# Passive fisheries on brown crab, velvet swimming crab and European lobster in Prinses Amalia Wind Park in the North Sea, Netherlands

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# Summary


**Introduction**
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, taking up space traditionally used for fishing. To address this concern, the concept of co-use of passive fisheries in offshore wind farms has emerged as a solution for part of the fishers.

Passive crab-pot-fisheries (gear code FPO) was considered to be a viable option of co-use in OWFs by fishers and government. To this extent an option was created to enable an experiment in the OWF Prinses Amalia Wind Park (PAWP). *Topconsortium voor Kennis en Innovatie Wind op Zee* (TKI) issued a grant programme on co-use and financed the Win-Wind project proposal.

The goal of the Win-Wind project was to research the possibilities for co-use of offshore wind farms, through a pilot project with passive low-impact fisheries *in casu* European lobster (*Homarus gammarus*) and brown crab (*Cancer pagurus*) fisheries. The pilot yielded insights in ecological and economic implications. It investigated safe working in order to reduce and mitigate the risks of fishing in offshore wind farms. It created a framework for co-use of wind farms and how to support the transition of the fishery sector.

This particular study investigated catches in PAWP and evaluated the operational aspects and risks involved with passive fisheries in OWFs and the work method statement that was established in cooperation between the OWF operator and the Win-Wind project.

**Results**
*Catches brown crab*
The catches of brown crab were on the high side in a national context but on the low side in an international context. The Catch per Unit Effort (CPUE) ranged from 0.2-1.2 crabs per pot per day. The Landing per Unit Effort (LPUE) ranged from 0.3 to 1 crab per pot per day. Using a Capture : Mark : Recapture approach an attempt was made to estimate the population size of brown crab in PAWP. However, it was not possible to estimate population size because the number of recaptures was too low. Furthermore, it was found that even after 25 days the crab pots continue to catch brown crab, enabling the fishers to keep the crab pots in the water for longer periods of time while still fishing. This may be beneficial since longer soaking times can reduce the operational costs for fishers.

*Catches European lobster*
In total only five European lobsters (four males and one undetermined) were caught during this project. All European lobsters were larger than the MLS (minimum landing size). The amount of caught European lobsters was too low to determine CPUE and LPUE. The European lobsters were marked for recapture and population estimates but no recaptures were observed.

*Catches velvet swimming crab*
An interesting bycatch was velvet swimming crab. In PAWP a CPUE was measured ranging from 0.18 to 4.66 animals per pot per day and a LPUE of 0.16 to 3.48. The amounts are comparable to results from the UK. Velvet swimming crab is potentially an interesting species for the Spanish market, but this market needs to be developed. The most conspicuous aspect of the soaking time: catch curve of the velvet swimming crab is the decrease after ~4 days in amounts caught. This could be either due to escapement of the smaller velvet swimming crab or predation of this species by the larger brown crab. If velvet swimming crab is targeted, it is important to use pots without escape gates and to reduce soaking time. On the other hand, increasing soaking time can reduce exploitation costs while the catch of brown crab still increases, so there is a trade-off.

*Other bycatch*
The commercially interesting species common cuttlefish (*Sepia officinalis*) was caught in large amounts. Other species caught were sea star, bull rout (*Myoxocephalus scorpius*), pouting (*Trisopterus luscus*) and striped red mullet (*Mullus surmuletus*).

*Other species observed*
Six passing gulls were observed during the experiment during the experiment during four days, and a gannet (*Morus bassanus*). The weather was quiet, not much wind. One harbour porpoise was observed. No seals or other bird types were observed.

*Evaluating operational aspects*
The Work Method Statement (WMS) is an elaborate description of the work procedures and risks and their mitigation. Most important, establishing the collaboration with Eneco together with Ministry of Agriculture, Nature and Food quality and Rijkswaterstaat, gave the latter two organisations more insights and ideas how to formulate co-use in the new OWFs in which co-use is part of the normal.

The potential mobilisation of crab-pot-strings and anchors was a major point of concern in the risk evaluation of passive fisheries in an OWF. Mobilised crab-pot-strings could get entangled in wind turbines and the (dragging) Bruce anchors could potentially damage infield cables. Nb other research had established the potential damage by Bruce anchors was minimal. Determining the locations of the crab-pot-strings in PAWP appeared difficult and were associated with a large measurement error. It seemed that the crab-pot-strings had not moved, not even during 7 Bft Northeast to North North East wind in PAWP. The results were inconclusive due to measurement error.

In a previous project a 'haul out indicator' was established. 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). The haul out indicator and its threshold were evaluated. The results suggested that the threshold can be raised. However, due the uncertainties in the measurements it is recommended to look into alternative measurements or make adjustments to the measurements to obtain more data that are more reliable.

In this case, a WMS was necessary to obtain a permit for access to PAWP from Eneco. The contributors made a complete inventory on risks and their mitigations. Several aspects of the WMS are now, due to the new situation for Borssele II on co-use passive fisheries, outdated. However, the WMS was a good exercise to analyse the risks involved. co-use. Moreover, the WMS, or an adapted form of it, can serve as a reference and guidance document available for risk evaluation of other projects with passive fisheries in OWFs.

*Concluding*
This experiment has obtained valuable data on what could be caught in an OWF. It has also generated more experience on working and performing passive fisheries in an OWF. This 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:

- 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.

- 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.

- 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

With the rapid upscaling of offshore wind farms (OWFs) on the North Sea, pressures are mounting on fisheries, other users (such as shipping, recreation and tourism) and nature. Successful development and exploitation of OWFs requires integration in the environment in relation to other users (and ecology). (Policy on) Co-use and nature inclusive design are used to meet these wishes and needs (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken, 2015).

## 1.1 Win-Wind project

Passive crab-pot-fisheries (gear code FPO) is considered to be a viable option of co-use in OWFs (Cramer et al., 2015, Stelzenmüller et al., 2021, Bonsu et al., 2024). To this extent a policy decision was established to enable an experiment in the at that time existing OWFs (Prinses Amalia Wind Park (PAWP, Figure **1**), Luchterduinen and Offshore Wind Farm Egmond aan Zee (OWEZ), Staatscourant 2018[1]). 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[2]. 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 OWP (risk evaluation and mitigation). An overview of the results and downloads (reports etc.) of Win-wind can be found on the website[3]. Win-Wind established a collaboration between the Government of the Netherlands, Eneco and the consortium Win-Wind to perform crab-pot-fisheries in PAWP.

### 1.1.1 Research questions and topics of Win-Wind

In summary the questions of the Win-Wind project were to research and demonstrate the possibilities for co-use of offshore wind farms. This was done through a pilot project with passive fisheries *in casu* European lobster (*Homarus gammarus*) and brown crab (*Cancer pagurus*) fisheries. The pilot yielded insights in ecological and economic implications. It investigated safe working in order to reduce and mitigate the risks of fishing in offshore wind farms. It created a framework for co-use of wind farms and how to support the transition of the fishery sector.

[1] https://zoek.officielebekendmakingen.nl/stcrt-2018-22588.htm (seen 9-8-2023)
[2] 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.
[3] Win-Wind - WUR (seen 9-8-2023)

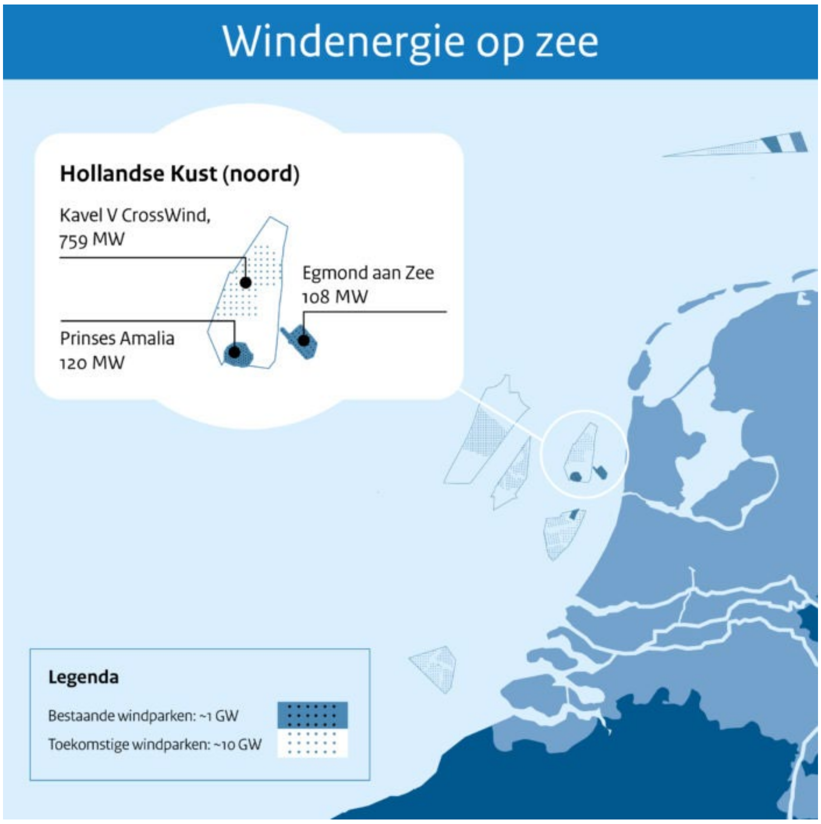


Figure 1 the position of Prinses Amalia Windpark (PAWP) along the Dutch coastline. It is integrated in the concession area of Hollandse Kust Noord.

### 1.1.2 Research topics and questions addressed in this report

The research questions of this report are:

1. What is the Catch per Unit Effort (CPUE) and Landable Catch per Unit Effort (LPUE[4]) of brown crab, European lobster, the potentially commercial relevant velvet swimming crab (*Necora puber*) and other species (bycatch)?
2. What is the population size of brown crab in PAWP with a catch : mark : recapture approach (Rozemeijer et al., 2021)?
3. To obtain more experience with the operational aspects and risks involved with passive fisheries in OWFs.
4. To evaluate the working method of offshore fishing in PAWP as established in a risk mitigation approach between Eneco and Win-Wind (formalised in the Work Method Statement (WMS, Rozemeijer et al., 2020, Rozemeijer, 2023).

## 1.2 Context of related research projects on passive fisheries within OWFs

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

[4] Landable Catch per Unit Effort is a non-existing term. LPUE usually stands for Landings per Unit Effort (actual landed amounts). Another definition could be Marketable Catch per Unit Effort (MPUE). However, this concept is not found in Google searches. Therefore it was decided to use LPUE.

1. A project on possible damage by anchors studies (Rozemeijer et al., 2022a) was financed by the Ministry of Agriculture, Nature and Food quality. This was initiated parallel to Win-Wind in order to 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. It was concluded that the Bruce anchor only caused a superficial bruising of the outer layer. In addition, adapted Bruce anchors with anti-hook-in-devices were tested but these proved not to be useful (preventing the actual anchoring).
2. Likelihood of crab-pot-string mobilisation (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 could be mobilised and moved under different weather and sea conditions was investigated. It appeared that the Bruce anchors and crab-pot-strings did not move under conditions of 8 Bft south west.
3. The project "Comparative fishing" investigates the potential of crab and European lobster pot fisheries in Borssele II (financed by the Ministry of Agriculture, Nature and Food quality, from 1-7-2022 till 31-5-2023, indicated by "Borssele II 2022" or the reference (Rozemeijer et al., 2023)). Its goal is to compare the catch statistics in Borssele II with those of PAWP, to get an idea of the influence of the maturity of the anti-scouring associated communities in the longer existing PAWP and the recently build Borssele II (reported in Rozemeijer et al., 2023).
4. In the project "Passive fisheries" (indicated as "Borssele II 2023" or the references Neitzel et al., 2023a,b) four forms of passive fisheries are investigated in Borssele I and II: 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 also financed by Ministry of Agriculture, Nature and Food quality. The testing phase started in April 2023.

## 1.3 Reading guide

In chapter 2 the materials and methods are described. In chapter 3 the weather conditions of the expedition period were described and analysed. The weather conditions are important because they influenced the amount of workable days and even set the boundary conditions for the operations (expeditions). Weather conditions were therefore important to answer the research questions 3 and 4.

In chapter 4 the potential mobilisation of the of the crab-pot-strings was analysed. In the WMS (Rozemeijer et al., 2020, Rozemeijer, 2023) the potential mobilisation of the crab-pot-strings was assessed as an important risk. Chapter 4 contributed to answer research question 3 (operational aspects and risks) and 4 (evaluation of the WMS).

Chapter 5 described the catches of brown crab, European lobster, velvet swimming crab, bycatch and other species observed. It contributed to answer research question 1 and 2 on catches, CPUE, LPUE and population estimates.

In chapter 6, the WMS is evaluated (answering research question 4 on evaluating the WMS). Although this chapter reads as a discussion it was decided to place it separately for readability purposes.

In chapter 7 (discussion) all topics except the WMS are evaluated. Chapter 8 provides the conclusions and recommendations for further research.

# 2 Materials and Methods

Giving a first overview of the set-up (detailed later in subsequent sections), six crab-pot-strings were placed in PAWP (Figure **2**, Figure 3). The positions were registered at deployment and at set times strings were hauled out, positions were registered again to determine displacement. The pots were emptied, baited and deployed. The caught brown crab and European lobsters were measured, registered, tagged and released upstream for recapture. Bycatch was registered as well.

Data on water and weather conditions were obtained from Rijkswaterstaat and if applicable related to the displacement.

The catch data were used for saturation versus soaking time and CPUE versus time determination. Catch : Mark : Recapture data on European lobsters and brown crab were obtained estimate population size of these species.

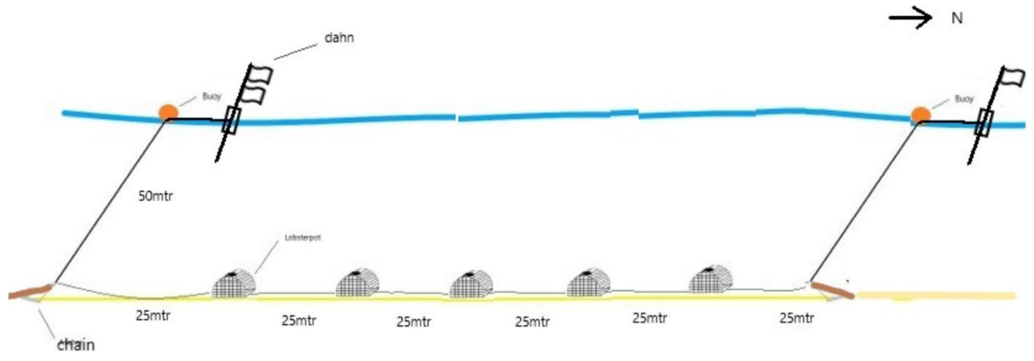


Figure 2 String with five cages and two chains. In the trips of this report the chains were replaced by 15 kg Bruce anchors. Next to the buoy a dahn is attached with flag and radar reflector. The double flag means the most southern buoy of the string. A single flag signs the most northern buoy. In this figure mutual distance between the pots is 25m. The actual distance was 40 m.

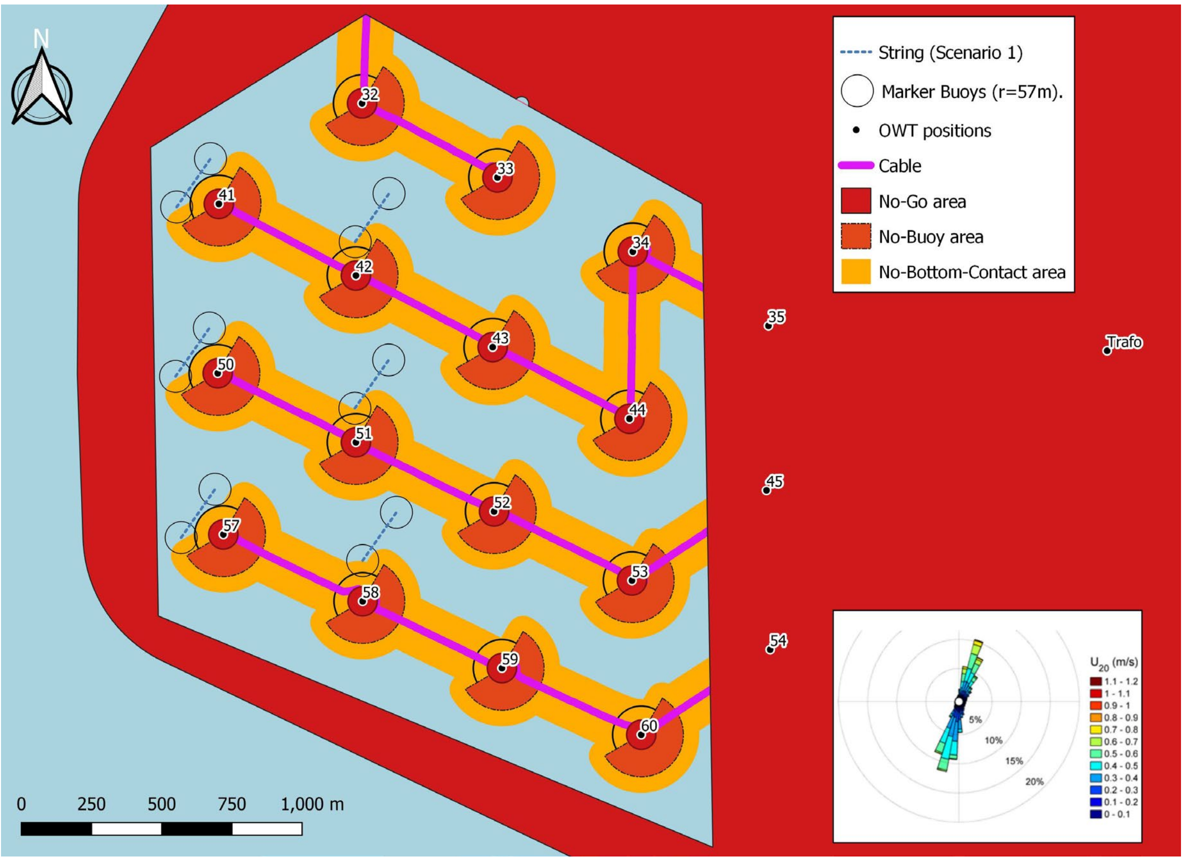


Figure 3. Area available for deployment of strings, southwestern area assigned, special no-go zones coloured in: black dot: offshore wind turbine (OWT); purple line: infield cable; blue dashed line: string; thin black circle at the tips of the blue dashed line: potential area of movement of the dahn with the currents (57 m). The vertical axis is the North : South axis of the compass rose. The inset at the right side is the current rose at -20 m (year overview at a location nearby, from Caires & Pathirana, 2019).
Red area: No-go area for everything, radius 50 m.
Dark Orange area: No Buoy area. CTV approach no entry zone where no buoys or anchors on the bottom are allowed. Ships can manoeuvre in this area: 100 m to red zone. 150 m radius to turbine.
Thick black circle within the light orange area: 50m radius to the red zone: summed 100 m radius to turbine (no anchoring zone in relation to the infield cable).
Light orange area around dark orange are: No-Bottom-Contact Area: no chains or strings on the bottom allowed to prevent dahns and buoys to enter the dark orange zone, buoys and ships can enter the area: 57 m.
Light orange area on either side of the purple line (infield cable): no anchoring or bottom contact zone: 100 m.

## 2.1 Natural system

A concise description of the natural system in and around PAWP is given in order to have a first context to be able to position the biological results of research question 1 and 2 (when needed).

PAWP is located within a part of the Dutch coastal system. Depth ranges between 20 to 25 m (Rozemeijer et al., 2020). The seabed is shallow soft sediments with associated benthic and fish communities. Grain size ranged between 275 to 309 μm with an organic content of 0.17 to 1.16%, Leewis et al. (2018).

### 2.1.1 Sandy seabed communities

The communities on the sandy seabed (soft sediments) belong to the Coastal zone community. This community is dominated by polychaeta and bivalves. The main bivalves of this community were *Spisula subtruncata* (cut through shell) and *Ensis leei* (Atlantic jackknife clam, formerly known as *Ensis directus*). Both species form shell fish beds and are staple food. The biomass is high in this zone as compared further offshore due to this shell fish beds (Leewis et al., 2017, 2018, van Son et al., 2022).

### 2.1.2 Hard substrates communities

The hard substrates (anti-scouring and wind turbines) at PAWP showed an increased biodiversity and higher biomasses, than found associated with soft sediments (Vanagt & Faasse, 2014). The species composition was different and was dominated in biomass by anemones (*Metridium senile* mostly) and mussels (*Mytilus edulis*) and in number by the amphipods *Jassa herdmani, Jassa marmorata*, *Stenothoe monoculoides*, and the linear skeleton shrimp *Caprella linearis*. The hard substrate communities showed large overlap with the communities on oil wrecks and rocky substrate (Coolen et al., 2020). Vanagt & Faasse (2014) encountered brown crab and velvet swimming crab on the anti-scouring (similar to Bouma & Lengkeek, 2009, 2012, 2013 in the nearby OWEZ).

### 2.1.3 Brown crab in relation to hard substrate

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.

Hard substrate in soft bottom environment such as oil platforms, wrecks and monopiles attract benthic biodiversity (Vanagt & Faasse, 2014, Bouma & Lengkeek, 2009, 2012, 2013, Coolen et al., 2020).

### 2.1.4 Fish

Van Hal (2013) caught a total of 17 fish species in eight tows. Species present were herring, sprat, whiting, cod, dab, plaice and greater sand-eel. It seemed that the roundfish communities were unaffected by the presence of an OWF.

### 2.1.5 Birds

The bird community consists of various species of gull that were shown to forage within the wind farm (Leopold et al., 2012). The most abundant gull species occurring in the area and within PAWP were the lesser black-backed gull *Larus fuscus*, herring gull *Larus argentatus* and common gull *Larus canus*, In wintertime the great black-backed gull *Larus marinus* and the black-headed gull *Larus ridibundus* and kittiwake *Rissa tridactyla* were observed. In addition cormorants (*Phalacrocorax carbo*) are attracted to the wind farm, mostly because the landing platforms of turbines provide the resting place that these birds require to dry their feathers (Leopold et al., 2012).

## 2.2 PAWP

PAWP is operated by Eneco. It was formerly known as Offshore Wind Farm Q7. It is located over 23 km off the coast of IJmuiden. It covers an area of 14 km² and consists of 60 Vestas V-80-2.0 wind turbines. The turbines have a shaft height of 60 metres and a blade length of 40 metres, reaching a height of 100 metres. Each turbine has a capacity of 2 MW. A total capacity of 120 MW has been installed in this wind farm. The wind turbines can supply about 422 GWh of electricity annually, enough to power 125,000 households. The wind farm is connected to the power grid with a 150kV high-voltage connection coming ashore at Wijk aan Zee beach. To this end, the turbines themselves are connected to a central transformer station (Offshore High Voltage Station) with 34kV connections.

### 2.2.1 Experiment with passive fishing in PAWP

With the coming into force of the Beleidsnota 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[5]). 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. Eneco was willing to participate in coming to such an 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. The Win wind project got elected to carry out the experiment in PAWP (Staatscourant 2019, 50033). To gain access to the safety zone of the wind farm for the experiment, permission was necessary from Rijkswaterstaat Zee en Delta and the Ministry of LNV. The locations for the crab-pot-strings were coordinated with Eneco. For all activities taking place within the safety zone of the wind farm it is mandatory to keep a minimum distance of 50 metres from turbines with boat and fishing gear (this also applies to objects from the vessel, such as lines, floats and hooks) and 500 metres from a transformer platform.

## 2.3 Experiment

The experiment consisted of ten expeditions to sea. The expeditions to PAWP served to catch crabs and European lobsters and determine CPUE, LPUE and population size. The experience gained was used to evaluate the operations and the WMS. A planning was made with an even spread in periods of soak time (time between deployment and retrieval of pots) to establish a curve of numbers of brown crab caught versus soak time over the total range. Weather conditions (wave height, wind) and potential simultaneous operations of PAWP maintenance, however, determined the final expedition dates. Workable conditions were defined at an anticipated summed significant wave height ($H_s$) and swell of 1.0 m max, usually between wind force 0-3 Bft. The weather and condition predictions of PAWP (provided by Eneco), KNMI and Rijkswaterstaat waterdata and Windfinder professional were used. A total of 10 expeditions were planned. On expedition day 1 of the experiment the strings were placed for the first time and on expedition day 10 the strings were removed. All expedition days in between, the strings were hauled, emptied, rebaited and placed back.

### 2.3.1 Vessel

The ship that was used for the experiment was a newly registered vessel, Anna-Lotte; Registered Fishing license: WR147 (MMSI: 244609000, Call Sign: PBHW) (former ZK18). The vessel was a fishing ship adapted for pot fisheries (Figure 4, reconstructed in 2022). It is constructed of steel, with a length of 18.8 m and a width of 4.5 m. It has a JRC GPS Kompas (type and age unknown).

5 Staatscourant 2018, 22588 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl) (seen 29-11-2023).


Figure 4 view of the WR147 (former ZK18).

### 2.3.2 Location and Measurements

In coordination with Eneco the locations were chosen using the following considerations: i) amount of passing vessels (leading to the southwest corner with the least passing vessels); ii) no-go zones. The resulting locations are given in Figure 3.

At each expedition day the position of the strings was determined on hauling and deploying. For the first anchor the moment the A1 Polyform Buoy line was hauled on board a signal was given and the position was registered from the GPS system of the vessel and with a Garmin 67i. For the second anchor the moment the fourth pot was hauled on board a signal was given and the position was registered from the GPS system of the vessel and with a Garmin 67i.

When hauling, the strings were checked for damage of the string and excessive accumulation of sediment in and on the pots that would 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. Afterwards, the cages were emptied from caught animals. Sex and carapace width (CW) were registered for brown crabs and sex and carapace length for European lobsters. For velvet swimming crab, the sex was registered and the CW (not the measure but < 6.5 cm or ≥6.5 cm). Brown crabs and European lobsters were tagged and registered and, next, all animals were released at the site of catch (Figure 3). Pots were then baited with horse mackerel. Next the crab-pot-strings were placed back on the seabed.

## 2.4 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., 2003, 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) showed 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 do 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.

Figure 5 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).

For lobsters, the tag was placed between carapace and first tail somite (tail harness segment). To that extent the lobsters abdomen was bent carefully till the bare flesh of the tail muscle was visible. Then the tagging tool was directed tailward (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.

## 2.5 Observations on other species

Birds and sea mammals can be unwanted bycatch of fishing gear (Neitzel et al., 2023a,b). Furthermore, attracting birds with fishing activities within offshore wind farms, could potentially increase the number of bird casualties being hit by a wing of a wind turbine. Monitoring data and knowledge of these species are needed to evaluate the presence of birds and sea mammals and the importance of unwanted by-catch. On regular intervals the environment was checked for birds and sea mammals. The birds were categorised according to gulls, cormorants, songbirds and others. Sea mammals were scored as harbour porpoise (*Phocoena phocoena*) and seals (or grey seal (*Halichoerus grypus*) and harbour seal (*Phoca vitulina*) when possible) (according Neitzel et al., 2023b).

## 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 question on evaluating operations and the WMS). The meteorological and hydrodynamic data were derived from https://waterinfo.rws.nl/ 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 cages again). Conform Rozemeijer et. Al. (2021, 2022a,b) conditions were taken from Hoek Van Holland, E13 buoy. The assessed conditions were: significant wave height ($H_s$, m), swell (m) and maximal 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. As a replacement, the land station Hoek van Holland was used (conform Rozemeijer et al., 2023).

### 2.6.1 Haul out indicator

It is mandatory to use dahns (buoys with marker flags) as the end markers of crab-pot-strings[6] However, these could make a crab-pot-string unstable because waves and currents have a lot of grip on the dahn (Rozemeijer et al., 2022a). 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. The haul out indicator is the sum of

[6] 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.

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 exceeded. However, when the weather and waves change too quickly, 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). As a first sensitivity analysis, it was also investigated what happens if a higher value (exceedance) than the value of the workable days threshold (100 cm) was allowed six times between 07:00 and 21:00. With this approach the potential of workable days was determined for the period 18-07-2023 to 25-08-2023.

## 2.7 Statistical methods

#### 2.7.1 CPUE/LPUE modelling 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. Since the catch number per pot contains 41.6% zero catches for brown crab and 6.7% zero catches for velvet swimming crab. A generalized linear model (GLM) was applied with response catch number modelled as negative binomial distribution[7]. A total of three covariates were tested for their effects on catch number:

1) Soaking time (hour) : [19,25], [38,48], [92,139], [582,629]
2) Pot type: Medley, Parlour
3) Normalized pot position: 1-5

Due to the discrete and skewed distribution of soaking time, it was grouped into a categorical variable with 4 groups: 19~25 hour, 38~48 hour, 92~ 139 hour and 582~629 hour. All three covariates and their possible interactions were tested. The best model was selected based on minimum Akaike information criterion (AIC)[8]. Models were tested using likelihood ratio test. Model fitting diagnosis was also conducted.

Once the null hypothesis (i.e. all group means are equal) was rejected for a covariate, a Tukey's Honest Significant Difference (HSD) post hoc test was applied to test the difference between pairwise group means. The test used adjust p-values to account for the family-wise error introduced by multiple comparisons.

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[7] A generalized linear model (GLM) is a flexible generalization of ordinary linear regression. The GLM generalizes linear regression by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value. Negative binomial regression is used to model count data for which the variance is higher than the mean.

[8] The Akaike information criterion (AIC) is an estimator of prediction error and thereby relative quality of statistical models for a given set of data.

# 3 Weather results

## 3.1 Expeditions and conditions

The weather conditions were assessed in order to be able to evaluate the operations and the WMS. The expeditions were performed from 18-07-2023 (baiting and first deployment of the strings) to 25-08-/2023 (final haul out, Table 1). The soaking time (deployment duration) ranged from 1 day to maximum 25 days (average 4.3 days). Usually the increase in caught animals follows a Holling Type II functional response (which involves a curve reaching a plateau, representing saturation, demonstrating the decreasing attraction because the bait disappears, (ICES, 2005, Tully et al., 2006a,b, Spencer, 2013, Skerrit, 2014, Rozemeijer et al., 2021, 2023). Expeditions were ideally planned to include a range of soaking times (that differed in length) but weather conditions had to be taken into consideration resulting in the actual implementation of soaking time. The vessel that was used, the WR-147, could only sail under certain conditions, limited by significant wave height and swell. Limiting conditions were determined by a Sum of significant wave height and swell of ~1 m.

### 3.1.1 Windspeed

The development of the windspeed is given in Figure 6. In general the windspeed was not higher than 10.7 m/s (Bft 5). Only the period between the 01-08-2023 to 09-08-2023 wind speed of 17m/s was reached (Bft 7, North-West to North North West). Between 22-07-2023 and 14-08-2023, a period with high wind speeds made it impossible to work in the OWF.

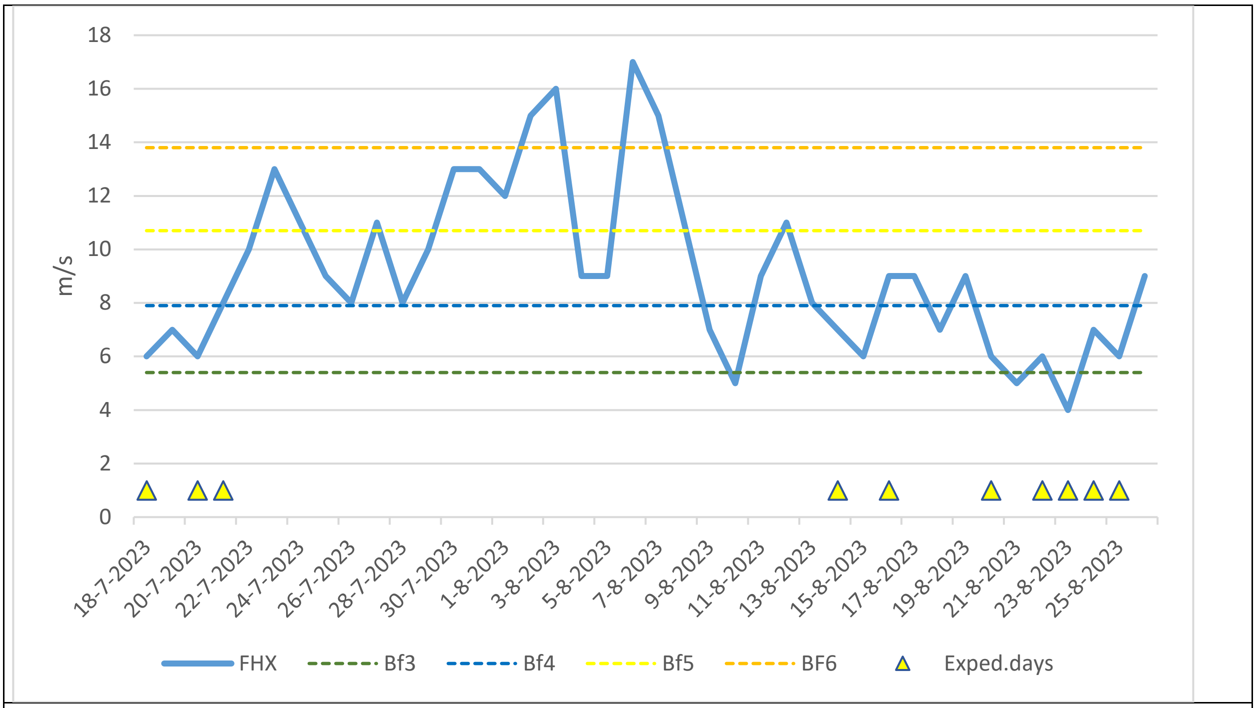


Figure 6 Windspeeds (in m/s) during the experimental period from 18-07-2023 till 25-08-2023. X-axis: time in days (by dates); Y-axis: wind speed in m/s. The blue line is the development of the wind speed in time. The dashed lines represent the upper limits of steps in the Beaufort scaling. The yellow triangles represent the expedition days.

Table 1 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 |
| 18/7/2023 | Bait, deploy | 0.0 | 21:53 | 136 | 4.3 | 7 | 235 | 58 | 122 | 6 | 14 | 252 |
| 20/7/2023 | Haul, rebait, measure and tag animals, deploy pots | 1.6 | 11:53 | 148 | 3.4 | 7 | 290 | 64 | 75 | 20 | 33 | 244 |
| 21/7/2023 | Haul, rebait, measure and tag animals, deploy pots | 0.9 | 9:19 | 131 | 7.9 | 8 | 276 | 136 | 327 | 17 | 81 | 542 |
| 14/8/2023 | Haul, rebait, measure and tag animals, deploy pots | 25.0 | 18:30 | 136 | 4.6 | 17 | 321 | 47 | 116 | 2 | 6 | 241 |
| 16/8/2023 | Haul, rebait, measure and tag animals, deploy pots | 1.8 | 14:38 | 148 | 5.7 | 9 | 41 | 74 | 119 | 3 | 8 | 245 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20/8/2023 | Haul, rebait, measure and tag animals, deploy pots | 4.8 | 13:04 | 204 | 3.2 | 9 | 221 | 35 | 84 | 2 | 4 | 192 |
| 22/8/2023 | Haul, rebait, measure and tag animals, deploy pots | 2.0 | 12:46 | 127 | 4.0 | 6 | 237 | 43 | 62 | 2 | 4 | 170 |
| 23/8/2023 | Haul, rebait, measure and tag animals, deploy pots | 1.0 | 13:00 | 140 | 3.3 | 4 | 320 | 31 | 51 | 2 | 3 | 175 |
| 24/8/2023 | Haul, rebait, measure and tag animals, deploy pots | 1.0 | 12:39 | 132 | 5.1 | 7 | 158 | 31 | 48 | 3 | 6 | 142 |
| 25/8/2023 | Measure, tag, final haul out | 0.9 | 9:37 | 126 | 5.4 | 9 | 304 | 37 | 54 | 7 | 55 | 150 |
| | **Average** | 4.3 | 12:49 | 144 | 4.7 | 7.9 | | 55 | 104 | 7 | 22 | 233 |
| | **Standard Deviation** | 7.8 | 2:43 | 24 | 1.5 | 3.8 | | 34 | 88 | 7 | 28 | 122 |

## 3.2 Haul out indicator

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). It is based on predictions of extra water level compared to NAP, significant wave height and swell. To indicate whether conditions are suitable for haul out the cumulative height of NAP, wave height and swell should not exceed 445 cm. When a haul out indicator threshold level of 445 cm is predicted, the crab-pot-strings need to be removed keeping good seamanship[9] in mind. The haul out indicator was an important aspect in the WMS (Rozemeijer, 2023) and topic for evaluation and gaining experience. During the expedition period the haul out indicator exceeded the threshold of 445 cm three times with a maximum of 542 cm and wind from the direction of North West to North North West (Table 1, Figure 7). This was during the storm period when waves were too high to be able to sail out and retrieve the crab-pot-strings (Figure 7, Figure 6).

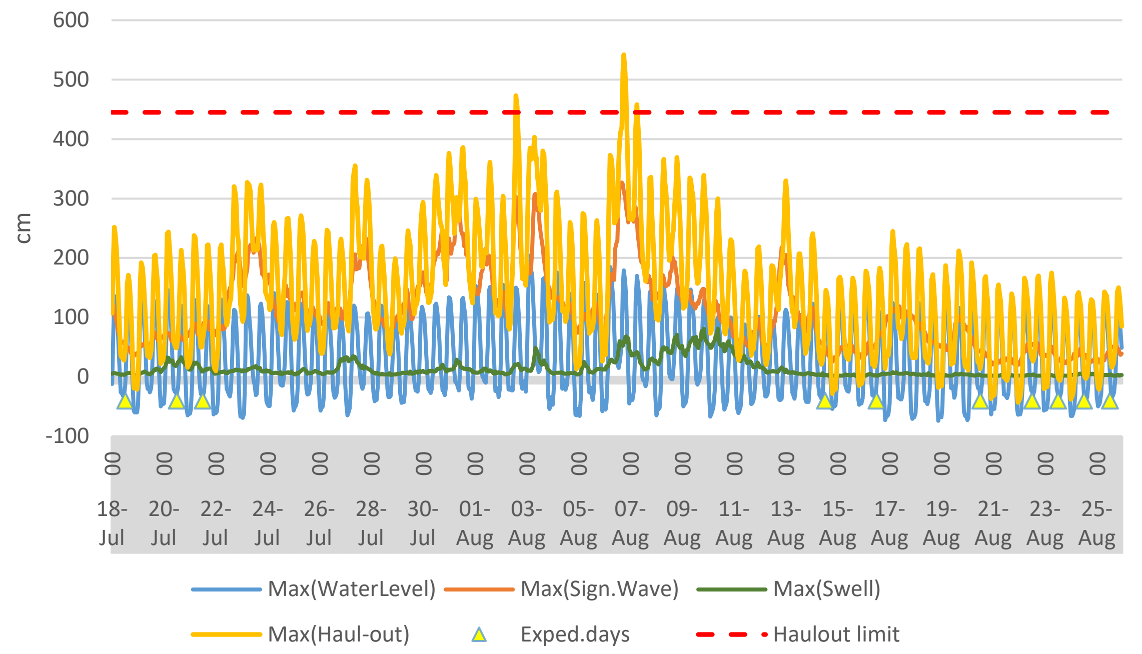


Figure 7 The evolution of the haul out indicator in time. X-axis: time in days (dates, starting at 00:00); Y-axis: height of the different variables (in cms). The deployment dates are indicated with yellow triangles (see also Table 1). Extra water level to NAP is the blue line. Maximum significant wave height is given as an orange line. Swell is given as a green line. The haul out indicator is given as an yellow line. The threshold for the haul out indicator is given as a dashed red line.

## 3.3 Current velocity in time

As an extra check on the haul out indicator, the current velocity was analysed. In the end, currents are the most direct measure (though not measured in sufficient resolution). At the location of PAWP, the current velocity was not measured, therefore three other locations were selected (Schouwenbank Stroomgat, Buitenbanken west, IJgeul stroommeetpaal, Figure **8**). The development of the current at

[9] Good seamanship in this case: the safety of crew and vessel should be kept in consideration all the time and in this case prevail over material like crab-pot-strings and wind turbines (Rozemeijer, 2023).

three locations is given in Figure **9**. It is difficult to choose the most appropriate station. IJgeul stroommeetpaal is closer to PAWP but also closer to the coast which can lead to higher velocities, as was observed in Figure **9**. Schouwenbank Stroomgat and Buitenbanken west are far away from PAWP. In the end it is not so much about the values itself. The current velocity (Figure **9** was used as an extra indication if the results of the string mobilisation were hard to explain by means of the haul out indicator.


Figure 8 Positions of the current velocity measurement locations relative to the OWP (green hatched polygons). Borssele II is the southern polygon; Prinses Amalia Windpark is the northern polygon. SCHS = Schouwenbank Stroomgat, BUBW = Buitenbanken west, SPY = IJgeul stroommeetpaal

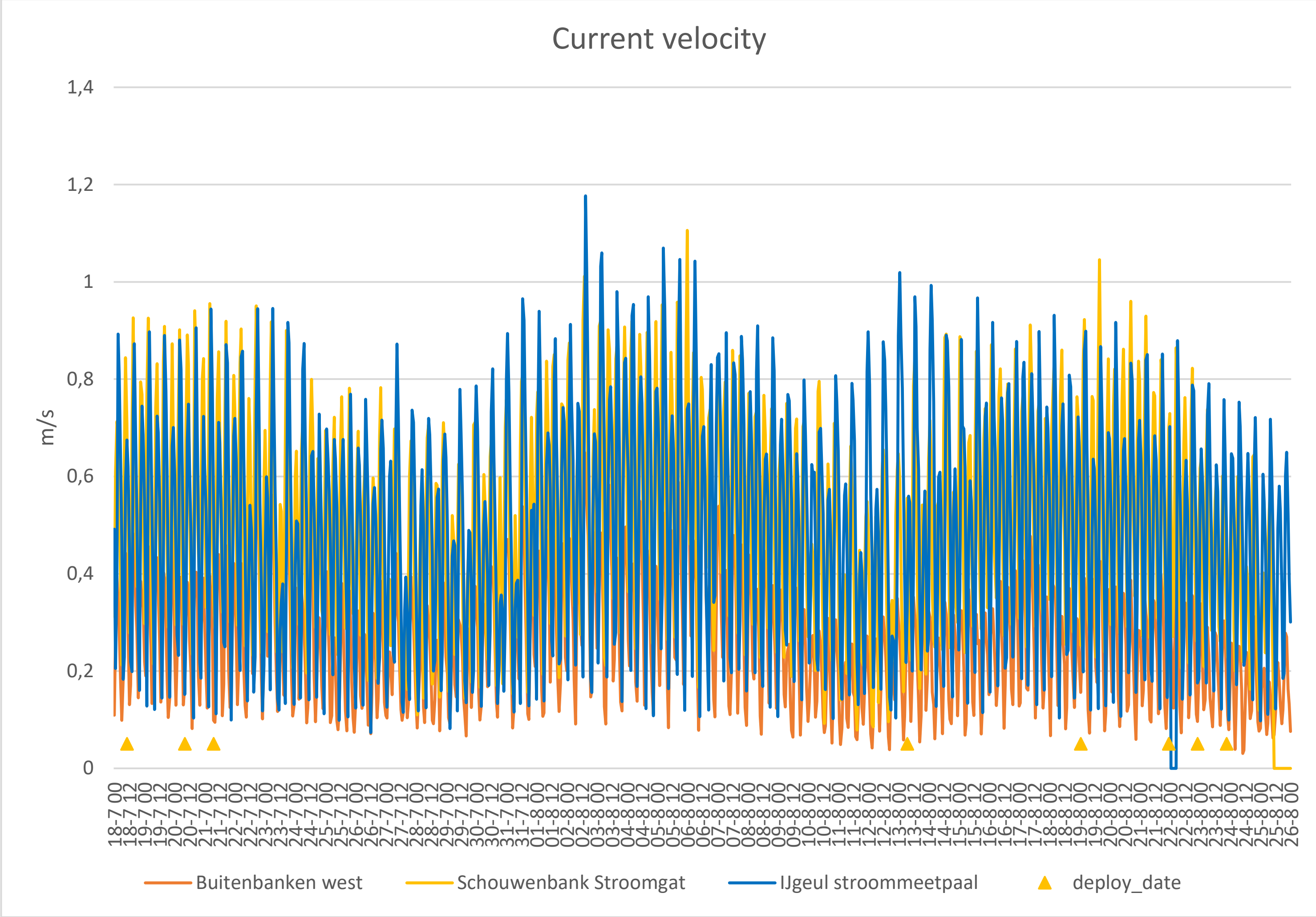


Figure 9 Current velocity in m/s at Schouwenbank Stroomgat, Buitenbanken west, IJgeul stroommeetpaal, The deployment dates are indicated with yellow triangles (see also Table 1).

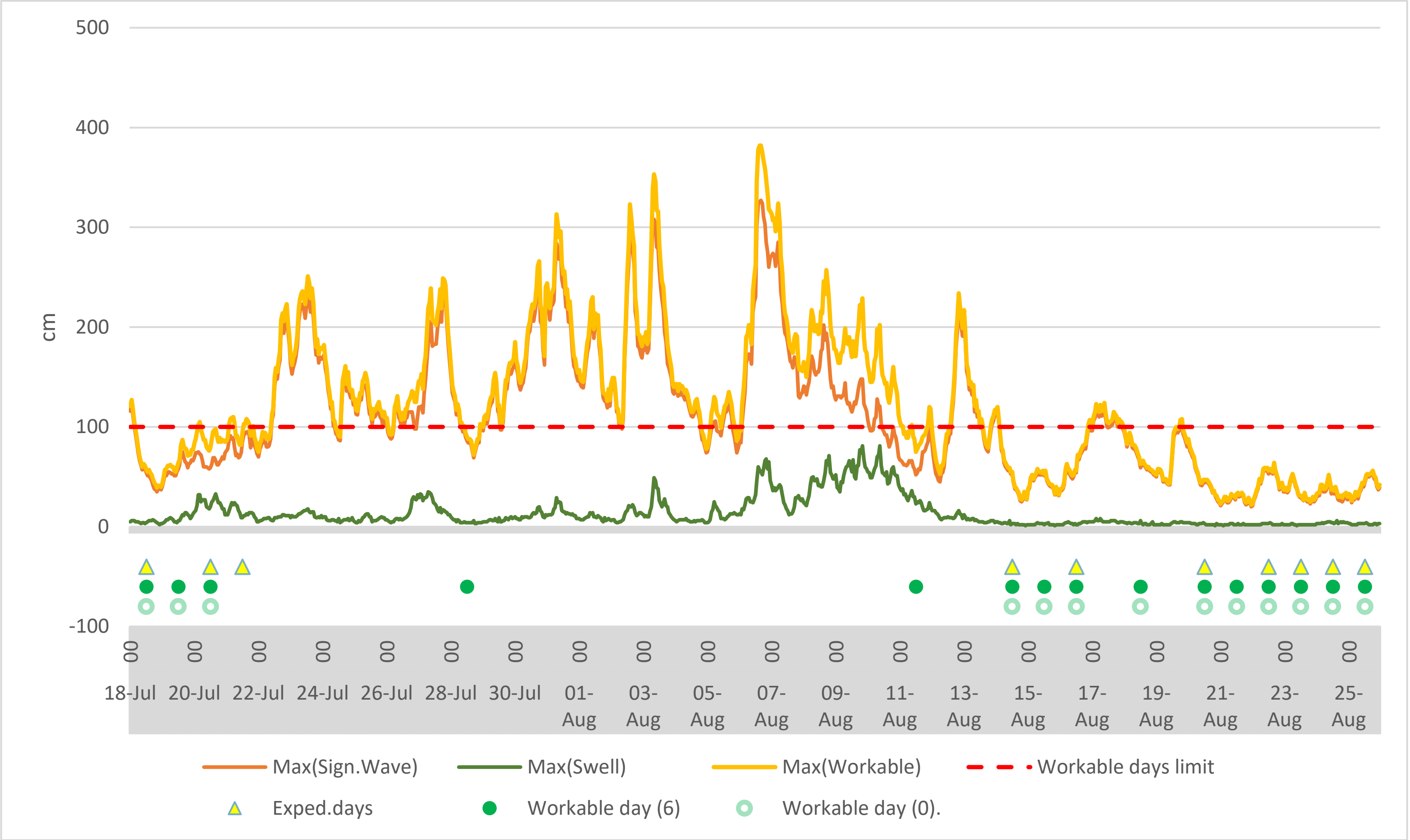


Figure 10 Registration of the Sum (yellow line) of the significant wave height (orange line) with swell (green lines) (all in cms). The actual expedition days are given with yellow triangles. The potential workable days are given in green dots. The workable days were determined according to section 2.6.2. The limit for the workable days is given with the red dashed line.

## 3.4 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 10. Applying a strict implementation of the threshold of 100 cm resulted in 12 workable days of which nine were used and one expedition day was performed on a non-workable day. Twelve workable days is ~31% of the 39 days the expeditions lasted.

If the workable days indicator was allowed to have pass the 100 cm threshold for six times per day, as a first sensitivity analysis, 14 days were estimated to be workable. This is ~36% of the 39 days the expeditions lasted. Applying the exceedance showed that days within stormy periods could also be used (see e.g. 11-08-2023 in Figure 10).

# 4 Mobilization of crab-pot-strings

To determine the chance part of the risk, we approximated the probability of mobilization of crab-pot-strings anchored with regular Bruce anchors. It was a windy summer with a lot of waves and a low number of workable days in 2023 (Section 3.1, 7.1.2, Figure **10**).

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 basic information.
2. Next the first step to assess the reliability of the measurement method was performed in section 4.1. This assessment 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. For the second step to determine the measurement error, the difference between the deployment and haul out was determined for the expeditions 23-08-2023 until 25-08-2023. During these days there was approximately one day of soaking time with calm weather and suitable current and wave conditions (Figure **7**). It can safely be assumed the crab-pot-strings will not be moved during such conditions (Rozemeijer et al., 2022a,b).
4. The potential displacement of the anchors and strings was assessed by measuring the deviation in position between deployment and haul out for the first and second Bruce anchors separately. This deviation was then compared with the measurement error (explained in 2 and 3).

## 4.1 Positions and averaged string lengths

The deployment of the crab-pot-strings is given in strings is in Figure 11. The crab-pot-strings were named A to F for identification purposes. The average string length measured is given per string in Figure 12 and Table 2. The averages ranged from 163.1 to 213.2 m. The average lengths for the crab-pot-strings on the outside (A-C, Figure 11) were close to the theoretical length of 210 m. The average lengths for the crab-pot-strings on the inside (D-F, Figure 11) were shorter (~165 m) as compared to the theoretical length of 210 m, which indicates that either the Bruce anchors were drifting or a measurement error. Between 78 to 100% of the measurements was successful (yielded reliable results).

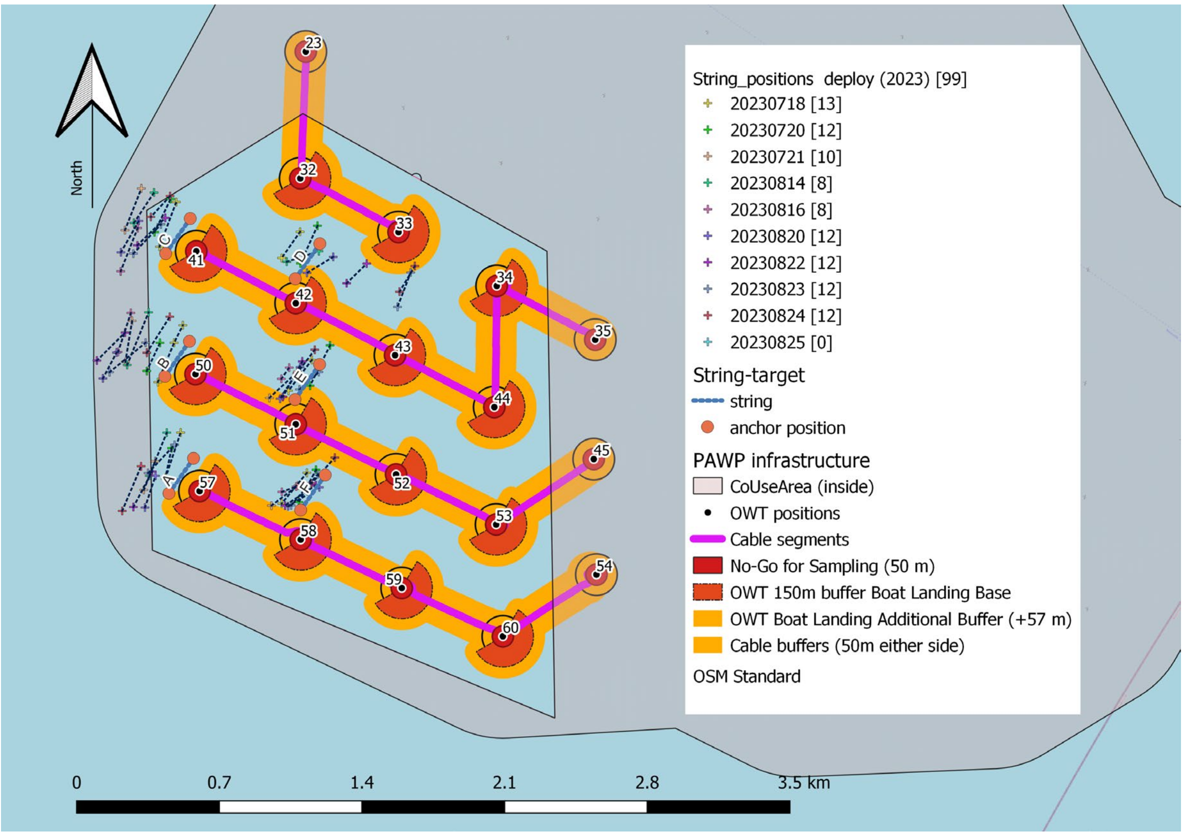


Figure 11. The different deployments of the crab-pot-strings. The letters A to F are the identities given to the crab-pot-strings. The vertical axis is the North : South axis of the compass rose.
Red area: No-go area for everything, radius 50 m.
Dark Orange area: No Buoy area. CTV approach no entry zone where no buoys or anchors on the bottom are allowed. Ships can manoeuvre in this area: 100 m to red zone. 150 m radius to turbine.
Thick black circle within the light orange area: 50m radius to the red zone: summed 100 m radius to turbine (no anchoring zone in relation to the infield cable).
Light orange area around dark orange are: No-Bottom-Contact Area: no chains or strings on the bottom allowed to prevent dahns and buoys to enter the dark orange zone, buoys and ships can enter the area: 57 m
Light orange area on either side of the purple line (infield cable): no anchoring or bottom contact zone: 100 m.

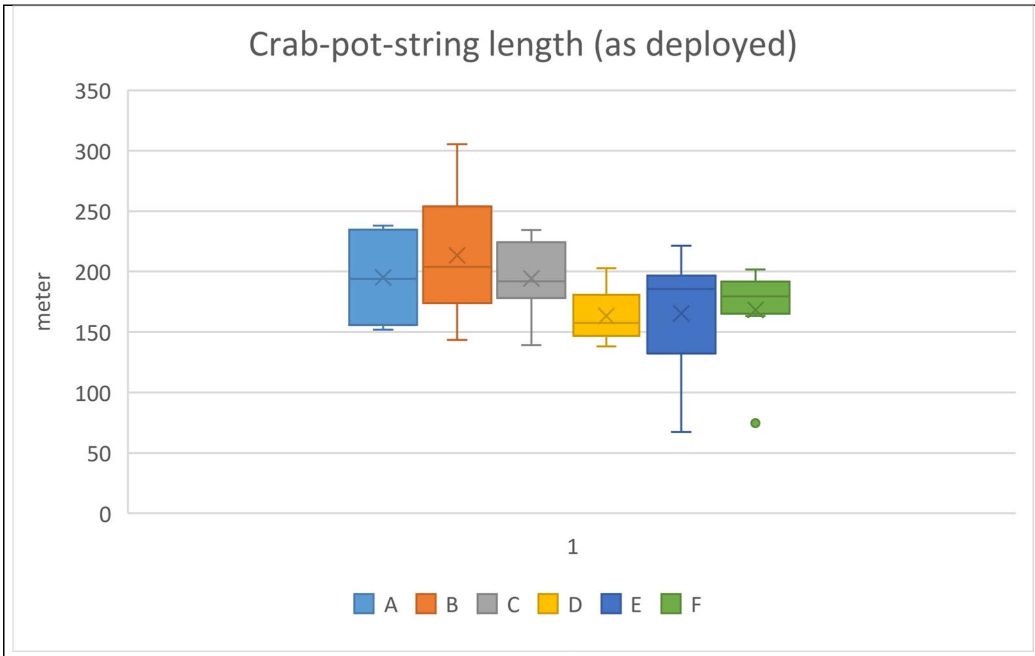


Figure 12 Box and Whisker Plots of the average length of each string as measured in the expeditions. A- F: code for the different locations (Figure 11).

Table 2 The average crab-pot-string length per string, with standard deviation (St Dev), number of observations (N). See Figure 11 for the positions of the different crab-pot-strings.

| **String-Id** | **A** | **B** | **C** | **D** | **E** | **F** |
|---|---|---|---|---|---|---|
| **Average** | 195.1 | 213.2 | 194.2 | 163.1 | 165.2 | 168.1 |
| **St Dev** | 36.5 | 52.6 | 29.9 | 22.2 | 49.4 | 39.6 |
| **N** | 8 | 9 | 9 | 7 | 8 | 8 |
| **% successful** | 89 | 100 | 100 | 78 | 89 | 89 |

### 4.1.1 Actual positions as compared to the planned positions

Beforehand theoretical positions were planned (Figure 11, Figure 3). Under the influence of risk evaluation of the captain, currents, movement and precision of the vessel the actual deployments differed from the planned deployment. Figure 11 showed the actual deployments. The outward strings A-C were placed at a more outward distance from the original planning. The captain wanted more distance from the wind turbine to prevent accidental collisions. Also for crab-pot-string D the captain perceived the position as being too close by or in the vicinity of wind turbines and sought a better position to prevent collision.

## 4.2 First assessment of the measurement error

In order to estimate the general measurement error a first assessment was made based on the positive (surplus) length difference of a crab-pot-string longer than the theoretical length of 210 m (alike Rozemeijer et al., 2023). A crab-pot-string can differ from the theoretical length for different reasons e.g. drift in the currents because the Bruce anchor did not hook in the seabed immediately; the first Bruce anchor is dragged by the vessel; GPS measurement errors etc. The surplus length differed between 11 m and 95 m. Ten out of a total of 49 measurements were longer than 210 m (20%). The average positive length difference was 32.0 (±27.7, n = 10) m. 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.

## 4.3 Second assessment of the measurement error

In the total experimental period, the haul out indicator was lower than the approved threshold level of 445, except from 02-08-2023 to 07-08-2023 (Figure **7**). However, deviations of the original anchor positions were seen even in the quiet periods with haul out indicator values much lower than 445 cm, leading to a need to assess the general measurement error again. The first assessment of the general measurement error was 32.0 m (±27.7 m, n = 10, section 4.2). Based on a first analysis of the results the general measurement error is likely larger. Therefore a second assessment of the general measurement error was done in which the difference of the position of the Bruce anchor between the deployment and haul out was determined for the expeditions on 23-08-2023 until 25-08-2023. During these days there was approximately one day of soaking time with calm weather and suitable low current and wave conditions (Figure **7**). Based on Rozemeijer et al. (2021, 2022a,b) it can safely be assumed the crab-pot-strings will not be moved during these conditions. The haul out indicator was well below the 445 cm (Figure **7**) and the currents were low (Figure **9**). The deviation of the first Bruce anchor (between deployment and subsequent haul out) is 78.7 m (±49.9 m, n = 18) for this period. It is unlikely that the Bruce anchors would have moved during this calm period (Figure **7**, Figure **9**, Rozemeijer et al., 2021, 2023). Therefore the measurement error for the first Bruce anchor was assumed to be 78.7 m (±49.9 m). The deviation of the second Bruce anchor (between deployment and subsequent haul out) is 186.1 m (±54.3 m, n = 18) for the period with calm weather, which was assumed to be the final measurement error for the second Bruce anchor.

## 4.4 Assessing displacement of the anchors and strings

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. Figure **13** gives an overview of the average deviation per first anchor per string. The average deviation in the position of the first Bruce anchor is 74.7 (±43.9, n = 49). Figure **14** gives an overview of the average deviation per second anchor per string. The average deviation of the second Bruce anchor is 165.3 (±69.5, n = 49).

The deviation of the second Bruce anchor is larger than the first Bruce anchor. This is likely caused during the hauling during which the ship deviates from its course and already hauls the second anchor towards the vessel. In Figure **15** the curved blue line represents such a typical vessel course. The vessel is much heavier than the remaining string and anchor so it can easily mobilise the remaining crab-pot-string.

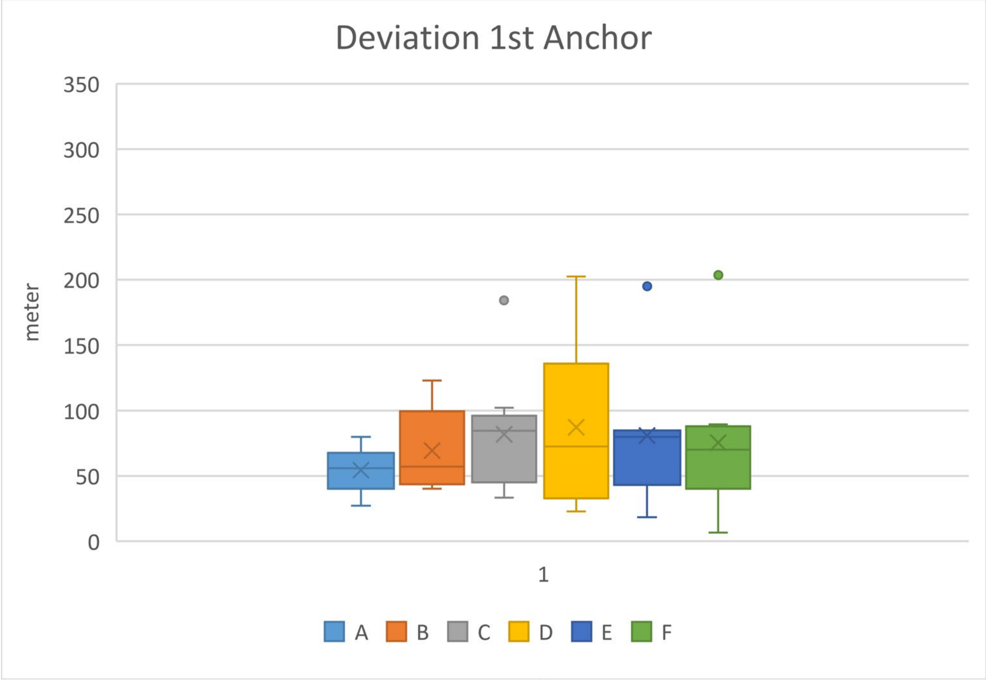


Figure 13 Box and Whisker Plots of the average deviation from its intended position of the first Bruce anchor of each string as measured in the expeditions. A- F: code for the different locations (Figure 11).

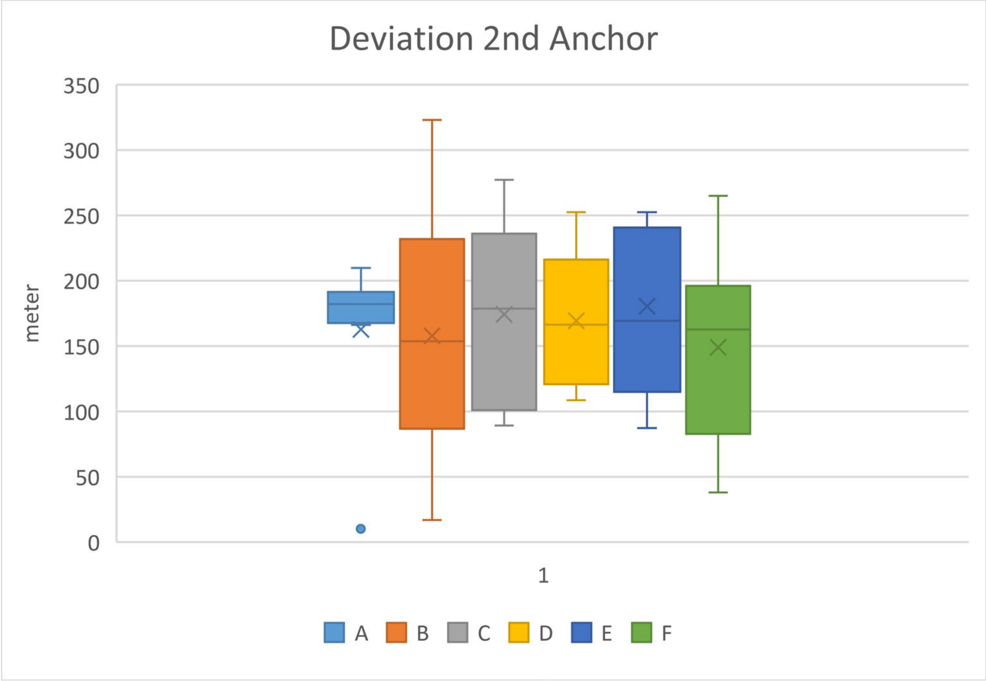


Figure 14 Box and Whisker Plots of the average deviation from its intended position of the second Bruce anchor of each string as measured in the expeditions. A- F: code for the different locations (Figure 11).

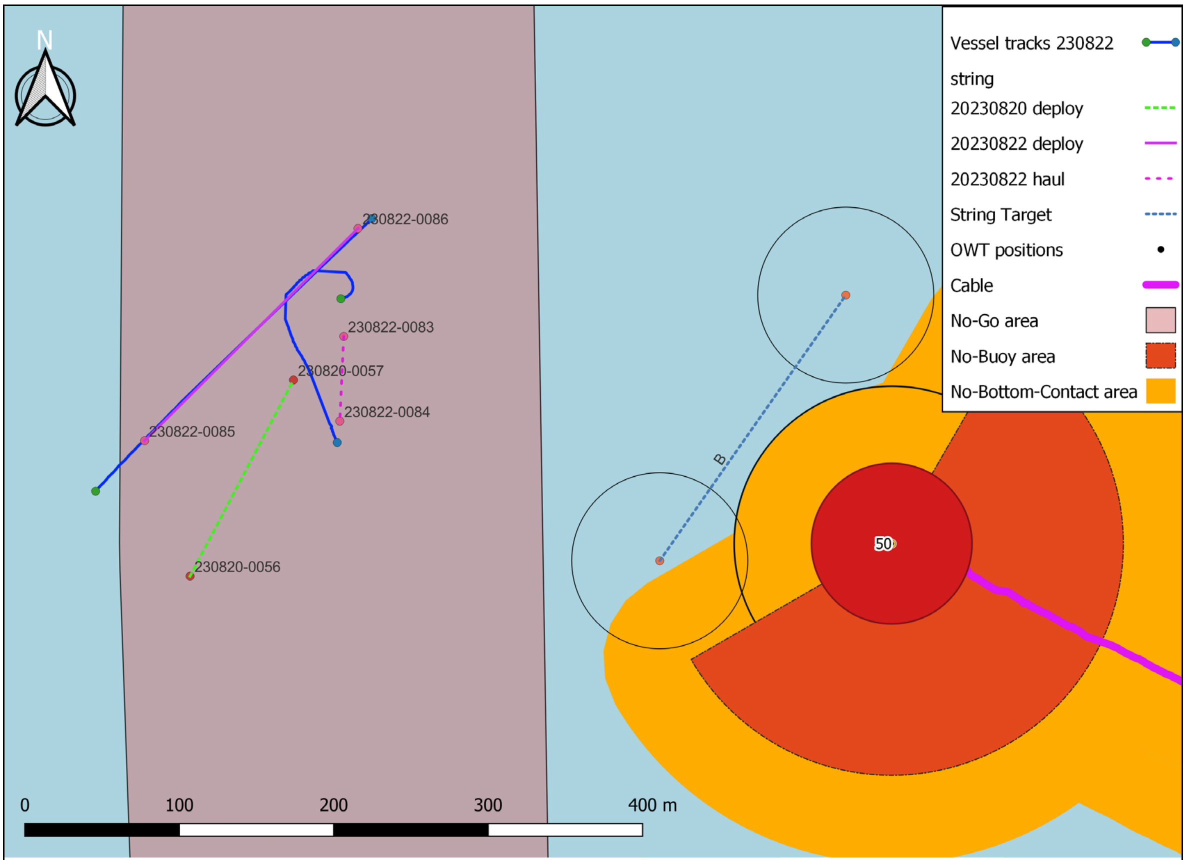


Figure 15 View of hand-held GPS fixes vs. vessel track (from vessel GPS) at string position B (next to OWT 50), shown are: deployment 20-8-23 (230820-0056, southern; 230820-0055, northern); subsequent haul-out on 22-08-23 (230822-0084, northern; 230822-0084, southern) and redeployment (230822-0085, southern; 230822-0086, northern). The curved blue line is the vessel track while hauling, the straight blue line while deploying on 22-08-2023.B: code for the location (Figure 11).

### 4.4.1 Does the deviation represent mobilisation of the string?

The overall average deviation for the first Bruce anchor is 74.7 (±43.9, n = 49) and the assumed measurement error for the first Bruce anchor is 78.7 m (±49.9 m). The average deviation of the second Bruce anchor (between deployment and subsequent haul out) is 165.3 (±69.5, n = 49) for the entire expedition period. The assumed measurement error was 186.1 m (±54.3 m). For both positions the assumed measurement error was larger than the measured displacement.

There is no reason the Bruce anchors of both sides of the crab-pot-strings should have moved in this period of calm seas (Figure **7**), with a low haul out indictor, low currents and only one day of soaking (Figure **9**). As a consequential interpretation, the Bruce anchors have most likely not been displaced during the experimental periods, not even during the high wind period between 21-07-2023 and 14-08-2023 with a maximum haul out indicator value of 542 cm (Table 1, Figure **7**). Due to the large general measurement error, the results on string mobilisation are inconclusive.

# 5 Catches

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

## 5.1 Species caught

The total number of animals caught per species are summarized in Figure 16. Among 255 pots catches, velvet swimming crab were caught the most (1330 individuals) while 503 brown crab were caught. In total five European lobsters were caught, all larger than the MLS (minimum landing size), four males and one undetermined. The common cuttlefish (*Sepia officinalis*) was also caught (39 individuals). Other species caught were sea star, bull rout (*Myoxocephalus scorpius*), pouting (*Trisopterus luscus*) and striped red mullet (*Mullus surmuletus*). See right panel in Figure 16 for the incidentally caught species.

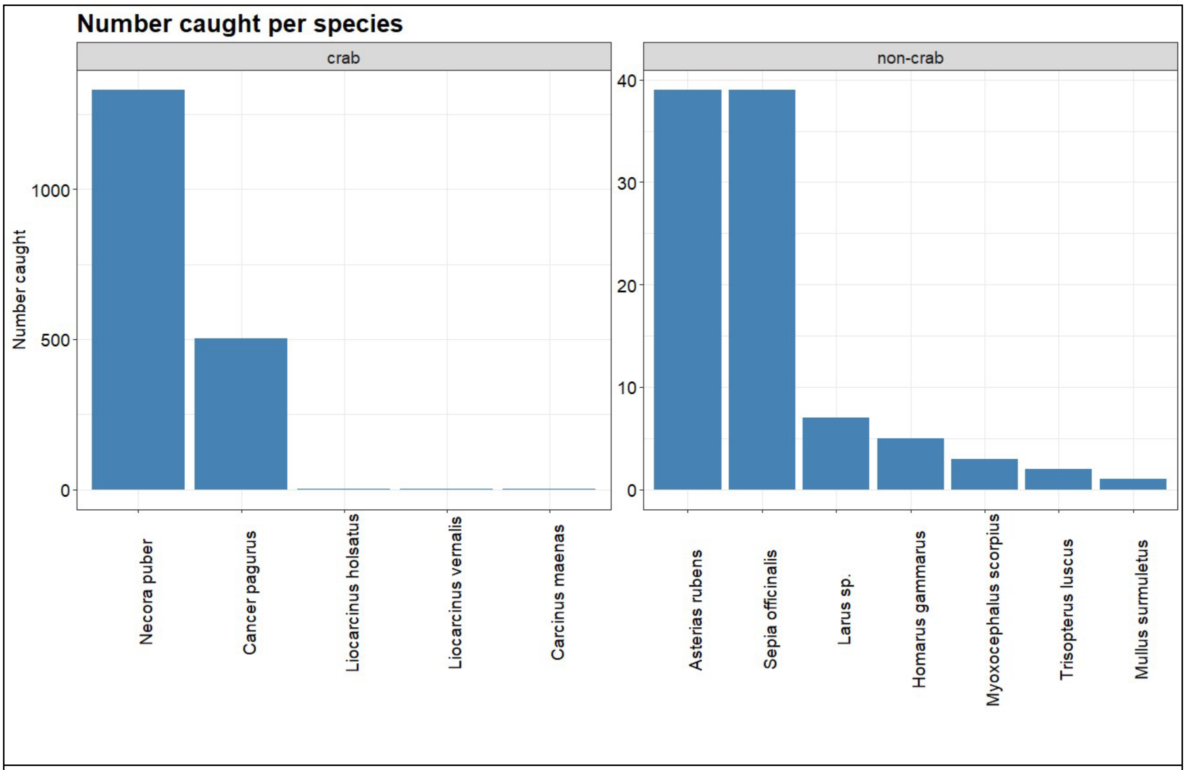


Figure 16 overview of all species caught from 255 pot catches during the ten experimental days in PAWP in 2023. *Necora puber*: velvet swimming crab. *Cancer pagurus*: brown crab; *Liocarcinus holsatus*: flying crab; *Liocarcinus vernalis*: grey swimming crab; *Carcinus maenas*: shore crab; *Asterias rubens*: common starfish; *Sepia officinalis*: common cuttlefish; H*omarus gammarus*: European lobster; *Myoxocephalus Scorpius*: bull rout; *Trisopterus luscus*: pouting; *Mullus surmuletus*: striped red mullet.

In Figure **17** a frequency plot is given on the number of brown crab and velvet swimming crabs caught per pot. For the brown crab a large number (106 pots, 41.6%) of pots with zero catches were observed. This is due to the large number of short soaking times of only ~one day as well as some excessive long soaking days. Ideally the soaking time would have been at least two days. Due to weather circumstances the soaking time was often shorter.

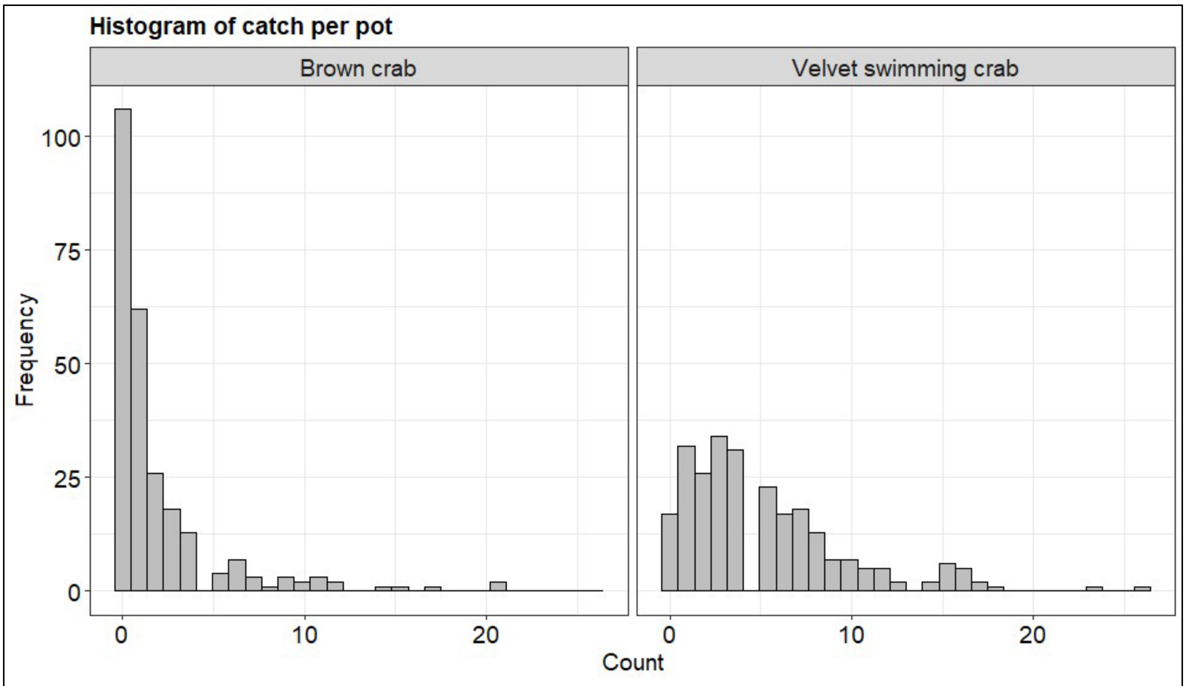


Figure 17 histogram of catch number per pot for brown crab and velvet swimming crab. X -axis number of a crab species per pot, Y-axis number of times the species occurs. Left panel: brown crab, right panel: velvet swimming crab.

The histogram of soaking time was shown in Figure **18**. There is a big gap in the time line from ~139 hours to ~582 hours due to the harsh weather conditions. As a consequence a Generalized Additive Models approach (GAM)[10] as in Borssele II 2022 study (Rozemeijer et al., 2023)could not be applied as the CPUE model and soaking time was grouped according to the data availability: [19, 25], [38, 48], [92, 139] and [582, 629]. Numbers represent the soaking time in hours.

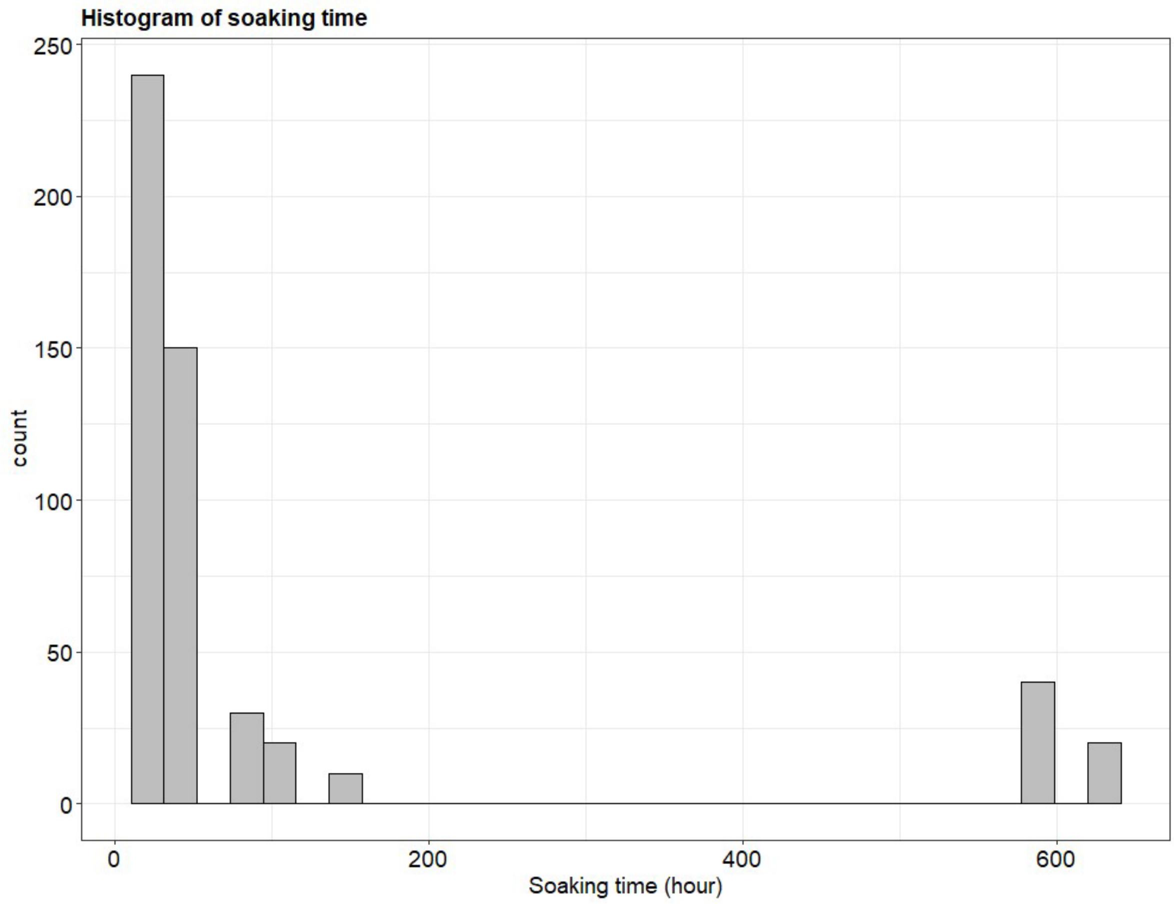


Figure 18 histogram of catch number per pot for brown crab and velvet swimming crab in relation to soaking time. X -axis count of number of a crab species per pot, Y-axis soaking time. Left panel: brown crab, right panel: velvet swimming crab.

## 5.2 Other species observed

In order to gather data to determine the risks for potential bycatch by fishing gears, regular observations were made from the environment. Furthermore, attracting birds with fishing activities within wind farms, could potentially increase the number of bird casualties being hit by a wing of a wind turbine. Six gulls were observed during the experiment during four days and a gannet (*Morus bassanus*). The weather was quit, low winds and waves. The birds were not attracted by our activities. One harbour porpoise was seen, no seals or other bird types were observed.

## 5.3 Sex distribution of the species of interest

The caught number and percentage by sex are listed in Table 3. Of the main species of interest, only five European lobsters were caught: four males, one undetermined, (all landable size (> 8.7 cm CL),

[10] 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.

average carapace length 12.7±1.6 cm). For both crab species a majority males was caught. A total of 503 brown crab was caught: 129 females and 373 males. A 391 out of 503 brown crab were above the minimum conservation reference size (MRCS). Large numbers of velvet swimming crab were caught: 1330 of which 494 were females and 833 males. The number of female velvet swimming crabs decreased from 61.2% for the group <6.5cm to 30.7 for the group ≥6.5cm. For velvet swimming crab a MCRS is not available for the Netherlands. Therefore a MCRS conform the UK of 65 mm CW was applied (Wallace & Rae, 2018). This is the general UK MCRS whereas in colder region like Scotland a MCRS of 70 mm CW is used[11].

Table 3 number of animals by sex, brown crab and velvet swimming crab are also grouped by their MCRS size.

| Species | Female | Male | Unknown | Total |
|---|---|---|---|---|
| *Brown crab* | | | | |
| Total | 129 (25.6%) | 373 (74.2%) | 1 (0.2%) | 503 |
| ≥14cm | 93 (23.8%) | 297 (76.0%) | 1 (0.3%) | 391 |
| <14cm | 34 (35.1%) | 63 (64.9%) | 0 | 97 |
| Brown crab unknown width | 1 (20%) | 4 (80%) | 0 | 5 |
| | | | | |
| *Velvet swimming crab* | | | | |
| Total | 494 (37.1%) | 833 (62.6%) | 3 (0.2%) | 1330 |
| ≥6.5cm | 297 (30.7%) | 667 (69.1%) | 1 (0.1%) | 965 |
| <6.5cm | 79 (61.2%) | 50 (38.8%) | 0 | 129 |
| unknown width | 118 (50.0%) | 116 (49.2%) | 2 (0.8%) | 236 |
| | | | | |
| *European lobster* | 0 | 4 | 1 | 5 |

[11] 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.

## 5.4 Carapace width distribution by sex

The carapace width distribution by sex is given in Table 4 and Figure 19. The mean and median CW of both female and male brown crab were above MCRS. Males were significantly larger than females.

Table 4 Mean and median carapace width (CW) in cms of brown crab

| ***Species*** | **CW Female Mean (median)** | **CW Male Mean (median)** | **Wilcoxon rank sum test on median** |
|---|---|---|---|
| Brown crab | 14.9 (15.1) | 15.8 (16.2) | Significant (p<0.001) |

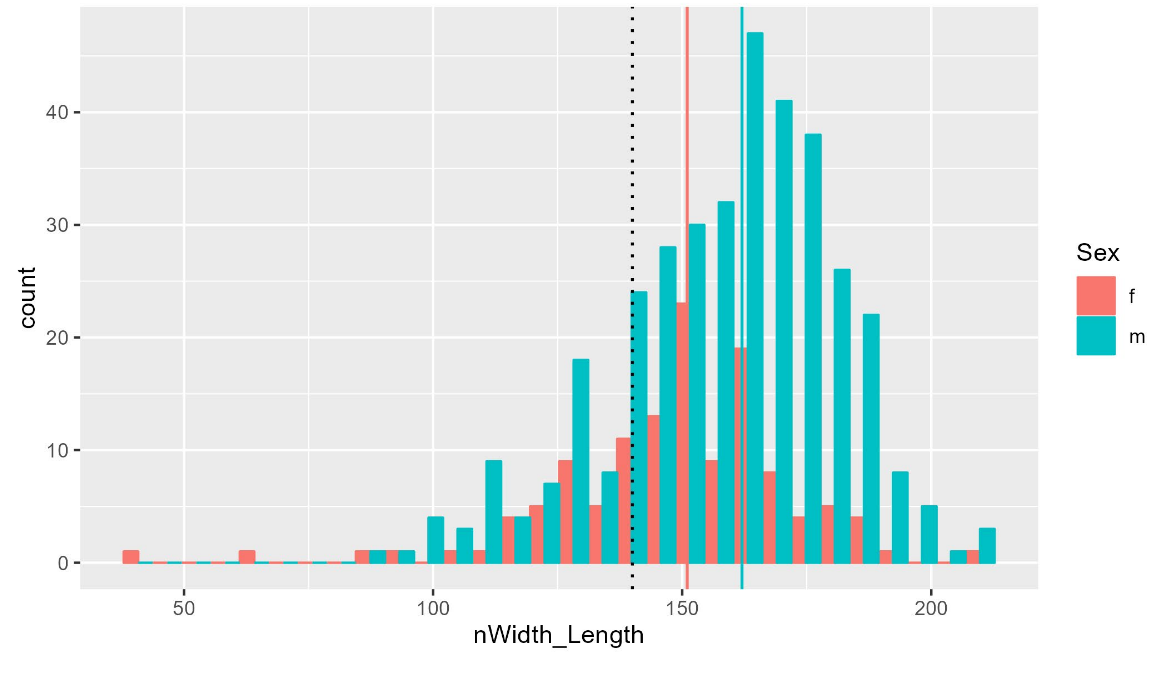


Figure 19 Width length distribution Brown crab by sex. Solid coloured vertical lines correspond to median width length of males (blue; 162 mm) and females (red; 151 mm). The dashed black line corresponds to MCRS (140 mm).

# 5.5 Catch numbers of animals in time

Results are presented on brown crab and velvet swimming crab. The number of caught brown crab increased steadily up to ~26 days/629 hours (Figure 20 Box and Whisker Plots of the observed catch number per pot for different categories of soaking time (in hours, p<0.001) and pot type (Parlour or Medley) for brown crab and velvet swimming crab.). The catch of velvet swimming crab increased up to the category [38, 48] and decreased starting from category [92, 139] to category [582, 629].

The catches of European lobster were too low to apply a statistical analysis.

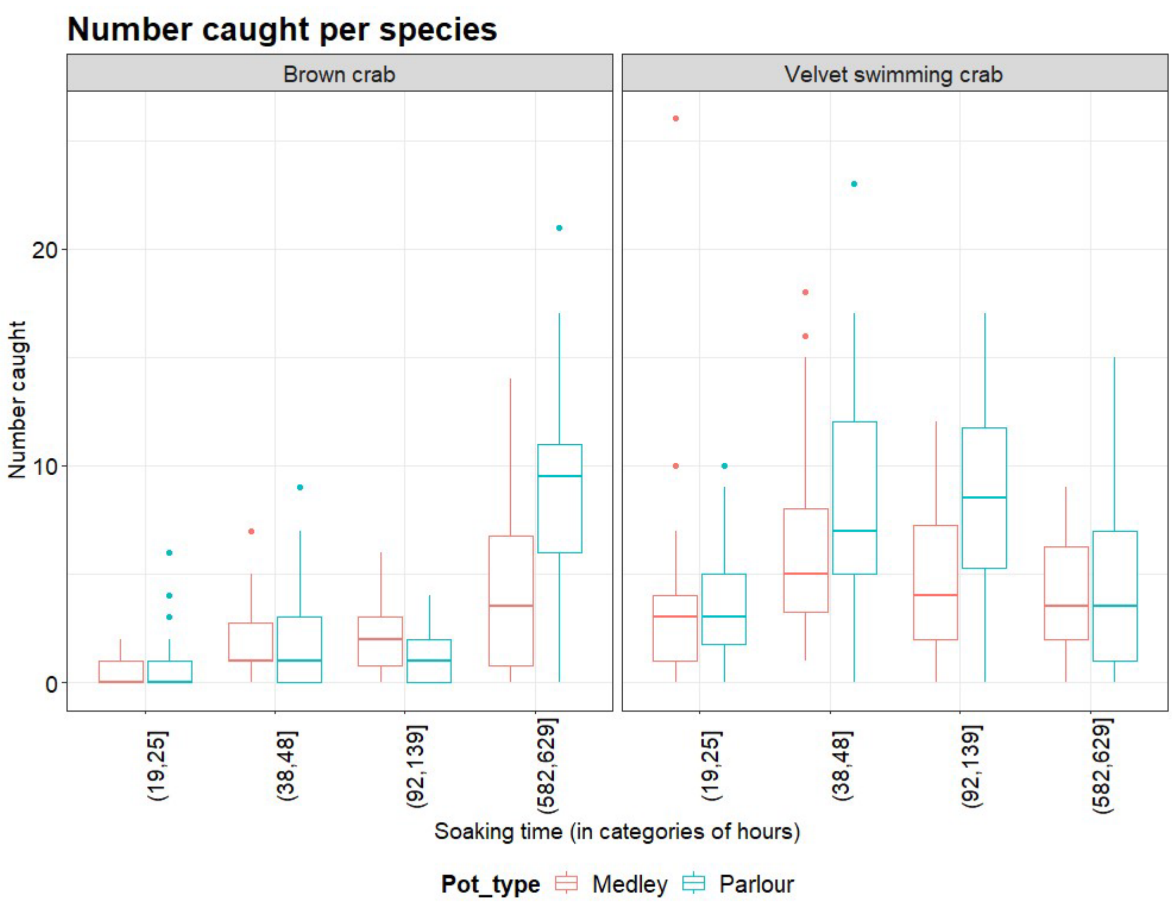


Figure 20 Box and Whisker Plots of the observed catch number per pot for different categories of soaking time (in hours, p<0.001) and pot type (Parlour or Medley) for brown crab and velvet swimming crab.

# 5.6 CPUE and LPUE of brown crab

The average CPUE and LPUE from observed data are illustrated in Figure 21. CPUE and LPUE were tested in two ways. Firstly a generalized linear model (GLM) was applied with catch number as response to test the effects of covariates. Once the null hypothesis (i.e. all group means are equal) was rejected for a covariate, a Tukey's Honest Significant Difference (HSD) post hoc test was applied to test the difference between pairwise group means. The test gives adjust p-values to account for the family-wise error introduced by multiple comparisons.

Figure **18** The GLM analysis showed that the CPUE of the brown crab was driven by soaking time but not by pot type (Medley or Parlour) or pot order (pot #1 most southern pot, pot #5 most northern pot) (Table 5, Figure 21).
The estimated CPUE for the Medley pots ranged from 0.19 to 1.17 and the CPUE for the Parlour pots ranged from 0.33 to 1.21 brown crab per pot per day (Figure 21 Table 6).

Table 5 GLM tests on the CPUE of brown crab

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

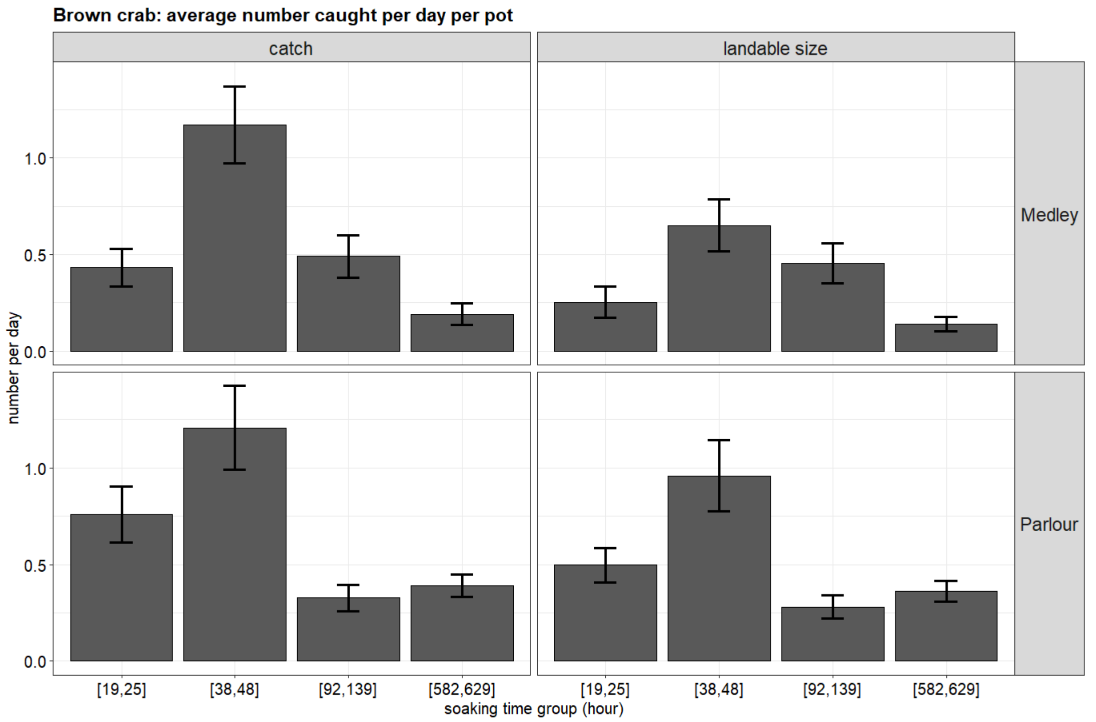


Figure 21 Average CPUE (left) and LPUE (right) and standard error for different categories of soaking time and pot type (Parlour or Medley) for brown crab. X-axis: soaking time group (category) in hours; Y-axis numbers caught per day (24 hours: CPUE and LPUE)

| Table 6 Mean CPUE (left) and LPUE (right) with Standard Error (SE_XPUE) for different categories of soaking time (p<0.001) and pot type (Parlour or Medley) for brown crab and velvet swimming crab. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **category soaking time** | **English name** | **Pot type** | **Mean CPUE** | | **SE_CPUE** | **Mean LPUE** | | **SE_LPUE** |
| [19,25] | Brown crab | Medley | 0.43 | ± | 0.10 | 0.25 | ± | 0.08 |
| [38,48] | Brown crab | Medley | 1.17 | ± | 0.20 | 0.65 | ± | 0.14 |
| [92,139] | Brown crab | Medley | 0.49 | ± | 0.11 | 0.45 | ± | 0.10 |
| [582,629] | Brown crab | Medley | 0.19 | ± | 0.06 | 0.14 | ± | 0.04 |
| | | | | | | | | |
| [19,25] | Brown crab | Parlour | 0.76 | ± | 0.14 | 0.50 | ± | 0.09 |
| [38,48] | Brown crab | Parlour | 1.21 | ± | 0.22 | 0.96 | ± | 0.18 |
| [582,629] | Brown crab | Parlour | 0.39 | ± | 0.06 | 0.36 | ± | 0.05 |
| [92,139] | Brown crab | Parlour | 0.33 | ± | 0.07 | 0.28 | ± | 0.06 |
| | | | | | | | | |
| [19,25] | Velvet swimming crab | Medley | 3.68 | ± | 0.68 | 2.38 | ± | 0.62 |
| [38,48] | Velvet swimming crab | Medley | 3.74 | ± | 0.43 | 2.05 | ± | 0.40 |
| [92,139] | Velvet swimming crab | Medley | 1.17 | ± | 0.28 | 1.09 | ± | 0.27 |
| [582,629] | Velvet swimming crab | Medley | 0.17 | ± | 0.03 | 0.13 | ± | 0.03 |
| | | | | | | | | |
| [19,25] | Velvet swimming crab | Parlour | 3.93 | ± | 0.33 | 2.37 | ± | 0.32 |
| [38,48] | Velvet swimming crab | Parlour | 4.66 | ± | 0.46 | 3.48 | ± | 0.48 |
| [92,139] | Velvet swimming crab | Parlour | 2.03 | ± | 0.31 | 1.94 | ± | 0.31 |
| [582,629] | Velvet swimming crab | Parlour | 0.18 | ± | 0.04 | 0.16 | ± | 0.04 |

### 5.6.1 LPUE brown crab

The GLM analysis showed that the LPUE of the brown crab was driven by soaking time and pot type (Medley or Parlour) and the interaction of both but not by pot order (pot #1 most southern pot, pot #5 most northern pot) (Table 7).

The estimated LPUE for the Medley pots ranged from 0.14 to 0.65 and the LPUE for the Parlour pots ranged from 0.28 to 0.96 brown crab per pot per day (Figure 21, Table 6). Two Tukey's Honest Significant Difference (HSD) post hoc test were performed. The highest LPUE categories for Parlour and Medley: [38,48]-Parlour-[38,48]-Medley resulted in an adjusted p-value of 0.620, which is not statistically significant. The highest LPUE category with the longest soaking time for Parlour: [38,48]-Parlour vs [582,629]-Parlour resulted in an adjusted p value of 0.085, marginally significant.

Table 7 GLM tests on the LPUE of brown crab

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

## 5.7 CPUE and LPUE velvet of the swimming crab

### 5.7.1 CPUE velvet swimming crab

The GLM analysis showed that the CPUE of the velvet swimming crab was driven by soaking time and by pot type (Medley or Parlour) but there was no significant interaction, nor pot order (pot #1 most southern pot, pot #5 most northern pot) (Table 8, Table 5, Figure 22). The estimated CPUE for the Medley pots ranged from 0.17 to 3.74 and the CPUE for the Parlour pots ranged from 0.18 to 4.66 velvet swimming crab per pot per day (Figure 22, Table 6). Note that the CPUE dropped markedly after two days, more than for brown crab (Figure 21).

Table 8 GLM tests on the CPUE of velvet swimming crab

| **covariates** | **p-value (from likelihood ratio test)** |
|---|---|
| Soaking time | <0.001 |
| Type of pot (Medley, Parlour) | 0.04 |
| Pot order (1~5) | N.S. (not significant) |

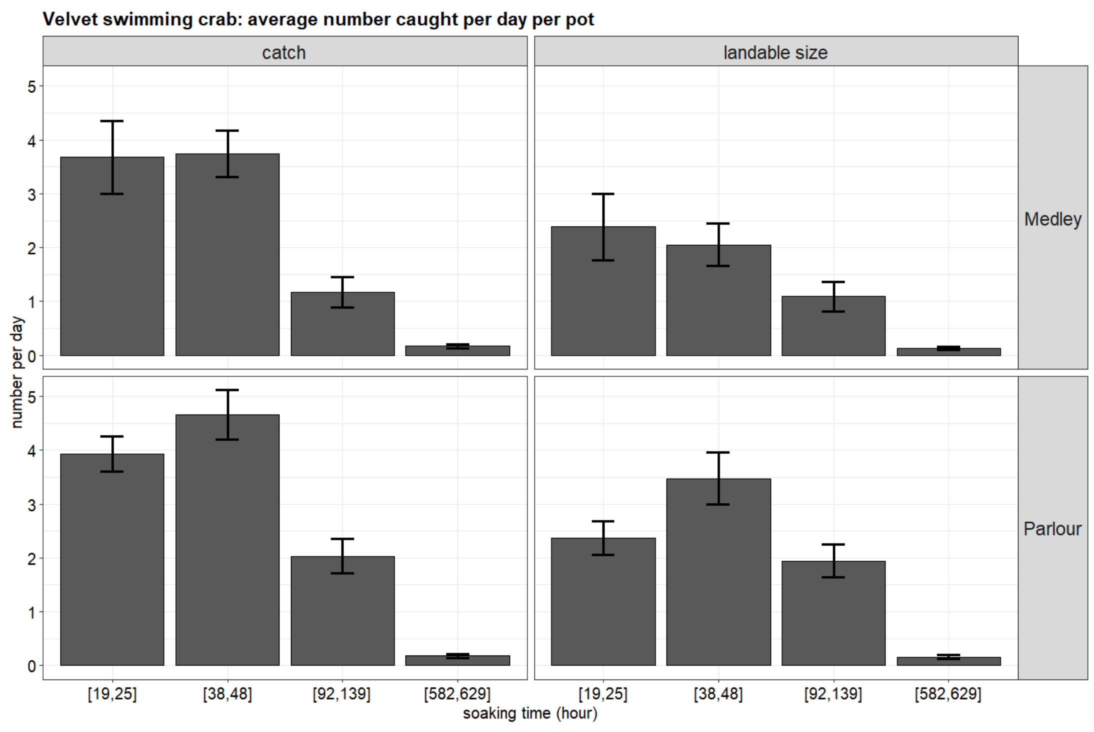


Figure 22 Average CPUE (left) and LPUE (right) and the standard error for different categories of soaking time and pot type (Parlour or Medley, P = 0.04) for velvet swimming crab.

### 5.7.2 LPUE velvet swimming crab

The GLM analysis showed that the LPUE of the velvet swimming crab was driven by soaking time and pot type (Medley or Parlour) but not their interaction. Again pot order was not significant (pot #1 most southern pot, pot #5 most northern pot) (Table 7).

The estimated LPUE for the Medley pots ranged from 0.13 to 2.38 and the LPUE for the Parlour pots ranged from 0.16 to 3.48 velvet swimming crab per pot per day (Figure 22, Table 6). Two Tukey's Honest Significant Difference (HSD) post hoc test were performed. The post hoc test on the highest LPUE categories for Parlour and Medley: [38,48]-Parlour-[38,48]-Medley resulted in a p adjust value of 0.373, not significant. The post hoc test on the highest LPUE category with the longest soaking time for Parlour: [38,48]-Parlour vs [582,629]-Parlour resulted in a p adjust value of 0.001, highly significant.

Table 9 GLM tests on the LPUE of velvet swimming crab

| **covariates** | **p-value (from likelihood ratio test)** |
|---|---|
| Soaking time | 0.05 |
| Type of pot (Medley, Parlour) | <0.001 |
| Pot order (1~5) | N.S. (not significant) |

## 5.8 Catch : Mark : Recapture

A total of nine marked brown crabs was recaptured: eight males, one female. Three were recaptured near the same wind turbine, six were recaptured at a neighbouring wind turbine. This number of nine recaptures is too low to perform population analysis (Chen & Rozemeijer, 2023, internal memo).

# 6 Evaluating the Work Method Statement

The Work Method Statement (WMS, Rozemeijer et al., 2020, Rozemeijer, 2023) is an elaborate description of the work procedures of the crab-pot fishing in PAWP and the associated risks and their mitigation. Up forehand it needs to be stated that the situation concerning fisheries as a form of co-use have changed. The policy for Eneco is described in section 2.2. In Borssele II in new situation was defined around co-use passive fisheries (Staatscourant 2021, 37376[12]). In Borssele II Rijkswaterstaat set some requirements (maximum overall length of forty-five metres; Automatic Identification System in operation; VHF system on board; not using 250m maintenance zone around assets). More details are given in the following subsections. Evaluating the WMS has relevance to reflect on lessons learned for the future.

Different forms of evaluation are available. There are plan evaluation, process evaluation and effect measurement. With an effect measurement the end result is the focus: how the end result relates to the way in which the work was done. A process evaluation focuses instead on how the result was achieved. Finally, the plan evaluation evaluates the creation of a plan

The result of the WMS was a complete view of the risks involved and the measures to mitigate the risks. This was achieved, no accidents have happened. Therefore a process evaluation seems better at its place: which elements were used in which case, and does the evaluation lead to suggestions for improvement. The WMS will be evaluated by both comparing the approaches with the Borssele II 2022 experiment in Borssele II where a different safety regime applies (Staatscourant 2021, 37376[12]) and personal experience with both approaches. For each aspect two final evaluations will be made: i) is this aspect achievable by fishermen; ii) is this contribution to safe working essential and achievable.

The WMS was reviewed twice (Rozemeijer et al., 2020, Rozemeijer, 2023) by the Wageningen Marine Research offshore wind HSE expert. A slightly adapted WMS was evaluated by Ørsted for the processes of fishing in Borssele II in 2022 (Rozemeijer, 2022, Rozemeijer et al., 2023). The comments of the fishers and involved researchers were gathered. The concept evaluation was reviewed by experts.

### 6.1.1 Role operator

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[1]). 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. Eneco was willing to participate in coming to such an 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[13]). The Win wind project got elected to carry out the experiment in PAWP (Staatscourant 2019, 50033[14]). To gain access to the safety zone of the wind farm for the experiment, permission was necessary from Rijkswaterstaat Zee en Delta and the Ministry of LNV. The locations for the crab-pot-strings were coordinated with Eneco. For all activities taking place within the safety zone of the wind farm it is mandatory to keep a minimum distance of 50 metres from turbines with boat and fishing gear (this also applies to objects from the vessel, such as lines, floats and hooks) and 500 metres from a transformer platform.

In addition, up forehand the Win-Wind consortium had already made arrangements on permission for access with Eneco in the phase of writing the project plan to the call of TKI Wind op Zee (Rozemeijer

[12] Staatscourant 2021, 37376 n1 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)
[13] Staatscourant 2019, 22588 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)
[14] Staatscourant 2019, 50033 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl) and the later contract

et al., 2018). To that extent, Eneco was sub-contractor of the consortium to accommodate their expenses. Based on the proposal agreements and later established cooperation agreement between Win-Wind Eneco and the government and an updated contract between WMR and Eneco, Eneco set the boundary conditions for the conditions of the ship, personnel and operational aspects.

A major concern of Eneco of the operational aspects was the use of Bruce anchors in PAWP where infield cables were possibly at risk. In several studies (Rozemeijer et al. 2021, 2022ab) it was determined that the use of Bruce anchors posed a low risk. In addition an early warning signal was defined (the haul out indicator) with a threshold that signals when weather conditions get too adverse. When the threshold level for the haul out indicator is predicted, the crab-pot-strings need to be taken out.

The necessary documents to enter PAWP were the cooperation agreement, a document giving permission to Access (an internal Eneco document to grant permission for access) and the Daily Transfer Plan, (DTP) with the WMS as basis for the cooperation agreement. The final Permission to Access (PtA, principle decision to grant the potential of access) was based on the time schedule, planning, positions of the strings and condition of the ship (IMCA approved) and the Work Method Statement in which e.g. the need for an adequate insurance was established. The actual DTP was based on final crew list (both vessel and scientific crew), acceptance of the crew (induction performed, with upload of the appropriate documents like Basic Safety Certificate and the certificate of passing the Eneco safety awareness exam).

Borssele II represented a new situation in which the OWF operator (in this case Ørsted) has authority over the maintenance zone in Borssele II (the turbines and infield cables and 250m around these assets, the "fingers") and Rijkswaterstaat holds authority the remaining space (in between the "fingers").The procedure for entering Borssele II consisted of sending the day before the final crew list (both vessel and scientific crew) and connecting Ørsted at the day itself on leaving and entering port and on entering and leaving Borssele II. In reflection, the induction (an aspect regular for all vessel entering an OWF on operators authority but connected to the old policy of co-use) of Eneco was a hard task for the fishers and vessel crew. The questions were difficult. In addition the questions specifically concerned working in Offshore Wind, and were not related to fisheries. Total licensing system (PtA, DTP, planning, overview on crew, daily coordination and meeting with minutes, communication on entering) is an excellent approach but not custom-made to reduce risks and create a safe working environment in these complex circumstances with CTVs, large jack-ups and (quickly) changing weather and sea conditions.

The question then rised that if this procedure was to be followed by fishers, would it be feasible? Given the complexity of e.g. the induction, the large administrative burden relative to fisheries, it seems not feasible. Reducing the needs to the essence: planning, overview on crew, day to day coordination is needed to have a workable and safe environment. Aspects like PtA, DTP seem more related to the responsibility of Eneco as a contractor, which is not the case in the new co-use situation in Borssele II where the fisher operates within the terms and conditions as set by Rijkswaterstaat (the permission, Rozemeijer et al., 2023)[12]. For a subsequent experiment or even commercially fishing in an old policy OWF (above and section 2.2) like PAWP preferably an additional induction is adapted to the appropriate task. Generating such a new induction by either Eneco, fishers themselves or the government seems commercially not feasible given the low anticipated number of fishers.

A major issue is the sense of responsibility of the OWF operator and addressing primary response to emergency calls. Operators feel responsible and are made responsible for local rescue operations. Eneco mentioned incidents in which passing ships had to be assisted in PAWP and Luchterduinen. In another context, a workshop on risks of co-use was organised (Wageningen Marine Research, 2023: Stakeholder-sessie: Medegebruik op Zee - Veiligheid en risicobeoordeling, 28-09-2022). In this workshop the coast guard did not consider itself responsible for the first reaction in case of emergencies. That should be performed by the local users. in this workshop, is was suggested that per OWF a central coordination centre could be defined, organised by the community of local users. Such a central coordination centre might also be responsible in coordinating first responses to emergency situations, alleviating the pressures on OWF operators.

Table 10 overview of the topics of evaluation of the Work method as established for PAWP, compared with the Work Method Borssele II 2022 (Rozemeijer 2022, Rozemeijer et al., 2023). PAWP was managed under the old policy regime (section 2.2), Borssele II representing a new situation (Chapter 6)[12]. The different items are explained in the text below the table. International Marine Contractors Association: IMCA. Personal protective equipment: PPE. Simultaneous operations: SIMOPs.

| **Topic** | **PAWP 2023** | **Borssele II 2022** |
|---|---|---|
| *Role operator* | Go : no go | Co-ordination between multi users |
| *Vessel* | IMCA | RWS and legal requirements |
| | Double propulsion | (OWF operator) |
| *Crew* | Basic safety | Basic safety |
| | Basic fisheries | Basic fisheries |
| | Drills | |
| | PPE | PPE |
| *Insurance* | Mil€ 15 | Mil€ 500 |
| *Work description* | WMS | Plan of Operations |
| | | RAMS (on initiative of WMR) |
| *Safety zone* | ≤150m | 250m |
| *SIMOPs* | Limiting | Limiting |
| *Gear location* | After trip | After trip |

### 6.1.2 Vessel requirements

For the entrance of PAWP an International Marine Contractors Association (IMCA) certificate was required by Eneco. This is a very high level offshore standard. Although for fishery vessels this certificate increased the safety levels within PAWP, it is doubtful that this certificate is achievable for fishery vessels. Especially since obtaining the IMCA certificate requires investments (like e.g. fulfilling all requirements and the yearly IMCA certification). In addition the normal regulations apply e.g. one which dictate that fishery vessel >12m have a certificate of reliability/certificate of seaworthiness (Certificaat van Deugdelijkheid, Box 1). This gives a basic level of safety which the government considers to be sufficient to fish offshore and also to fish in OWFs.

As explained in Box 1 a problem exists for fishery vessels < 12m. In the Borssele II 2022 expedition the 10m YE 152 was checked according to the "Under 500 GT Requirements Template" that Ørsted uses. The inspector adapted the template to make it more suitable for small seize vessels while still ensuring minimal demands on safety. Such an adapted template might serve for fisheries vessels <12m.

| Box 1 Concise explanation of the regulations around safety for fishery vessels. See Neitzel et al. (2023a) for more in depth analysis. |
|---|
| Vissersvaartuigenbesluit 2002 (BWBR0013342)[15] is valid for fishery vessels >24m. It dictates a set of safety measures. When a vessel is compliant it leads to a certificate of reliability/certificate of seaworthiness (certificaat van deugdelijkheid). For vessels <24m Vissersvaartuigenbesluit 1989 is valid, which does not mention a minimal length to obtain a 'Certificaat van Deugdelijkheid'. So also vessels <24m need to obtain a 'Certificaat van Deugdelijkheid'. However, in practice, fishery vessels smaller than 12 metres cannot meet the requirements of the Vissersvaartuigenbesluit 1989. Still fishery vessels smaller than 12 metres can obtain a fishing licence from the Rijksdienst voor Ondernemend Nederland (RVO), through a tolerance construction. So fishery vessel 12 – 24 m have an obligatory 'Certificaat van Deugdelijkheid' and associated safety measures. |

15 wetten.nl - Regeling - Vissersvaartuigenbesluit 2002 - BWBR0013342 (overheid.nl)

Additional measures for the used vessel WR147 are related to the activities that were required for the scientific research. The location for scientific measurements was behind the line hauler, due to considerations of having the working deck free and to avoid exhaust fumes of the engine. This could lead to high-risk situations in case lines snap during hauling. This was recognized during the experiments and the scientist was therefore never at the measuring table when hauling. In the future a plexiglass screen will be placed on the WR147, high and strong enough to block overflying objects.

In addition a removable work table will be designed to increase the working comfort for the scientific personnel.

### 6.1.3 Crew

For the crew for vessels <12 m: crew needs a seafarers medical examination and Basic Safety Certificate. For fishery vessels > 12 meters the crew need certificate of sailing competency (according to rank), Basic Safety Certificate and seafarers medical examination. This Besluit zeevarenden (1 april 2019)[16] was adopted in the Work Method Statement. Therefore no additional evaluation is needed here.

**Safety drills**

During final inspections of the vessel, Eneco stressed the importance of doing safety drills (Man Overboard, Collision with fixed structure, Water egress, Abandon ship, Fouled propellor, Engine room fire and abandon ship). In principle these drills are obligatory by Vissersvaartuigenbesluit 1989. During the final check by Eneco, it appeared, a routine of performing the drills was lacking. Performing the drills became one of the actions to perform during the expeditions. It was highly endorsed by the management of WMR. It has strongly enhanced the basic safety level of the vessel (reflection of Eneco and scientist’s experience).

**Personal protective equipment**

The required PPE were Safety boots S3, Working clothes, Head protection, Ear protection, Safety glasses, Gloves, Life vests with Personal Location Beacon (PLB), Survival suits and Climbing and Fall prevention equipment.

Survival suits were present at an easily accessible location but not worn due to the warm water (>15°C, according standard procedure). Survival suits and Climbing and Fall prevention equipment, Safety glasses and Ear protection were not relevant due to the type of work.

The lifejacket (with PLB) leads to questions both during the PAWP expeditions and the Borssele II 2022 expeditions. The advantage of lifejackets is clearly the prevention of drowning and could be lifesaving. However, for typical fisheries activities the lifejacket appear inconvenient for fishermen due to the fact that the jacket and harness hook in easily in moving and stable objects. This could lead to accidents like Man Overboard, injuries etc (enhancing the risks). As a result some fishermen do not wear the life jackets which is of great concern in part of the fisheries community[17]. As an example, during one of the expeditions in this project, a lifejacket was lost because the manual activation cord hooked into a pot. Also on the measuring table the lifejacket hooked in frequently, leading to irritation. The habit of not wearing lifejacket is quite strong in the fisheries community[17]. The appropriate steps should be evaluated: e.g. better designed lifejackets and/or analysis of the working conditions to adapt labour activities or work floor design so that lifejackets will be worn more voluntarily.

16 wetten.nl - Regeling - Besluit zeevarenden - BWBR0012778 (overheid.nl) (read 28-11-2023)
17 Zorgen om gebruik van reddingsvesten in de visserij - Nederlandse Vissersbond (read 10-10-2023); Veiligheid op kotters blijft aandacht vragen - VisNed (read 16-10-2023)

### 6.1.4 Insurance

Part of the WMS is the guarantee to be insured for € 15.000.000,- for infield cable damage. Normally every professional fishery vessel has a professional insurance with an P&I coverage[18] of € 500.000.000. Two preconditions are important. The vessel needs to have a 'Certificaat van Deugdelijkheid'. In addition the P&I is valid for 'normal execution of operations'.

Another important aspect is the fact that fishery vessel <12 m will not have a 'Certificaat van Deugdelijkheid'. These fishers will need to apply for an additional tolerance situation of this lacking of the 'Certificaat van Deugdelijkheid' by the insurance (NB not only to be able to work in an OWF but to be insured in any case). In both PAWP and Borssele II 2022 the working in OWFs was accepted as normal business as usual. And for the YE 152 (10 m, Borssele II 2022) the tolerance situation of the lacking of the 'Certificaat van Deugdelijkheid' was achieved.

So the necessary potential damage can be insured, even if an indexation is necessary for inflation and rising costs of resources. There is a precaution to ascertain that the fisherman has taken the appropriate steps with the insurance company.

### 6.1.5 WMS

The WMS has made an overview of all potential risks and their mitigation measures. It encompasses not only the OWF related risks but also the other risks associated to working on sea. The collaboration of Win-Wind with Eneco together with Ministry of Agriculture, Nature and Food quality and Rijkswaterstaat establishing the WMS gave the latter two organisations more insights and ideas how to formulate co-use in the new OWFs in which co-use is included as standard.

It has served as the basis for the Risk Assessment Method Statement that was used to describe the Borssele II 2022 project to Ørsted. Here it received the compliments of Ørsted staff and vessel inspector as being a very elaborate and complete RAMS. The risk evaluation matrix currently serves as the basis within WMR to define an WMS for offshore working.

Two different situations apply for evaluating the WMS: towards Eneco and towards the new situation for Borssele II. Concerning Eneco the WMS has functioned well to inform Eneco and to ensure safe working. One of improvements is the approach to come to the WMS. In first instance it was chosen to do this by written concepts, which failed to convey the message. Later on it was decided to organise a workshop with relevant stakeholders, that lead to a convincing WMS.

Concerning the current situation in Borssele II and the practical added value it seems unlikely fishermen will generate a new WMS or RAMS. To obtain a permission to exploit a fisheries concession a project plan is required in the current situation. In the Borssele II 2022 situation (Rozemeijer, 2022, Rozemeijer et al., 2023) the voluntary RAMS was based on this WMS and was part of the project plan. A workable approach can likely be that current WMS or adaptations of it serve as a generic basis for future applications (with e.g. project plans).

### 6.1.6 Special no-go zones

In PAWP a set different ranges of special no-go zones were used (Figure 3) where ranging from a total of 100m to the turbine (outward turbines) to 207 m to the turbine at the Crew Transfer Vessel (CTV) approaching area. As compared to the generalised approach of Borssele II (250 m around the OWF assets) the crab-pot-strings could be placed closer to the turbines and anti-scouring. The foraging distances of brown crab range from 12 to 48 m (Skajaa et al., 1998). European lobster is attracted to bait in cages at maximally 126 m with a minimum of 5.4 m (Lees et al., 2018). In addition the radius of the area of influence of the bait plume is also quite small (≤11 m, McQuin et al. 1988, Watson et al, 2009), so the closer the crab-pot-strings can be placed towards the anti-scouring, the better. Stelzenmüller et al. (2021) showed local spill-over mechanisms up to distances of 300 to 500 m to the

[18] Protection and Indemnity (P&I) is a type of insurance that shipowners purchase to cover the potentially huge costs of any harm they accidentally cause to people, property and the environment.

nearest turbines. Spill over means that due to the higher population and densities crabs on the anti-scouring and its immediate vicinity (Stelzenmüller et al., 2021). So it seems that closer to the anti-scouring and wind turbine is better for the fishing with crab-pot-strings, although it showed that distances up to 300-500 m still can have higher catches compared to further away from the anti-scouring.

### 6.1.7 Simultaneous Operations

The overview and coordination around simultaneous operations (SIMOPs) appeared very important. This summer (2023) there were usually two or three CTVs in the PAWP area and several times a large Jack Up vessel. Luckily all these vessels were at ample distance and the expeditions did not have to be delayed or moved. The coordination itself gave no issues of importance (personal experience first author). The only relevant aspect was that the Coast Guard requested a reduction in communication moments. In the WMS it was established the vessel crew would contact them on leaving and entering the port and on leaving and entering the OWF. The Coast Guard was satisfied with the daily reports of Eneco in which the expeditions were mentioned.

In Borssele II in 2022 the start of the expeditions was delayed because a large stone laying vessel occupied the area of investigation. Coordination between the different users of the OWF area is necessary to reduce the encounters, mutual hinderance and potential collisions, especially when dealing with the larger vessels. In the Stakeholder-sessie: Medegebruik op Zee - Veiligheid en risicobeoordeling (28-09-2022, Wageningen Marine Research, 2023) it was advocated that in the future with multiple stakeholders the coordination is not necessarily done by the OWF operator. In the stakeholder session, it was advocated that all (multi-)users organise and finance an (independent) coordination centre (similar to what is happening in Borssele between all OWF operators and Tennet).

### 6.1.8 Gear location

The gear locations were transmitted to Eneco and coast guard by the researcher on board after every trip. In evaluation, the locations have a large error in establishing position by hand Garmin and vessel GPS. In addition it would be a large administrative burden for the fishermen if they would have to transmit the new positions every trip. The strings were deployed on more or less the agreed positions and they appeared not to have moved. The large error in establishing position of the dahns is a serious issue. The problems associated with the uncertain location determination are i) placing strings in the agreed safety zone; ii) collision of working vessels with the dahns; iii) placing gear on the incorrect spot thereby missing the desired fishing ground and associated higher CPUEs and LPUEs; iv) finding the gear when returning for haul out.

Not being able to pinpoint the exact locations by GPS could be caused by the electromagnetic fields of the turbines. This error in determining locations was also seen in Borselle II 2022 (Rozemeijer et al., 2023). There is a clear difference between the assessed position on the outside of PAWP (more certain) and those were the vessel is surrounded by turbines (less certain). Both in PAWP and Borssele II the vessels used older GPS systems. It is advisable that a fishery vessel will use an automatic identification systems (AIS) of class A instead of class B. The handheld GPS functioned better in determining positions. The GPS should be multiband. Another option could be to assign the total area with fishing gear to be an area for extra attention for visiting vessels where dahns and buoys can be encountered. This measure might be applicable for the new to come OWFs in the future. Dahns are legally obligatory and defined with regards to national and European fisheries legislation (EU 2011, Article 15)[19]. The responsibility is also with the captains of the vessels. It implies that OWF-operators assure the appropriate contracts and insurances with their captains and contractors to arrange the liabilities on collisions with dahns. In addition the buoyance and thereby visibility of the dahn could be increased by having a A1 Polyform buoy nearby (see research suggestion, section **8.2**).

[19] https://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX%3A32011R0404 (seen 23-11-2023)

# 7 Discussion

## 7.1 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 out and harvest the crab-pots. This aspect supported in answering the research questions on evaluating operations and the WMS.

During the expedition period from 18-07-2023 to 25-08-2023, three days of 7 Bft winds occurred (Figure 6). When analysing the wind data of IJmuiden from 1971 to 2022, a total of one day of 7 Bft or higher occurred on average during the period (July-August). The period of expeditions therefore appeared  more windy than is expected based on average.

### 7.1.1 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. During the expedition period the threshold of 445 cm was exceeded three times (Figure 7). Also during the Borssele II 2022 expedition period the threshold was exceeded a number of times (Rozemeijer et al., 2023). During the PAWP expeditions the exceedances occurred after a period of strong winds and high waves (Figure 6, Figure 7). It was too dangerous to sail out and retrieve the crab-pot-strings safely at these times.

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). In current study the haul out indicator was higher (542 cm) with a windspeed of 17 m/s (7 Bft) but with a wind direction of North West to North North West. Probably the longer wind fetch due to the North West to North North West wind direction as compared to the experiment in 2021 (Rozemeijer et al., 2021) caused a higher Haul out indicator at a slightly lower wind speed.

As discussed in 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, the addition of significant wave and swell are too much too sail out safely (see e.g. Figure 10 on workable hours). 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. 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.

### 7.1.2 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 threshold of 100 cm. This threshold is below the threshold set in the WMS (>150 cm significant wave height, Rozemeijer, 2023). This approach was used in both PAWP and Borssele II by both fishers. Applying the threshold, 31 % of the days were workable. Making the threshold slightly less strict raised the percentage to 36% workable days. This is low as compared to the average percentage of workable days normal. 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 **10**). However, 2023 appears to be a year with more and higher waves and swell than usual.

Applying the threshold of the workable days (100 cm) to be exceeded six times between 07:00 and 21:00 resulted in a few more workable days. The date 28-07-2023 seemed workable in hindsight. Additionally, an important aspect was the perception of the risks by the captain. As higher winds were predicted for the next day and the arrival of higher winds was unpredictable in the summer of 2023, the captain did not want to take the risk to be caught by earlier arriving wind and associated waves. So the personal risk perception and the anticipated weather are both factors of influence that should be taken into account when estimating the amount of workable days. Another factor could be the amount of crabs per crab-pot. Longer soaking times lead to higher amounts of caught crabs and better statistical range.

Smaller vessels are more influenced by waves and swell. Both the WR-147 (~20 m) and the Ye-152 (~10 m) had limits when sailing during significant wave plus swell of 100 cm. Bigger vessels are less influenced but with size, expenses increase as well, e.g. because more crew is needed and the vessel is more expansive (more fuel). A vessel like the We-147 (~20 m) has the advantage that it is easier to stay out over night at sea near an OWF and has the option to accommodate more pots without having to return to shore every night (thereby reducing costs of exploitation). Adverse unexpected circumstances are typical for the marine environment. Fishers are used to having to adapt their business management according to this irregular loss of income due to reduced possibilities to fish.

## 7.2 String length and measurement error

To evaluate the WMS and the operations, the displacement of crab-pot-strings is important. To determine the displacement, first the measurement error needed to be assessed. The general measurement errors were set at 78.7 m for the first Bruce anchor and at 186.1 m for the second Bruce anchor. In the Borssele II 2022 report (Rozemeijer et al., 2023a) an elaborate error analysis was performed. In essence, this measurement of anchor position is very uncertain. There is no fixed point towards which one can direct the approach. The vessel was moving, with its course not fixed due to weather and water conditions (mainly current). The anchor was moving either while searching holdfast in the seafloor on deploying or dragged towards the vessel too early while hauling took place (caused by the weight differences). These causes of error are difficult to improve.

Based on the analysis of Rozemeijer et al. (2023a) improvements were made as compared to the Borssele II 2022 expedition. Both the vessel GPS and a handheld Garmin GPS were used simultaneously. The accuracy of the vessel GPS was unknown, however. The moment of calling anchor position was adapted. For the first anchor the moment the A1 Polyform Buoy line (Figure **2**) was hauled on board a signal was given and the position was registered from the GPS system of the vessel and with a Garmin 67i. For the second anchor the moment the fourth pot was hauled on board a signal was given and the position was registered from the GPS system of the vessel and with a Garmin 67i. The accuracy of these PAWP 2023 measurements was similar to the Borssele II 2022 expeditions (Rozemeijer et al., 2023a). The major improvement was in the processing time of the raw data into results which was quicker for PAWP 2023.

### 7.2.1 Vessel GPS disturbed by wind turbines?

The vessel GPS results appeared quite unreliable. Especially when in between the wind turbines the registration resulted in impossible positions. E.g. at some point the crab-pot-string was supposedly laid across an infield cable according to the vessel GPS. This was not the case and confirmed by the Garmin GPS that showed different results. 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 is potentially more vulnerable because of the open cables that are susceptible to disturbance (Kocewiak et al., 2012). Eneco had not encountered issues with the vessel GPS of vessels entering an OWP. More research is needed to understand the interaction of the different GPS systems and conditions in an OWF and improve the methodology of measuring positions of the anchors.

### 7.2.2 Improving the method of determination of location

Several optimisations have been tried on the method of location determination while hauling. As stated the disadvantage is the lack of a fixed point in an approach of simultaneously hauling and measuring. An alternative approach could be to sail close to the dahn, lay still and measure position and then sail to the next dahn, lay still and then measure the second position and start hauling. In this manner the only deviation will be the drift of the dahn in the currents in relation to anchor. The position of the anchor can be traced back using current direction and length of the buoy line. In this approach the uncertainties are reduced to those involved with the GPS systems. The uncertainties of the potential moving of the anchors can be evaded.

It is advisable to have two means of determining position: a modern vessel GPS, preferably AIS class A, and a handheld multi band GPS. For Garmin GPS a RINEX log output[20] is available. With this type of output it is possible to improve the assessed positions. It is laborious and takes processing time but it can be an option to test effectiveness and efficiency. In addition a second Garmin can be taken on board duplicating measurements and thereby increasing reliability.

## 7.3 Displacement of the crab-pot-strings

Evaluating the operations and the WMS, the uncertainties in the measurements of the positions of the Bruce anchors are high. The measurement error of the first Bruce anchor was assumed 78.7 m (±49.9 m, n = 18), similar to the average deviation of the entire first Bruce anchor set (74.7 ±43.9, section 4.4). The measurement error of the second Bruce anchor was assumed to be 186.1 m (±54.3 m, n = 18), similar to the average deviation of the position of the second Bruce anchor set (165.3 ±69.5). It is not possible to conclude whether the deviation is due to measurement error or actual mobilisation of the crab-pot-strings. Given the fact that the deviation was also found during calm weather conditions, it seems unlikely that the crab-pot-strings moved during this period. However, since uncertainties remain, it is therefore recommended to perform tests according to the method as described in section 7.2.2.

## 7.4 CPUE and LPUE

### 7.4.1 CPUE and LPUE brown crab

CPUEs are subject to uncertainties due to 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).

In PAWP a CPUE for brown crab was measured of 0.1 to 1 crab per pot per day. Table 11 gives an overview of several publications on CPUE and LPUE. In Borssele II 2022 the CPUE ranged from 0.3 to 1 crab per pot per day for the period 1-8-2021 to 18-9-2021 (Rozemeijer et al., 2023a). 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 during summer (pers. comm., no LPUE estimate possible).

[20] The RINEX log output allows recording of raw GPS data, such as distance to satellites, line of sight speed between the receiver and satellite and signal strength. This raw data can be saved from the device and used with third party1 programs to create more accurate locations, sometimes as accurate as 10 cm.

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 11), 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 and September. Using a recalculation factor based on density, LPUE would approach 4.4 crabs per pot per day. Spencer (2013) showed 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, time 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).

An important finding is that the crab-pots continued catching for at least 25 days. The number of brown crab in the pot increased (Figure 20, Figure 21) while the bait was gone. The same was observed in Borssele II 2022 (Rozemeijer et al., 2023a). Öndes et al. (2019) calculated no discernible effect of soaking time on CPUE suggesting catch continued prolonged periods. Bell, Tully & Robinson (in ICES 2005) also modelled continuing CPUE after longer soaking times. In summary, the continued catch of crabs in pots after the bait is gone, is observed before.

Concluding, with a CPUE of 0.3 to 1 crab per pot per day the results of present study relatively high in a national context but on the low side in an international context.

Table 11 overview of the Catch Per Unit Effort (CPUE, crab per pot per day) 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 density/total density |
| 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 to 8 | ~1 to 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 | | |
| Rozemeijer et al. (this study) | 0.2-1.2 | 0.1-1 | PAWP 2023 | 14 | This study |
| Rozemeijer et al. (2023) | 0.08 - 0.2 | 0.01 -0.05 | Borssele II 2022 | 14 | |

### 7.4.2 CPUE and LPUE velvet swimming crab

The velvet swimming crab *N. puber* (L.) is thought to be a main by-catch species for OWF cases (van de Boogaard et al., 2020, Rozemeijer et al., 2021). In PAWP a CPUE was measured ranging from 0.18 to 4.66 animals per pot per day and a LPUE of 0.16 to 3.48 (Table 6, Figure 22). In Borssele II 2022, 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 (Rozemeijer et al., 2023a). 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, Roach et al., 2022). These results are comparable to the CPUEs of present study. 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.

Velvet swimming crab are cautious to enter a trap when European lobsters or brown crabs are already present in a pot (Skerrit et al., 2020). Roach (2019) 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 noticeable aspect of the soak curve of the velvet swimming crab is the decrease after ~4 days (Figure 18, Figure 22, Table 6). This is similar to the results found in wrecks near Scheveningen in 2021 (Rozemeijer et al., 2021) and the results from Borssele 2022 (Rozemeijer et al., 2023a). This could be either due to escapement of the smaller velvet swimming crab or predation of this species by the larger brown crab.

Concluding, velvet swimming crab could be an important exploitable by-catch. Prices can be € 5,- a kilo (Stefan Tijsen, Pers. Comm.). For this type of crab trade routines should be developed with Spain to find out whether it is profitable. If velvet swimming crab is targeted, it is important to use pots without escape gates and to reduce soaking time. On the other hand, increasing soaking time can reduce exploitation costs while the catch of brown crab still increases, indicating that there is a trade-off.

### 7.4.3 Pot-position

Table 7 and Table 9 showed that pot position was not significant: upstream northward pots had no higher catches than southward pots, similar to the results of Borssele II (Rozemeijer et al., 2023a). 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 three locations. In the area of PAWP, high tide and low tide current are more or less equal in force (Caires & Pathirana, 2019), similar to Borssele II. In PAWP the low tide current velocity is 93% of the high tide current. In Borssele II the low tide current is about 97% of the high tide current whereas for Scheveningen larger differences occur. In Scheveningen the low tide current velocity is about 74% of the high tide current velocity (Duik de Noordzee schoon App, Ministerie van Binnenlandse zaken, 2020). With these differences it can be anticipated that in PAWP the bait plume is evenly distributed along the crab-pot-string, whereas in Scheveningen the bait plume was more concentrated around the northern pots.

# 8 Conclusions and recommendations

## 8.1 Conclusions

In this section the research questions posed in section 1.1.2 are addressed and additional conclusions are described.

The expeditions were severely hampered by adverse weather circumstances. North East winds delayed the start of the experiments with a month. During the expeditions pots had to remain in the water up to ~25 days or were hauled too early. As a result the soaking times were unevenly distributed. The haul out indicator was exceeded three times during the period of ~25 days.

***Research question: What are the CPUE and LPUE of brown crab, European lobster, the potentially commercial relevant velvet swimming crab and other species (bycatch).***

**Brown crab**
The CPUE for brown crab ranged from 0.19 to 1.21. It showed an optimum curve with soaking time with ~2 days as optimal. The catching continued until ~25 days while the bait must have been gone. This phenomenon has been observed before. The CPUE was significantly influenced by soaking time but not by pot type (Parlour of Medley) nor pot order (northern versus southern). The LPUE ranged from 0.14 to 0.96. It showed an optimum curve with soaking time with ~2days as optimum. It was correlated with Soaking time * Type of pot (Medley, Parlour) including the interaction. Pot order was not significant.

**European lobster**
Only five European lobsters were caught during 10 test days: four males, one undetermined, (all above MLS). This low number was not enough to determine CPUE not LPUE.

**Velvet swimming crab**
The CPUE for velvet swimming crab ranged from 0.17 to 4.66. It showed an optimum curve with soaking time with ~2 days as optimal and a sharp decrease after 4-6 days. The CPUE for velvet swimming crab was driven by soaking time and by pot type (Medley or Parlour) but there was no significant interaction between these factors. Pot order showed no influence on the CPUE of velvet swimming crab. The sharp decrease in caught velvet swimming crabs could be caused by escaped velvet swimming crabs or predation by brown crab. The LPUE ranged from 0.13 to 3.48. It showed an optimum curve with soaking time with ~2 days as optimal driven by soaking time and pot type (Medley or Parlour) but not their interaction. Again pot order did not show a significant effect. Velvet swimming crab could be commercially interesting, but it would be necessary to develop trading routes.

**Population size estimate of brown crab in PAWP with a catch : mark : recapture approach**
The numbers of recaptured brown crabs and European lobsters (none) were too low for population size estimates.

***Research topic: Obtained experience with the operational aspects and risks involved with passive fisheries in OWFs.***

The fishing experiments during the PAWP 2023 expeditions was the third time a fishing vessel was operating in an OWF. The first time was during the Borssele II 2022 expeditions (Rozemeijer et al., 2023). In the Borssele II 2022 expeditions the determination of the position of the anchors was difficult. Despite the improvements that were made in assessing the exact location of the anchors on haul out based on experiences in Borssele II in 2022, it was not possible to estimate the locations of the anchors with improved confidence. It is possible that the (electromagnetic field of) wind turbines interfered with the GPS signal on board. Given the unsure positions of the anchors and thereby also the attached dahns, the dahns can pose risks for other users. Improvement of the positioning is recommended and a different approach how to deal with the positions.

The captain of the vessel adapted the proposed positions of the crab-pot-strings since he experienced the wind turbines to be too close by when using the intended positions. This is an important finding, urging to place crab-pot-strings not too close but leave more distance for manoeuvring. Literature suggested that closer to the anti-scouring and wind turbine is better for the fishing with crab-pot-strings, but based on our findings distances between crab-pot-string and wind turbine up to 300-500 m still could have high catches.

The coordination with the OWF operator on e.g. SIMOPS occurred without issues. The communication with the Coast Guard could be reduced to the daily reports of the OWF operator on anticipated visits. This reduces the administrative burden for fishers substantially.

***Research topic: Evaluation of the offshore fishing method in PAWP as established in a risk mitigation approach between Eneco and Win-Wind (formalised in the Work Method Statement (Rozemeijer, 2023).***

The WMS has generated a clear insight in the risks and consequently measures have been taken to reduce the risks. In the expeditions described in this report no accidents happened. From the WMS it also became clear that the high standards for Offshore operations are difficult to attain by fishers and fishing vessels, partly due to their smaller size, the investments needed and the administrative requirements.

The collaboration of Win-Wind with Eneco together with Ministry of Agriculture, Nature and Food quality and Rijkswaterstaat establishing the WMS gave the latter two organisations more insights and ideas how to formulate co-use in the new OWFs in which co-use is included as standard. In this new current policy the safety arrangements and risk mitigation measures are defined in defined in Staatscourant 2021, 37376[12]. They are (indirectly) connected to the 'Certificaat van Deugdelijkheid' (certificate of seaworthiness) and measure. However, fishing vessels <12 m are usually too small to have all necessary measures installed and they usually have a tolerance construction for the 'Certificaat van Deugdelijkheid'.

For these ships < 12 m it is very important that an explicit acceptance is obtained by the insurance company, both for the fact that there is no 'Certificaat van Deugdelijkheid' and that the insurance company includes working in an OWF as regular work. For vessels > 12 m the insurance company also needs to accept that working in an OWF is regular work.

The expeditions were hampered by the weather. The start was delayed by a month due to the high northern winds. In addition, during the expeditions, the crab-pot-strings could not be hauled during a period of ~25 days. This hampered statistical analyses. More importantly, during the expeditions the threshold level of the haul out indicator was exceeded three times. `Due to the prolonged heavy winds and waves the vessel was unable to sail out in order to retrieve the crab-pot-strings (as agreed for being good seamanship and agreed thresholds for no-entering PAWP).

The measurements on the positions of the anchors and their potential displacement were uncertain. Taking the measurement error into account anchors and crab-pot-strings appeared not to have moved.

The WMS (or variants of it) could serve as a generic document made available by the government to support fishers in their applications for a permission to fish within OWFs.

## 8.2 Recommendations

### 8.2.1 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 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 11). 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.

### 8.2.2 Safety

**Dahns and Polyform A1 buoys set up**
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 “IJgeul stroommeetpaal” and “Buitenbanken West” but it is not clear how representative these locations are for PAWP or other locations. Figure **9** 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.

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# 10 Quality Assurance

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

# References


Bell M.C., Addison J.T., Bannister R., Colin A. (2001) Estimating trapping areas from trap-catch data for lobsters and crabs. Marine and Freshwater Research 52: 1233-1242. https://doi.org/10.1071/MF01175

Bell, M.C., Eaton, D.R, Bannister, Robert, Addison, Julian (2003). A mark-recapture approach to estimating population density from continuous trapping data: Application to edible crabs, Cancer pagurus, on the East coast of England. Fisheries Research 65: 361-378.

Bennett D.B., (1974). The effects of pot immersion time on catches of crabs, Cancer pagurus L. and lobsters, Homarus gammarus (L.), ICES Journal of Marine Science 35: 332–336, https://doi-org.ezproxy.library.wur.nl/10.1093/icesjms/35.3.332

Bonsu, P.O., Letschert J., Yates K.L., Svendsen J.C., Berkenhagen J., Rozemeijer M.J.C., Kerkhove T.R.H., Rehren J., Stelzenmüller V. (2024). Co-Location of Fisheries and Offshore Wind Farms: Current Practices and Enabling Conditions in the North Sea." Marine Policy 159: 105941. https://doi.org/https://doi.org/10.1016/j.marpol.2023.105941.

Bouma S., Lengkeek W. (2009). Development of underwater flora- and fauna communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ). Research commissioned by Noordzeewind. Noordzeewind reference OWEZ_R_266_T1_20090126. Bureau Waardenburg Rapportnummer 08-220.

Bouma S., Lengkeek W. (2012). Benthic communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ). Including results of samples collected in scour holes. Bureau Waardenburg Rapport Nummer 11-205. OWEZ_R_266_T1_20120206_hard_substrate

Bouma, S, & Lengkeek, W. (2013). Benthic communities on hard substrates within the first Dutch offshore wind farm (OWEZ). Nederlandse Faunistische Mededelingen 41: 59–67.

Caires, S., Pathirana I. (2019). Hollandse Kust (noord) Field Measurement Campaign. Campaign Report - April 2017 to April 2019. Deltares Fugro report 1230377.001

Chen C. & Rozemeijer MJC (2023). Determining population size of brown crab using Capture : Mark : Recapture. Wageningen Marine Research Internal Memo. In prep.

Coolen, J.W.P, Van Der Weide, B., Cuperus J., Blomberg, M., Van Moorsel G.W.N.M, Faasse M.A., Bos O.G., Degraer S., Lindeboom H.J. (2020). Benthic Biodiversity on Old Platforms, Young Wind Farms, and Rocky Reefs. ICES Journal of Marine Science 77: 1250–65.

Cramer R., Korving A., van der Tuin E. (2015). Project Vissen voor de Wind, Eindrapport. Ursa Major Services BV/CPO Nederlandse Vissersbond U.A.. Europees Visserijfonds 4600010913291.

Fogarty M.J., Addison J.T. (1997). Modelling capture processes in individual traps: entry, escapement and soak time, ICES Journal of Marine Science 54: 193–205, https://doi.org/10.1006/jmsc.1996.9998

ICES (2005). Report of the study group on the biology and life history of crabs (SGCRAB), 9–11 May 2005, Galway, Ireland. ICES CM 2005/G:10. Available at http://www.ices.dk/sites/pub/CM%20Doccuments/2005/G/SGCRAB05.pdf

Kocewiak Ł.H., Arana I., Hjerrild J., Sørensen T., Leth Bak C., Holbøll J. (2012). GPS Synchronization and EMC of Harmonic and Transient Measurement Equipment in Offshore Wind Farms. Energy Procedia 24: 212-228. https://doi.org/10.1016/j.egypro.2012.06.103

Lees, K.J., Mill A.C., Skerritt D.J., Robertson P.A., Fitzsimmons C. (2018). Movement Patterns of a Commercially Important, Free-Ranging Marine Invertebrate in the Vicinity of a Bait Source. Animal Biotelemetry 6: 8. https://doi.org/10.1186/s40317-018-0152-4.

Lees, K.J., Mill A.C., Skerritt D.J., Robertson P.A., Fitzsimmons C. (2020). Spatial Overlap, Proximity, and Interaction between Lobsters Revealed Using Acoustic Telemetry." Marine Ecology Progress Series 645: 109-24. https://www.int-res.com/abstracts/meps/v645/p109-124/.

Leewis L., Verduin E.C., Stolk R. (2017). Macrozoobenthosonderzoek in de Rijkswateren met Boxcorer, Jaarrapportage MWTL 2015. Waterlichaam: Noordzee. Eurofins AquaSense rapport J00002105, RWS 3 1072166.0004

Leewis, L., Klink, A.D., Verduin, E.C. (2018). Benthic development in and around offshore wind farm Prinses Amalia Wind Park near the Dutch coastal zone before and after construction (2003-2017). A statistical approach. Eurofins AquaSense J0002328.

Leopold, M.F., van Bemmelen, R.S. A., Zuur, A.F. (2012). Responses of Local Birds to the Offshore Wind Farms PAWP and OWEZ off the Dutch mainland coast. IMARES Wageningen UR Report C151/12. IMARES. https://edepot.wur.nl/279573

Linnane, A., Mercer J.P. (1998). A Comparison of Methods for Tagging Juvenile Lobsters (Homarus gammarus L.) Reared for Stock Enhancement. Aquaculture, 163: 195–202.

Lovewell S.R., Howard A.E., Bennett D.B. (1988). The effectiveness of parlour pots for catching lobsters ( Homarus gammarus (L.)) and crabs ( Cancer pagurus L.). ICES Journal of Marine Science 44: 247–252. https://doi.org/10.1093/icesjms/44.3.247

McQuinn I.H., Gendron L., Himmelman J.H. (1988). Area of attraction and effective area fished by a welk (Buccinum undatum) trap under variable conditions. Can J Fish Aquat Sci. 45: 2054–60.

Miller R.J. (1979). Saturation of crab traps: Reduced entry and escapement. Journal du Conseil 38: 338-345.

Miller R J. (1990). Effectiveness of crab and lobster traps. Canadian Journal of Fisheries and Aquatic Sciences 47: 1228 1251.

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2020) Handreiking gebiedspaspoort Borssele. Ministerie van Binnenlandse Zaken en Koninkrijksrelaties met bijlage.

Ministerie van Infrastructuur en Milieu, and Ministerie van Economische Zaken. (2015). Beleidsnota Noordzee 2016-2021. December 2015: Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken.

Moland E., Moland Olsen E., Knutsen H., Knutsen J.A., Enersen S.E., André C, Stenseth NC (2011) Activity patterns of wild European lobster Homarus gammarus in coastal marine reserves: implications for future reserve design. Mar Ecol Prog Ser 429:197-207. https://doi.org/10.3354/meps09102

Moland E., Olsen E.M., Andvord K., Stenseth N.C., Knutsen J.A. (2011). Home range of European lobster (Homarus gammarus) in a marine reserve: Implications for future reserve design. Canadian Journal of Fisheries and Aquatic Sciences 68: 1197–1210. https://doi.org/10.1139/f2011-053

Montgomery S.S. (2005). Effects of trap shape, bait, and soak time on sampling the eastern rock lobster, Jasus verreauxi. New Zealand Journal of Marine and Freshwater Research 39: 353 363.

Neitzel S.M., Serraris J.J., de Graeff P., Deetman B., Taal K. (2023b). Stand van zaken kleinschalige, passieve visserij in windparken op zee. Een bundeling van bestaande kennis en een verkenning naar de mogelijkheden voor kleinschalige, passieve visserij in windparken. Wageningen Marine Research rapport in prep.

Neitzel S. M., Jurrius L.H., Deetman B., Serraris J.J.,, Taal K., Rozemeijer M.J.C., de Graeff P. (2023a). Stand van zaken kleinschalige, passieve visserij in windparken op zee. Een bundeling van bestaande kennis en een verkenning naar de mogelijkheden voor kleinschalige, passieve visserij in windparken. Wageningen Marine Research rapport C055/23. https://doi.org/10.18174/637589

Öndes F., Emmerson J., Kaiser M., Murray L., Kennington K. (2019). The catch characteristics and population structure of the brown crab (Cancer pagurus) fishery in the Isle of Man, Irish Sea. Journal of the Marine Biological Association of the United Kingdom 99: 119-133. doi:10.1017/S0025315417001849

Reidenbach M.A., Koehl M.A.R. (2011). The spatial and temporal patterns of odors sampled by lobsters and crabs in a turbulent plume. The Journal of Experimental Biology 214: 3138-3153.

Roach M., Revill A., Johnson M.J (2022). Co-existence in practice: a collaborative study of the effects of the Westermost Rough offshore wind development on the size distribution and catch rates of a commercially important lobster (Homarus gammarus) population, ICES Journal of Marine Science 79: 1175–1186. https://doi.org/10.1093/icesjms/fsac040

Roach M., Cohen M. (2020). Westermost Rough Offshore Wind Farm Shellfish Survey 2017. A study commissioned by the Holderness Fishing Industry Group. DOI: 10.13140/RG.2.2.15450.57289

Roach M. (2019). Interaction between the Yorkshire coast static gear fishery and offshore wind energy development Biological & Marine Sciences UofH. University of Hull Thesis for: PhD. DOI: 10.13140/RG.2.2.20483.73766

Rozemeijer M.J.C, Chen C., Cramer R., Korving A., Meeldijk C. (2021). Assessing the stability and mobilisation of crab-pot-strings anchored with Bruce anchors under different marine conditions.

With information of catchment of brown crab (Cancer pagurus), European lobster (Homarus gammarus) and other species. Wageningen Marine Research Report C107/21.

Rozemeijer M.J.C, Chen C., van der Wal J-T. (2023). Experimental pot fishing on brown crab and European lobster in offshore windfarm Borssele II. The first passive fishing as a form of multi-use in an offshore windfarm in the Netherlands. WUR Wageningen Marine Research Report C052/23.

Rozemeijer M.J.C, Cramer R., Deetman B., Korving A. (2022a). Defining a haul-out indicator for removal of crab-pot-strings in Offshore Windfarms under anticipated adverse weather conditions. WUR Wageningen Marine Research report C052/22. https://doi.org/10.18174/576836

Rozemeijer M.J.C, Cramer R., Deetman B., Korving A. (2022b) An overview and conclusion concerning the use of Bruce anchors to anchor crab-pot-strings in Prinses Amalia Offshore Windpark. Wageningen Marine Research Report C051/22. https://doi.org/10.18174/576750

Rozemeijer M.J.C. (2023). Work Method Statement Project Win-Wind to catch brown crab and lobster in Princess Amalia Offshore Wind Park 2023. Wageningen Marine Research report C011/23.

Rozemeijer M.J.C., Korving A., Don J., Zaalmink W. (2020) Work Method Statement Project Win-Wind to catch brown crab and lobster in Princess Amalia Offshore Wind Park. Wageningen Marine Research report C028/20.

Rozemeijer, M.J.C, Cramer R., Korving A., Röckmann C., Zaalmink W. (2018). Win-Wind. Making offshore wind farms winning for society. Enabling commercial multi-use. Phase 1: Collaboration, harvest potential and risk reduction of low-impact fisheries in offshore wind farms. Projectplan voor TKI Wind op zee R&D 2018.

Skajaa K, Ferno A, Lokkeborg S, Haugland EK. (1998). Basic movement pattern and chemo-oriented search towards baited pots in edible crab (Cancer pagurus L.). Hydrobiologia. 371/372(165583): 143–53.

Skerritt D.J., Bell M.C., Lees K.J., Mill A.C., Polunin N.V.C., Fitzsimmons C. (2023) Estimating catchability and density of the European lobster Homarus gammarus from continuous, short-term mark-recapture data. Mar Ecol Prog Ser 715:79-89. https://doi-org.ezproxy.library.wur.nl/10.3354/meps14351

Skerritt, D.J. (2014) Abundance, interaction and movement in a European Lobster Stock. Newcastle University. MSc Thesis School of Marine Science and Technology.

Skerritt D.J., Bell M.C., Lees K.J., Polunin N.V.C., Fitzsimmons C. (2020). Inter- and intra-specific interactions affecting crustacean trap fisheries—Implications for management. Fisheries Management and Ecology. 27. 10.1111/fme.12425.

Smith I.P., Jensen A.C., Collins K.J., Mattey E.L. (2001). Movement of wild European lobsters Homarus gammarus in natural habitat. Mar Ecol Prog Ser 222:177–186

Spencer A. (2013). An assessment of the Northumberland edible crab Cancer pagurus and velvet crab Necora puber fisheries. MSc Phil Thesis 300313, School of Marine Science and Technology, Newcastle University.

Spirent Communications (2022). Fundamentals of GPS Threats. White Paper. Spirent Communications DWP0003 Issue 1-02 | 03/22.

Steenbergen J., Rasenberg M., van der Hammen T., Biermans S. (2012) Gerichte visserij op Noordzeekrab. WUR IMARES Rapport C153/12.

Stelzenmüller V., Gimpel A., Haslob H., Letschert J., Berkenhagen J., Brüning S. (2021). Sustainable co-location solutions for offshore wind farms and fisheries need to account for socio-ecological trade-offs Sci. Total Environ. 776 , Article 145918

Strietman, W.J., Deetman B., Rozemeijer M.J.C., Kunz M.C. (2023). De commerciële haalbaarheid van passieve visserij op Noordzeekrab in windparken voor de Hollandse kust. Een verkenning naar de potentiële kosten en opbrengsten. Wageningen, Wageningen Economic Research, Rapport 2023-026.

Sundberg, P. (1985). A model for the relationship between catch and soak time in baited fish traps. Océanogr. trop. 20: 19-24.

Tonk L., Rozemeijer M.J.C. (2022). Passive fisheries of brown crab (Cancer pagurus) and European lobster (Homarus gammarus) in Dutch offshore wind farms. With reflections on its feasibility as a form of multi-use in offshore wind farms. Wageningen Marine Research Report C050/22. DOI: https://doi.org/10.18174/576744

Tonk L., Rozemeijer M.J.C. 2019. Ecology of the brown crab (Cancer pagurus) and production potential for passive fisheries in Dutch offshore wind farms. Wageningen, Wageningen Marine Research (University & Research centre), Wageningen Marine Research report number C064/19.

Tully O., Bell M., O'Leary A., McCarthy A., O'Donovan V., Nee D. (2006). The Lobster (Homarus gammarus L.) Fishery: Analysis of the Resource in 2004/2005. Fisheries Resource Series, Bord Iascaigh Mhara (Irish Sea Fisheries Board), Dun Laoghaire, Ireland, Vol. 6, ISSN 1649-5357

Ungfors A, Hallbäck H, Nilsson PG (2007) Movement of adult edible crab (Cancer pagurus L.) at the Swedish West Coast by mark-recapture and acoustic tracking. Fish Res 84: 345–357.

van den Bogaart L., van der Wal J-T., Tonk L., Bos O., Coolen J., Poelman M., Vergouwen S., van Duren L., Janssen H., Timmermans K. 2020. Geschiktheid zeewindparken voor maricultuur en passieve visserij: een kwantitatieve beoordeling van de kansrijkheid van de gebieden voor de potentiële productiviteit van een selectie aan commercieel interessante soorten. Wageningen Marine Research Report C127/19a. https://doi.org/10.18174/509196.

van Hal R. (2013) Roundfish monitoring Princess Amalia Wind Farm. WUR IMARES Report C117/13-A

Van Stralen M.R., Smeur E.W.M. (2008) Effecten van sleepnetvisserij en visserij met vaste vistuigen op vogels, zeezoogdieren, migrerende vissoorten en kreeften. Deelstudie Kreeft. Bureau MarinX, Rapport nummer 2008.49.

Vanagt T., Faasse M. (2013). Development of hard substratum fauna in the Princess Amalia Wind Farm. Monitoring six years after construction. eCOAST report 2013009.

Vissersvaartuigenbesluit 1989.

Wageningen Marine Research (2023). Stakeholder-sessie: Medegebruik op Zee - Veiligheid en risicobeoordeling, 28-09-2022. Brouwer, E. Rozemeijer M.J.C., Jurrius, L. Wageningen Marine Research Workshop verslag 2328057.MR.fh.

Wallace N., Rae V. (2018). Escape Gap Project 2016-17. Northumberland Inshore Fisheries and Conservation Authority report.

Watson WH III, Golet W, Scopel D, Jury S. (2009). Use of ultrasonic telemetry to determine the area of bait influence and trapping area of American lobster, Homarus americanus, traps. New Zeal J Mar Freshw Res.43: 411–8. https ://doi.org/10.1080/00288 33090 95100 10

Woll A.K., van der Meeren G.I., Fossen I. (2006). Spatial variation in abundance and catch composition of Cancer pagurus in Norwegian waters: biological reasoning and implications for assessment. ICES Journal of Marine Science 63: 421–433. https://doi-org.ezproxy.library.wur.nl/10.1016/j.icesjms.2005.10.004

Ziegler P.E, Frusher S.D., Johnson C.R. (2003). Space–time variation in catchability of southern rock lobster Jasus edwardsii in Tasmania explained by environmental, physiological and density-dependent processes. Fisheries Research 61: 107-123. https://doi.org/10.1016/S0165-7836(02)00240-0.

# Justification

Report C078/23
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: Linda Tonk
Researcher

Signature:

Date: 1-12-2023

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Bonsu, P. O., et al. (2024). "Co-location of fisheries and offshore wind farms: Current practices and enabling conditions in the North Sea." Marine Policy **159**: 105941.

Current expansion in offshore wind farm (OWF) development is resulting in increased spatial conflicts with other uses. In the North Sea, marine spatial planning (MSP) processes include co-existence strategies, with co-location between fisheries and offshore wind farms often discussed. However, current legal regulations and the lack of adequate scientific evidence to document economic viability of proposed passive gears, coupled with uncertainties regarding the implementation approach, continue to limit progress in developing co-location solutions. We synthesized current regulations and practices relevant to offshore wind farms and fisheries and conducted spatial-temporal overlap analysis of pot and trap fisheries targeting crustaceans in offshore wind farms to understand their potential for co-location. Our results showed the largest potential for co-location of pot and trap fisheries targeting crustaceans is located in OWFs that already exist or will be constructed until 2030. We also identified 1) gaps in fisheries and (OWF) regulations and 2) sector challenges that hindered the successful implementation of fisheries and offshore wind farm co-location. We discuss and recommend enabling conditions, including more science-based evidence on socio-economic and ecological viability of passive fisheries in offshore areas. Experiments on pot and trap gear safety and spillover evidence of artificial reef effects (AREs) are needed to inform the implementation of new safety distances and economically beneficial passive fisheries. Finally, we highlight needs for new insurance regimes and straightforward funding provision to support transitions to co-location and absorb the shocks from mobile fisheries displacement.