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

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Summary

Passive fisheries of European lobster (*Homarus gammarus*) and brown crab (*Cancer pagurus*) have been proposed as viable opportunity to be combined with offshore windfarms (OWFs). However, it is currently unknown whether fisheries of European lobster and brown crab in OWFs in the North Sea are feasible from an ecological and economic point of view.

As a desk study we describe three types of passive fishery techniques used for catching European lobster and brown crab (1. fykes; 2. gill nets and 3. pots and creels[1]) and their applicability to fisheries in North Sea OWFs. Based on the literature and interviews with fishermen (done in May2021), pots and creels appear to be the most suitable method in OWFs. The main advantages of this type of fishery are limited bycatch, less work involved (compared to gill nets) and the pots and creels are not prone to damage. The use of pots or creels to catch brown crab and lobster is mainly practised by fishermen in the United Kingdom and France. Three boats of Dutch fishermen target brown crab in the North Sea (northwest of Den Helder and above Texel to Terschelling, the so called Texelse Stenen) using pots with European lobster on the side (bonus catch). Lobster fisheries mainly occur in the Eastern Scheldt. In the subsequent parts all attention was given to the technique of pots.

Although the actual density of both species in OWFs needs to be determined, based on German results, brown crab is currently the most promising target species when considering the population density and economic viability of passive fisheries in OWFs. Due to low population density trapping European lobster is considered a bonus for fishermen that target brown crab in the North Sea. The application of population enhancement strategies to increase harvest potential of lobster is investigated in a separate desk study. Information derived from interviews with Dutch crab fishermen coupled with knowledge on passive fisheries described in this desk study imply that the application of passive fisheries such as potting for brown crabs and European lobster is technically possible within OWFs and crab fishermen are willing to do so. The ecological feasibility however deserves further attention as well as the practicalities surrounding passive fisheries. The economic aspects are studied in a separate study. Besides population stock density uncertainties regarding safety, gear retrieval, insurance and liability are important factors of concern when it comes to the feasibility of passive fisheries in OWFs.

In addition, it is important to realize that fishing in OWFs cannot be seen as an alternative to trawling. It is mainly a complementary form of small-scale fishing for a small group of fishermen, depending on the number and location of the OWFs being built. Recommendations point towards more insight in requirements for a combination of alternative fishing strategies (shorter strings, less spacing between pots or strings) designed to the specific lay-out of OWFs and exploring innovative design options of future OWFs that are more spacious or have additional features that allow for more multi-use opportunities in terms of low impact fisheries. Given the expected higher water currents, strings are laid out preferably parallel to the currents. Therefore it would be an option to have the infield-electricity cables of the OWF parallel to the currents, so that longer strings are possible. Also infield cables could be covered with rocks rather than to be buried in. The rocks would offer additional preferred habitat for brown crab and European lobster.

1 Traps in the form of cages or baskets made with various materials designed to catch crustaceans or fish that are set on the seabed either singly or in rows connected by ropes (buoy-lines) to buoys on the surface showing their position and having one or more openings or entrances

1 Introduction

Offshore wind farms (OWFs) are seen, amongst others, as needed to facilitate energy transition and meet the climate agreement goals. With the rapid upscaling of wind farms on the North Sea, pressures are mounting on the environment and on other users, such as activities from the Department of Defence, oil and gas industry, shipping, protected nature reserves, aquaculture and fisheries. Because space is scarce at sea, the Dutch government is focusing on efficient 'multiple use of space'. This means that different activities are combined as much as possible or take place next to each other in the same space. Examples of potential multi-use in OWFs are nature development, passive fishing (with stationary nets, pots or fykes, Cramer et al., 2015), aquaculture and other forms of sustainable energy such as solar panels and tidal energy. Especially for the fisheries sector co-use is important since many OWFs are situated in areas that were previously used for trawl fishing. Trawl fishing, the most commonly used fishing method in Dutch fisheries, is currently not allowed in OWFs since it poses a safety hazard of potential damage to the turbines and infield-electricity cables.

Multi-use requires amongst others spatial and operational integration of activities in OWFs. This poses an innovation challenge for multiple parties. OWF operators need to know that there are minimal risks involved in multi-use such as with fisheries. Spatial design of OWFs might need to be adapted. Fisheries need knowledge on alternative species with commercial potential and innovation on catch methods.

Passive fisheries of European lobster (*Homarus gammarus*) and brown crab (*Cancer pagurus*) have been proposed as viable opportunity that can be combined with OWFs. To that extent a TKI tender has been awarded and the project Win-Wind on enabling this type of fisheries has commenced. The current proposal represents phase 1 “preconditions for a demonstration pilot”. Subsequent future phases comprise phase 2 “implementation pilot” and phase 3 “business implementation and upscaling”.

This desk study on passive fisheries of European lobster and brown crab in OWFs is part of phase 1. Phase 1 encompasses a number of studies in order to determine whether passive fisheries on European lobster and brown crab are feasible and have the potential to be economically viable from an ecological point of view. In a coherent approach the necessary knowledge is assembled in order to determine ecological feasibility (Rozemeijer and Wolfshaar, 2019, Tonk and Rozemeijer, 2019), and potential enhancement strategies of European lobster and brown crab in OWFs (separate report, in progress). Strietman et al. (2022) is making an earning model in order to estimate the viability of this type of fisheries in OWFs. Additionally a subsequent pilot study in OWF Princes Amalia (PAWP) is planned (Rozemeijer, pers. comm.).

In this desk study we focus on describing passive low impact fisheries techniques of European lobster and brown crab in the North Sea with a focus on potential application of pot fisheries in Dutch OWFs. We will also focus on the catching practice as performed by two Dutch crab fisheries.

1.1 Problem definition

It is currently unknown whether passive fisheries of European lobster and brown crab in OWFs in the North Sea are feasible from an ecological and economic point of view. Basic knowledge is needed to describe the entire setting and potential of this type of fisheries in OWFs. In this desk study we describe the passive fishery techniques used for catching European lobster and brown crab as well as some examples of daily practice of this type of fisheries.

1.2 Objectives

A desk study to generate knowledge on (passive) fisheries of brown crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*) and the application in Dutch OWFs. The objective of the desk study is to provide a general description of possible techniques, evaluate feasibility of the techniques based on an ecological (is it feasible in terms of population density etc.) and economic viewpoint (is it profitable enough for the fishermen) and provide a more extensive description of the most suitable method (based on the evaluation). The following types of passive fisheries will be described with a focus on the main techniques used in brown crab fisheries in the North Sea and lobster fisheries (mainly in the Eastern Scheldt):

1. Fykes
2. Gill nets
3. Pots and creels

Additionally this report aligns facts and aspects that were used by Strietman et al. (2022) to calculate an earning model for the fisheries on crabs and lobsters in OWFs.

2 Background

The brown crab is a commercially important decapod and is exploited throughout Western Europe, from Norway to northern France (Karlsson & Christiansen, 1996). It was worth £13.8 million (€16.1 million) in 2013 in Scotland alone and is the most valuable crab fishery in UK waters (Tonk & Rozemeijer, 2019). Total annual catches in Europe are in the order of 50,000 tonnes (FAO, Figure 1, Figure 2). In the UK, which encompasses the largest brown crab fishery industry, landings have increased by 57% since 1996 to 34,000 tonnes in 2017 (Tonk & Rozemeijer, 2019). Ireland comes second with a brown crab fishery fluctuating around 7000 tonnes and France and Norway approximately 5000 tonnes that are harvested annually (Figure 1). In the Netherlands crab fisheries is limited (~1000 tonnes, Figure 2).

While active fisheries such as trawling are not allowed inside OWFs because of the potential damage to cables and turbines, passive fisheries such as fishing with pots and creels may provide alternatives as long as it can be done in a safe approach (without damaging cables and turbines, amongst others topic of the TKI financed project Win-Wind). The scour protection and turbines provide hard substrate and thereby habitat for brown crab and European lobster. The expectation is that brown crab population sizes will increase in OWFs in the North Sea with the addition of scour protection around wind turbines (Tonk and Rozemeijer, 2019). Moreover, in a recent study on experimental fisheries, using baited pots, spill-over of brown crab from a German OWF was observed. Economic analyses of these spill overs showed a potential for economically viable pot fisheries (Stelzenmüller et al., 2021). Also large populations of brown crabs was measured in two Germain OWF in the Germain Bight of the North Sea. A maximum density of ~5 individuals / m^2 was estimated (Krone et al., 2017).

However, European lobster densities are expected to be considerably lower in Dutch OWFs. Firstly European lobster have a high energy density and need substantial amounts of food to grow. E.g. in a first modelling assessment Modelled European lobster productivity was estimated at one lobster per monopile given that each monopile has an anti-scouring surface area of 364 m^2 (Rozemeijer and Wolfshaar, 2019). In this case only one food source was used; mussels. Increasing food availability with other realistic sources (like small crustaceans and polychaetes) in the modelling would decrease the surface required (would be more realistic) but the message remains that lobsters need a lot of food that should be available. Secondly the habitat seems limiting for European lobsters. European lobsters prefer crevices for all sizes and available crevices of the anti-scouring are rather small (6-8 cm deep) for landable European lobsters (>26 cm total length). Enhancement strategies of habitat, stock and food have the potential to increase production capacity and will be assessed in a follow up report.

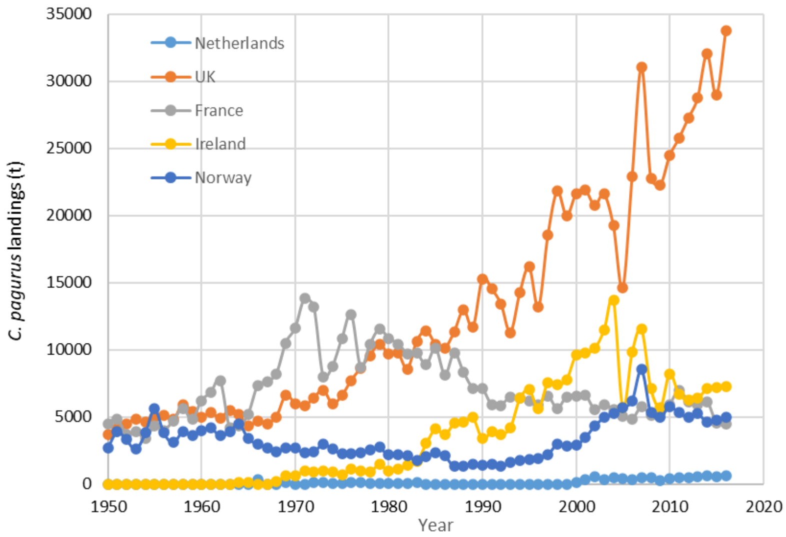

Figure 1: Commercial catch of *Cancer pagurus* in tonnes (t) 1950 – 2019 registered for the four main parties (UK, Ireland, France and Norway) and the Netherlands. Data from FIGIS - Fisheries Statistics - Capture (fao.org) (access date: 23-05-21).

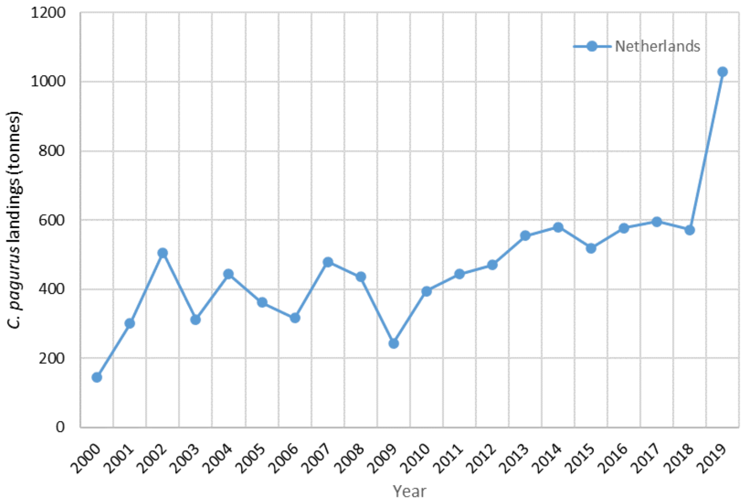

Figure 2: Commercial catch of *Cancer pagurus* in tonnes (t) 2000 – 2019 accumulated for the Netherlands. Data from FIGIS - Fisheries Statistics - Capture (fao.org) (access date: 23-05-21). The increase in 2019 is mainly caused by catch for export to China (Hoekstra 2021).

3 Passive fisheries techniques

In this section three types of passive fishery techniques and gears used for catching brown crab and European lobster are described: 1. fykes ; 2. gill nets and 3. pots and creels. The application of pots and creels are described separately for European lobster fisheries and brown crab fisheries. To provide insight in the methods applied by Dutch fishermen, a case study of two brown crab fisheries in the Dutch North Sea is included in which these two fishermen are interviewed. Fishing methods are classified as either active or passive. Active fishing can be defined as actively pulling or pushing the fishing gear. While in passive fishing the fishing gear is placed in the same location for some time before retrieval. In passive fishing, the capture of fish is based on movement of the target species towards the gear (e.g. traps). Bait can be used to attract fish, or a passive approach is used by waiting for fish to swim into a net or trap. Examples of passive fishing gear are gill nets, longlines, traps and pots. Passive fishing gear used to fish lobster and brown crab comprises of pots and creels, fykes and gill nets. Crabs and lobsters are additionally caught, mostly as bycatch, using active fishing methods such as beam trawling. The description of active fishing methods however, is not within the scope of this desk study as these are currently not allowed within OWFs.

3.1 Types of gear and catch methods: fykes

To target lobster fykes with a mesh size of 36-50 mm are used. Two types of fykes are used to catch lobsters (Figure 3). Longer fykes (a.k.a. 'schietfuik' in Dutch) of approx. 0.8 m in height which are tied together in rows of 10 and placed on the bottom with anchors and different shorter fykes (a.k.a. 'kubben' in Dutch) consisting out of two parts (instead of three parts) that are deployed in a row. Bait is often used to attract the lobsters (van Stralen and Smeur, 2008). The fyke has a wing (vertically placed net) so the lobster (and often other animals) are guided to the entrance of the fyke (Figure 4). Once in the fyke, larger organisms are not able to get out. Fykes are commonly used in shallow coastal waters such as the Eastern Scheldt (van Stralen and Smeur, 2008). Fishing with the relatively vulnerable fykes often takes place in shallower and more sheltered locations. The high susceptibility of fykes to damage make them less suitable for use in OWFs and the North Sea area (personal communication Rems Cramer).

Bycatch and sustainability.
A case study in the Eastern Scheldt comparing instant and secondary death of bycatch of non-marketable lobster (egg-bearing and undersized lobsters) using different fishing methods showed that bycatch was high when using fykes mainly due to a relatively high number of undersized lobster (334 undersized lobsters per 100 marketable lobsters were placed back) (van Stralen and Smeur, 2008). The rate of deceased bycatch in fykes lies between 7 and 19% of marketable lobsters (van Stralen and Smeur, 2008). Other animal such as seals may potentially get caught in the fykes, however by-catch of seals are only incidentally reported in the Eastern Scheldt (Wijsman and Goudswaard, 2015). In addition the risk of ghost fishing and waste from lost fykes applies.

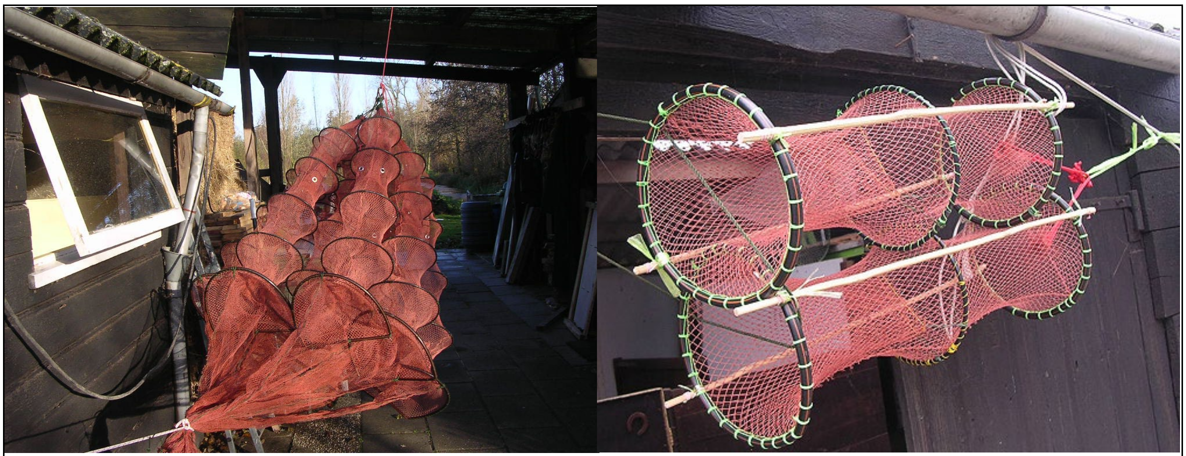

Figure 3: Two types of fykes that are used to catch lobster. Left fykes or 'schietfuiken' and right shorter fykes or 'kubben'.

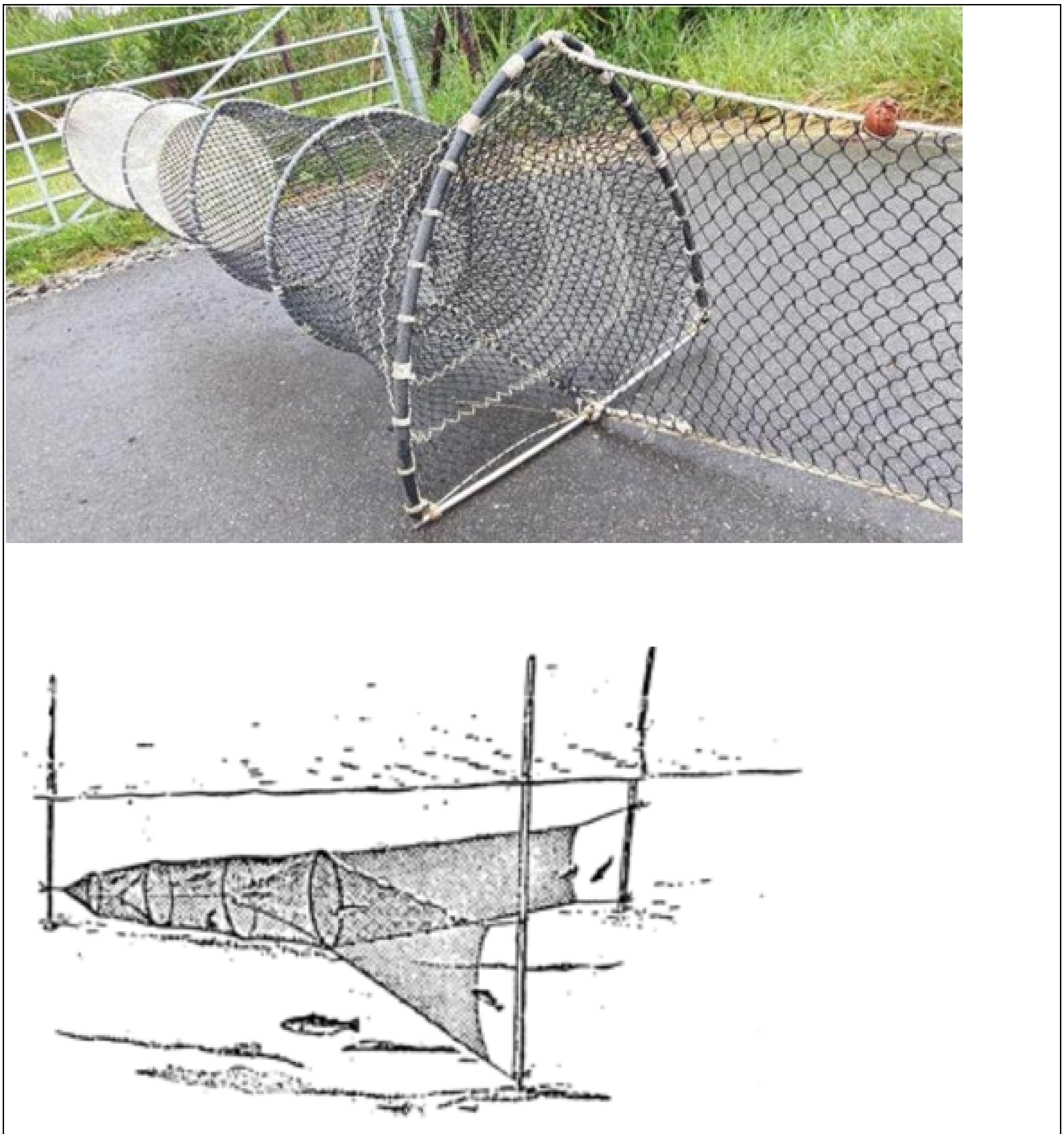

Figure 4: Fyke attached to the bottom.

3.2 Types of gear and catch method: gill nets

Gill nets are known in Dutch as “staand want” and are traditionally used to catch fish species such as European bass, mullet, flounder and sole. The vertically placed nets are deployed on the seafloor and fish get caught in the mesh (Gill net (from sportvisserij.nl) Figure 5.). Gill nets vary in size, mesh size and deployment technique. Different mesh sizes are used to target different fish species, such as 90 to 110 mm for sole, 90 to 130 mm for sea bass and mullet, over 130 mm for cod, turbot and brill (Jongbloed et al. 2013). They are generally deployed in the direction of the high tide current.

Gill nets are also suitable to catch lobster and are used as such in the Eastern Scheldt (van Stralen and Smeur, 2008). The gill nets used in the Eastern Scheldt are nylon nets of 0.8m high and 100m long with a lead string at the bottom and floats at the top. In between there is a fine mesh, where the lobsters get trapped. When fishing with gill nets for lobster and/or sole, a smaller mesh size of 80 to 90 mm is used. This net is secured on two sides with anchors and provided with a buoy. Additional anchors may also be placed in the middle part to secure the net. Fishing for lobster takes place in the sublittoral areas and the nets are generally retrieved within a day (Wijsman and Goudswaard, 2015). In the Eastern Scheldt 20% of lobster landings stem from gill net and beam trawl fisheries (based on the average from 2002 to 2007). Catch of lobsters in gill nets amounts to 3% (500kg) and beam trawl to 17% (2700kg) of total lobster catch (Figure 6). The remaining 80% of lobsters are trapped with fykes or pots. Gill nets are primarily used to catch fish and seem not as effective in catching lobsters such as fykes or pots (interpretation based on the interviews).

Figure 5: Gill net (from sportvisserij.nl).

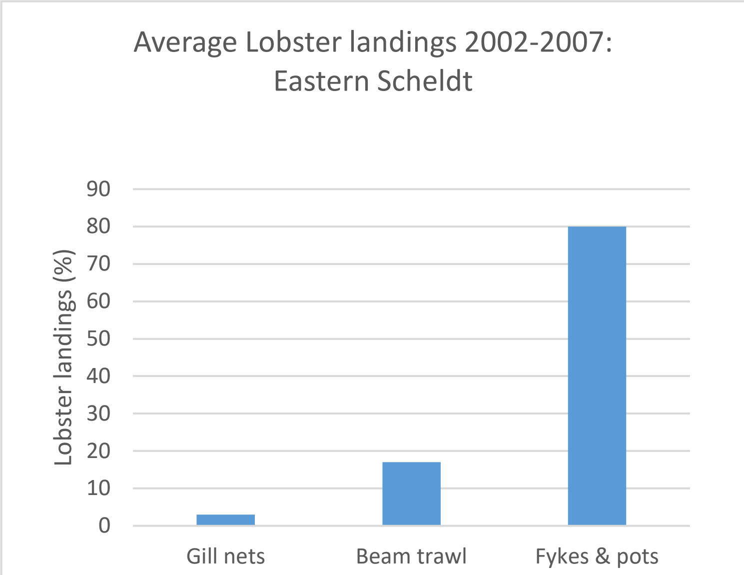

Figure 6: Average lobster landings (%) in the Eastern Scheldt

The following information is based on personal communication with Rems Cramer. When fishing with gill nets the weather plays an important role. In bad weather the nets will not be deployed because of safety reasons and the risk of losing the nets. Fishing with gill nets also requires experienced fishermen. When strong currents prevail the nets tend to lie flat which reduces the catch efficiency. Upon spring tide they are preferably not used because of the higher change of ground waste getting trapped. In addition gill nets are labour-intensive, not only deployment and recovery of the nets, also the removal of trapped animals requires a lot of work. Gill nets require several anchor points. Especially crabs can cause damage to the gill nets. Gill nets are generally retrieved between a few hours up to 24 hours.

Bycatch and sustainability
Gill net fishing is generally seen as a selective fishing method with little bycatch of undersized fish and no bottom disturbance. Seals can potentially get caught in the nets but only incidental reports are known. Bycatch of harbour porpoises in the North Sea is a major point of criticism when using gill nets, however research has shown that the bycatch of harbour porpoises by the Dutch commercial net fishing is low (annual mortality of between 0.05 and 0.07% of the Dutch harbour porpoise population) (Scheidat et al., 2018). In a study in 2006-2007 of the bycatch of marine mammals (and birds) from gill net fisheries in the Dutch coastal waters (Wadden Sea, Western Scheldt, Eastern Scheldt and Voordelta), harbour seals were not detected in any year. Seals were regularly spotted near the nets, but did not become entangled (Klinge, 2008).

In addition, the costs are limited compared to other fishing methods. Although gill nets are generally retrieved within 24 hours, static nets can be lost for various reasons. The possible effects of this are continued fishing of the net in the sea (ghost nets), entanglement of seabirds and marine mammals in the lost nets and waste from lost fishing gear at sea. The plastic components in particular can have negative effects. Although gill nets are viewed as a sustainable method of fishing with little bycatch of undersized fish or damage to the seafloor, the application of this method is limited due to its seasonality and the labour-intensive nature of this method.

3.3 Types of gear and catch methods: pots and creels

The traditional fishing gear for catching both crab and lobster are pots, also known as traps or creels (Figure 7). Pots are used in combination with bait and placed on the seabed and are primarily used to catch shellfish such as lobsters and crabs. Pots are immersed for varying periods of time known as the ‘soak time’, depending on the fishermen, but are generally retrieved after 1 to 3 days (Roach and Cohen, 2020, Roach et al., 2018). Pots can be left for longer periods of time, up to 2 weeks depending on the season (Bannister, 2009). However, the longer pots are left on the seabed the more chance the bait is lost and the higher the risk of fighting and predation between animals trapped within the pot as well as risk of predation of the trapped animals from outside the trap. Rozemeijer et al. (2021) e.g. encountered a marked decreased in the smaller velvet swimming crab in pots filled with brown crab.

The use of pots and creels is a selective method of passive fishing. An opening in the device allows the lobster/crab to enter a tunnel of netting or another one-way device. The D-shaped creel with two openings is a favoured trap by many lobster fishermen (Figure 7A). These creels generally have two entrances in the side, diagonally opposite each other. These entrances sometimes have a plastic ring on the inner end to keep the entrance open, others will just have the raw netting at the end. Creels with an extra separate section to retain the catch in until the creel is hauled (a.k.a. the parlour chamber) are called parlour pots (Figure 7B). Inkwell pots are round with an opening at the top (Figure 7C). Pots with openings at the top are often used in waters with a lot of seaweed. The retaining chamber that contains the bait is called the "chamber" or "kitchen" and exits into the "parlour chamber", where the animal is trapped, preventing escapement (Figure 7D). Parlour pots are typically 0.8–1.0 m long. Most commercial creels consist of a steel frame, often plastic coated, covered with netting. Generally, a series of pots is attached to a rope and anchored to the seafloor (Figure 7E). In European waters, pots are fished individually or in strings ranging from 5 of up to 100 pots with an anchor and buoy at each end (Seafish, 2013). This number of pots often depends on the number of pots that can be handled comfortably on deck at one time. The total number of pots used is determined by boat size and design, the number of crew, the fishing ground and type of seabed.

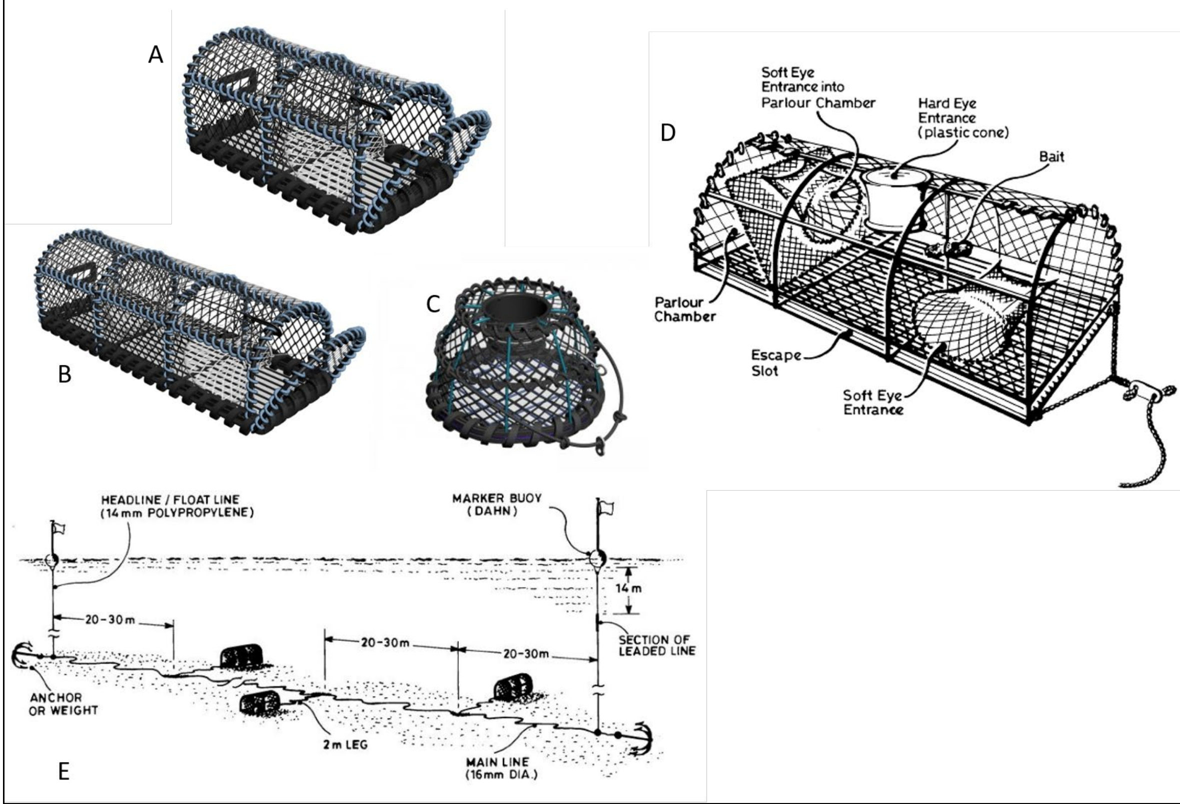

Figure 7: D-shaped creel (A), parlour pot (B) and traditional inkwell pot (C). Schematic drawing of a parlour pot (D). Typical gear configurations (E). The length of a string of pots varies according to environmental conditions (figure from Seafish 2013).

Pots or creels can be deployed by using a chute or hatch to place the baskets overboard. In this case the baskets are deployed one by one while sailing forward, as opposed to putting each basket overboard manually, which is labour intensive. Once deployed, strings can remain on location and will only be hauled out to harvest catch and replenish bait. They are generally left to fish for at least 24 hours up to more than a week before being hauled but this is a trade-off between expected catches and costs and weather off course. When catch is taken out of the trap, any by-catch or undersized crabs and lobster will immediately be returned to sea and the traps will be re-baited. The re-baited pots are stowed in correct order so that they are all ready to be shot away again. If the catch was not good the skipper may opt to keep the pots onboard and move fishing grounds. This routine and layout is fairly standard on all UK vessels, and many overseas vessels fishing with traps and pots (Seafish, 2013).

A disadvantage is that pots take up a lot of space on board when hauling up. The advantage of using pots and creels is that they are less susceptible to damage compared to fykes and are therefore used at locations with for example a high abundance of Japanese oysters. The use of pots or creels to catch brown crab and lobster is mainly practised by fishermen in the United Kingdom and France. Although Dutch and Belgian fishermen have experimented with these fishing methods, fishing for brown crab and lobster with pots is still limited in the Netherlands, with the exception of lobster fishery in the Eastern Scheldt. The few fishermen in the Netherlands that target brown crab use single chambered pots. provides an overview of information on two Dutch crab fisheries that is further detailed in section 3.5 (Case study of two brown crab fisheries in the Dutch part of the North Sea).

Table 1: Overview of brown crab fisheries information

Fisherman		*1*	*2*
Technique	Boat size (length in m)	*15*	*11.5*
	Crew	*2 or 3*	*1*
	Pot size/type	*24 inch Medley*	*26 inch Uk Creel*
	String length (m)	*1200-1400*	*1000*
	Pots per string	*50*	*30*
	Distance between pots (m)	*25-30*	*30*
	Distance between strings (m)	*800*	*800*
Frequency	AVG days fishing per year	*50-60*	*48*
	Immersion time summer	*2 or 3 days*	*2 or 3 weeks*
	Immersion time winter	*1 or 2 weeks*	*4 or 5 weeks*
Scale	Total pots	*1800*	*400*
	Total strings	*30*	*14*
	Strings per day	*16*	*5*
	Pots per day	*800*	*150*
Area	Where	*Texelse stenen, North of Terschelling*	*Westpoint, 20-23 mile NW Den Helder*
	Type of grounds (sea bed)	*stony*	*stony*
	Depth (m)	*±20*	*±20*

3.3.1 Pots and creels: European lobster

Commercial fisheries on European lobster mainly takes place in the coastal areas of northern France, Britain and Ireland (Rozemeijer and Wolfshaar, 2019) where the D-shaped creel or parlour pot is mainly used to catch lobsters. In the Dutch part of the North Sea the focus of fisheries is on brown crab and European lobsters are a rare by-catch (A. Keuter, personal communication). In the Netherlands lobster fisheries mainly occur in the Eastern Scheldt. The population of European lobster in the Eastern Scheldt is suggested to be a genetically distinct population from the larger Atlantic population (including the North Sea) (Prodöhl et al.,2006, review in Rozemeijer and Wolfshaar, 2019). In the Eastern Scheldt specific lobster cages made out of steel mesh are used in combination with bait to trap the lobsters (Figure 8). These traps generally hold very little bycatch of fish and few brown crabs (Wijsman and Goudswaard, 2015). Alternatively pots used in the Eastern Scheldt are made of plastic pipe and netting. lobstering the Eastern Scheldt these lobster cages and pots are attached 2m apart to a line of about 25m. Multiple cages or pots (approx. 10) are attached to one line. The line is anchored to the seafloor and marked with a buoy. These pots are placed below the low tide mark, preferably near the rocky areas at the base of the dyke and are typically emptied and re-baited with fish waste every day or up to 4 days (Wijsman and Goudswaard 2015). The license to catch lobster in the Eastern Scheldt allows fishing from the last Thursday in March until the 15th of July.

Most of the supplied lobster in the Netherlands (13,000 kg of the yearly average of 16,200 kg since 2001 until 2008) is fished with fykes and pots. Whereas 500 kg (3%) lobster is fished with gill nets. (van Stralen and Smeur, 2008). The efficiency of pots and creels for catching lobster and crab is described in section 3.3 along with the impact of the various types of bait that are used.

Figure 8: Lobsterpot that is typically used in the Eastern Scheldt. Figure from (Wijsman and Goudswaard, 2015).

3.3.2 Pots and creels: brown crab

In the Netherlands most brown crab is caught as bycatch in fish trawling and only a few Dutch fishermen use creels to catch brown crab. Most live crab that is suitable for export is caught with pots and creels. Crab that is caught as bycatch in fish trawling is often dead or damaged. In the United Kingdom and Ireland targeted fishery on North Sea brown crab mainly takes place by means of baited pots and creels. Both inkwell pots and D-shaped creels (including parlour pots) are used for catching brown crab. In the UK the growth in potting has been facilitated by the parlour pot, which accumulates catch by reducing the escape rate, especially of lobsters, so that fishers can use longer soak times. Because of this the soak times in Cornwall (UK) have increased from 3 or 4 days to 7-10 days. Potters can therefore avoid hauling in bad weather, can expand by working more sets of gear that are hauled less frequently, and can hold (protect) fishing ground by leaving the gear out for long periods, in some cases for the whole year (Bannister, 2009).

Targeted fishing on brown crab in the Netherlands, albeit small scale, occurs both at the Texelse Stenen in the North Sea and in the Eastern Scheldt. Brown crab is more abundant in these areas as compared to the southern Dutch coastal waters because of the available hard substrate (respectively moreen deposits and dykes consisting of stones and boulders) at these locations. The expectation is that brown crab population sizes in OWFs in the North Sea will increase due to the addition of hard substrate (scour protection) around wind turbines (Tonk and Rozemeijer, 2019).

Fishing for brown crab can take place year round it does however depend on the weather. Particularly in wintertime fisheries will be less efficient. Peak season in the United Kingdom is May/June. In Norway brown crab fisheries mainly take place between April and November (Vistikhetmaar.nl, 2021). In autumn brown crab migrate to deeper water (also see section 4.1.5 Seasonality).

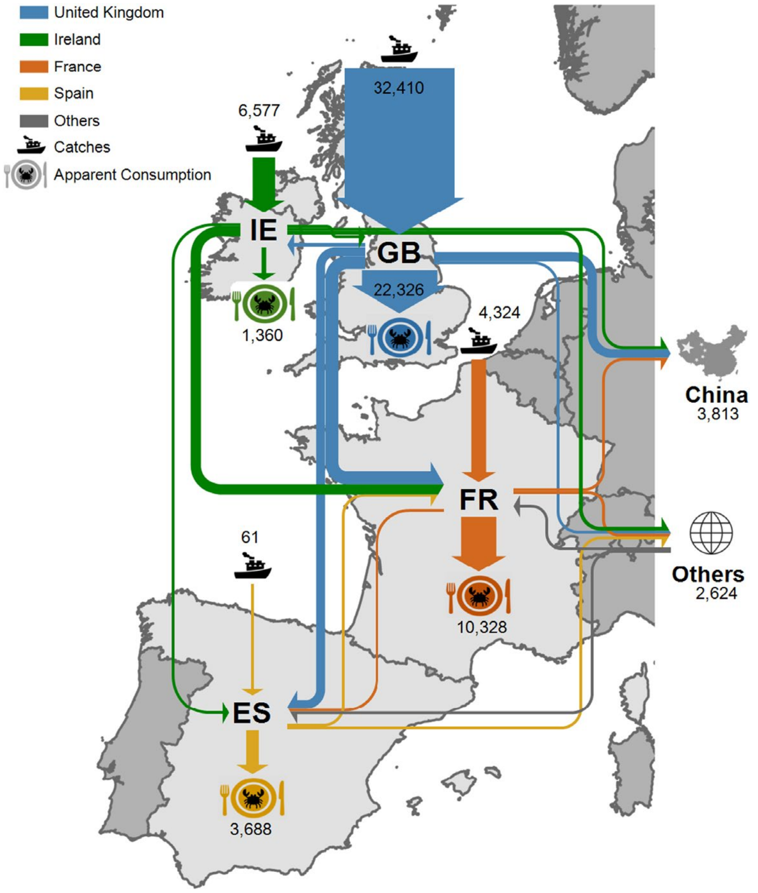

Figure 9: Illustration of relative catches and apparent consumption of brown crab in UK, Ireland, Spain and France and trade between these, "others" and to China in tonnes live weight equivalent. Image from Stelzenmuller et al. 2021, data from 2017, not taking into account the increased export to China in 2019 (Hoekstra, 2021).

3.3.3 Sustainability and ecosystem effects

Fishing with pots is considered a sustainable fishing method. It is a passive way of fishing, where capture is facilitated by the search of target species for food. In addition, there is a behavioural buffer against overexploitation, because capture relies on crabs and lobsters being attracted to the pot only when they are feeding. Feeding rates of brown crab and European lobster are temporarily lower during moulting (Miller, 1990), while female crabs that carry eggs (a.k.a. berried females) do not feed, but instead remain in pits dug in the sediment or under rocks and are therefore unlikely to be caught in a baited pot (Howard, 1982).

In addition, fishing with pots is considered to have limited effect on the seabed or other organisms in the fishing area. Although pots and creels sit on the seabed and can be associated with disturbance to marine habitat they are not typically damaging to the habitat. Small individuals can escape the traps and the shellfish are brought aboard live so bycatch can be returned to sea. Pots and creels are not particularly associated with unintentional bycatch of vulnerable species but can be associated with capture of non-target fish, juvenile commercial species and other marine life. When potting for brown crab in the North Sea bycatch is low. Besides European lobster generally no other species of commercial interest are caught. One of the crab fishermen that was interviewed in section 3.3.4 mentions the velvet swimming crab as bycatch. The velvet swimming crab (*Necora puber*) or spider crab (*Maja brachydactyla*) are also mentioned as potential species to include in a feasibility assessment in OWFs (Bogaart et al., 2019). Pot fisheries catchment data near wrecks at the height of Scheveningen showed bycatch of velvet swimming crab mostly, and some grey swimming crab (*Liocarcinus vernalis*), common shore crab (*Carcinus maenas*), European common cuttlefish (*Sepia officinalis*) and an individual Atlantic cod (*Gadus morhua*) and common Hermit Crab (*Pagurus bernhardus*) (Rozemeijer et al., 2021).

However, lost or unchecked pots and creels can continue catching animals in the water for a long time, especially when made of non-biodegradable plastic and wire. This is referred to as ghost fishing (Adey et al., 2008). Biodegradable joints or panels can be integrated in order to reduce ghost fishing when lost during fishing (see e.g. https://www.vims.edu/ccrm/_docs/marine_debris/biodegradablepanel_factsheet.pdf). To mitigate bycatch escape panels can be incorporated into the traps to allow small fish and shellfish to avoid capture (https://www.sustainweb.org/goodcatch/pots_and_creels/).

The lowest numbers in deceased bycatch were with pots (2 to 9% of marketable lobsters) indicating again that pot fisheries has less impact than other methods.

3.3.4 Means of fishing/technique

Two fishermen that target brown crab and operate in the Dutch North Sea were interviewed on their practice. The questions focused on:

1) Means of fishing/technique
2) Location of fishing
3) How often fishing takes place
4) The scale fisheries take place at
5) Earnings

Fisherman 1 uses a 15m long English boat known as a stern cutter (hekkotter, Figure 10) with a crew of 2 or 3 people. He fishes with 1800 pots but these pots are never on board at the same time. The pots are retrieved, emptied and immediately placed back. The pots (Medley) are 24 inch rectangular in shape and have a single chamber and two side entries (Figure 10). They are always kept in the water and last about 10 years. About 50 pots are attached in one string (1200-1400m long) about 25-30m apart. The depth at the fishing grounds visited is generally around 20m. In areas with stronger currents (for example near Newcastle, UK) pots are placed 40m apart, twice the water depth as a safety measure to prevent a pot from dangling midwater while working the just hauled pot. This safety measure seems unnecessary for the waters above the Wadden Islands where currents are less strong (S. Tijsen, pers. comm.). At locations like PAWP and Borssele II currents seems to urge to larger distances as well but it should be kept in mind distances between pots have a maximum since the areas of bait influence (scent trails) need to overlap as well. A 40m seems a good trade off distance (Skerrit, 2014).

The strings are kept in place with heavy bunches of chains (60-70kg) on either end of the string. No anchors are used. The strings are stable and will only drift in extreme weather conditions. They are marked with buoys or fenders attached to a rope (similar to marking used when fishing with gill nets). Fisherman 1 uses 30 lines and depending on the location places them about half a mile apart (800m). For example, at the Texelse stenen 450 pots are deployed in lines 800m apart. The pots on strings are deployed with a slide over the side of the boat and slide in the water. The pots are left to fish for about 2 to 3 days in summer, depending on the catch success. In winter when crab activity slows down they can be left for 1 to 2 weeks. The traps are baited with whatever is available, generally horse mackerel or fish heads.

Fisherman 2 operates an 11.5m catamaran with a 2x200 pK outboard motor. Fisherman 2 fishes with 400 pots in total. The pots are 26 inch (61 cm) rectangular UK Creel (www.UKcreels.com) HDPE single chamber with two soft eye side entries. The pots are spaced 30m apart 30 pots on strings of approx. 1000m. He never hauls more than 5 strings a day. The strings are anchored with a small 10kilo anchor combined with heavy bunches of chain (3.5m approx. 30 kilo) on either end of the string. Strings are marked with buoys (A1 orange buoy) attached to a rope (about 100m). Fisherman 2 operates 14 strings with 400 pots in total. Spacing between strings varies, the strings are deployed at least 0.5 mile (800m) apart, often further. The pots are deployed by means of a chute in the middle of the catamaran. Fisherman 2 leaves the pots for about 2 to 3 weeks in summer and 4 to 5 weeks in winter. He uses large bait bags filled with whatever fish waste he can get from the fish shop.

Strings are generally deployed parallel to the current otherwise it is too difficult to maintain steering control over the boat during deployment and retrieval. However, at locations where currents are relatively low, such as the fishing grounds above the Wadden Islands, the pots may also be deployed perpendicular to the current. Fisherman 2 has changed from deploying the strings parallel to perpendicular to the current to increase catch rates (broader bait plume) and reduce entanglement within a string. This, however, is less likely to be an option at more southern locations in the North Sea where stronger currents prevail.

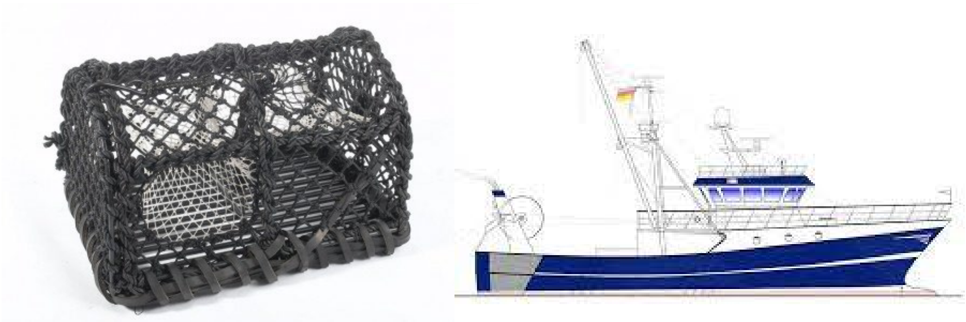

Figure 10: Crab pot (Medley) 24 inch with two side entrances as used by Dutch fishermen and stern cutter on the right.

3.3.5 Location of fishing

Both fishermen are based in Den Helder, The Netherlands. Fishing grounds of choice of fisherman 1 are the Texelse stenen and a location behind the Isle of Terschelling (moreen deposits). These locations are hotspots for crab because of the stony ground. More crabs are caught on stony grounds then on sand. Sites are scarce because of co-use with fellow fishermen (shrimp fisheries for instance). Areas that are used by other fishermen need to be avoided because of potential damage to the strings. A preference exists for stony ground (were most crab is found) and which are less preferred by fishermen with other techniques. Fisherman 1 always visits these two locations and does not change to other spots. Catch is consistently good at these two locations. Fisherman’s 2 fishing area is Westpunt, a stony area 20-23 mile north west from Den Helder, The Netherlands. This is the only area where he fishes for brown crab.

3.3.6 Frequency of fishing

Crab fisheries of the two interviewed fishermen continue throughout the year, also in winter although frequency is lower in winter (every 2 to 3 weeks) with more focus on maintenance of fishing gear. The pots are kept at the fishing ground all year and are never brought back to shore. Taking the pots back to shore involves too much work. The optimal time for crab potting is from May until October. About 50-60 trips take place per year, these are mainly daytrips and sometimes 2- to 3-day trips. Crab fisheries are not combined with other fisheries, the focus is on crab. Fisherman 1 has an additional shrimp boat. Generally 2 or 3 crewmembers are on board. Fisherman 2 also fishes year round however since the demand has dropped (due to COVID-19) his frequency has also dropped and fishing trips have become more irregular. According to fisherman 2 the best season to fish is autumn. Because he has a small catamaran he will only go out fishing up to maximally wind force 3 or 4. Wind force 5 Bft is too high (significant wave height estimated at approx. 1m). On average he will go out fishing 4 times a month, although this varies. These are daytrips of about 14 hours. He operates his boat by himself with no other crew on board. He combines potting for brown crab with work on shrimp cutters (sailing other people's boats).

3.3.7 The scale of fisheries

The amount of pots and lines varies per day. Fisherman 1 only collects what he needs according to demand. He also owns a shrimp boat and doesn't rely entirely on the earnings from crab fisheries. He sells the crabs himself. On a good day he collects approx. 1500 kilo, about 5 kilo per pot. When catch is low, 50 kilo is caught in 100 pots (0.5 kg per pot), for instance in winter. Capacity of fisherman 1 is about 800 pots per day depending on how full pots are. Full pots involve more manual work (such as securing crabs with rubber bands). When pots are full the maximum capacity of 800 pots is not achieved. The amount of crabs per pot varies considerably also depending on size. A maximum of 16-17 crabs are found in a single pot or sometimes just one, this varies. Seldomly a pot stays empty. The amount of crab that needs to be caught for economic feasibility depends on the price. According to his estimations, with brown crab being sold at 5 euro/kilo, 600 kilo brown crab per trip (€ 3000/trip) would suffice to cover costs and even make a small profit.

Fisherman 2 has a capacity of 5 strings per day, because he is by himself and securing crabs with rubber bands is time-consuming. In winter fisherman 2 catches 300 kilo a day with a maximum of 2 kilo per pot. In summer 500 kilo a day with an average 5 kilo per pot. Sometimes he leaves the pots out longer, using big bait bags the pots will continue to fish. In certain good location he can catch 300 kilo in a single string. The maximum crabs in a pot is about 15 (10 kg maximally, about ~0.7 kg a crab). It is hard to indicate what catch is needed for economic feasibility. Fisherman 2 is fishing for 3 years now. He can leave the pots out longer in case of low demand. An estimate of costs is difficult since last year he had a lot of costs on his outboard motor and during COVID-19 he only went fishing once a month. In between he will get his income from fishing on other people's shrimp boats.

<u>Bycatch and lobsters.</u>
Bycatch is small, and mainly consists of undersized brown crab that are placed back. Sometimes lobster is trapped. Fisherman 2 also mentions velvet swimming crab (*N. puber*) as bycatch. Unfortunately there is no demand for this species in the Netherlands. In Portugal the velvet swimming crab is on the menu. Maximum amount of lobsters caught by fisherman 1 are 5 or 6 individuals on a good day (sizes vary between 0.5 and 2 kilo), or sometimes none. Highest chance of catching lobster is in September when the lobsters migrate. Lobster is not actively targeted but is a nice extra when caught. Fisherman 2 also catches lobster, about 20 to 55 kilo maximum per trip. Sometimes he has 10 lobsters in a single string.

The economic feasibility was assessed in Strietman et al. (2022).

3.3.8 Permits

Permits are needed to fish for brown crab, anyone can apply for a permit which is easily granted provided that the applicant owns a fishing vessel that is registered in the vessel register. It is not allowed to fish for crabs in Natura 2000 areas[2] within zone 1. In Natura 2000 areas within zone 2 fishing with pots is allowed. According to fisherman 1 this should be allowed because fishing with pots is low impact, does not involve bycatch and does not disturb the seafloor. When asked if fisherman 1 would like to fish in OWF's he replied that he would be willing to try although he is not sure whether there would be enough brown crab to be worthwhile (in terms of being profitable). Proximity to shore is also important in his decision, too far would imply larger boats (to ensure safety at sea) and thus higher costs (fuel costs and investment in a larger boat). Considering he has good spots close by, he does not see the advantage in fishing in OWF's. Fisherman 2 would like to fish in OWF's provided that they are reasonably close by (again in relation to costs and safety). His motive is mainly to avoid

[2] Natura 2000 is European network of protected nature areas where certain species of animal and their natural habitats are protected in order to preserve biodiversity.

damage to his fishing gear from other fisheries (and thereby reducing costs). An overview of the factors that need to be taken into consideration when fishing in OWF's is provided in Table 4.

3.3.9 Other comments

Gathering of comments not readily categorizable in larger categories:

- Considering the potential limitation of space between turbines (in combination with regulations in OWF's regarding the distance that needs to be kept from turbines safety-wise and to avoid damage) fisherman 1 mentions the possibility to fish with shorter strings with for example 20 pots instead of 50.
- Fishing gear is rarely lost, sometimes another fisherman will fish through his lines. The storm that caused the MSC Zoe to lose containers on 01/01/2019, was estimated at wind force 8 Bft and a sign. wave height of 6.5-11m. In these conditions some of fisherman 1's lines did go adrift and where retrieved 800m further. Displacement of lines to this extent due to a storm and currents (Rozemeijer et al., 2022), however, rarely occurs (once every 10 years) (according to fisherman 1).
- A third boat that fishes for crabs at a larger scale (3500 pots) is a UK owned boat that also operates in the area under the Dutch flag (May 2021). Between May 2021 and the moment of publication (October 2022) three other fishermen started with crab fisheries as well.
- At the Borkumse Stenen crabbing with pots occurs at a much larger scale. Large boats with 8 crewmembers fish with approx. 7000-15.000 pots per boat. This occurs throughout the German Bight. Since no pot limits are applied, there appears to be unlimited fishing for crabs. According to fisherman 2 this is noticeable in the smaller amount of berried female brown crabs (females with eggs) that have been trapped this year. Without regulation, fisherman 2 thinks the crab population will decline considerably. Moreover, when fishing with large boats the percentage dead crabs is a lot higher, mainly because these crabs are not secured with rubber bands, instead the muscle in the scissors are cut, which results in a quicker death. Additionally far more crabs are fitted in the storage area on board and are often stood on. This is inherent to large scale crab fishing with pots.
- Fisherman 2 mentions he now fishes perpendicular to the currents (before he fished parallel with the current) and catches about 0.5 to 1 crate (30 kilo in a crate) more due to a supposedly better scent trail. In addition he has less trouble with strings that get tangled when fishing perpendicular to the current.

4 Efficiency of pots and creels for catching lobsters, crabs and mixed populations

In section 4.1 we will elaborate on several aspects of catch efficiency such as immersion time, gear saturation, choice of bait, seasonality, spatial design of deployment and life stage. Additionally we will do a brief gear comparison. In 4.2 we will describe the application of baited traps to estimate abundance and in 4.3 we elaborate on several aspects such as sustainability and bycatch.

4.1 Aspects of catch efficiency

Specific species and sizes can be targeted using different trap designs and choice of bait (Steenbergen et al., 2012). Catch efficiency is additionally affected by: gear saturation, immersion time, population density (which varies spatially and per season), positioning on the seabed and the life cycle of the target species (Miller, 1990). Increasing the ease of entry and reducing the effect of gear saturation have been mentioned as having the largest potential for increasing trap efficiency (Miller, 1990).

4.1.1 Immersion time

The effect of pot immersion time (time between setting and hauling of the trap) on catch per unit effort (CPUE) was studied in a crab and lobster fishery off Devon, UK (Bennett, 1974). When male crabs were most abundant, there was an increase in CPUE with pot immersion time, indicating that the traps continued to fish. At other times on the same fishing ground, stock density appeared to be too low to enable increased catches of male crabs with increased immersion time. In autumn, when female crabs were most abundant, female CPUE decreased with immersion time, probably due to gear saturation (see 4.1.2). However, mature females in particular are often less vulnerable to traps than males (Miller 1990). See 4.1.6 Life stage.

Lobster CPUE decreased after the first day's immersion and this was potentially related to the greater manoeuvrability of lobsters as compared to crabs, which enabled the lobsters to escape (Bennett, 1974).

4.1.2 Gear saturation

Gear saturation occurs when animals that are caught inside traps prevent the animals outside the trap from entering (Groeneveld et al., 2003). For European lobster it was found that, due to agonistic interactions, trap entry is inhibited by the presence of other lobsters already in the trap (Addison, 1995). A recent study by Skerrit et al. (2020) found no significant effect for European lobster catches in traps pre-loaded with other European lobsters. Inconsistencies between findings of Skerrit et al. (2020) and Addison (Addison, 1995) could partly be due to disparities in local European lobster catch rates. Addison reported catches of one or more European lobsters per trap and mean number of European lobsters per trap was more than twice that in the study by Skerrit et al., where 67% of traps caught no lobsters. Causes could be found in local densities of lobsters and agonistic behaviour by European lobster.

In the same study by Skerrit (2020) pre-loaded traps with lobster did on average reduce brown crab catches by a factor of 12. Agonistic behaviour in traps is likely to occur in brown crab (Bannister and Addison, 1998), but it is thought to be much less important in determining catch rates of brown crabs as in lobsters. Much higher catch rates are recorded for brown crabs than for lobsters in European waters. This difference may be partly a result of differences in density, but it is nevertheless clear that trap saturation must act at a much higher catch rate in crabs than in lobsters (Bell et al., 2002).

4.1.3 Bait

Bait quantity and quality can affect catch rates. Bait choice experiments have indicated that fresh bait is chosen over stale bait, marine species are chosen over mammals, and cut bait is chosen over live prey. In the field, fresh flatfish caught more European lobster and brown crab than salted flatfish (Miller, 1990). Dead decapods in traps can greatly reduce catches of conspecifics and can be used to reduce the catch of nuisance decapod species (Miller, 1990).

Lobsters and crabs are attracted using a wide range of bait. In Scotland the species composition used as bait is mixed, with both oily (mackerel, horse mackerel and herring) and white fish (saithe, gurnard and scad) making up the majority of species. The heads and frames of salmon and whitefish are also used to bait creels in this fishery (MSS, 2017). In practice, there is a preference for firmer fish species such as horse mackerel and ray, because this bait attracts fish longer and attracts fewer starfish (www.vistikhetmaar.nl).

Different types of bait were tested to catch brown crabs with creels in Steenbergen et al. (2012). The study of Steenbergen shows that most brown crabs were caught using common dab (*Limanda limanda*) as bait. Additionally Atlantic horse mackerel (*Tracherus tracherus*), Atlantic cod (*Gadus morhua*), small European plaice (*Pleuronectes platessa*) and a combination of European plaice and common dab show a high catch rate. However, common dab was mainly used as bait in week 24, 25 and 26, when numbers of caught crab were highest and not all bait types were tested in an equal amount. Location and date may also confound results on preferred bait type.

4.1.4 Spatial design of deployment

Informal observations and anecdotal evidence from fishers suggest that, in strings of traps for lobsters and crabs, catch rates are often highest in the traps at the ends of the strings (Bell et al., 2002). One possible interpretation of this observation is that the individual trapping areas interfere with one another. End traps compete with neighbours on one side only and hence have higher catch rates. The distance between pots or creels in a string may vary from a couple of meters to 40 m (Bell et al., 2003, Skerritt et al., 2012). The standard commercial distance between pots or creels is 20 m (Skerritt et al., 2012).

4.1.5 Seasonality

Catchability of decapods often increases with temperature because the activity raise and appetite of the target species. Also the rate of diffusion of the bait molecules increase with temperature (Morrisey 1975 in Miller 1990). Seasonal changes in catch per unit effort (CPUE) have been shown in a study off Devon, UK (Bennett, 1974). This study showed that female crabs were most catchable in the autumn, large male crabs in winter, and lobsters in spring and for a short period in autumn.

Highest average landings of brown crab in the Netherlands over a period from 2000 to 2010 were found from August until November (Steenbergen et al., 2012). In a study of brown crab fisheries with 17 inch D shaped creels or pots over a period of 7.5 months from June 2011 until February 2012 the average CPUE was highest in June and July and decreased from week 29 (Steenbergen et al., 2012). However, from week 29 the creels were left in the water longer. This may influence the catch success, the longer creels are left in the water the lower the CPUE. This is due to the bait that is finished. A decrease in catch success in week 52 is possibly due to lower activity of crabs due to the low water temperature.

4.1.6 Life stage

Female brown crabs, especially mature females, are often less vulnerable to traps than males (Miller, 1990). This is possibly linked to their behaviour and the fact that from November until May female crabs may carry eggs (berried females). While female crabs carry the eggs (a.k.a. berried females), they do not feed, remaining in pits dug in the sediment or under rocks and are therefore unlikely to be caught in a baited pot (Howard, 1982). In fact, in a survey determining catch characteristics in the

Irish sea a total of 5795 commercial pots were hauled and only 16 ovigerous females were found in the pots (Ondes et al., 2019). Reduced catch rates are also associated to moulting (ecdysis) when feeding rates of brown crab and European lobster are temporarily lower (Miller, 1990). The crab fishery is managed, with minimum conservation reference size (MCRS) applied as a primary tool to preserve the reproductive potential, but there are no quota or effort regulations. The MCRS is set at 130 and 110 mm carapace width (CW) for crabs caught north and south of 62°N, respectively (Bakke et al., 2018). For European markets, males may come under higher fishing pressure as markets desire the larger claws with higher white meat yield. On the other hand the Chinese market prefers females (Hoekstra, 2021). Therefore, it would be important to manage towards a suitable length frequency for both sexes (Tonk and Rozemeijer, 2019).

In most areas lobsters do not mature before 5–8 years and males reach sexual maturity earlier than females (depending on water temperature). Reproduction takes place during summer (around July) and is linked with the moulting cycle. Mating usually takes place shortly after the female moults. *H. gammarus* egg sizes are large, clutch sizes small, and brood period long relative to other marine decapods of similar size (e.g., spiny lobsters and crabs) (Rozemeijer and Wolfshaar, 2019). There are a number of European regulations put in place in an attempt to maintain lobster numbers. These include minimum size limits (MCRS is 85 mm carapace length in Dutch, Belgium and German waters), rules to always return berried (egg carrying) lobsters and V-noticing, a system where notches are cut into the tail of female lobsters at peak breeding age, is applied after which they are returned ensuring at least one possibility to bear eggs (Rozemeijer and Wolfshaar, 2019).

4.1.7 Gear comparison

Trap size and design can be adjusted to target desired species and sizes. For instance, preventing escape through the entrance affects catch efficiency. In several studies the efficiency of different crab and lobster gear have been compared (see Table 2). A study comparing the effectiveness of traditional Yorkshire double-chambered parlour pots versus single-chambered creels shows that parlour pots caught twice as many lobsters and slightly more crabs than the creels with a one-day immersion period (Lovewell et al., 1988). With a longer immersion period, parlour pots appeared to be even more effective. In a comparative fishing experiment using inkwell pots and Scottish creels to catch brown crabs and lobsters no significant difference in the numbers of crabs or lobsters caught by the two types of gear (Shelton and Hall, 1981). However, crabs caught in inkwell pots were significantly larger than those caught in Scottish creels. The sizes of the lobsters taken by each gear did not differ significantly. In a survey using pots determining catch characteristics in the Irish Sea a total of 5795 commercial pots were hauled (Ondes et al., 2019). Despite the use of escape gaps the traps still retained 13% of females and 20% of males that were under the MCRS (130 mm). Experimental fishing comparing fine-meshed small-ringed Norfolk pots and Yorkshire parlour pots was carried out off Cromer in north Norfolk and in Bridlington Bay, Yorkshire. Analysis of size composition of catches showed that both lobsters and crabs retained by the Norfolk pots were significantly smaller than those retained by the Yorkshire pots (Addison and Lovewell, 1991).

Carapace length (CL) of parlour pot-caught European lobsters were compared to CL of diver-caught lobsters inside a Swedish reserve in 2017 and showed that the pot was strongly size selective for both small individuals and large males with a CL of 63 – 149mm. Dive-caught lobsters had a CL of 46-170mm and 25% were larger than the largest pot-caught male (Oresland et al., 2018).

Table 2: Efficiency of different crab and lobster fishing gear (explained in the text).

Gear 1	Gear 2	Lobster (gear 1)		Brown crab (gear 1)		Reference
		number	size	number	size	
Parlour pot	Yorkshire creel	Doubled or more	na	na	na	(Lovewell et al., 1988)
Inkwell pot	Scottish creel	equal	equal	equal	bigger	(Shelton and Hall, 1981)
Fine-meshed small-ringed Norfolk pots	Yorkshire parlour pots	na	smaller	na	smaller	(Addison and Lovewell, 1991)
Carapax (parlour) pot	Diving		Smaller individuals of both sexes and large males		Larger lobsters	(Oresland et al., 2018)

4.2 Application of baited traps to estimate abundance

Using catch per trap as an index of abundance is attractive for both fisheries management and ecological studies. However, correlations between catch and abundance have not been well established, probably because of the many factors affecting catchability (e.g. stage of moulting and reproductive cycles, sex, animal sine, lunar and diurnal cycles, temperature, and water motion). Methods for conducting trapping surveys, measuring catchability, and comparing fishing strategies are critically reviewed (Miller, 1990). In addition the use of baited traps to estimate population density depends on the area from which the catch is drawn and homogeneity of the capture probability in this area. For instance higher average CPUE was found on soft ground by Wallace (2015), in contrast to a previous study by Skerrit (2014) where population estimates of European lobster for North-Cumberland showed higher abundance on hard ground (Skerritt, 2014). This may be due to how the substrate data was classified or bias due to bait use, trap selectivity and area fished (Wallace, 2015).

A review of the different techniques to measure lobster abundance and distribution was performed by Wallace (2015). The strengths and weaknesses of the various data collection methods pointed out in this review are provided in Table 3 (taken from Wallace 2015). From this review it was concluded that trap-catch data was the most convenient and cost effective technique to understand distribution and population characteristics of European lobster and inform management of the fisheries (Miller, 1990, Wallace, 2015). Currently there is no data on lobster abundance in OWF’s and due to the restrictions that apply in OWF’s fishing is not possible yet. Therefore catch, mark and return (CMR) studies have been chosen to estimate lobster abundance and distribution in the Princes Amalia OWF pilot study. CMR with tagging has the advantage that individuals can be monitored over time and it provides an estimate of population size (Wallace 2015).

Table 3: Examples of data collection methods; their strengths and weaknesses and locations of studies which have used the technique taken directly from Wallace (2015). For references refer to Wallace (2015).

Method	Strengths	Weaknesses	Location	Useful References
Diving	Limited interference, Direct observation.	Intermittent, Restricted due to visibility, Weather, Sea conditions. Seasonality, Dive Time, Time of day, Depth, Produce snap shot data, Relatively expensive.	N.E USA N.E USA Gulf of Mexico N.E USA E. Mexico	Bologna and Steneck (1993) Geraldi *et al.* (2009) Rios-Lara *et al.* (2007) Selgarth *et al.* (2007) Briones-Fourzan and Lozano-Alvarez (2001)
Snorkeling	Limited interference, Cheaper than diving, Direct observation.	See diving weaknesses (excluding cost).	Turks and Caicos Is. N.E USA Florida USA	Claydon *et al.* (2009) Karnofsky *et al.* (1989) Eggleston and Dahlgren (2001)
Tagging/ CMR	Can monitor individuals over time, Estimate population size.	Repeat observations, Catchability, Snap shot data, Small sample size, lost tags, Needs further study.	Norway N.E USA N.E USA N.E England S. England	Agnalt *et al.* (2009) Dunnington et al. (2005) Geraldi *et al.* (2009) Skerritt (2014) Smith *et al.* (2001)
Acoustic Telemetry	Measure distances, not dependent on visibility or rates of recapture. Spatial resolution, Limited interference. Continuous tracking	Limited sample size, Relatively expensive, Limited range and depth.	N.E USA N.E England Florida USA Norway	McMahan *et al.* (2013) Skerritt (2014) Bertelsen *et al.* (2009) Wiig *et al.* (2013)
Commercial catch	Cheap, Large sample size.	Repeat observations, Bias in effort, Catchability, Bait interference, Snap shot data, Variable soak time, Different gear, Bias sex ratio.	Norfolk, UK Gulf of Mexico N.E England	Howard (1980) Rios-Lara *et al.* (2007) Turner *et al.* (2009)
Fishery Independent catch	Relatively cheap,	Repeat observations, Catchability, Bait interference, Snap shot data, Variable soak time	W. Australia N.E USA N.E England Cape Breton, Canada Nova Scotia, Canada	Bellchambers *et al.* (2013) Geraldi et al. (2009) Skerritt (2014) Smith and Tremblay (2003) Tremblay and Smith (2001)
Lab Studies	Direct observation.	Does not account for all factors, make several assumptions.	N/A	Cenni *et al.* (2010) Wahle, (1992) Miller and Addison (1995) Philips (2005)
Mesocosm Studies	Removes fishing pressure, natural environment, some the control of a laboratory experiment.	Limits long distance movement, requires other methods for observations, expensive.	N.E USA N.E USA	Golet *et al.* (2015) Karnofsky *et al.* (1989)

5 Application of fisheries in OWF’s

In chapter 5 the application of passive fisheries in OWFs is described. Feasibility of passive fisheries on brown crab and European lobster is addressed including the rules and regulations that apply in OWFs. The most suitable method for passive fisheries in OWFs and several case examples are discussed.

5.1 Aspects of feasibility of passive fisheries in OWFs

Considering the high potential for successful colonization of brown crabs in Dutch OWFs (Bouma and Lengkeek, 2012, van Hal et al., 2012, Tonk and Rozemeijer, 2019) and the spill-over of brown crab that was observed from a German OWFs the ecological feasibility and economic viability of passive fisheries in OWFs appear promising (Stelzenmüller et al., 2021). The first estimates of the lobster potential in OWFs are considerably lower (first estimates ~1 lobster per 364 m^2) due to potential lack of sufficient food and too small crevices for larger lobsters (Rozemeijer and Wolfshaar, 2019). Lobster fisheries would rely on enhancement strategies of habitat, stock and food to potentially increase production capacity (Rozemeijer and Wolfshaar, 2019). Population density is not the only factor of concern when it comes to passive fisheries in OWFs. Uncertainties regarding safety, gear retrieval, insurance and liability are part of the issues surrounding the feasibility of fisheries in OWFs. Scale may also limit potential benefits to fishermen, with regards to rules and regulations when operating near turbines (such as the distance that needs to be kept from the turbines) and the lay out of the OWF (available space between turbines). In order to estimate the scale at which passive fisheries may take place, the rules and regulations and the available space for fishery activities needs to be clear.

5.2 CPUE and LPUE

Important aspects for a viable earning model are population to be expected, Catch per Unit Effort (CPUE) and landable caught crabs (Landing Per Unit Effort, LPUE). Germain results suggest a high potency for OWFs (Krone et al., 2017, Stelzenmuller et al., 2021) but is this also true for the Dutch situation?

5.2.1 Brown crab

Factors influencing CPUE and LPUE
Important aspects influencing CPUE and LPUE are season (temperature) and area (many examples see e.g. Bennet, 1973, Öndes et al., 2019). Öndes et al. (2019) showed that pot type, bait type and boat are also important, as are the shape and structure of the entrance of the pot. Steenbergen et al. (2012) also showed the importance of bait type. E.g. horse mackerel and dab yielded higher CPUEs than crab. The placement of the strings parallel or perpendicular to the flow influences the shape and quality of the odour plume and is therefore also important for the CPUE (Rozemeijer et al., 2021, Stefan Tijsen, pers. comm.). In addition inter- and intra-specific interactions of target animals once present in the pot can affect the CPUE and LPUE (Skerrit et al., 2020).

CPUE
Comparing CPUEs of several areas, Rozemeijer et al., (2021) showed that between a CPUE of 0.3 and 1 crab per pot per day for brown crab next to wrecks near Scheveningen. Steenbergen et al. (2012) measured a CPUE of 0.3 to 0.6 at the Texelse Stenen near Texel and Vlieland, also in August, September. Stefan Tijsen (fisher using crab pots) estimated he caught 1.7 crab maximally per pot per day at the Texelse Stenen above Vlieland and Terschelling in summertime (pers. comm.). Bennet (1974) measured a CPUE of approximately 0.3 to 1.6 crab per pot per day for males and 0.5 to 5.7 crab per pot per day for females (depending on season, assuming a crab to weigh 0.454 kg). Lovewell et al. (1988) had CPUEs ranging from 0.28 to 2.81 crab per pot per day, depending on pot type and

soaking time, at Yorkshire, UK. Bell et al. (2003) calculated a CPUE of 2.74 per tide (one low and high water period) which is roughly 5.5 brown crabs per pot per day at the Race Bank, north Norfolk also in the months August, September. Spencer (2013) had an average CPUE of 1.79 per tide which is roughly 3-4 crabs per pot per day (4-22 brown crabs per pot) near Seaton Sluice (UK). Woll et al. (2006) found various CPUEs ranging from 3.6 to 13.4 crabs per pot per day at various locations in Norway 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 7 to 8 brown crabs per pot per day, depending on type of pot, type of bait and boat, moment of the year (Isle of Man, northern Irish Sea). Stelzenmüller et al. (2021) found an average CPUE of 14.5 brown crabs per pot per day (June and August) in transects an OWF located near the island of Helgoland (German Bight).

CPUE for earning model
For the earning model for fishing in OWFs a hypothetical CPUE valid for the OWFs at the Hollandse Kustboog needs to be defined to be applied in the subsequent study of Strietman et al.(2022). The data from Rozemeijer et. (2021), Tijsen (pers. com.), Stelzenmüller et al. (2021) are compared with distribution charts based on catchment of two surveys (BTS) and (SNS). The highest CPUE of Stelzenmüller et al. (2021) is found at the area with the highest densities for brown crab in sandy areas, and lowest CPUE in areas with low densities. Most OWFs are planned in the Hollandse Kustboog and near the Belgium border. This area has low natural densities of brown crab and European lobster on the sandy area (Rozemeijer & van de Wolfshaar, 2019, Tonk & Rozemeijer, 2019). In addition there is relatively little hard substrate compared to the total surface of the OWF. Therefore the catch data of brown crabs on sandy bottoms around shipwrecks by Rozemeijer et al. (2021) are a reasonable proxy for the OWF locations off the Hollandse Kustboog. Keep in mind that densities of brown crab on wrecks could be higher than the surrounding soft substrates due to the high amount of crevices (van den Bogaart et al., 2019, Tonk & Rozemeijer, 2019).

LPUE for earning model
Reanalysing the data from Rozemeijer et al. (2021, CPUE of ~1 crab per pot per day) it also appeared that 39% of the caught crabs were landable (LPUE) mounting to 1 to 3 landable brown crabs per cage per week. The average carapace width (CW) for the landable brown crabs was 15.1 cm. Using Öndes et al. (2017), the CW has been converted to 0.65 kg in weight. The range of landable catches of brown crabs is therefore 0.65 to 1.95 (3 x 0.65) kilos per week, rounded up to 2 kilos of landable edible crabs per cage per week. With 2 kilos of landable brown crab per week far more than 3 euros per kg is necessary to have a viable enterprise. E.g. using the assumptions in Strietman et al. (2022) a price of € 3 /kg when catching an average 2kg/pot/week means that the fisherman and his crew still has no earnings at all.

5.2.2 European lobster

The same considerations in catching European lobsters apply as defined for brown crab. In addition Bennet (1974) stated European lobsters are more dynamic thereby prone to escape more easily from the pot.

Rozemeijer et al. (2021) caught three European lobsters during 9 haul outs spread over ~60 days, in 30 pots. This is too low for determining CPUE and LPUE (all three were larger than minimum landable size, two in the same pot). This is congruent with estimations of van den Bogaart et al., (2019, 2020) that not all wrecks have high numbers of lobsters and that the area near Scheveningen has low numbers. Krone & Schröder (2011) investigated wrecks.Lobsters were detected at 15.6% of all wrecks, the majority with one lobster. Authors did mention that estimates are on the low side due to difficulties in monitoring wrecks. Densities in the sandy areas of the Dutch continental shelve are extremely low: a roughly estimated 0.000002 larger lobsters m^{-2} (2 lobsters km^{-2}, Rozemeijer & van de Wolfshaar, 2019). The renowned European lobster catch area Westermost Rough (east of Kingston upon Hull, UK) measured a maximum CPUE of ~4.1 and a maximum LPUE of ~0.6 lobsters per pot per day (Roach et al., 2018, 2022).

5.3 Rules and regulations in OWFs

In areas designated for activities of national importance such as generation of wind energy, other activities should not hinder this use. Until Beleidsnota Noordzee 2016-2021 OWFs were not open for passage and shared use. On the basis of the North Sea policy memorandum 2016-2021, passage for vessels up to 24m and fishing with a fishing rod in OWFs was permitted under certain conditions (Table 4). These conditions were laid down in the Policy Rule on Setting a Safety Zone for OWFs (Staatscourant 2018, 22588[3]). This policy rule also created the opportunity of conducting an experiment with passive fisheries in OWFs, with the aim of investigating whether passive fishing in OWFs was feasible and could be performed safely. Such passive fisheries should occur with the permission of the OWF-operators. In 2020 the approach was changed with the area passports for Borssele OWF (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020) and the announcement amongst others to enable passive fisheries in Borssele II OWP [4]. Here no permission of the OWF-operator was needed but it was obligatory not to disturb the ongoing operations of the OWF-Operator (see also section 5.4).

Table 4: Conditions for passage and shared use in wind farms LUD, OWEZ and PAWP (Rijkswaterstaat, 2018).

Icon	Description
	It is mandatory to have an AIS transponder (minimum class B) turned on and listen to VHF channel 16 on the radio and respond when you are called.
	The parks are only accessible during the day (after sunset access is prohibited and punishable). The exact times of sunrise and sunset of the KNMI are decisive in this.
	The wind farms are only accessible to ships with an overall length (LOA) of up to 24 meters.
	It is not allowed to enter the structures in a wind farm. Keep a distance of at least 50 meters from turbine poles and 500 meters from a transformer station. This also applies to objects from the vessel, such as lines, floats and hooks.
	It is not allowed to make contact with the ground in the wind farms; for example by anchoring or by dragging nets over the seabed.
	Only sport fishing with rods is allowed, subject to the above distance rules.
	Other gear shall be secured in such a way that it cannot be used immediately. The fishing gear must be visible in its entirety on the deck; so it is always clear that nothing is dragging on the bottom.
	Activities that can lead to dangerous situations and nuisance within a wind farm are prohibited. This includes diving, kite surfing and reckless sailing. It is also prohibited to throw (fish) waste overboard.

[3] Staatscourant 2018, 22588 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)
[4] Staatscourant 2021, 13511 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)

5.4 Case Borssele II

For the newer OWFs (Hollandse Kust en IJmuiden) specific guidelines called 'area passports' are being developed to indicate the designated areas for multi-use within the OWF. For OWF Borssele such a passport has already been created (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020)[5]. In the following section relevant rules and regulations from the area passport Borssele II are described. The accessibility of the wind energy assets within the OWF must remain guaranteed and maintenance must also be carried out safely. To ensure this, shared use activities may only take place outside the maintenance zones for wind turbines and the infield cables.

It should be noted here that although a permit holder has the exclusive right for the generation of wind energy in the area, the permit holder does not have the exclusive right for the overall use of the area concerned. In principle, there is space for multi-use provided that the license holder concerned does not experience disproportionate damage or hindrance. To ensure this, shared-use activities may only take place outside the maintenance zones for wind turbines and the infield cables (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020).

OWFs at sea involve two specific forms of multiple use of space: passage (of ships) and shared use (for example with fisheries). In Borssele OWF, passage and multi-use are mutually excluding forms of multi-use, which means that where passage is carried on, other activities like e.g. fishing or with fixed constructions in the water column cannot take place and vice versa. In Borssele OWF there is only local traffic and no free passage except for the specific ally designated corridor for ships <45m. The same basic rules for passage and shared use apply to all new wind energy areas. Within this framework of basic rules, it is examined what is possible for each OWF: which forms of multi-use can be combined or where priority should be given to passage (Rijksoverheid, 2021).

Safety zones are defined, see later. Transit through the OWF safety zones is allowed solely for ships up to 24 meters length for vessels with VHF communication equipment on board and with an assignment for either OWF, research or multi-use purposes. Within the OWF safety zone, it is forbidden to perform activities that endanger or obstruct the OWF exploitation. Any third-party activity within 50 meters from a turbine is considered to be dangerous or obstructing (Groenendijk, 2018).

5.4.1 Safety in Borssele II OWF

An important aspect of working in OWFs is safety. In the end it is an industrial environment with high voltage in a hazardous and unpredictable environment as is the North Sea. Onshore an industrial environment with high voltage would be fenced with permits for admission. In the Staatscourant 2021, 37376[6], safety in operations is demanded but not defined for OWFs under the new policy. Only safety zones around OWF objects are defined. In this section, some aspects of safety are discussed without trying to be extensive nor conclusive.

Safety zones in Borssele OWF
For the new OWFs there is a safety zone of 500 meters around the entire wind energy area, with the exception of the shipping corridor, In the zone of fisheries multi use a safety zone of 250 m is defined around monopiles and both sides of the infield cables and export cables. Here not any form of multi-use is allowed. An additional 250 m is defined around the monopiles to ensure manoeuvre space for maintenance ships in which passive fisheries may occur but no other activities. Crossing these zones is only allowed when the vessel is on duty e.g. performing experimental fishing as part of a research for Ministry of LNV.

A distance of 500 meters from a transformer station needs to be observed but this is of less relevance since the transformer stations are outside Borssele II.

NB: For PAWP is an example with the safety zones described in Table 7 and Figure 11.

[5] https://zoek.officielebekendmakingen.nl/stcrt-2021-37376-n1.html
[6] Staatscourant 2021, 37376 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)

Markings of the crab-pot-strings
Legally it is required to mark the crab-pot-strings with dahns. In daily practice dahns are not used since they destabilize the crab-pot-strings especially when chains are used for anchoring, necessary for stony seabed (Rozemeijer et al., 2022a). In addition they pose high risks for personal injury for the fishermen due to the large seize (4 to 6 m length) and attached objects like weights, radar reflectors and lights (R. Cramer and M.J.C. Rozemeijer, personal observations). In the WMS for working in PAWP (Rozemeijer et al., 2020) it was agreed that dahns had to be used in order to have maximum visibility for CTVs and other vessels (Figure 11), though it was also agreed polyform A1 buoys would have the same or even better visibility (Rozemeijer et al., 2022b in prep.). Exceptions on the use of legally required dahns could not be given by the Ministry of LNV. Dahns were therefore also used in Borssele II.

Figure 11: Deployment of a crab-pot-string in Borssele II. The dahns are the indicator of both endings of the crab-pot-string. Dahs are equipped with radar reflector and flash light (see laying dahns at the left side).

Vessel requirements
All vessel of 12 m or larger receive National Vessel Inspection by ILT (Inspectie Leefomgeving en Transport). For working in OWF with the old policy, also compliance with International Marine Contractors Association standards was obligatory (IMCA) (Rozemeijer et a., 2020). For working in Borssele II under the new legal policy, the used vessel was inspected according an Inspection Template of Environmental Survey Vessel Checklist. The compliance with inspection results is not obligatory but strongly preferable. It is advisable to define a sensible and affordable level of vessel requirements in order to meet to some level the higher standards of OWF industry on the one hand and meet “midways” the ILT standards that are affordable.

Risks of operation, potential interactions and coordination
Staatscourant 2021, 37376[6] states that the experimental fishing should not have any effect on the maintenance and continuity of the OWF. The risks of operation, potential interactions and coordination are usually evaluated by means of a WMS (also called Risk Assessment Method Statement, RAMS). Under the old legal policy a document like this is obligatory (see e.g. Rozemeijer et al., 2020). In the case of the new policy the RAMS for experimental fishing in Borssele II (Rozemeijer, 2022) was an excellent means to communicate the initiative and its implications with the OWF operator.

Another important aspect is the coordination in the OWF between all the activities running. Some activities like depositing rocks for anti-scouring require large ships with large safety zones. Fixed crab-pot-strings could hamper flexibility in operations. In addition regular maintenance and visits occur on daily basis. A central coordination point overviewing all these operations is highly preferred. This could be either the Coast Guard or the Daily Operations Management of the OWF operator. These discussions on organisation, costs etc. are still to be started at the moment of publication of the report.

5.5 Princes Amalia Wind Park case

In 2019, the Win-Wind project received permission from the Dutch government to perform an experiment with passive fisheries in PAWP[7]. For PAWP an approach was agreed with the OWF operator (Rozemeijer et al., 2020). PAWP is one of the first OWFs in the Dutch North Sea and has been operational since 2008. In PAWF, the access to the entire OWF is regulated through the OWF operator. Spatial lay-out of the OWF and available space between turbines may limit effective fishery for crab and lobster with pots (Rozemeijer et al., 2020). PAWP for instance covers in total 14.2 km^2. The 60 turbines are spaced approximately 500m apart. Each turbine is surrounded by 346.4 m^2 of scour protection (Rozemeijer and Wolfshaar, 2019). For the Dutch fishermen this is perceived as limited space to operate safely and effectively (personal communication R. Cramer and A. Korving).

5.5.1 Vessel requirements

In the risk evaluation (Rozemeijer et al., 2020) it was agreed between Eneco and the Win-Wind project that the vessel had to be under IMCA certification

5.5.2 Safety zones in PAWP OWF

Safety zones have been agreed between Eneco and the Win Wind project (Table 5, Figure 12, Rozemeijer et al., 2020)). The strings have been planned to be placed such that the buoys will least hamper the crew transport vehicle (CTV) routes.

Table 5: detailing the safety boundaries as agreed between Eneco and the project Win-Wind as shown in Figure 12 (Rozemeijer et al. 2020).

What	**Color**	**Legenda**
0-50 m circle Monopile	Red	No Go area
50-100 m cirkel Monopile	Orange	No Anchor area
0-150 m CTV approach zone	Dark orange	No buoys no anchor area
150-200 m CTV approach zone	Orange	No Anchor area
Cable	Purple	Cable
100 tot -100m zone around cable	Orange	No Anchor area

[7] Staatscourant 2019, 50033 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)

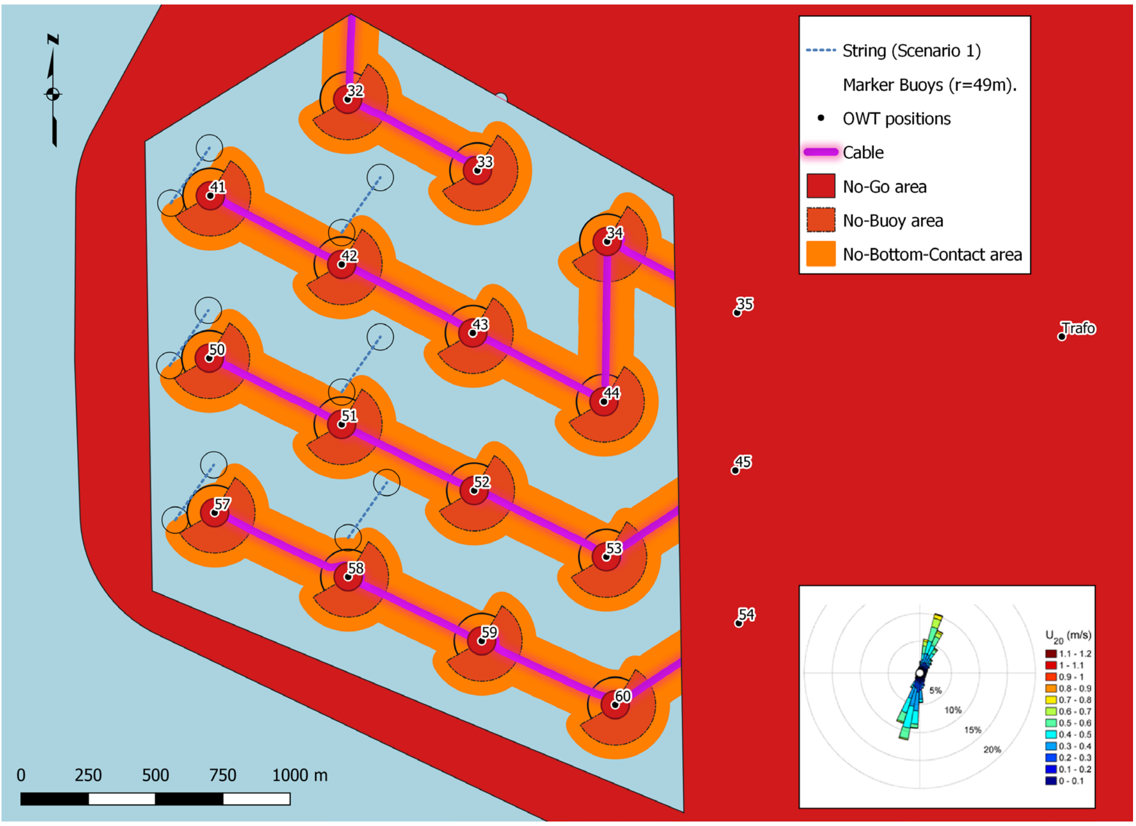

Figure 12: Chosen scenario for passive fishery string deployment, south western area assigned, safety zones colored in: black dot: monopile; purple line: electricity cable; Red area: No-go area for everything; Dark Orange area: No Buoy area: CTV approach no entry zone where no buoys or chains on the bottom are allowed. Ships are allowed to maneuver. Light orange area: No-Bottom-Contact Area: no chains or strings on the bottom allowed, buoys and ships can enter the area. Strings will be positioned on the opposite side of the CTV approach zones. Blue dotted lines: strings with cages to catch crabs. Circles: potential movement of buoys and dahns[8]. The vertical axis is the North : South axis of the compass rose. The inset at the right side is the current compass rose at -20 m (year overview at a location nearby, from Caires and Pathirana (2019)). Total figure from Rozemeijer et al. (2020).

5.6 Other OWF cases

Other OWFs may have a different policy: the OWF operator regulates the access to monopile and infield cable in a certain zone of several 100’s m. The competent authority determines access to the remaining area of the OWF and allows for multi-use. Most likely a 250 m safety safe around monopile and infield cable will be maintained (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). Assuming 1 km between monopiles it can be calculated from Table 1 how many pots and strings can be place in the available area between turbines (Figure 13). For optimal maneuverability of the ship the strings are deployed in the direction of (parallel to) the current. This positioning is crucial in OWF’s where there is generally less space to maneuver.

8 Dahn: end marker buoy with a mast having a height of at least 1,5 meters above the sea level measured from the top of the float. The top has one or two rectangular flag(s) indicating north and south extremities of the same net respectively.

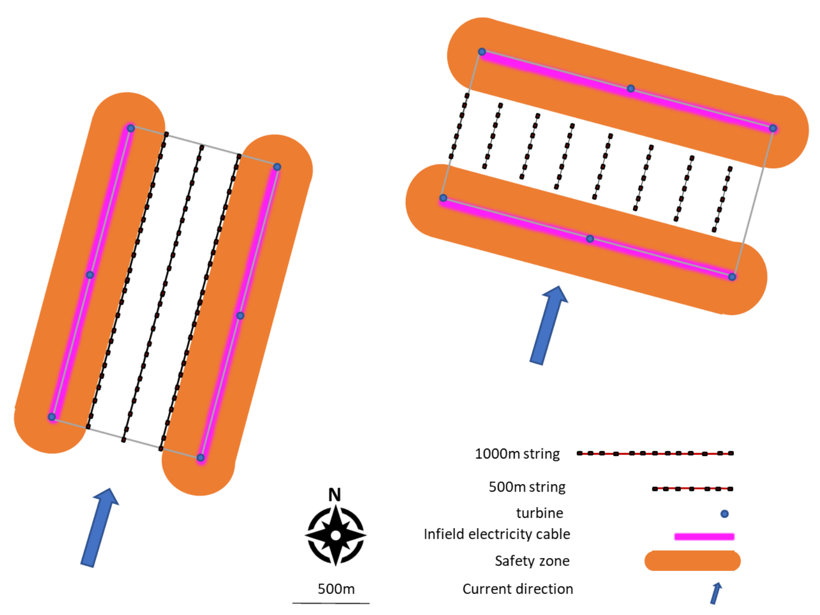

Figure 13: Schematic presentation of a 2 km^2 area with 6 turbines, including a 250m safety zone around the turbines and infield electricity cables. Two options for the deployment of pots on strings low-impact crab fisheries are shown, depending on the positioning of the infield electricity cables according to the current (left parallel and right perpendicular to the current).

Depending on the direction of the current and the positioning of the infield cables (either parallel or perpendicular to the currents), two different scenarios can be calculated. In situation 1 the effective space for the length of the string is 2000m and in situation 2 this is 500m. Assuming 25m water depth, 2*water depth spacing between pots, 3*water depth between dahn and anchor and 25m between anchor and first pot, 37 pots can be placed when infield cables are parallel to the prevailing currents and 7 pots when infield cables are perpendicular to the currents (Table 6).

Next variable is the spacing between the strings. Assuming 250 m between strings starting directly next to the border of the safety zones yields three strings and 111 pots in total for the situation with the infield cables parallel to the currents and 5 strings and 37 pots for the situation perpendicular to the currents (Table 6). A distance of 250m between the strings is already close (Table 1). Also strings spaced closer together could be applied and whether these are effective enough to be profitable are interesting follow-up questions that need to be further developed. When tackling this it is crucial that the various regulations that currently apply in wind parks are understood as well as the possibility that these regulations are modified in the future. In addition the direction of the current and factors such as spacing between pots and strings need to be taken into account.

Table 6: Data used for calculations of the number of pots, assuming independent 2-km² areas or cells for the parallel to the current infield cables and serried area for perpendicular 2-km² cells.		
	m	n
Water depth	25	
dahn-anchor-line	100	2
Distance between pots	50	
Spacing between strings	250	
Infield cables parallel to currents		
Available length	**2000**	
Available length - anchor line	1800	
Pots (available length/50)		37
Strings		3
Total pots per 2-km² Box		111
Cells of 2-km² (1000 pots)		9.0
Km² total (1000 pots)		18
Infield cables perpendicular to currents		
Available length	**500**	
Available length - anchor line	300	
Pots (available length/50)		7
Strings		8
Total pots per 2-km² Box		56
Cells of 2-km² (1000 pots)		17.9
Km² total (1000 pots)		36

Assuming a 1000 pots as a starting point for first calculations (comparable to the amounts of fisherman 1 and 2), 18 to 36 km² (or 9 to 18 2-km² areas) are needed depending on orientation of infield cables towards the tidal currents. When the 2-km² areas are serried (pressed closely together) in the case of parallel infield cables, strings could be longer (e.g. 50, Table 1) resulting in less surface needed. Areas that are not adjacent would lead to less surface in the perpendicular case.

Innovative design and lay-outs of future OWF's that are more spacious may allow for more multi-use opportunities in terms of low impact fisheries. For example wider corridors for low impact fisheries could be incorporated into the OWF design. Another option is to have all cables (both infield and export cable) obligatory parallel to the prevailing tidal currents. On the other hand such adaptations will lead to more expensive designs e.g. to more infield cables whereas one wonders if this can be counterbalanced with the revenues of fisheries. Spill-over crab populations from wind farms also offer opportunities for low impact fisheries in close vicinity of wind farms. A combination of wider corridors and extra scour that is strategically positioned around the wind farm which may offer connectivity for the crabs, has the potential to open up opportunities for passive fisheries. Artificial reefs are also a costly option that might be worthwhile if the removal obligation of all construction, including the potential artificial reefs (after license has expired) is released. A better understanding of the population size of the target species and technical challenges involved with low impact fisheries under OWF regulations are needed to update current cost-benefit analyses (Strietman et al., 2022) of various scenario's and designs. This however is not within the scope of the current desk-study.

5.7 Low impact method of choice in OWFs

Although there is a lack of reported experience of potting within OWFs, the passive fishing method of choice when it comes to low impact fishing for brown crab and lobster in OWFs appears to be fishing with creels or pots, mainly because this is the method that is most applied by fishermen (Bannister, 2009). The main advantages are that bycatch is limited and the pots are not prone to damage unlike the more vulnerable fykes (also see Table 7). Gill nets are unsuitable to catch brown crab because the crabs get stuck in the nets and can cause a lot of damage (pers. com. Rems Cramer). The amount of creels or pots used for fishing depends on the capacity of the boat and crew and the regulations in relation to fishing in OWFs (such as vessel size, minimum distance to be kept in between turbines and vessel, means of anchoring if allowed). When brown crab is targeted single chamber pots (24 or 26 inch) are preferred using large bait bags so the pots can be left out to fish for longer periods of time. Lobsters are caught as a bonus but not specifically targeted. In the UK a parlour pot (see Figure 7) is preferred when lobster is targeted since the extra chamber of a parlour pot prevents escapement of the lobster.

Table 7: Overview of the suitability of passive fishery methods to catch brown crab and European lobster.

Gear type	**Catch efficiency**	**Robustness**	**Bycatch**	**Deployment**
D-shaped creel	Targets brown crab	Not prone to damage	Low	1-2 weeks
Parlour pot	Often preferred for lobsters	Not prone to damage	Low	
Inkwell pot	Bigger crabs	Not prone to damage	Low	
Fyke		Prone to damage	High	
Gill net		Medium prone to damage but prone to damage from brown crab	Low	Loses efficiency when currents are strong, can only be deployed in good weather conditions, labour intensive

6 Conclusions and recommendations

The potential for successful colonization of especially brown crabs in Dutch OWFs seems high (Krone et al., 2017, Stelzenmüller et al., 2021, Tonk and Rozemeijer, 2019), on the other hand serious doubts have been expressed based on the distribution derived from the BTS and SNS surveys (on the sandy seabed). CPUE and LPUE data from inside the OWFs are needed to yield more insight (in preparation for Borssele II and PAWP, Rozemeijer, in prep.). The low population density of European lobster may require population enhancement strategies to increase harvest potential. The passive fishing method of choice in terms of low impact fishing for brown crab and lobster in OWFs appears to be fishing with creels or pots (61 to 66cm). The main advantages are that bycatch is limited, the traps or pots are less prone to be damaged by currents etc. compared to fykes and gill nets and this type of fisheries is not as labor intensive as fishing with gill nets.

The application of low-impact fisheries such as potting for brown crabs and European lobster is technically possible within certain OWFs. The access depends on the policy. For the Borssele II policy, the OWF operator regulates access to the 250m radius area around monopiles and infield cables. The legal authority determines access to the remaining area of the OWF which allows for multi-use, regulated by the area passports (see e.g. footnote 6). However the space available between the designated safety zones around the OWF related objects determines if the scale of fisheries is economically feasible and whether an adjusted form such as shorter strings and/or pots spaced closer together is needed. In PAWP the available space is limited (Figure 12). In Figure 13 the strings are placed closer together then usual (250m instead of at least 800m apart). The scale and design of such fisheries need further attention, not only regarding the economic feasibility but also when taking into account uncertainties regarding population stock density, safety, gear retrieval under adverse weather conditions, insurance and liability are important factors of concern when it comes to the feasibility of passive fisheries in OWFs. Strietman et al. (2022) made first calculations on an earning model for passive fisheries in an OWF with a sandy bottom that is 20 nautical miles (more than 37 km) from a port. Assuming similar low amounts of landable brown crab as in Rozemeijer et al. (2021) for wrecks near Scheveningen a high price per kg is necessary to have a viable enterprise. E.g. using the assumptions in Strietman et al. (2022) a price of > € 3 /kg is necessary for break even when catching an average 2kg landable brown crab/pot/week.

Keeping in mind that every OWF is different, various options or case studies on feasibility of passive fisheries in OWFs should be considered with a clear overview of the requirements for fisheries, local, ecology, OWF-operators and Legal Authority to operate safely and efficiently. In addition innovative design options of OWF need to be explored to enhance opportunities for passive fisheries perhaps through the lay-out of the monopiles in the park (distance between monopiles, positioning towards the current) or monopile scouring adaptions with more crevices at the seizes of ~≥27 cm (commercially interesting lobsters) or extra artificial reef. E.g. cables could be above the seabed in beds of stone. This might reduce vulnerability, reducing uncertainties on infield-cable maybe being washed out during storms and at the same time offer habitat, shelter and extra food for target species like brown crab and lobster. Although one wonders what are the costs of such design adaptions versus the revenues of the fisheries. It could however be obligatory OWF design criteria as a result of a broad integrating discussion on the spatial planning of the North Sea, the future of Wind on the North Sea and the future of fisheries and fishing as a potential sustainable source of food and proteins. It is important to realize that fishing in OWFs cannot be seen as an alternative to trawling. It is mainly a complementary form of small-scale fishing for a small group of fishermen.

6.1 Recommendations:

1) Passive fishery using pots on strings targeting brown crab has potential in OWFs. It has low risk to turbines and cables, although the exact risks and measures to reduce risks need to be further explored.

2) Passive fisheries targeting European lobster in OWFs will most likely require population enhancement strategies to increase harvest potential. Research is needed to define the best strategy. Preferably brown crab is taken in account as well.

3) In addition, CPUE, LPUE data and population estimates from inside the OWFs need to be determined for brown crab, European lobster and also velvet swimming crab, to assess the viability of this proposed form of multi-use of OWFs. A first review on CPUE and LPUE alerts that enhancement strategies like artificial reefs might be wanted in the future.

4) Further detailing is needed to answer follow-up questions regarding how alternative fishing designs of brown crab and European lobster could be applied in OWFs and whether these designs are effective enough to be profitable. This may vary per OWF and also per fishery depending on the boat and scale. Case studies are recommended including insight of various stakeholders (fisherman, OWF operators) and coupling this information with earning models. When tackling this it is crucial that the various regulations that currently apply in wind parks are understood as well as the possibility modify these regulations in the future.

5) Another option is to alter the design and lay-out of future OWF that are more spacious to allow for more multi-use opportunities in terms of low impact fisheries. And also infield and export cables could be aligned parallel to the currents. Again it is crucial that requirements both for fisheries and windfarm operators to operate safely and efficiently are well understood at an early stage. Workshops in which information from the various desk studies within this project on ecological and economic feasibility are coupled to requirements for fisheries and windfarms leading to a short-list of potential modifications to windfarm designs are suggested as part of this process. Next the options could be detailed and evaluated by additional research. A few examples are:

    a. Wider corridors for passive fisheries could be incorporated into the OWF design.
    b. Artificial reefs to increase number of shelters and biomass production.
    c. Artificial reefs can be arranged such that they have extensions leading outside an OWF. Spill-over of crab populations can potentially be harvested from the external extensions, thereby offering opportunities for passive fisheries in close vicinity of OWFs but not in OWFs. This could lead to considerable reduction in risks. Design and ecological and economical yield should be investigated to optimise this option.
    d. A combination of wider corridors and extra scour that is strategically positioned around the OWF which may offer connectivity for the crabs, has the potential to open up opportunities for crab fisheries.

6) Regulations: A point of attention is the scale at which crab fisheries are currently occurring north of the Netherlands from the Texelse Stenen throughout the German Bight. With no pot limits or regulation other than Minimum Conservation Reference Size (MCRS) there is a potential to exhaust brown crab population densities in this area, with potential impacts for crab populations in the Dutch part of the North Sea (Joint MAC-NSAC-NWWAC ADVICE, 2021). This becomes more urgent since a few more Dutch fishermen are investing in crab fisheries. Also investors from the UK and Ireland are coming to the Netherlands to locate vessels under Dutch flag since local crab populations are declining. The exploitation rate of female crabs is high in the southern part of the North Sea and high for males in both the southern and central part of the North Sea (CEFAS, 2020). Anecdotal reports suggest a recent expansion of fishing activity in pot number and distribution in these areas (CEFAS, 2020). In addition ICES WGCRAB and Joint MAC-NSAC-NWWAC ADVICE (2021) noted that habitats for

brown crab are shifting and populations seem under strain. High resolution data on brown crab are lacking from Netherlands. It is advisable to start stock assessments for the DCS based on Dutch landings and data. The data can be used to evaluate the necessity for regulation.

7) Concerning vessel safety requirements more research is needed to define an acceptable level of safety requirements for the fishery vessel. In principle the ILT inspection is sufficient to ensure safe fishing trips for ships of ≥12 m. However the environment in OWFs is more complicated and risky than open sea due to OWF objects, daily maintenance and other OWF operations in an unpredictable, harsh environment. For ships <12 m ILT inspection and licensing is still an open issue. Research is needed to define to an acceptable level of vessel safety requirements for both OWFs, regulating authorities and low income low capital fishermen.

8) The velvet swimming crab (*Necora puber*) or spider crab (*Maja brachydactyla*) are mentioned as potential species to include in a future feasibility assessment in OWFs (Bogaart et al. 2019). Rozemeijer et al. (2021) caught alike numbers velvet swimming crab to brown crab near wrecks in the same zone as PAWP. Also in Borssele II interesting numbers of velvet swimming crabs are caught (Rozemeijer, personal observations). More research is needed to the potential of velvet swimming crab as extra commercial source of income.

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8 Quality Assurance

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

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Justification

Report C050/22
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: Ralf van Hal
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