46 CPUE of brown crab in 2014 by the monitoring programmes BTS, SNS and DYFS.

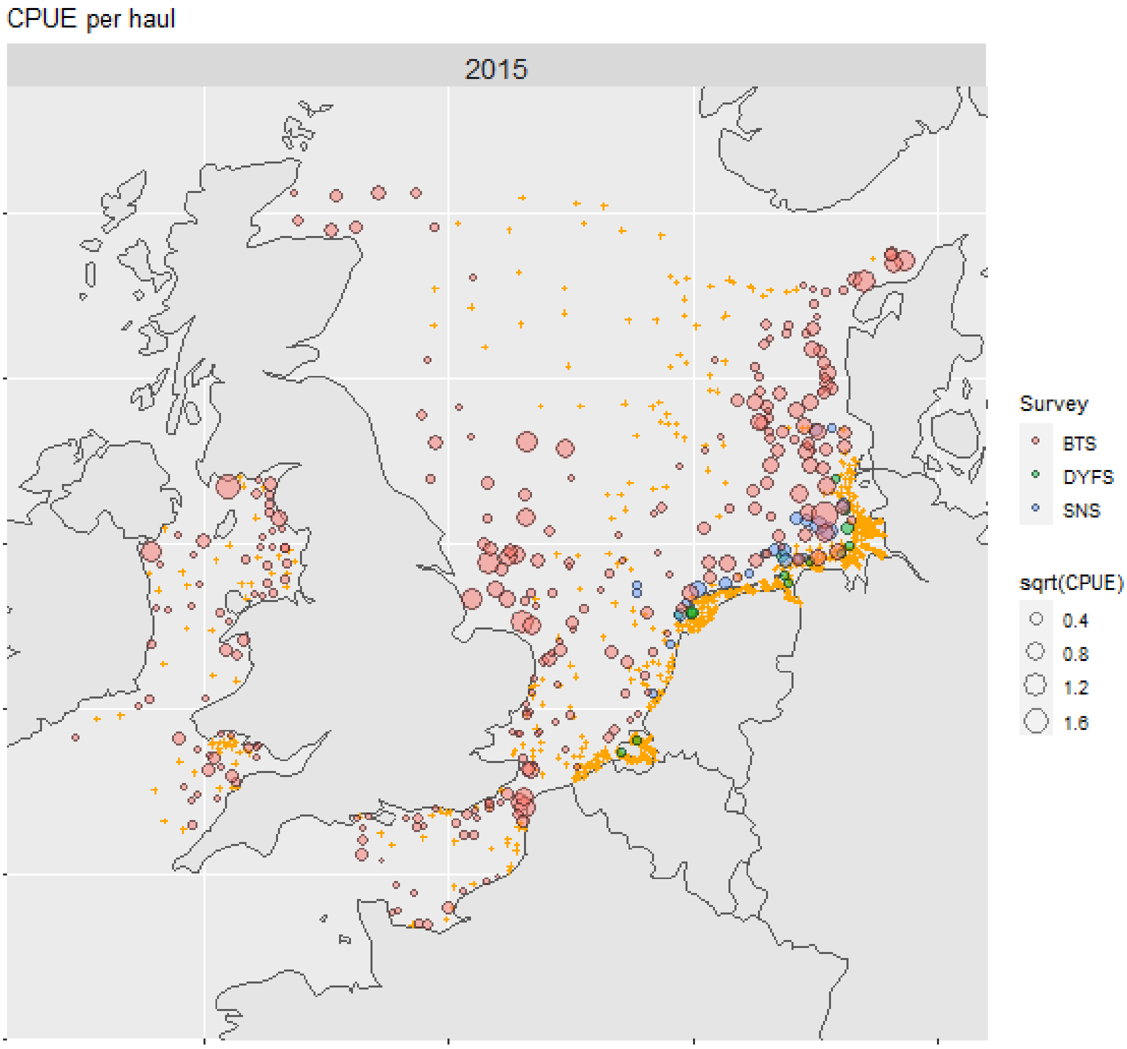

Figure 47 CPUE of brown crab in 2015 by the monitoring programmes BTS, SNS and DYFS.

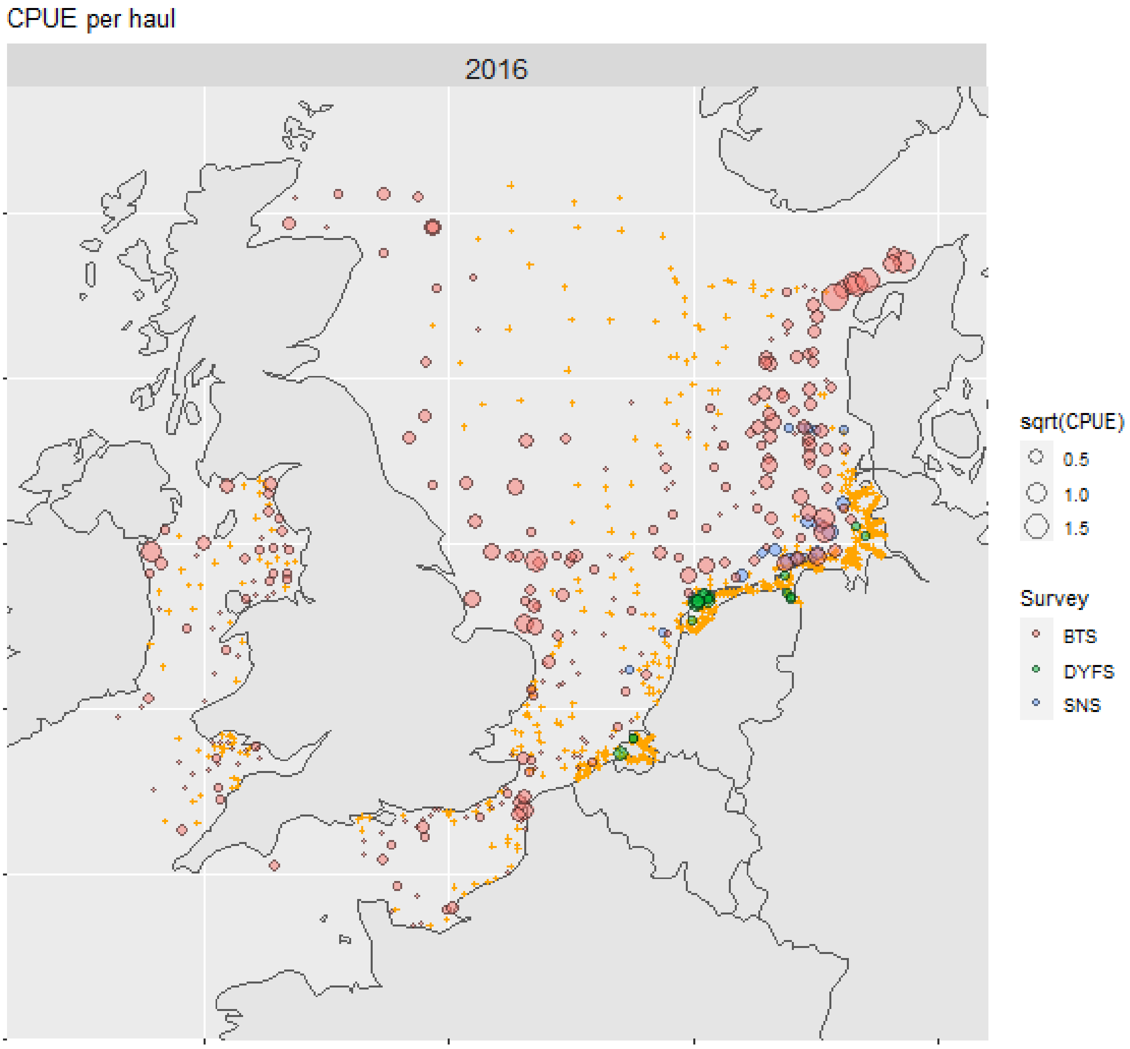

Figure 48 CPUE of brown crab in 2016 by the monitoring programmes BTS, SNS and DYFS.

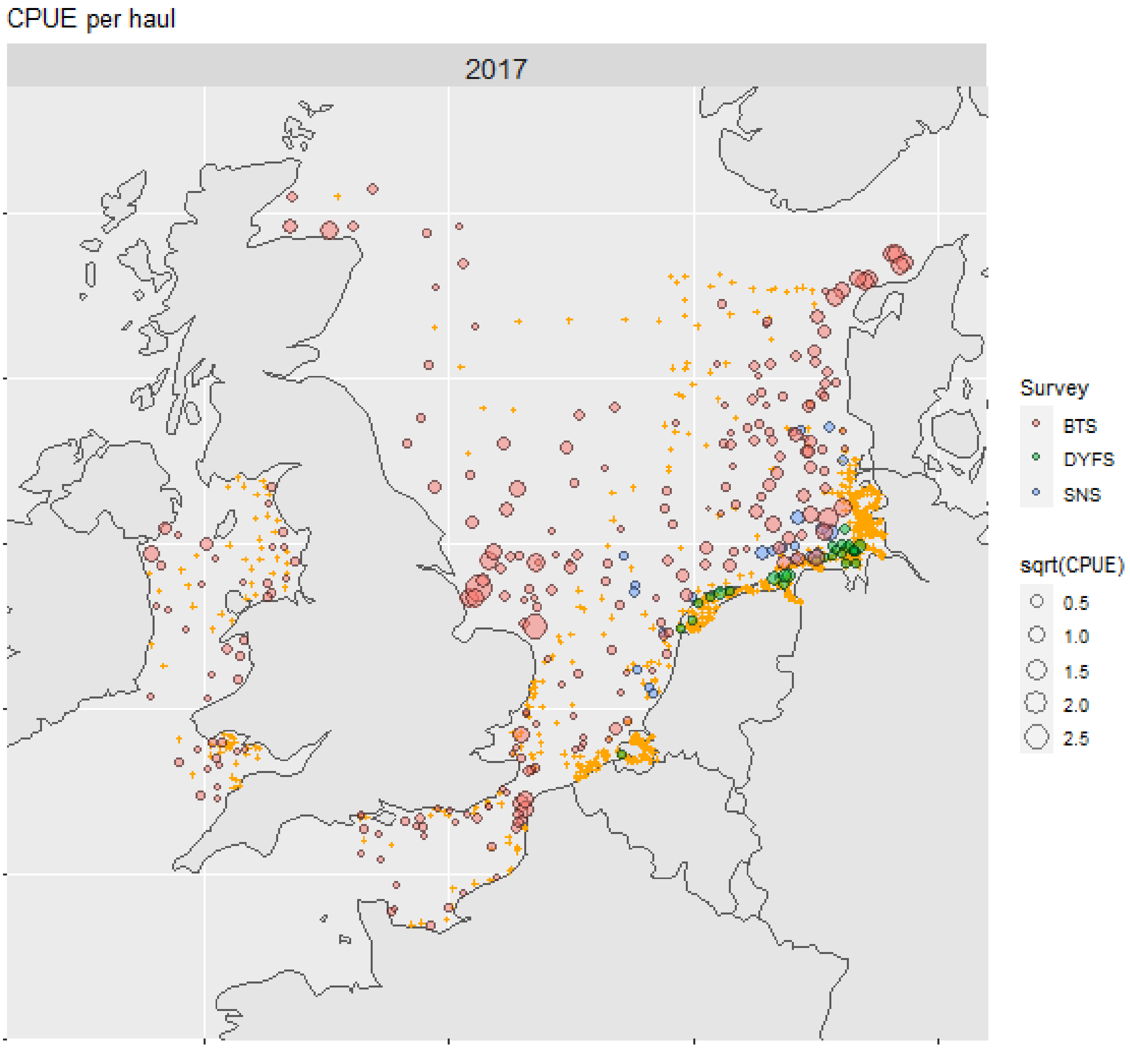

Figure 49 CPUE of brown crab in 2017 by the monitoring programmes BTS, SNS and DYFS.

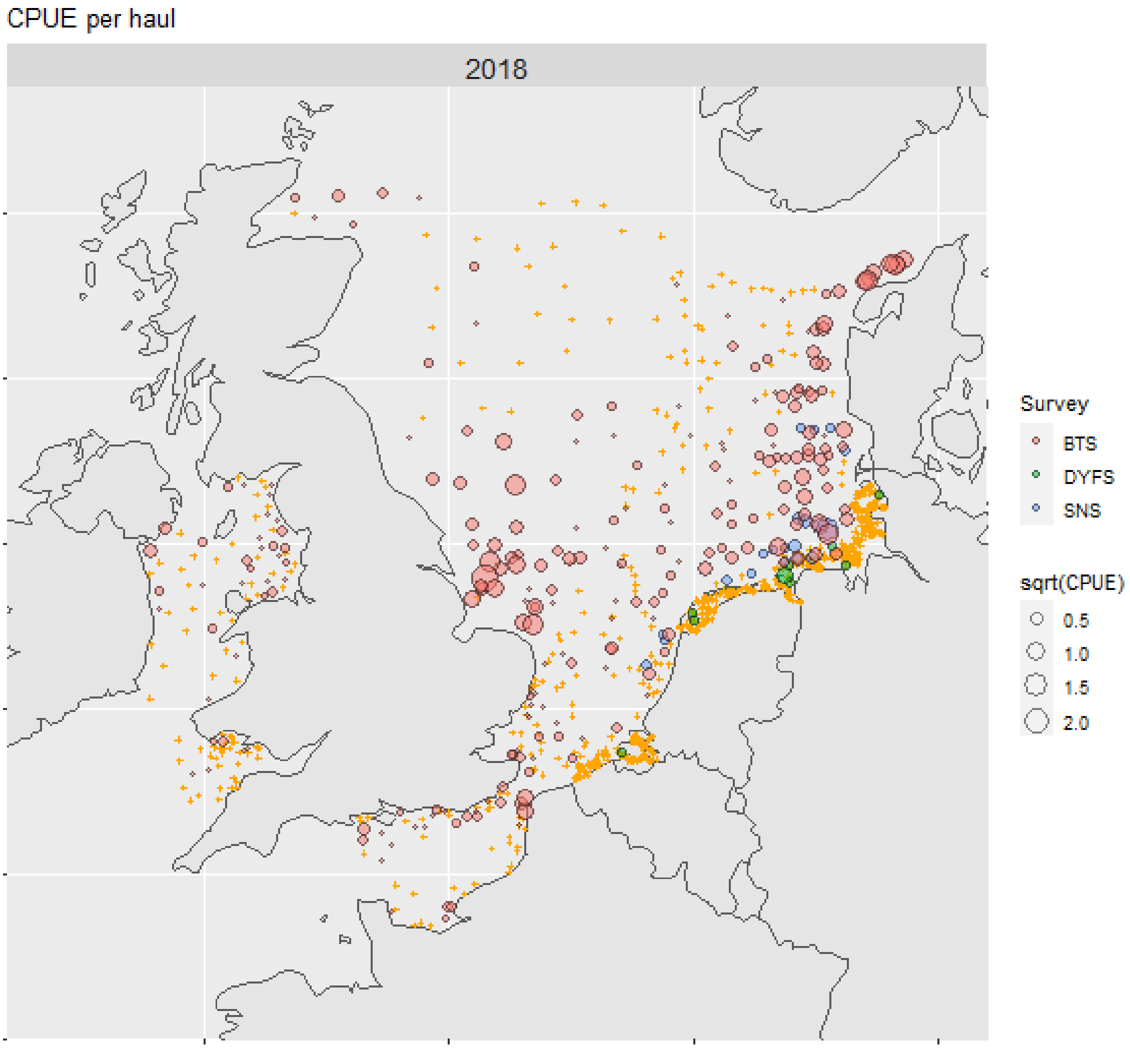

Figure 50 CPUE of brown crab in 2018 by the monitoring programmes BTS, SNS and DYFS.

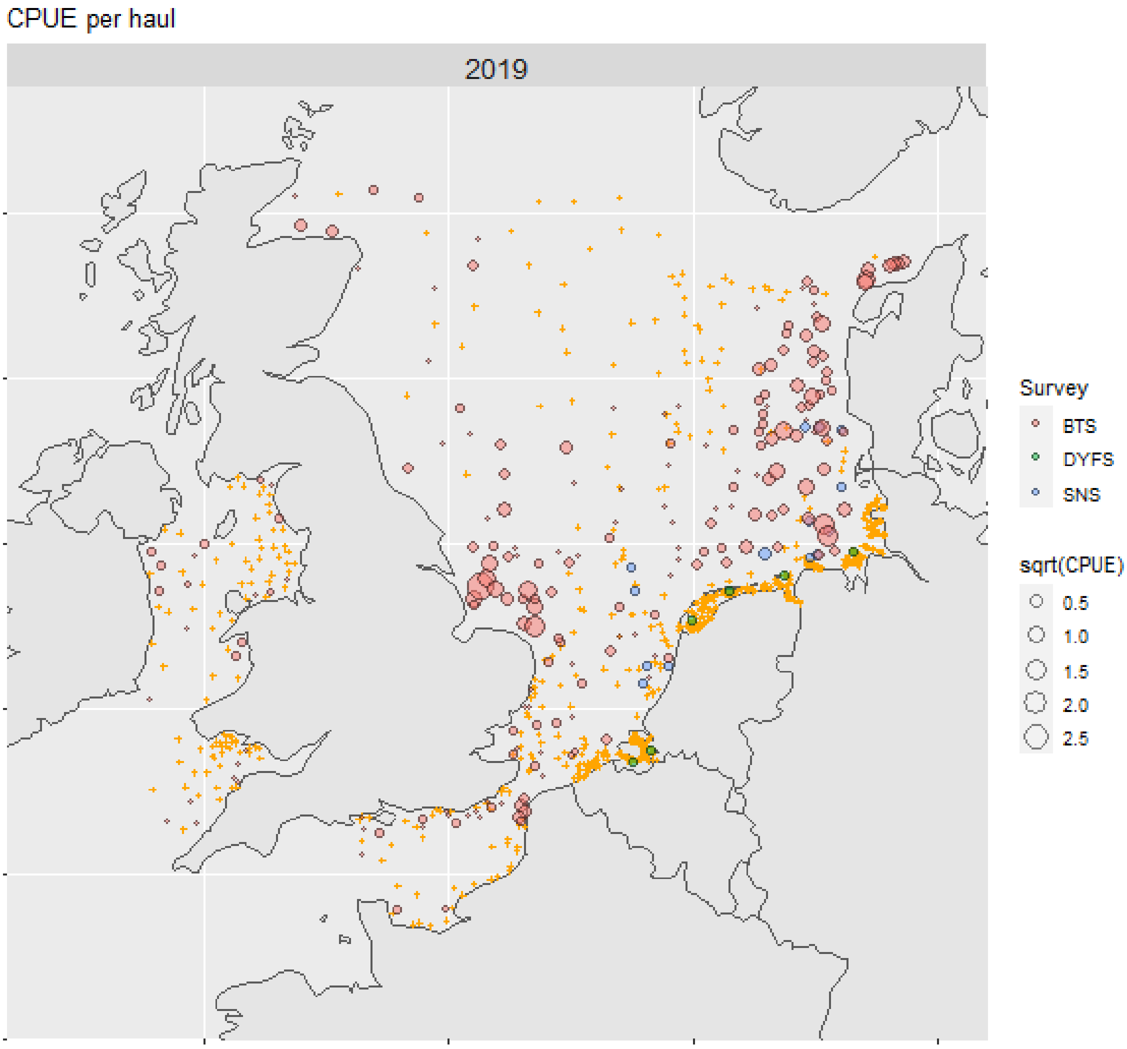

Figure 51 CPUE of brown crab in 2019 by the monitoring programmes BTS, SNS and DYFS.

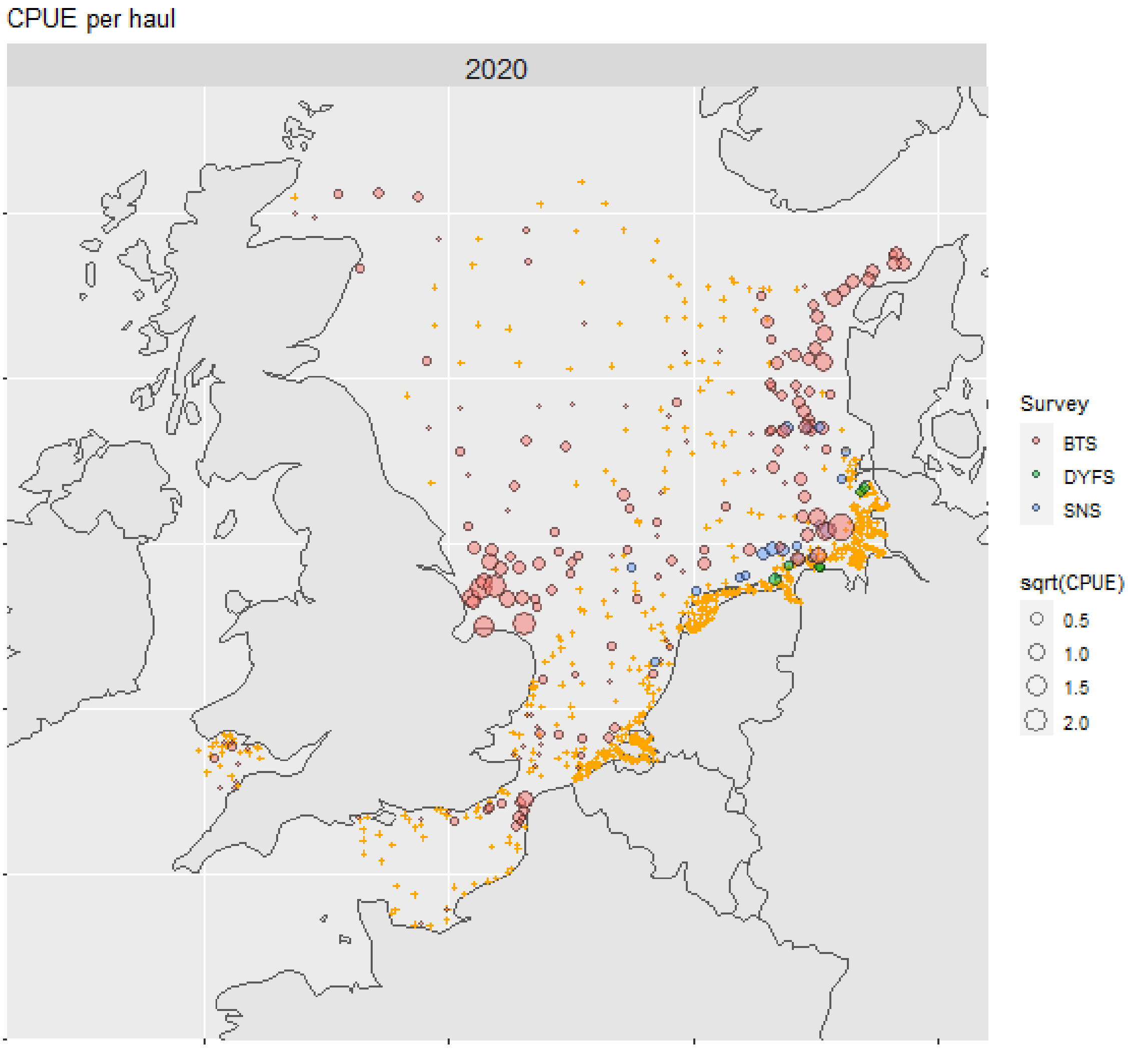

Figure 52 CPUE of brown crab in 2020 by the monitoring programmes BTS, SNS and DYFS.

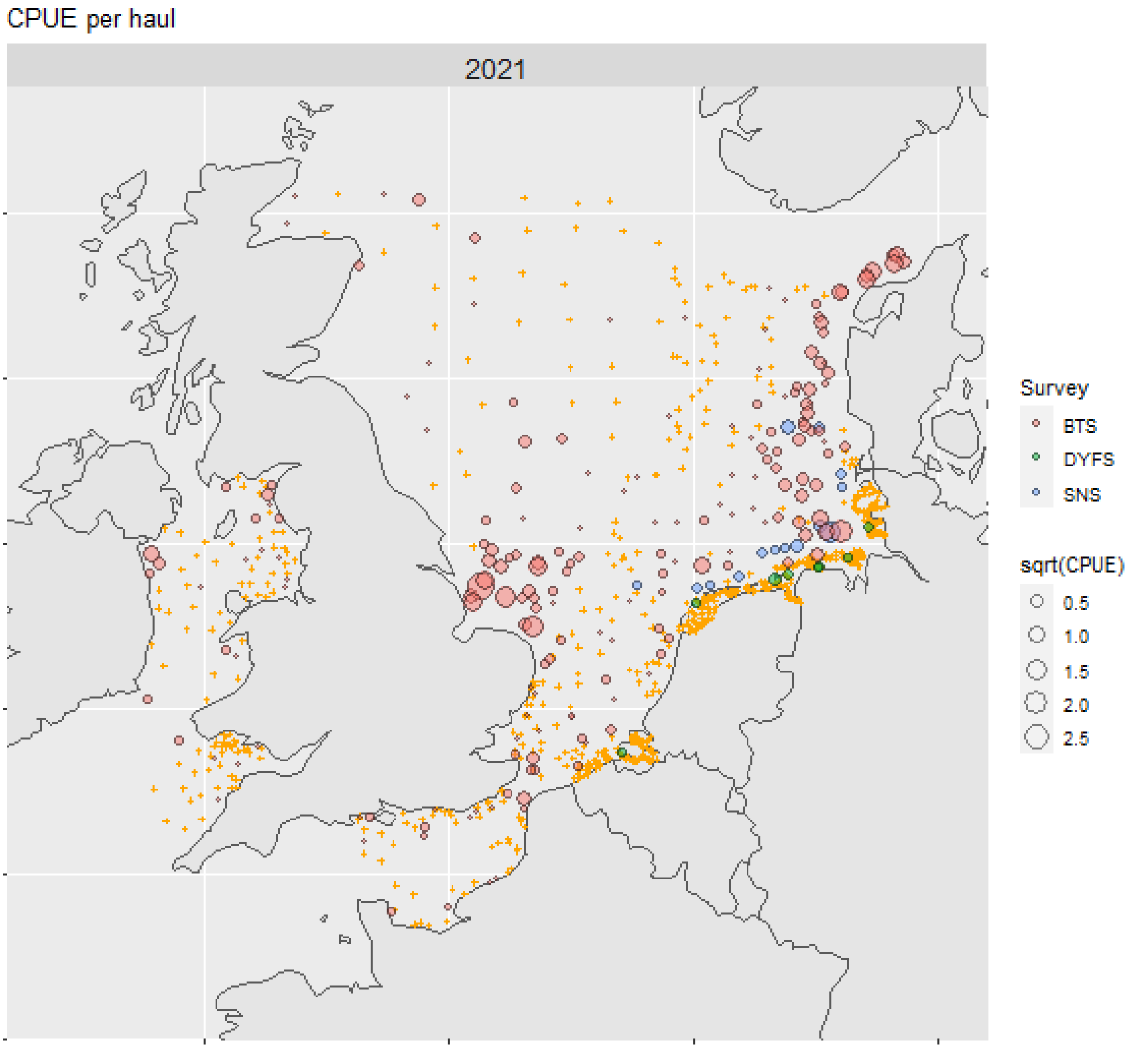

Figure 53 CPUE of brown crab in 2021 by the monitoring programmes BTS, SNS and DYFS.

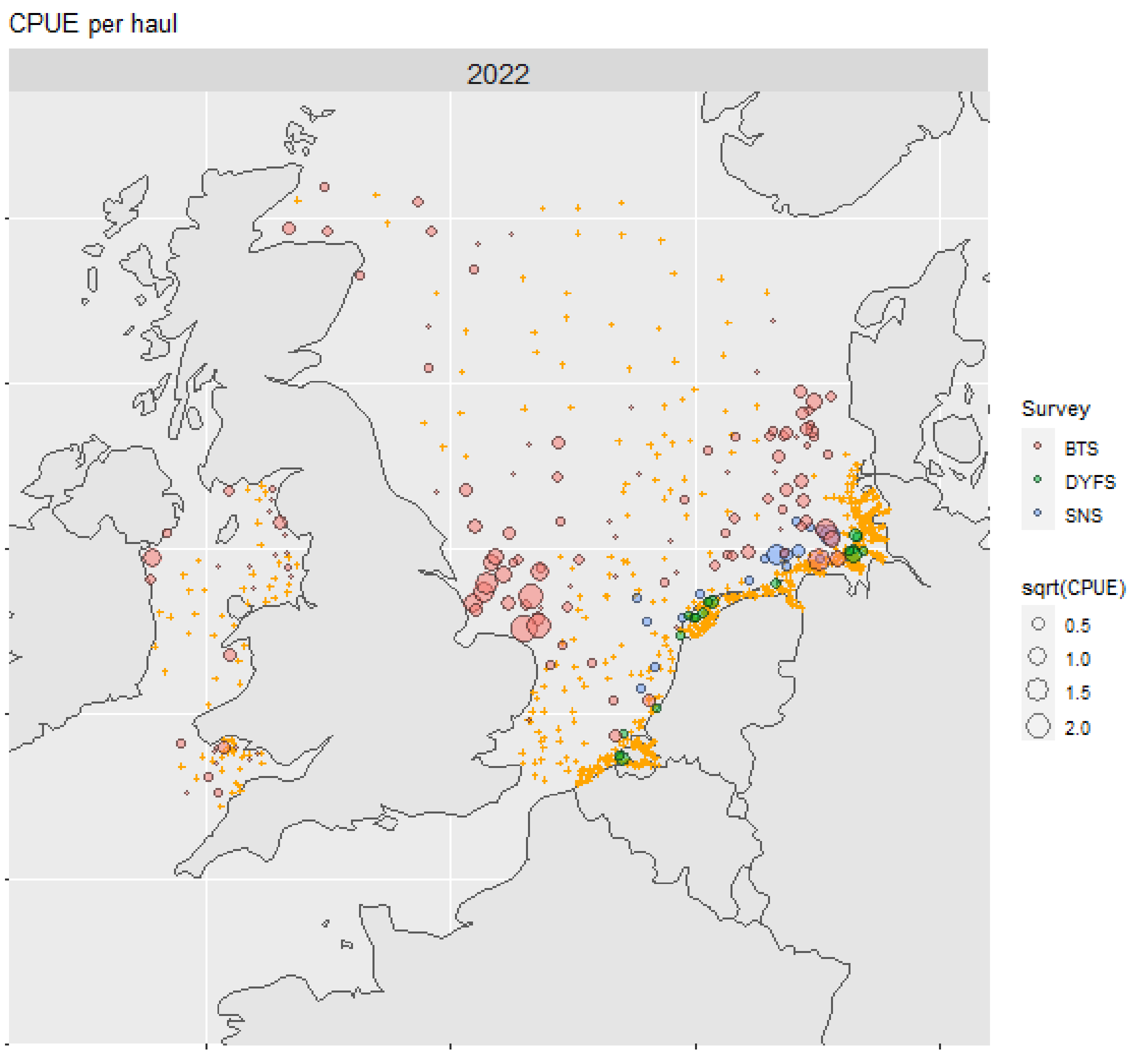

Figure 54 CPUE of brown crab in 2022 by the monitoring programmes BTS, SNS and DYFS.

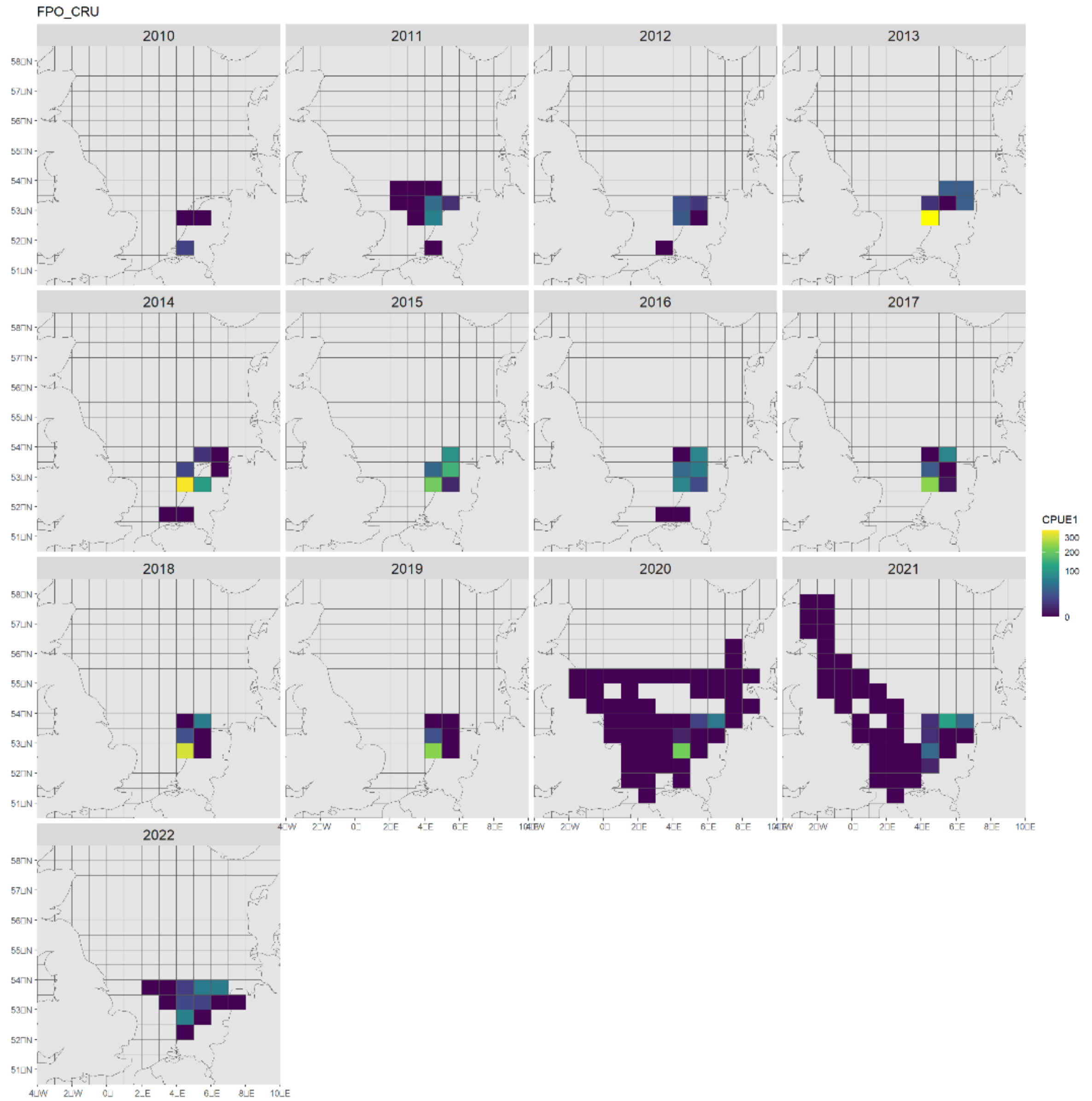

Figure 55 CPUE of brown crab 2010 : 2022 by pots for crustaceans (FPO_CRU)

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