Norwegian University of Life Sciences

Master's Thesis 2019 60 ECTS
Faculty of Environmental Sciences an Natural Resources Management

Ghost fishing: the spatial extent of gear loss and effects on marine animal life along the Norwegian coast

Ingrid Disch Løset
Biology

Ghost fishing: The spatial extent of gear loss and effects on marine animal life along the Norwegian coast

Ingrid Disch Løset

Forord

Denne masteroppgaven symboliserer avslutningen på min mastergrad i biologi ved Norges miljø- og biovitenskapelige universitet (NMBU). Oppgavens omfang utgjør 60 studiepoeng og ble skrevet høsten 2018 og våren 2019.

Min interesse for livet i havet og engasjement for miljøet har vært en viktig drivkraft gjennom de mange arbeidstimene som er lagt ned i denne masteroppgaven. Jeg ble først kjent med «ghostfishing»-begrepet det første året av min mastergrad, ved utvekslingsoppholdet i Australia. Omfanget og konsekvensene av tapte fiskeredskaper er en stor trussel globalt, men lite undersøkt i norske farvann. Da denne problemstillingen ble presentert som en mulig masteroppgave, var valget derfor ikke vanskelig.

Først og fremst så vil jeg rett en stor takk til Havforskningsinstituttet i Flødevigen som ga meg muligheten til å bo i huset under feltarbeidet med masteren. Jeg vil også takke for at jeg fikk muligheten til å skrive en særdeles spennende oppgave om et tema som engasjerer både meg og tusenvis av andre haventusiaster der ute. Stor takk til min hovedveileder Thrond Haugen ved NMBU for god veiledning og for ha hjulpet meg til å forstå statistikkens skjulte finesser og selv de mest komplekse ZIP modeller. Jeg vil også takke veilederen min Alf Ring Kleiven ved HI som til tross for forskningspermisjon på andre siden av kloden, har gitt meg god veiledning underveis. Jeg vil spesielt trekke frem muligheten jeg fikk til å besøke Fiskeridirektoratet i Bergen for å bidra i arbeid med «Fritidsfiske-appen» i samarbeid med HI og Norges dykkerforbund. Videre vil jeg rette en stor takk til Terje Jørgensen ved HI i Bergen som har bidratt med gode faglige innspill mot slutten. Jeg vil også rette en stor takk til Tord Aslaksen i «Green Bay Project» for å ha tatt bistått med feltarbeid til min masteroppgave og for å ha tatt meg med ut på «spøkelsesteinejakt» i den vakre skjærgården i Lillesand. Innsatsen som legges ned i de mange opprydningsaksjonene samt de enorme funnene av tapte fiskeredskap, har vært en viktig inspirasjonskilde.

Til slutt vil jeg takke familie og venner som har vært gode støttespillere underveis. En spesiell takk til mine foreldre som har vist stor støtte, gitt gode råd og ikke minst ha holdt ut med ett års snakk om tapte fiskeredskaper rundt middagsbordet.

Takk for 5 fine år NMBU. Klarer jeg dette – ja da klarer jeg alt!
Oslo, 14.05.19
Ingrid Disch Løset

Abstract

Derelict fishing gear, often referred to as abandoned, lost or otherwise discarded fishing gear (ALDFG), is one of the major contributors of the worldwide marine debris problem and has been recognized as a source of serious biological and socio-economic problems worldwide. Modern fishing gear are made of non-degradable synthetic materials that may persist in the marine environment for long periods of time, hence they may pose a great threat the marine wildlife as they can continue to fish for decades although all control of the gear has been lost by the fisher. This phenomenon is known as “ghost fishing” and may occur when animals get accidentally entangled in nets or confined in pots or traps. There is currently little knowledge about the extent of gear loss and the issue of ghost fishing in coastal fisheries, which is mainly a result of the reluctance of fishers to report such incidents and the efforts in undertaking long term studies. In Norway, this problem has received increased public attention through a citizen science project, where local diving clubs has contributed to research through trap clean-up events. Through this project, divers have reported large amounts of data on lost fishing gear retrieved from the Norwegian coast during the period 2015-2018. By analysing the submitted diving report forms, the objectives of this study were to examine the extent and geographical distribution of lost fishing gear from the coastal fishery in Norway. Secondly, this study estimated the ghost fishing catch rate and catch composition, as well as the impacts of ghost fishing on marine animal groups, focusing on the European lobster (*Homarus gammarus*). Furthermore, the captures were modelled to investigate whether gear type and different environmental variables could affect the ghost fishing catch rate.

A total of 4128 lost fishing gear were retrieved by divers during clean-up efforts in the period 2015-2018. Of these, 3456 (84 %) were traps, 461 fyke nets (11 %) and 211 gillnets (5 %). Folding traps (44%) was the most frequently found gear type, followed by 871 other traps (21%) and 794 parlour traps (19 %). The geographical distribution of lost fishing gear was significant different among regions, with the largest number of gear retrieved from the south-eastern coast (n=2045), which indicated that this region might be a “hot spot” for accumulation of gear loss. The analysis of ghost fishing catch estimated that 29 % of the retrieved gear contained animals. This suggested that lost fishing gear may actively ghost fishing in the shallow waters along the Norwegian coast. In total, 3779 crabs, 1406 fish and 160 lobsters were caught by different fishing gear, with mean catch ranging from 0.62-3.09 animals/per gear. Parlour traps had an average catch of 2.09 crabs, 0.12 lobster and 0.88 fish per trap and had the highest relative occurrences of catch (52 %) of all gear. These findings

suggested that parlour traps may have a greater impact on animals and become less selective when lost. Although gillnets were less represented in numbers, 41 % contained animals. Gillnets also had the greatest average catch of crabs (2.27 crabs/gear). Of all gear types, folding traps contained the least numbers of animals (15 %) where each trap captured on average 0.62 animals/trap, which suggested that folding traps are more a source of litter than a ghost fishing problem.

Furthermore, the analysis of factors influencing the ghost fishing catch rate showed clear differences in catch rates among lobsters, crabs and fish depending on gear type, depth, substrate and bottom slope. Significant interaction effects between many of the variables indicated that the combinations of these factors are important factors influencing the ghost fishing catch rates. Catch of lobsters was estimated to be influenced by several factors such as gear type, substrate, bottom slope and depth. Interaction effects between substrate and depth, suggested that the depth effect was dependent on the level of substrate, yet this was not statistically significant. Folding traps had the largest catch of all trap types, with a maximum a catch rate of 3-4 lobsters at middle depths on boulder and rock substratum. Although, the maximum catch rate is likely to be overpredicted due to noise in the data, these findings could reflect their habitat preference and therefore the locations where lobster traps are usually set for fishing. Furthermore, the probability of catch (given no occupants) was nearly 90 % in parlour traps found on rock substrate and flat slope, while folding traps had a low probability of catch. Differences between the predicted catch and probability of catch made the interpretation difficult, but could indicate that the ghost catch of lobsters also depends on the presence of occupants in the trap.

To date, there have been no studies investigating the extent of gear loss and the possible impacts of ghost fishing on marine animals in the coastal fishery in Norway. This study provides a good basis for further ghost fishing studies in this fishery. Although, a lot of noise in the data may have biased some of the analysis, the results showed clear tendencies that ghost fishing catch rate vary depending on gear type and environmental factors. Furthermore, the interaction effects revealed that the factors behind this pattern might be complex. Gaining knowledge about the extent of gear loss and the problem of ghost fishing is important for fisheries management, as ghost fishing is a major threat for fisheries, fish stocks and marine ecosystems.

Sammendrag

Tapte fiskeredskaper er en av de større bidragsyterne til verdens marine forsøplingsproblemer og de er blitt anerkjent som en kilde til alvorlige biologiske og sosio-økonomiske problemer over hele verden. Moderne fiskeutstyr er produsert av ikke-nedbrytbare syntetiske materialer og kan utgjøre en stor trussel for det marine dyrelivet ved at det kan fortsette å fiske i mange år selv om utstyret er gått tapt for fiskeren. Slikt «spøkelsesfiske» kan oppstå når dyrene vikles inn i garn eller fanges i teiner. Det er idag lite kunnskap om omfanget av redskapstap og problemer med spøkelsefiske i kystfisket. Dette skyldes i hovedsak at det er lite rapportering av slike hendelser samt at det er krevende å gjennomføre langsiktige studier på temaet.

I Norge er dette problemet gitt økt oppmerksomhet gjennom et prosjekt der lokale dykkerklubber har bidratt til forskning ved å rydde og rapportere om tapte fiskeredskaper. I dette prosjektet har dykkere innrapportert betydelige data på funn av tapte redskaper langs Norskekysten i perioden 2015-2018. Ved å analysere skjemaer utfylt av dykkerne, har målet for studien vært å undersøke omfang samt geografisk fordeling av tapte fiskeredskaper fra kystfisket i Norge. Dernest, å anslå et estimat på fangstrate og fangstfordeling av spøkelsesfiske samt å vurdere hvilke virkninger dette har på marine dyregrupper, med hovedfokus på europeisk hummer (*Homarus gammarus*). Videre ble fangstraten modellert for å undersøke om redskapstyper og ulike miljøvariabler kunne påvirke fangsten i spøkelsesfiske.

Totalt 4128 tapte fiskeredskaper ble funnet av dykkere under oppryddingsarbeider i perioden 2015-2018 fordelt på 3456 teiner (84%), 461 ruser (11%) og 211 garn (5%). Sammenklappede teiner (44%) var den redskapstypen som ble hyppigst funnet, etterfulgt av 871 i kategorien andre teinetyper (21%) og 794 skotteteiner (19%). Den geografiske fordelingen av de tapte fiskeredskapene var signifikant forskjellig mellom regioner, med største antall funn på sør-øst kysten (n = 2045). Dette kan indikere at denne regionen er et betydelig oppsamlingsområde for tap av fiskeredskap. Ut i fra analysene av fangstrate i spøkelsesfiske ble det anslått at 29% av fangstredskapene inneholdt dyr. Totalt 3779 krabber, 1406 fisk og 160 hummer ble fanget av ulike fiskeredskaper, der gjennomsnittlig fangstrate varierte fra 0.62-3.09 dyr/per redskap. Skotteteiner hadde en gjennomsnittlig fangst på 2.09 krabber, 0.12 hummer og 0.88 fisk per teine med høyest relative forekomst av fangst (52%) sammenliget med andre redskaper. Selv om garn var mindre representert i antall, ble det registrert dyr i 41 % av disser. Garn hadde i tillegg høyest gjennomsnittlig fangst av krabber

(2.27 krabber/garn). Av alle redskapstypene inneholdt de sammeneleggbare teinene minst antall dyr (15%), der hver teine fanget i gjennomsnitt 0.62 dyr/teine, som kan indikere at denne teinetypen er mer en kilde til søppel enn å ha effekt på spøkelsesfiske.

Analysene av faktorer som påvirker fangstratene viste klare forskjeller i fangstrate mellom hummer, krabber og fisk avhengig av redskapstype, dybde, substrat og helningsvinkel på bunnen. Signifikante interaksjonseffekter mellom mange av variablene indikerte at kombinasjonene av disse faktorene er viktige faktorer som påvirker fangstraten. Fangst av hummer ble anslått å være påvirket av både redskapstype, dybde, substrat og bunnskråning. Interaksjonseffekter mellom substrat og dybde, antydet at dybde-effekten var avhengig av helningsvinkel, men dette var ikke statistisk signifikant. Sammenleggbare teiner hadde den største fangsten av alle teinetypene, med en maksimal fangstrate på 3-4 hummer ved middels dyp på hardbunn. Selv om den maksimale fangstraten trolig er overpredikert på grunn av feilkilder i dataene, kan disse funnene reflektere habitat preferanse og områder hummerteiner vanligvis plasseres. Videre var sannsynligheten for fangst (gitt at det ikke var andre dyr) nesten 90% i skotteteiner funnet på steinete substrat og slak skråning, mens sammenleggbare teiner hadde en lav sannsynlighet for fangst. Forskjellene mellom den estimerte fangsten og sannsynligheten for fangst gjorde tolkningen vanskelig, men det kan tyde på at fangstraten på hummer også er avhengig av forekomst av andre dyr i teina.

Hittil har det ikke vært noen studier som har undersøkt omfanget av redskapstap og potensielle virkninger av spøkelsefiske på marine dyr i kystfisket i Norge. Denne studien gir et godt grunnlag for videre studier av spøkelsefiske. Selv om feilkilder i dataene kan ha virket inn på analysene, viste resultatene klare tendenser til at fangstraten i spøkelsesfiske varierer avhengig av redskapstype og miljøfaktorer. Videre indikerer interaksjonseffekter mellom disse faktorene at mekanismene som styrer spøkelsesfiske kan være komplekse. Å skaffe kunnskap om omfanget av redskapstap og spøkelsefiske er viktig for fiskeriforvaltningen, da spøkelsefiske er en trussel for fiskerier, fiskebestander og marine økosystemer.

Contents

1 Introduction

Derelict fishing gear, here referred to as abandoned, lost or otherwise discarded fishing gear (ALDFG), is one of the major contributors of the worldwide marine debris problem and has been recognized as a source of serious biological and socio-economic problems worldwide (Breen, 1989; Brown et al., 2005; Gilman, 2016). An estimated 6.4 million tonnes of marine debris are added to the global marine environment annually, of which ALDFG accounts for 10 % of the total volume (Brown & Macfadyen, 2007; Brown et al., 2005) The extent of lost fishing gear in the world's oceans has increased significantly over the years, as a result of increased fishing activity and transition to more modern gears made of non-degradable synthetic materials (e.g. plastics and stainless steel) (Breen, 1989; Gilman 2016). If these fishing gears are lost or discarded at sea, they can persist in the marine environment for long periods of time, posing a prolonged threat to the marine life, as a source of litter, entanglement or capture by traps (Brown & Macfadyen, 2007). ALDFG may also cause economic losses for fishers through loss of gears and lost catch of valuable species and create navigational hazards in areas with heavy boat traffic (Macfadyen et al., 2009).

Fishing gear may be abandoned, lost or discarded for several reasons, both intentionally and unintentionally. Gear conflicts is the main reason of loss and may occur if gear that is set for fishing becomes snagged on the seabed (Adey et al., 2008) or towed away by active gears or passing vessels (Pawson, 2003). Fishers may also lose gear if the marker buoys are cut off by storms, strong currents, propeller strikes or ice (Breen, 1989; Bullimore et al., 2001; Godøy et al., 2003). Bad designs and materials, improper fishing methods, inadequate maintenance or intentionally theft or vandalism can also lead to gear loss (Adey et al., 2008; Breen 1989; Humborstad et al., 2003; Pawson, 2003). Furthermore, gears may be abandoned or discarded intentionally, often if they are too difficult or time consuming to retrieve (Brown et al., 2005; Santos et al., 2003). Gear may also be abandoned if bad weather conditions makes the retrieval process to dangerous (Gilman, 2016).

One major problem resulting from ALDFG is their potential to continue to catch commercially and non-commercially important species such as fish, crustaceans, sea birds, marine mammals (Brown & Macfadyen, 2009), and even endangered species such as turtle (Wilcox et al., 2014). This phenomenon is known as "ghost fishing" and is defined as the ability of fishing gear to continue fishing after all control of that gear has been lost by the fisherman (Smolowitz, 1978). Ghost fishing is considered as one of the most serious negative impacts of the capture fisheries (FAO, 1995) and may have severe impacts on both target and non-target species (Adey et al., 2008). It is often related to static fishing gears including gillnets, trammel nets, pots and traps, that are left to fish passively on the seabed (Adey et al., 2008; Jennings & Kaiser, 1998). Little is known about the extent and frequency of lost static gears and for how long these are likely to fish. This is mainly a result of the reluctance of fishers to report such incidents and the efforts in undertaking long term studies (Pawson, 2003). The annual losses appear to be substantial (Jennings & Kaiser, 1998). For example, approximately 50 000 blue crab traps were lost per year in a commercial blue crab (*Callinectes sapidus*) fishery in Lousiana (Guillory, 1993). However, the estimates on the loss of gears varies greatly between studies (Bilkovic et al., 2014; Bullimore et al., 2001). Studies from the North American Bristol Bay king crab (*Paralithodes camtschaticus*) fishery have highlighted the difficulties of estimating trap loss, reporting significant variations in estimates ranging from 7000 to 31 600 lost traps per year (Kruse & Kimker, 1993; Stevens, 1996). Another study reported an annual loss of 11 % of the traps used in the Dungeness crab (*Cancer magister*) fishery in British Colombia (Breen, 1987). Furthermore, for the American lobster (*Homarus Americanus)* fishery, it was estimated an annual loss of 20-25 % of all traps (Sheldon & Dow, 1975). Gaining knowledge about the extent of lost gears and the problem of ghost fishing is important for fisheries management, as ghost fishing is a major threat for fisheries, fish stocks and marine ecosystems worldwide (FAO, 1995)

The phenomenon of ghost fishing first gained global recognition at the 16th Session of the FAO committee on Fisheries in April 1985 (Brown & Macfadyen, 2007). The "Code of Conduct for Responsible Fisheries" (FAO, 1995) later recognized the problem as a serious negative impact for the worlds capture fishery and recommended that states should implement appropriate technological measures to prevent the loss of fishing gear and the subsequent ghost fishing. Until this period, most research on ghost fishing were undertaken in the waters of North America, mainly concerning the loss of enmeshing gill nets (Carr et al., 1992; Carr and Cooper, 1985; Pawson, 2003). As the effects of ghost gear became a significant concern in European waters around the mid-1990s, the European Commission funded studies to investigate the problem on commercial fishing grounds that covered several European countries (Brown & Macfadyen, 2007; Pawson 2003; Sancho et al., 2003). The FANTARED I project ("ghost net" in Spanish) were carried out in order to investigate the extent, impacts and potential causes of lost gears in shallow waters. The FANTARED II project studied the impact of deliberately and naturally lost gillnets in deeper waters (Santos et al., 2003). It was concluded that the fishing efficiency varied between fisheries (depth, gear design, habitat type) and that the unaccounted mortality caused by ghost fishing were relatively low in these fisheries (>10%) (Pawson, 2003).

Research on lost gillnets has been undertaken in Norway for about 40 years. The Norwegian Directorate of Fisheries (DOF) has conducted annual retrieval cruises on commercial fishing grounds along the Norwegian coast in since 1980 (Humborstad et al., 2003). Through this effort approximately 20 000 gill nets have been removed from commercial grounds off the Norwegian coast between the period 1983-2016 (Grimaldo et al., 2018). The conclusion from these surveys is that the unaccounted mortality by lost gillnets may have significant effects in some fisheries (Huse, 2003). This is the case for the Greenland halibut (*Reinhardtius hippoglossoides*) fishery in Norway, where ghost catches have been substantial and gillnets has been observed fishing for 8 or more years (Humborstad et al., 2003). A recent retrieval survey in 2017 along the Norwegian coast retrieved 850 gillnets and 150 king crab traps containing about 10 000 kg of various fish species and 5600 kg of crabs (CNO, 2017a). Furthermore, it is likely that the ghost fishing mortality rate might be underestimated as dead animals will decay over time. To reduce the risk of ghost fishing by lost traps, the Norwegian authorities introduced the requirements that all traps set for fishing should have at least one escapement hole attached with a cotton wire, that within a given time-period would rotten, allowing trapped animals to escape (Forskrift om utøvelse av fisket i sjøen, 2018, Vedlegg 8. Krav til rømningshull). The use of biodegradable materials has also been suggested as a potential solution to the ghost fishing problem (Grimaldo et al., 2018). However, the issue of ghost fishing by lost traps has been poorly investigated in European waters.

Ghost fishing may occur through a range of different mechanism. Animals may get accidently entangled in lost nets or confined in lost pots or traps (Matsouka et al., 2005). However, the duration and ability to ghost catch depends on local environmental conditions. For example, gillnets that are lost in shallow areas exposed to storm activity are usually rapidly destroyed. Gears lost in shallow areas are rapidly overgrown by encrusting biota, which makes them more visible and may reduce their catch efficiency (Erzini et al., 1997). While gillnets may be set in a range of different environments, they usually follow a typical pattern with rapid declines in catch rates after a few days after deployment, as the increased weight of the catch cause the net to collapse (Brown & Macfadyen et al., 2009; Jennings & Kaiser, 1998). Then, the catch rate will stabilize over time, as the decaying bodies of fish and crustaceans will attract a large number of scavengers that might also become entangled. Thereafter, an auto-rebaiting cycle of capture, decay and attraction will continue for as long as the net remains its capture function (Jennings and Kaiser, 1998; Adey et al., 2008; Bullimore et al., 2001). Similar pattern has been observed in lost traps. For example, Pecci et al (1978) suggested that this mechanism was operating in lost American lobster traps. One particular concern is the "re-baiting" mechanism, where the trap continues fishing even after the bait is exhausted (Adey 2008, Bullimore, et al 2001, Matasuoka et al. 2005). This was evident in the United Kingdom, where lost parlour traps continued to fish months after the bait was consumed (Bullimore et al., 2001). Lost traps may also be rebaited by other species, thus attracting unwanted bycatch (Breen, 1989). Furthermore, Breen (1987) studied ghost fishing in unbaited traps and suggested that some species were attracted to live conspecifics or to the trap alone, for the use of shelter.

Several factors affect the duration, efficiency and ghost fishing potential of lost gear. The gear design and materials of the gear including whether it was abandoned, lost or otherwise discarded are important factors determining the ghost fishing potential of ALDFG. For example, escape vents in traps, that allows undersized animals to escape affect the ghost fishing potential of lost traps. The gear design is also a significant factor determining ghost fishing catch rates (Smolowitz, 1978). This was observed in the Norwegian king crab fishery, where smaller crabs tend to escape rectangular traps more easily than conical traps (Godøy et al., 2003). Lost traps have received increased concern in recent years as they tend to consist of more durable and robust materials, which do not deteriorate easily. These attributes make them likely to preserve a higher catch efficiency for much longer compared to lost nets (Jennings & Kaiser, 1998). High and Worlund (1979) reported that Alaska king crab traps consisting of metal and synthetic materials could have an effective longevity of 15 years after loss. Another study found that parlour traps targeting crabs (*Cancer pagaris*) and lobsters (*Homarus gammarus*) continued to fish for more than one year (Bullimore et al., 2001). Other studies have suggested that the fishing capacity of lost gears may depend on the amount of target species in the area, the cause of loss and the gears exposure to environmental forces (i.e. storms, currents, weather), depth, bottom type, habitat, location, biofouling (Adey et al., 2008; Brown and Macfadyen, 2009; Pawson, 2003; Macfadyen et al., 2009).

The unaccounted mortality by ghost gear, has been a particular concern in several trap fisheries. Once a trap is lost it may result in mortality for several reasons, affecting both target and non-target species (Pawson, 2003). Animals that are captured in ghost traps for longer periods of time are subject to various factors of stress, such as starvation, injuries, predation, diseases and long-time exposure to poor water quality (Guillory, 1993). Furthermore, cannibalism has also been observed in lost American lobster traps and for Dungeness crabs, which is common for moulted crustaceans (Breen, 1987; Pecci et al., 1978). Animals may also be confined in lost traps that may cause severe physical damage (Laist, 1995). Furthermore, the long-term confinement of animals in ghost gears is also a serious welfare issue, as animals may be subjected to delayed effects, such as physiological stress, injuries, reduced growth rates, behaviour changes and mortality, even after they manage to escape (Guillory et al., 2001; Godøy et al., 2003). However, the lack of estimates on ghost fishing mortality rates is of great concern to both fishers and fisheries management (Jennings & Kaiser, 1998). High levels of mortality due to ghost fishing has been reported in several crustacean fisheries (Breen 1987; Bullimore et al., 2001; Kimker, 1994). For example, Breen (1987) estimated that the ghost catch rate from lost traps accounted for 7 % of the annual landings in a Dungeness crab (*Cancer magister*) fishery. A study investigating ghost fishing in the American lobster fishery found that parlour traps led to mortalities of 12-25 % of the animals trapped (Smolowitz, 1978). In contrast, studies of red king crab (*Paralithodes camtschatica*), slipper (*Scyllarides aquammosus*) and spiny lobsters (*Panulirus marginatus*) have reported that most animals entering lost traps were able to escape (Godøy et al., 2003; High & Worelund, 1979; Parrish & Kazama, 1992). High escapement rates has also been reported in the Norwegian king crab fishery and the Norway lobster (*Nephrops norvegicus)* fishery, where the target species was the only species that remained in the trap, suggesting that these traps may be very selective for their target species (Adey et al., 2008; Brown & Macfadyen., 2007). However, incidents of bycatch of non-target species has been reported in several studies of ghost fishing (Gilman et al., 2016; Matsouka et al., 2005). For example, Bullimore et al (2001) found that parlour traps designed to catch crabs and lobsters led to the mortality of several species of crustaceans and fish when left on the seabed over time. While studies have investigated ghost fishing on several species of crustaceans, the impacts on the European lobster (*Homarus gammarus*) in Norway, is poorly investigated.

Lobster fishing has a long tradition along the Norwegian coast and extends from the Swedish border in the south to Tysfjord in Nordland in the north. The lobster fishery in Norway is dominated by recreational fishing and trap fishing for European lobster is popular among recreational fishers (Kleiven et al., 2011). A previous study estimated the recreational catch to account for 65 % of the total landings in South-Eastern Norway in 2008 (Kleiven et al., 2012). The same study estimated the trap loss from recreational and commercial fishing to be 9 % and 4 % respectively, and that approximately 2200 lobster traps were lost during that year.

Furthermore, Bakketeig et al., (2017) reported the annual trap loss to be between 5-10 % of all traps that is set during the lobster season. It is predicted that the fishing pressure from recreational fishing has increased over time, indicating that the proportion of lost gear from this fishery may be greater than previously assumed. Consequently, this may raise particular management challenges as there is currently no catch data from this fishery in Norway (Kleiven et al., 2012)

In Norway, professional fishers are obligated to attempt to recover the loss of gear. If they do not succeed, they shall report the loss to the Norwegian Coast Guard (Forskrift om utøvelse av fisket i sjøen, 2009, §78). Recreational fishers, however, are not obligated in regards of these regulations. This is problematic as the lobster fishery is dominated by recreational fishing. Gaining knowledge about this issue is necessary to make accurate stock assessment and establish sustainable fisheries management measures that could reduce gear loss and the implicit hidden exploitation. To date, there have been no studies investigating the extent of gear loss and the possible impacts of ghost fishing on marine animals in the recreational fishery in Norway.

In order to address this issue, the Institute of Marine Research (IMR) has conducted a citizen science project in collaboration with the DOF and the Norwegian Diving Federation. The project commenced in December 2015 and is still ongoing. Through the participation of local diving clubs, gear clean-ups have been carried out and data on lost gear collected using diver report forms. For every large parlour trap and other gear retrieved by a diver, the corresponding diving club receives a reward of 400 and 200 NOK respectively, on the condition that a diver report form is completed. Funding is provided by "Sparebankstiftelsen DNB" and "Plastretur". The project has received significant public engagement, where diving clubs, local clean-up organisations, and other public participants have been involved in efforts to retrieve lost gears in their local coastal community. As a result, approximately 4200 lost fishing gears have been retrieved and reported from shallow coastal areas along the Norwegian coast between the period 2015-2018. In order to collect lost gear more efficiently, the DOF also launched a smartphone app named "Fritidsfiske" (www.fiskeridir.no/Fritidsfiske/Appen-Fritidsfiske) in 2017, which allows recreational fishers and divers to record details of lost or found gear.

Using this data, the objectives of this thesis is to:

(i) examine the quantity and geographical distribution of lost fishing gear from the recreational fishery along the Norwegian coast.

(ii) estimate the ghost fishing catch and catch composition of lost gear and the effects on marine animal groups, focusing on the European lobster

(iii) reflect on environmental factors that could be potential ecological drivers influencing the ghost fishing catch.

This will be achieved by analysing diver report forms with corresponding pictures and app-data that contains information on gear type, location, environmental factors (i.e. substrate, habitat, depth), number and types of animals caught.

2 Materials and Methods

2.1 Study area

The present study is based on data collections obtained through a citizen science program, where the goal was to remove lost fishing gear from the seabed, mainly traps, along the coast of Norway. During the period 2015-2018, trap clean-ups events were conducted from Hvaler municipality (59.203998, 10.792351) in the south-eastern part of Oslofjorden, to Tromsø municipality (69.643619, 18.952856) in the north (Figure 1), enclosing the coastal waters Skagerrak, North Sea and the Norwegian sea. The Norwegian coast is characterized by numerous archipelagos, fjords, islets and skerries that together with a fragmented sea line forms a diverse coastal landscape including both exposed and sheltered areas (Sætre, 2007). The elongated coastline causes variations in local conditions that provides a gradual transition from a warm-tolerant Atlantic biota in the south, to a more cold-water-adapted subarctic biota in the north. The study area comprises a wide variety of habitats with geographical variations in topography, temperature, climate, salinity, water depth, currents and bottom type. The marine seabed varies greatly, ranging from soft bottoms of sand and mud, to hard bottoms of boulders and rocks (http://geo.ngu.no/kart/marin_mobil/). Norway has a milder coastal climate compared to other nations at the same latitude, as a result of the Norwegian coastal current, which is a branch of the North Atlantic Current, part of the Gulf stream, that flows northwards along the Norwegian coast, transporting warm nutrient-rich water from the eastern Skagerrak coast into the Barents Sea (Sætre, 2007). The study area harbours a total of 112 municipalities with people living scattered along the coast and on islands, particularly in proximity to more sheltered and shallow areas. In addition to being important recreational areas for many people, these coastal areas have a high species richness with diverse ecosystems that supports stocks targeted by both commercial and recreational fisheries.

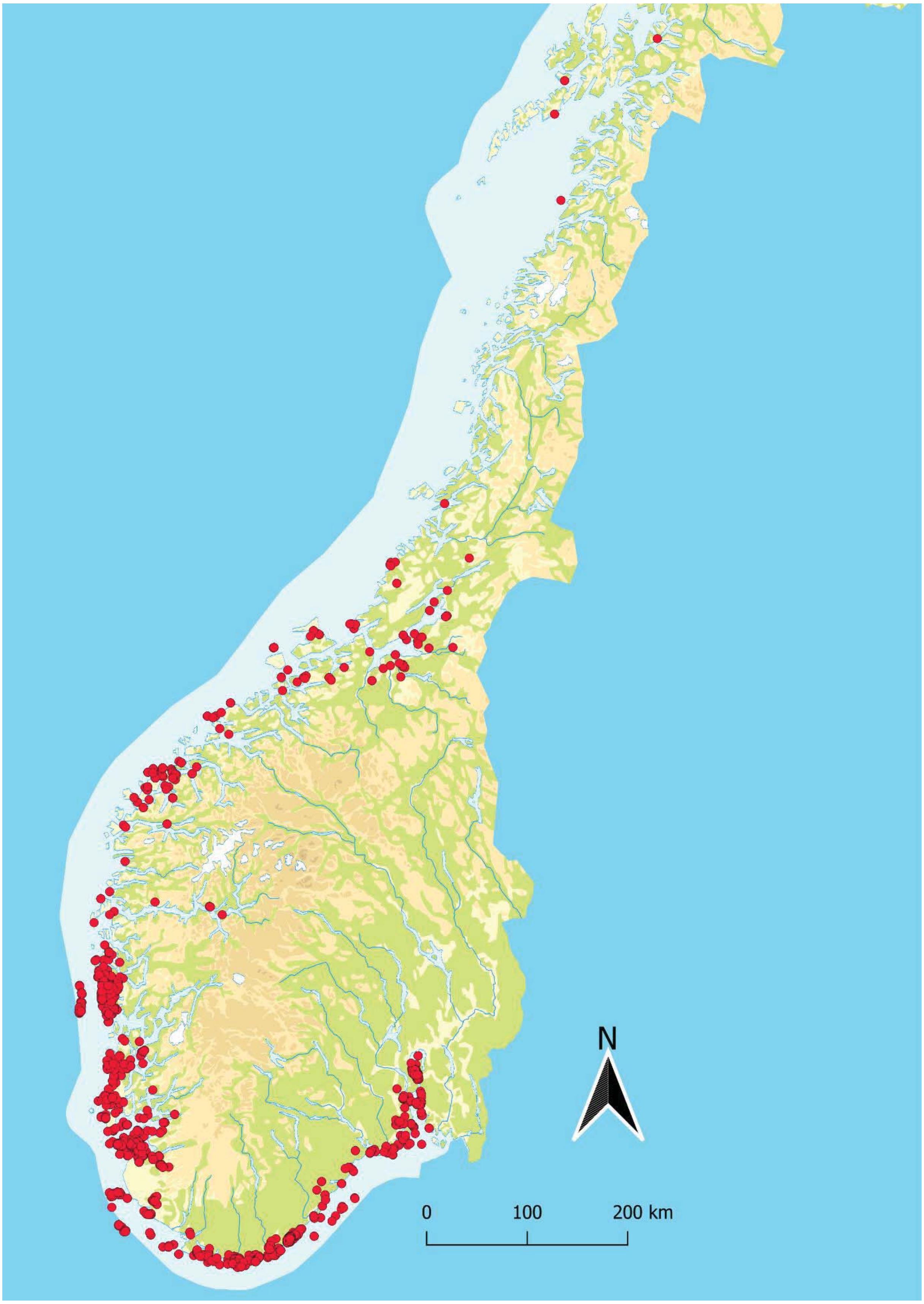


Figure 1: Map of survey areas. Position of lost fishing gear (red dots) retrieved during surveys along the Norwegian coast in 2015-2018. (n=3971).

2.2 Survey methods

The study was undertaken as a part of a citizen-science project in collaboration with the Norwegian Directorate of Fisheries (DOF), Institute of Marine Research (IMR) and the Norwegian Diving Federation. Citizen science projects relies on volunteer participation of citizens who provides information to scientific research (Hildago-Ruz & Thiel, 2015). This methodology may offer a cost-efficient way of collecting large quantities of data across vast areas over a long time (Bonney et al., 2009; Dickinson et al., 2012; Nelms et al., 2017;). The project commenced in December 2015 and aimed at removing lost traps from the seabed and thus prevent them from continuing to catch and kill animals. Additionally, divers where asked to submit reports of retrieved gear that could be used as scientific basis to assess the extent and impacts of ghost fishing on marine animals and the potential causes of gear loss from coastal fisheries in Norway.

Figure 2: Retrieved fishing gear found and reported by divers during the period 2015-2018 along the Norwegian coast. a) Rectangular folding trap (Biltema), b) Heavily biofouled folding trap, c) Rigid two-chambered (parlour) steel framed trap with synthetic mesh (skotteteine) containing crabs, d) Crabs entangled in gillnet, e) Fykenets containing large amounts of crabs, f) Rigid two-chambered wrasse trap with rope and bouy intact. Source: Norges dykkeforbund (NDF) and Tord Aslaksen.

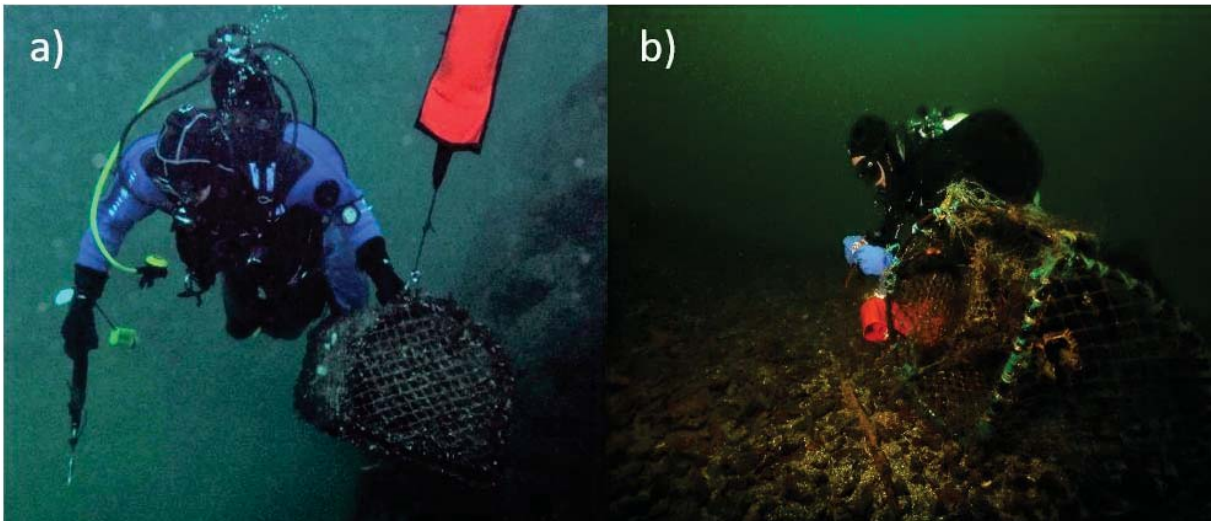


Figure 3: Underwater surveys carried out by scuba divers. Retrieval of a parlour trap (a) and folding trap (b). Source: NDF

To assess this, retrieval surveys were conducted in the period December 2015 to September 2018. Through the involvement of local diving centres, lost or abandoned fishing gear were retrieved by scuba divers at multiple sites along the coast, at depths of 0 – 80 m (Figure 3). The survey areas were primarily selected on the basis of tips received by fishers that had lost their gear and the diver's own experiences. Remotely operated vehicle (ROV) was used to explore areas in deeper waters (>30m), as divers seldom goes deeper than 30 meters (Figure 4). For every lost gear found by a diver, the gear was brought on land, in which a detailed report form was completed, and a picture of the fishing gear was taken. For each report, the diver was asked to report the following information; gear type (i.e. gillnet, traps, fyke nets), location, survey date, bottom type, slope gradient, presence of attached items (rope, buoy), gear condition and its potential of ghost fishing, presence of dead/alive animals, biofouling and predicted time of loss (See Appendix, Figure 5 for examples). This information was digitalized and organised into a database for validation and further analysis. The diver reports and associated pictures were given a similar ID number to ensure data consistency. In order to simplify the reporting and registration of data, an app named "Fritidsfiske" (www.fiskeridir.no/Fritidsfiske/Appen-Fritidsfiske) was created in June 2017 by DOF (See Appendix, Figure 6). A subset of the data material is provided by this app (n=38).

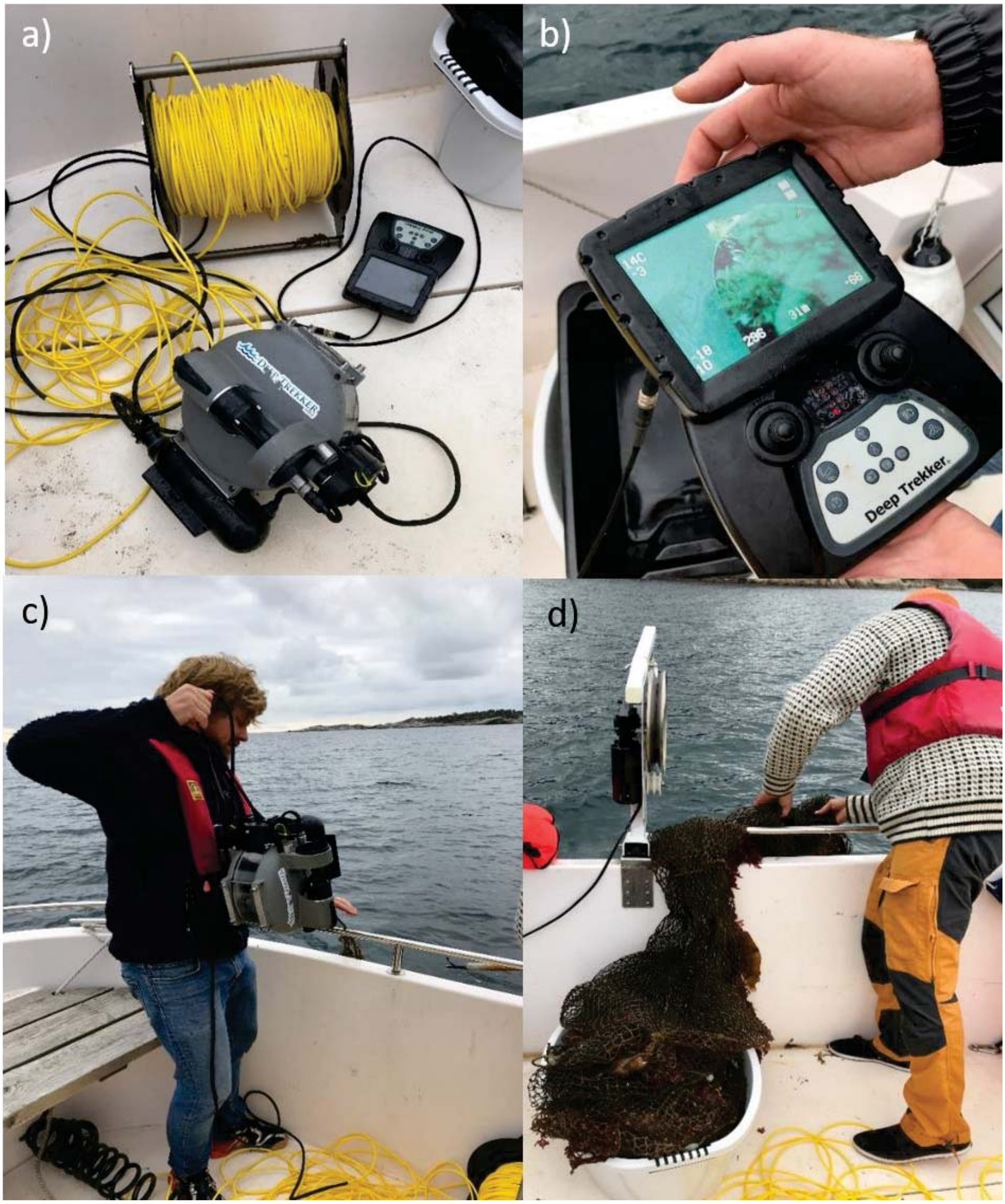


Figure 4: Retrieval process using ROV camera during fieldwork in Lillesand. A) ROV camera with gripstick, cable and remote control) B) Remote control with screen used to locate lost fishing gear underwater C) Lost gear is picked up by ROV camera, hanging in the gripstick of the camera while the camera is pulled up by the cable d) Gillnet retrieved by ROV surveys.

2.3 Data analyses and statistics

2.3.1 Data preparation

Prior to the analysis, data was carefully quality controlled and reports with incomplete data were excluded from the analysis. A total of 4202 gears were reported on diver forms, of which 4128 were used for further analysis. For the spatial analysis, a subset of data (n= 3971) was used, as information on retrieval location was absent or indefinite. The time scope of data was limited to the period 5th December 2015- 17th December 2018.

2.3.2 Extent and spatial analysis of lost gear

All calculations of the amount and proportion of lost fishing gear were performed using Microsoft Excel, in order to quantify the extent of lost gear along the Norwegian coast in 2015-2018.

Spatial analysis and generating of maps were conducted using QGIS 3.4.4 open software. Based on available data of location names and depths, coordinates were manually plotted using nautical charts (https://kart.gulesider.no/), when coordinates were not reported (n=1972). In QGIS, a map showing the positions of retrieved fishing gear in the survey/study area was generated using a subset of data including ID number with corresponding coordinates (n=3971), location name and gear type (trap, gillnet, fyke net). This map was made using the function "Add Delimited Text Layer/ Point vector layer" and then adding 'points' to layer by changing the symbology to 'single symbol' in 'Layer properties' (Figure 1). In order to display the distribution of gear types, a new point layer was created. The symbology was changed to 'categorized symbols', then the column 'gear types' was chosen, and vector data classified. In layer properties each gear type was assigned different symbols (Figure 6). A third map was generated in order to display the proportion of gear types found in each municipality (Figure 7). Mean coordinates were calculated in R for each of the 112 municipalities, then using the function 'Pivot table' in Excel, data was organized by municipality with the corresponding proportion and total number of gear types and mean coordinates. This map was made by adding a point vector layer in QGIS, then using the function 'Diagram' in layer properties and selecting 'Pie chart', then choosing the attributes 'trap', 'fyke net', 'gillnet' and 'unknown'. In order to avoid overlapping and allocate the placement of pie charts, leading lines were created. Within the 'Placement' properties of the diagram 'Around centroids' was selected and 'Data defined position' activated. Then, within the layer properties and 'style options' the symbol layer type was changed to 'Geometry

Generator' and 'Geometry Type' to 'LineString/MultilineString'. Finally, the following function was entered using the 'Expression' tool;

make_line(make_point("Average,lo" , "Average,la"), centroid($geometry))

The final map design was made using the Print Composer tool in QGIS.

2.3.3 Statistics

The statistical analysis and generation of figures were conducted using the statistical computing software R version 1.1.463 (R Development Core Team, 2018) with the following packages: *pscl* (Jackman, et al., 2017), *AICcmodavg* (Mazerolle, 2017), *ggplot* (Wickham & Wickham, 2007), *rcompanion* (Nagelkerke, 1991), *car* (Fox & Weisberg, 2011) , *stat* (R Core Team, 2013).

Ghost fishing catch and catch composition

Analysis and calculations of the proportion of retrieved fishing gear that were actively ghost fishing, catch rates and catch composition, were made using Microsoft Excel. In order to compare the catch rates of animals between gear types, data was categorized by the following gear types; gillnets, fyke nets, rigid two-chambered (parlour) steel framed traps, folding traps and other traps (i.e. fish traps, wooden traps, måløyteine, vestlandsteine, crayfish traps and unknown), and catch data into animal groups (lobster, crabs and fish). The data was summarized and analysed in R. The mean catch per gear was calculated and plotted using the package *ggplot* in R.

Figure 5: Main animal groups caught by retrieved fishing gear recovered by divers during the period 2015-2018 along the Norwegian coast. a) Crab in escapement hole of a trap, b) lobster entangled in gillnet, c) injured cod (Gadus morhua L.) found in a retrieved fish trap.

Analyses of factors affecting ghost fishing

In order to assess whether gear type and environmental factors (substrate, bottom slope, depth) influence catch rates in lost gear, a Zero-Inflated Poisson (ZIP) regression modelling approach was used (Lambert 1992). Zip models can deal with data sets containing large numbers of zero observations (zero-inflated) and are useful for modelling the distribution of count data with excess zeros (Lambert, 1992). The distribution of catch data for all animal groups, showed explicit signs of excessive zero-observations (See Appendix, Figure 1, 2 & 3). Hence, the data was analysed using zero-inflated Poisson models (ZIP), where the probability of observing zero values was modelled by a zero-inflated model (i.e., logit-linked generalized linear models (GLM)) and non-zero observations as a Poisson count model (i.e., log-linked GLM) (Zeileis et al., 2008; Wagh & Kamalja 2017). A Voung test (Voung, 1989) was performed to compare other potential modelling approaches to the ZIP approach, all fitted with the most supported prediction model structure with the lowest AICc value (See 2.3.3). In all cases, the ZIP approach was the best alternative ($p<0.0001$). Generally, ZIP-models can be produced as follows:

$$Pr(y_j = 0) = \pi + (1 - \pi)e^{-\lambda}$$

$$Pr(y_j = h_i) = (1-\pi)\frac{\lambda^{h_i} e^{-\lambda}}{h_i}, \quad h_i \geq 1$$

Where the response variable y_j may have all non-negative values and λ is the expected Poisson-value for *i* observations of catch. Hence, the zero-inflated Poisson model can simultaneously estimate the expected number of catch per gear given catch (y_i= count) under a Poisson- distribution, and the probability that a gear could catch (1-p(0)) under a binominal distribution. π denotes the probability for excess zero values (zero-inflated) beyond what might be expected of the Poisson distribution. The average of the models can be estimated as (1- π) λ and the variance as $\lambda(1-\pi)(1+\pi\lambda)$.

2.3.3 Model selection

Model selection was undertaken using Akaike's Information Criterion (AIC) (Burnham & Anderson, 1998) in order to find the set of explanatory variables and their interactions that most optimally balances model bias and precision given the data (Akaike, 1974). In order to predict the number of lobsters, crabs and fish per gear as a function of gear type and environmental factors, a list of candidate models was made, conducted at complete datasets. Correlation between the variables were used to check for collinearity to avoid confounding variables, prior to the model selection. Different combinations of predictor variables including gear type, depth, substratum and bottom slope were fitted to both count-model and zero-model in the ZIP model. In order to find the optimum model structure, the selection process was performed in two steps where initially, the catch data, which was reflected by the zero-inflated model was modelled prior to the Poisson model. A fully additive count model including all predictor variables were kept conditional (e.g. *gear type+substrate+depth*^{2}*+bottom slope)* and fitted to zero-candidate models with several combinations of multiplicative and additive effects of predictor variables. Gear type was included in all candidate models and the depth-effect was modelled as a second-degree polynomial in order to allow for a catch peak as a function of variables. The top model with the lowest AICc score was chosen as the most supported zero-model structure. In order to find the ZIP-model with the most support, the most opted zero-model structure was fitted to candidate-models on the count model part where the same previously described selection procedure was pursued. The model with the smallest AICc was selected as this model most effectively balanced the precision of the estimates towards the explained variation based on the principle of parsimony (Burnham & Anderson,1998). The model selection process was performed separately for the catch data of each animal group.

Additionally, using the package *car* in R, analysis of variance (ANOVA) was conducted for the most supported ZIP models of each animal group, to assess potential interaction effects of variables on the catch rate.

3 Results

3.1 Extent and geographical distribution

Members of the diving association retrieved a total of 4128 pieces of gear from the shallow coast of Norway during clean-up-efforts during the time period 2015-2018. Of these, 3456 (84 %) were traps, 461 fyke nets (11 %) and 211 gillnets (5 %). Folding traps (44%) were most frequently found followed by 871 other traps (21%) and 794 parlour traps (19 %) (Figure 6 and Figure 7)

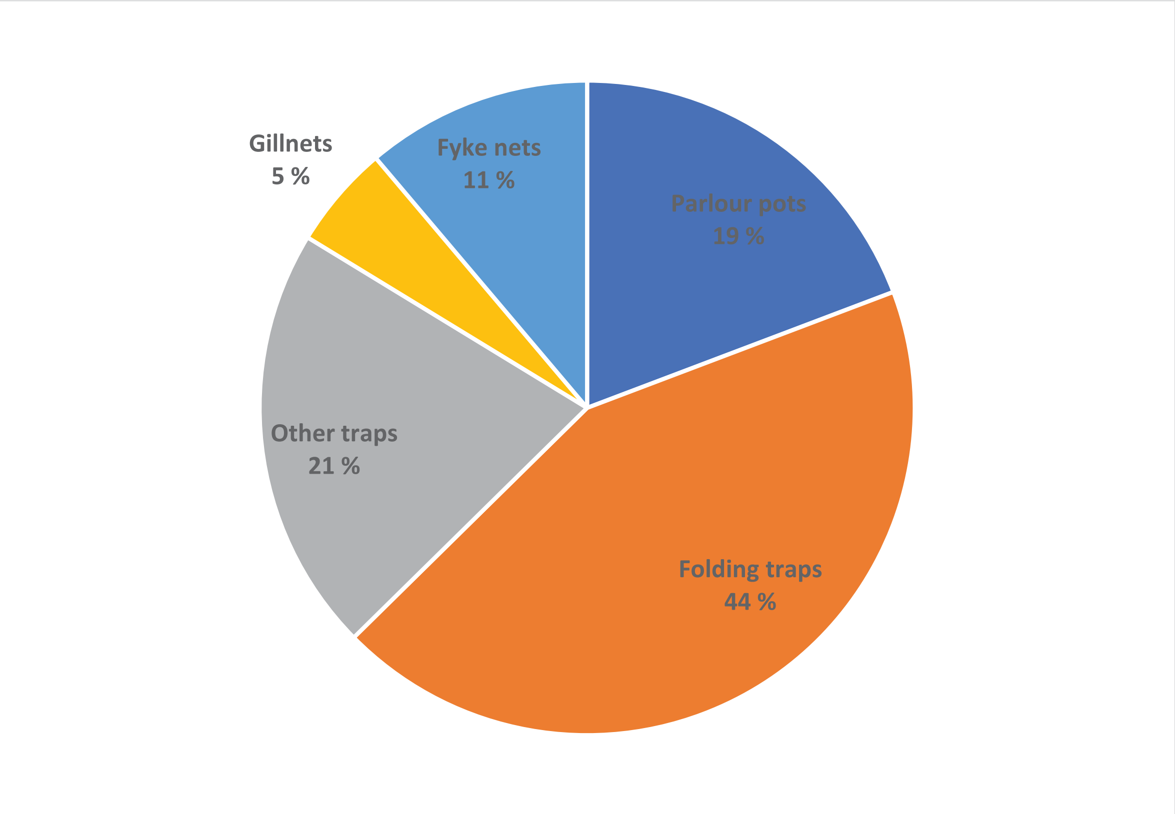


Figure 6: Total number of gear types retrieved from the Norwegian coast during the time period 2015 – 2018 (n=4128). Other traps: Fish traps, wooden traps, måløyteine, vestlandsteine, crayfish traps and unknown.

The Chi-Squared test revealed significant difference in gear distribution among regions (X-squared = 114.83, df = 4, p-value <0.0001). A greater number of gear was retrieved from the South-East region (n=2045) and the West-region (n=1615), while the mid region (n=513) amounted to a smaller proportion of the total gear retrieved, probably reflecting less retrieval efforts in this region compared to the other regions (Figure 8). The predominant gear type across all regions were traps (n = 3456), representing 84% of all gear, followed by fyke nets (11%) and gillnets (5%) (Figure 7).

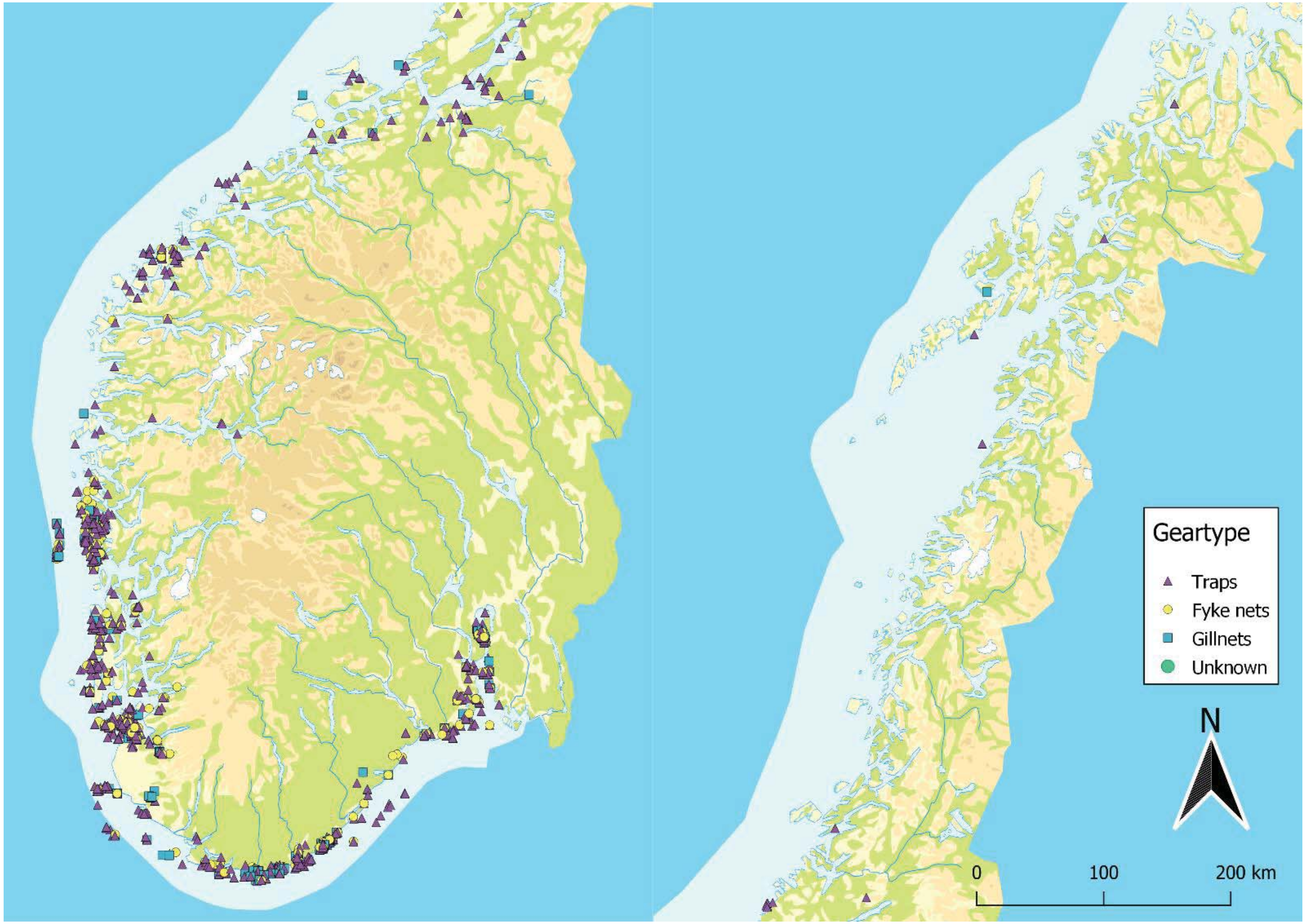


Figure 7: Map showing the position of lost gear retrieved along the Norwegian coast in 2015-2018. Purple triangles indicate traps, yellow circles are fyke nets and blue squares are gillnets. (n=3971)

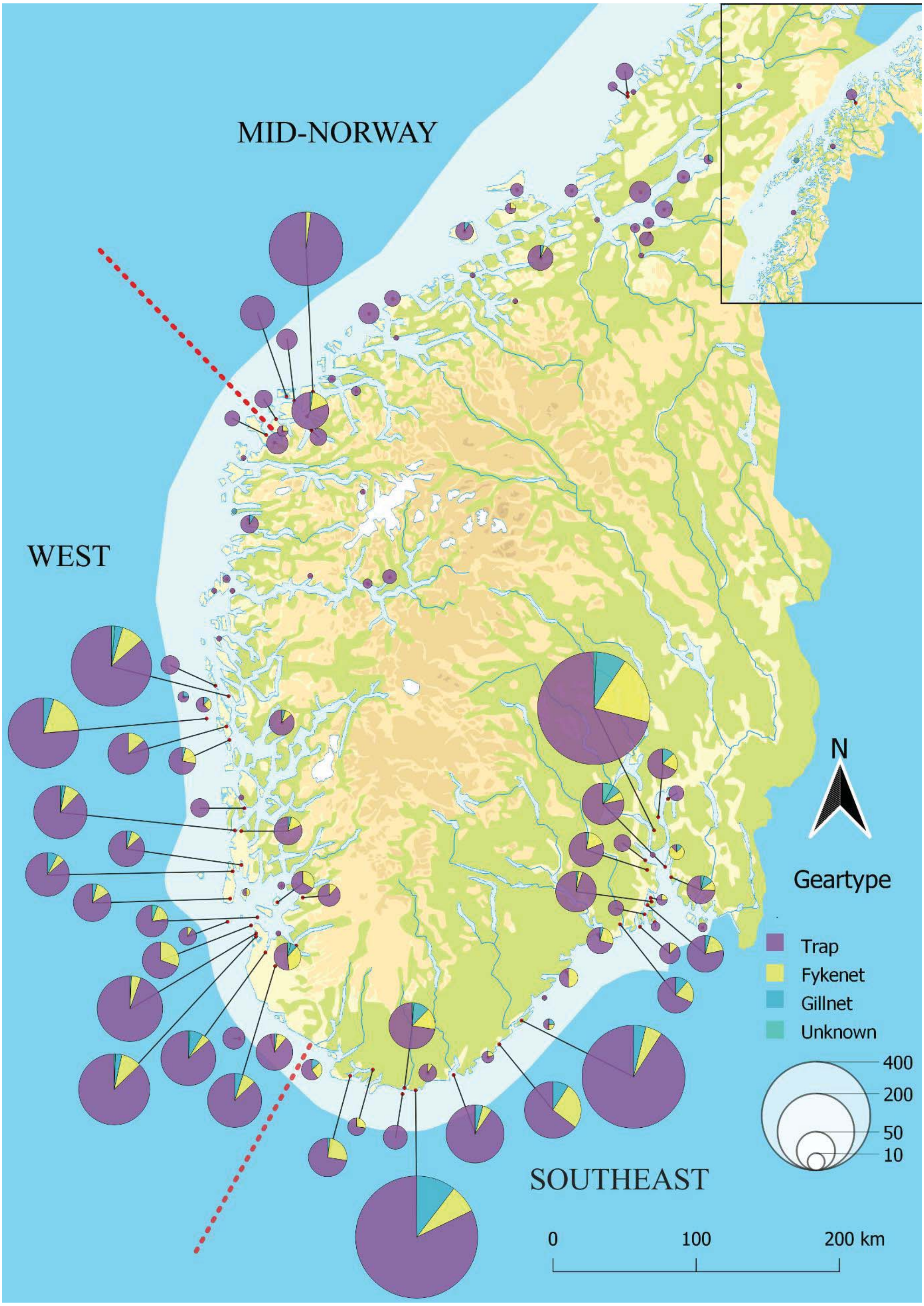


Figure 8: Map of the survey area. Pie chart indicates the proportion of gear types found in each municipality in the regions south-east, west and mid-Norway, along the coast of Norway during retrieval surveys in the time period 2015-2018. Dotted red line indicates regional boundaries (n=3971)

3.2 Ghost fishing catch and catch composition

Of all 4128 fishing gear that were retrieved from the surveyed areas along the Norwegian coast in 2015-2018, a total of 29 % (n=1202) contained animals (lobster, crabs, fish). Parlour traps had the highest relative occurrences of catch with 52 % of the traps ghost fishing to the total number of traps, in which 52% of the traps were actively ghost fishing, followed by gillnets (41%), other traps (33%), fyke nets (32%) and folding traps (15%) (Figure 9 and Table 1).

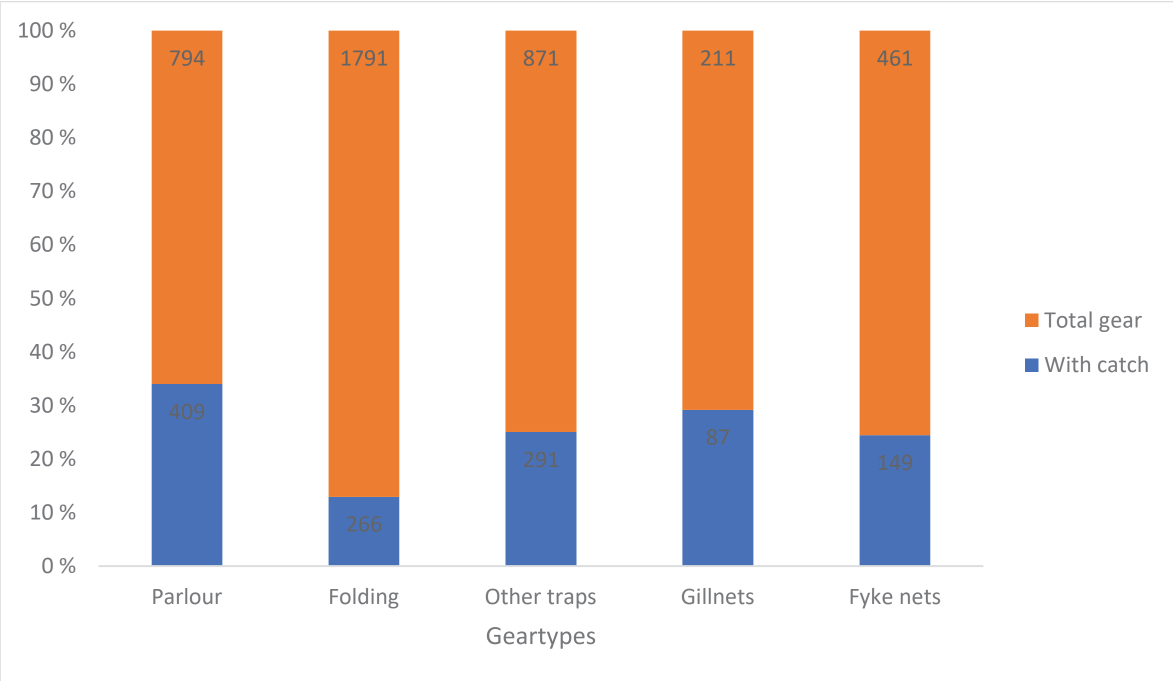


Figure 9: Total number of retrieved (orange bars) and portion of retrieved pieces of gear that contained animals (blue bars) for the various gear types (parlour traps, folding traps, other traps, gillnets and fykenets) based on submitted data reports from the divers during the time period 2015-2018. (n=4128).

Table 1: Total number of lost gear (n=4128), % of catch and total number of animals captured.

	Lost gear	Ghost fishing	
Gear type	n	% of catch	Total no. of animals captured
Parlour	794	52%	2451
Folding	1791	15%	562
Other	871	33%	1202
Gillnets	211	41%	508
Fyke nets	461	32%	624

In total, the number of animals captured by lost gear was 3779 crabs, 1406 fish and 160 lobsters (Table 2). Retrieved parlour traps and other traps contained the largest numbers of animals with catches of 2451 and 1202 individuals, respectively (Table 1). Parlour traps dominated the catches and had a mean catch of 3.09 animals/trap, including 0.12 lobsters, 2.09 crabs and 0.88 fish per trap (Table 2). While parlour traps dominated the captures of lobsters and fish, gillnets dominated the catch of crabs with a mean catch of 2.27/gear. Of all gear types, folding traps contained the least amount of animals where each trap captured on average 0.62 animals/trap.

Table 2: Mean catch of lobster, crab and fish per gear type. Numbers in brackets indicates total numbers of catch per gear (n). (n=4128)

	Gear type					
Mean catch per gear	Parlour	Folding	Other	Gillnet	Fykenet	Total (n)
Lobster/gear	0.12 (92)	0.02 (14)	0.05 (44)	0.02 (5)	0.01 (5)	160
Crab/gear	2.09 (1663)	0.45 (433)	0.89 (777)	2.27 (478)	0.93 (430)	3779
Fish/gear	0.88 (696)	0.15 (115)	0.44 (381)	0.12 (25)	0.41 (189)	1406
Total animals/gear	3.09 (2451)	0.62 (562)	1.38(1202)	2.41 (508)	1.35 (624)	5345

3.3 Factors influencing ghost fishing

The results from the model selection showed that different models were favoured for each animal group, with differences in both model structure and predictor variables between the count and zero model. Overall, the animals differed in catch numbers as a function of gear type, depth, substrate and bottom slope.

Lobster catch rate

The most supported model predicting the number of captured lobsters included the variables *gear type, depth, substrate* and *bottom slope* in both submodels. The count model part contained mostly additive effects, with the exception of an interaction effect between *substrate* and a second-degree polynomial of *depth* (Table 3). The zero-inflated model contained an interaction effect between *bottom slope* and *substrate* and had additive effects between the variables. An ANOVA of the most supported model showed that there were significant effects of both bottom slope and substrate on the lobster catch (ANOVA; $p<0.05$, Appendix; Table 6), however, there was no significant effect of gear type or significant interaction effects detected.

Table 3: AIC table for the five most supported ZIP models of lobster catch as a function of gear type, depth, substrate and bottom slope, retrieved along the Norwegian coast in 2015-2018. The top model is referred to as the most supported model. General model structure: Y=count | Pr (y=0). K: number of parameters; AICc: corrected for Akaike's information criterion; ΔAIC: deviation relative to the most supported model. See appendix for complete model selection (Appendix, Table 1).

Model structure	**K**	**AICc**	**ΔAIC**
geartype + Bottom.slope + Substrate * $Depth^2$ | geartype + Bottom.slope * Substrate + Depth	25	844.15	0.00
geartype + Bottom.slope + Substrate * Depth| geartype + Bottom.slope * Substrate + Depth	22	844.30	0.14
geartype + Bottom.slope + Substrate * $Depth^2$| geartype + Bottom.slope * Substrate + $Depth^2$	26	845.38	1.23
geartype+ Bottom.slope + Substrate + Depth | geartype + Bottom.slope * Substrate + Depth	20	848.09	3.94
geartype * Bottom.slope + Substrate * Depth| geartype + Bottom.slope * Substrate + Depth	26	849.59	5.44

The parameter estimates of the model is presented in appendix, Table 4 and prediction plots of both count- and zero model are shown in Figure 8. The Nagelkerke's R squared for the selected model, revealed that 22 % of the variation in lobster catch is explained by the model. The prediction plots showed that the predicted number of lobster catch is affected by gear type, depth, substrate and bottom slope (Figure 10A). The model predicts that folding traps had the largest catch rate of lobster compared to parlour and other traps, with maximum catches of 3-4 lobsters peaking at middle depths of 10-20 m on boulder and nearly 30 m on rock substratum. Generally, the catch rate tends to decrease towards zero with increased depths for the various types of substrate. While there was a clear effect of both substrate and depth on the catch of lobsters, there were marginal effects of bottom slope, where the catch rate on steep slope was predicted to zero for various types of substrate.

The predicted probability of catch also differed with various types of gear, depth, substrate and bottom slope (Figure 10B). The probability model differed from the predicted catch and predicted a higher probability of catch in parlour pots and low probability of catch in folding traps. Generally, the probability of catch increases with greater depths for both parlour traps and other traps, while the catch probability of folding traps was nearby zero for most various types of depths, substrate and bottom slopes. The probability of catch was greatest on rock substrate and flat slope, in which parlour trap had 90 % probability of catch. Furthermore, the probability of lobster catch was predicted to zero for gear found on soft substrate and steep bottom type, irrespective of depth.

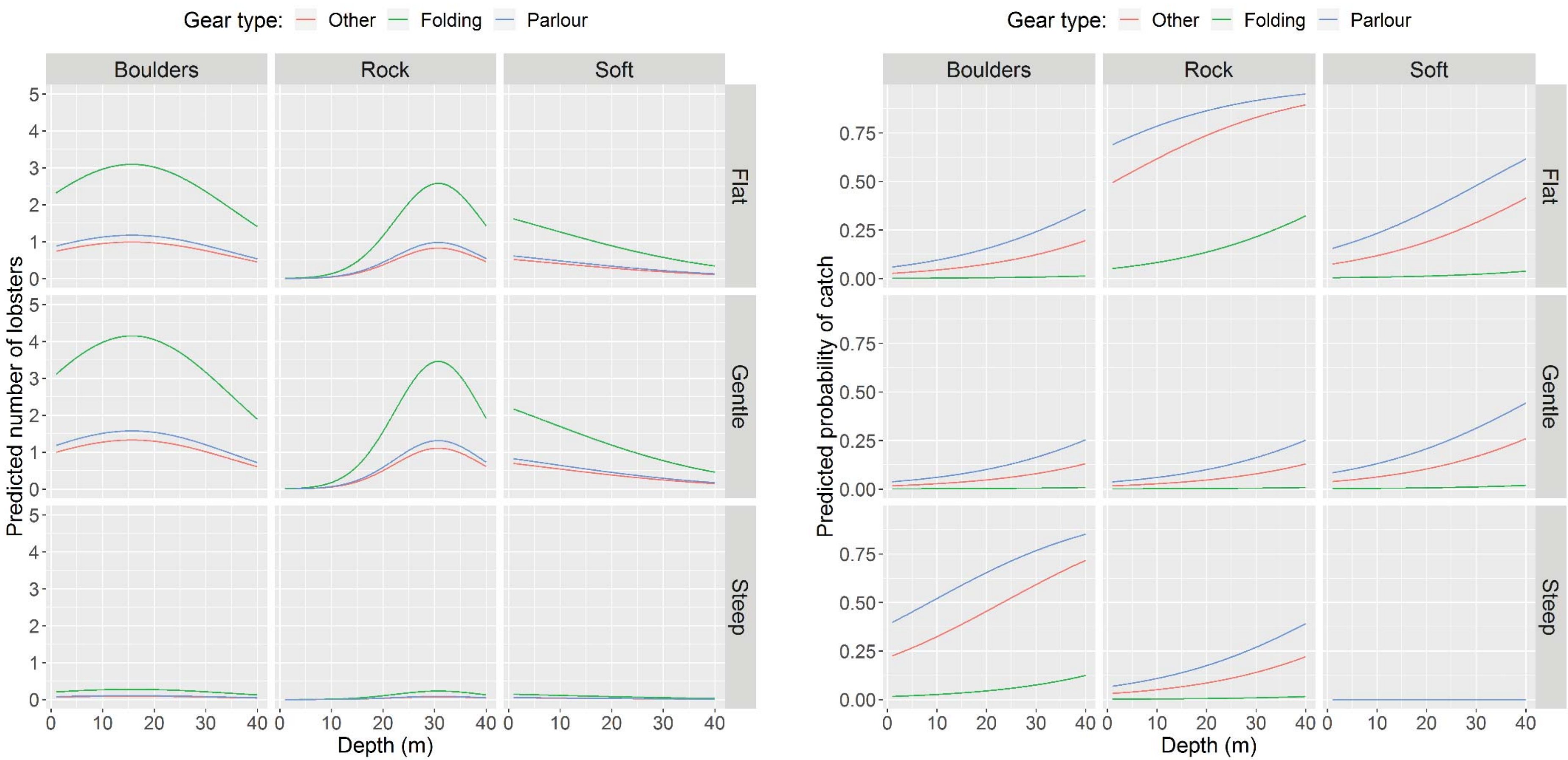


Figure 10: A) Predicted number of lobsters (Y=count) captured by lost gear as an effect of gear type, bottom slope, substrate and depth. Predictions of the model were estimated from the most supported ZIP-model provided in Appendix, Table 4. B) Predicted probability of lobster catch (1-Pr (0)) of the most supported ZIP model.

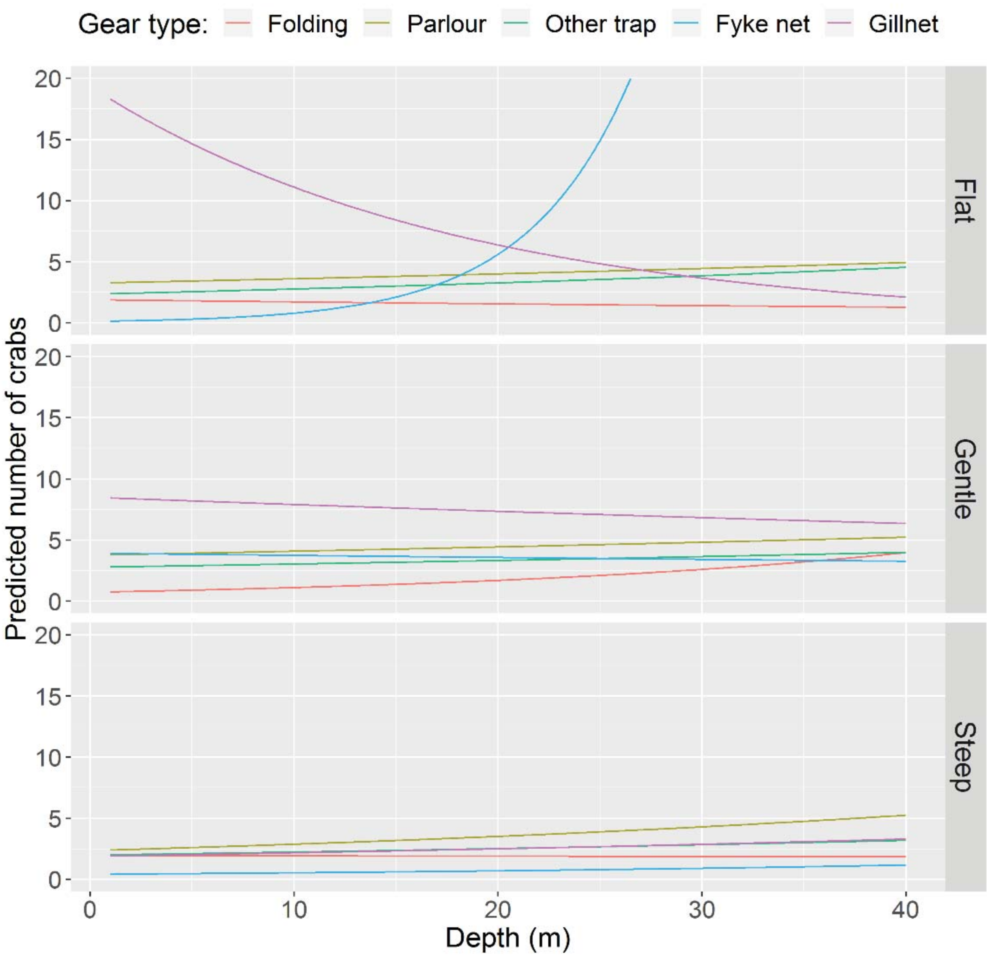
Crab catch rate

Table 4: AIC table for the five most supported ZIP models of crab catch as a function of gear type, depth, substrate and bottom slope, retrieved along the Norwegian coast in 2015-2018. The top model is referred to as the most supported model. General model structure: Y=count | Pr (y=0). K: number of parameters; AICc: corrected for Akaike's information criterion; ΔAIC: deviation relative to the most supported model. See appendix for complete model selection (Appendix, Table 2).

Model structure	K	AICc	ΔAIC
geartype * Bottom.slope * Depth | geartype + Bottom.slope * Substrate * $Depth^2$	61	8539.34	0.00
geartype + Bottom.slope * Substrate * $Depth^2$| geartype + Bottom.slope * Substrate * $Depth^2$	62	8634.14	94.80
geartype + Bottom.slope * Substrate * $Depth^2$| geartype + Bottom.slope * Substrate * $Depth^2$	62	8634.14	94.80
geartype + Bottom.slope * Substrate * $Depth^2$| geartype + Bottom.slope * Substrate * $Depth^2$	62	8634.14	94.80
geartype * Bottom.slope * Substrate | geartype + Bottom.slope * Substrate * $Depth^2$	76	8634.18	94.84

The parameter estimates of the model is presented in appendix, Table 5 and prediction plots of both count- and zero model are shown in Figure 9. The Nagelkerke's R squared for the selected model, showed that 30 % of the variation in crab catch is explained by the model. The analysis of prediction models showed that the predicted number of crabs is affected by gear type, depth and bottom slope (Figure 11A). The effect of substrate on catch rate was not significant. The predicted catch of crabs was relatively constant among gear at various depths and bottom slopes, with catch rates ranging from 0-5 crabs. Overall, gillnets had the largest catch rates at flat and gentle slopes, while parlour traps dominated the catches at steeper slopes. The catch rate in fykenets increases highly after 20 m, which indicates greater catch at deeper depths. There was a tendency of increased catch rates with slightly greater depths for most gear, with the exception of gillnets that had greater catches of 15-20 crabs at shallower depths with flat bottom slopes, that declined towards zero with greater depths. Predictions indicate that folding traps caught the least amount of crabs, which was representative of the lower probability of catch.

The probability of crab catch differed among gear types depending on depth, substrate and bottom slope (Figure 11B). Predictions indicated that gear types had the same catch ratio independent of substrate, depth and bottom slope, although there were great differences in catch probability among various types of substrate and bottom slopes. The catch probability was generally greater for parlour pots and gillnets than folding traps, which is representative of the predicted catch. Generally, the probability of catch increases with greater depths for all gear types, predicting a 100% probability of catch at depths of 30-40 meters at boulder and rock substratum with flat slope. This indicates that the probability of catch is overall greater in deeper waters, although there was a tendency of greater catches at shallow depths for various types of bottom slopes at boulder and rock substratum.



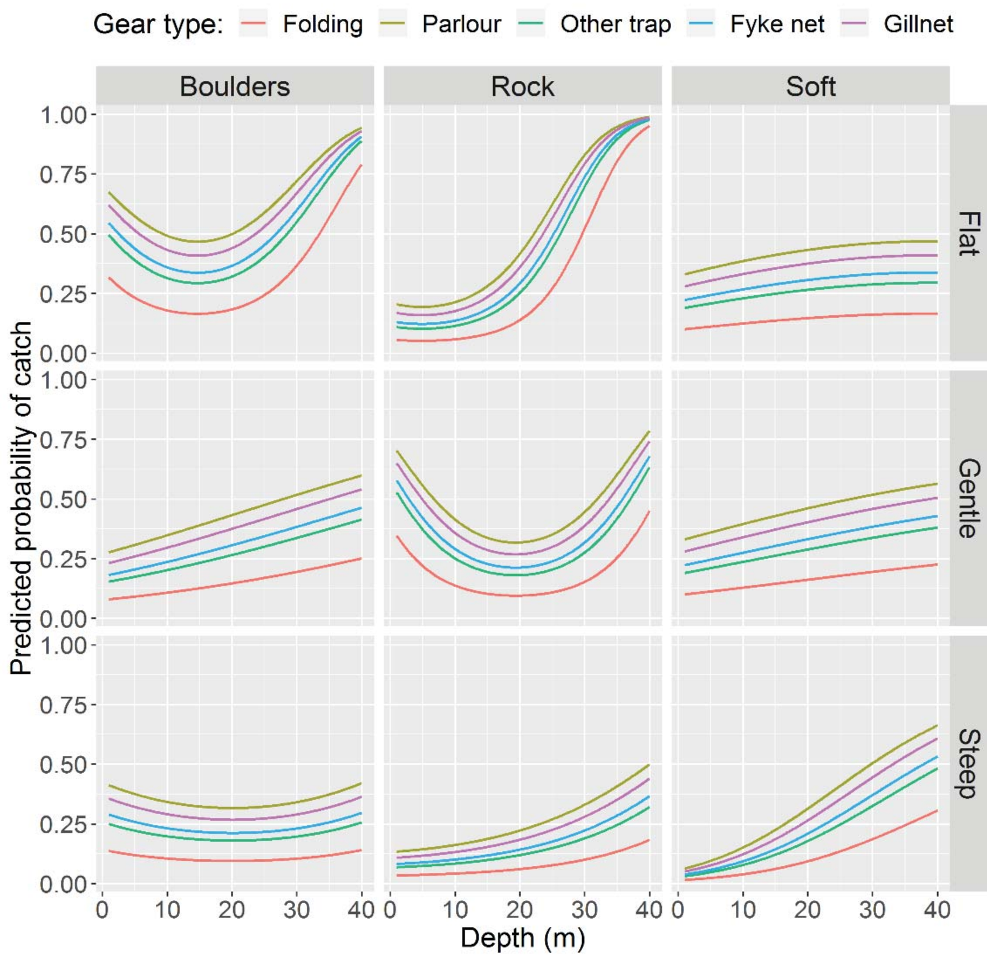


Figure 11: A) Predicted number of crabs (Y=count) captured by lost gear as an effect of gear type, bottom slope, substrate and depth. Predictions of the model were estimated from the most supported ZIP- model provided in Appendix, Table 5. B) Predicted probability of crab catch (1-Pr (0)) of the most supported ZIP model.

Fish catch rate

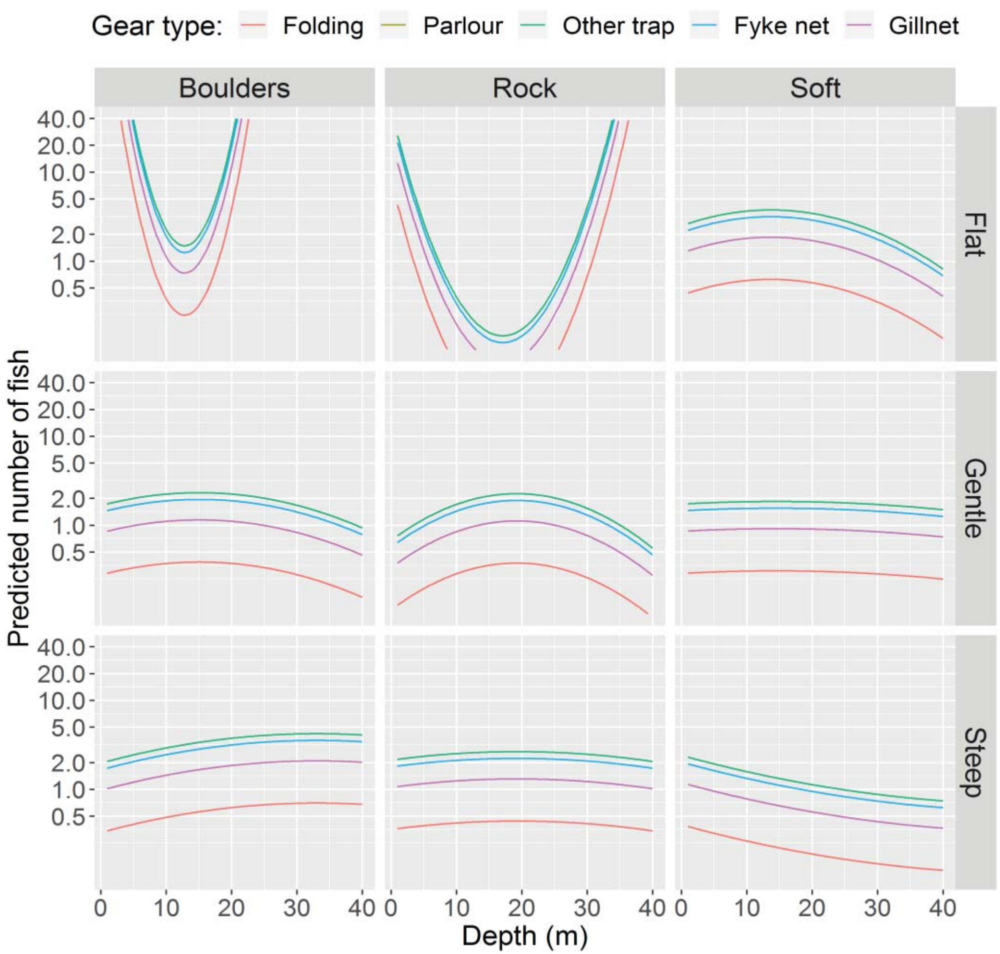
The most supported model predicting the number of captured fish by lost gear included all variables in the count model part with additive effects between *gear type* and *bottom slope* and interaction effects for *substrate* between *bottom slope* and a second-degree polynomial of *depth* (Table 5). The zero inflated model composed of a fully factorial design, including the variables *gear type*, *bottom slope* and *depth*. The ANOVA of the most supported model revealed that there were significant interaction effects between gear type, bottom slope and depth (ANOVA; $P_{Bottomslope*Substrate*Depth^2}<0.0001$; Appendix; Table 10).

Table 5: AIC table for the five most supported ZIP models of fish catch as a function of gear type, depth, substrate and bottom slope, retrieved along the Norwegian coast in 2015-2018. The top model is referred to as the most supported model. General model structure: Y=count | Pr (y=0). K: number of parameters; AICc: corrected for Akaike's information criterion; ΔAIC: deviation relative to the most supported model. See appendix for complete model selection (Appendix, Table 3).

Model structure	**K**	**AICc**	**ΔAIC**
geartype + Bottom.slope * Substrate * Depth^2| geartype * Bottom.slope * Depth	61	3676.50	0.00
geartype + Bottom.slope * Substrate * Depth | geartype * Bottom.slope * Depth	52	3704.87	28.38
geartype * Bottom.slope + Substrate * Depth | geartype * Bottom.slope * Depth	50	3741.57	65.07
geartype + Bottom.slope + Substrate * Depth^2| geartype * Bottom.slope * Depth	45	3758.36	81.87
geartype + Bottom.slope + Substrate + Depth^2| geartype * Bottom.slope * Depth	41	3768.13	91.63

The parameter estimates of the model is presented in appendix, Table 6 and prediction plots of both count- and zero model are shown in Figure 10. The Nagelkerke's R squared for the selected model, showed that 22% of the variation in fish catch is explained by the model. The prediction plot of the most supported model showed variations in catch rates of fish among gear types at various types of depths, substrate and bottom slope, indicating that the catch was affected by these variables (Figure 12A). The predictions indicate that other traps caught the greatest number of fish followed by gillnets, while folding traps caught the lowest numbers. The predicted catch of fish was generally low and ranged from 0 to a maximum of 5 fish for most gears that peaked at depths of 20 m, and then decrease towards zero catch. The exceptions were gear on boulder and rock substrate with flat slope, where the model predicted large catches at shallow depths, which dropped to a minimum catch of zero at depth of approximately 15 m. Then, the catch rate increased remarkably with greater depths.

The predicted probability of fish captured showed great variations in catch rates depending on gear type, bottom slope and depth (Figure 12 B). The effect of substrate on catch rate was not significant. Overall, the probability of catch was generally low among gear types with catch probabilities lower than 30 % for most gear types. Gillnets and other traps had overall higher probabilities of catch on flat bottom slopes, increasing with greater depths of 15 m and 20 m, respectively. Gillnets found on gentle slopes, however, had a higher probability of catch at shallower depths which declined with greater depths. This contrasted with the greater catch probability of parlour traps that increased towards greater depths. There was no clear pattern of catch probabilities on steep slope, although folding traps had a greater probability of catch which increased from a depth of 20 m.



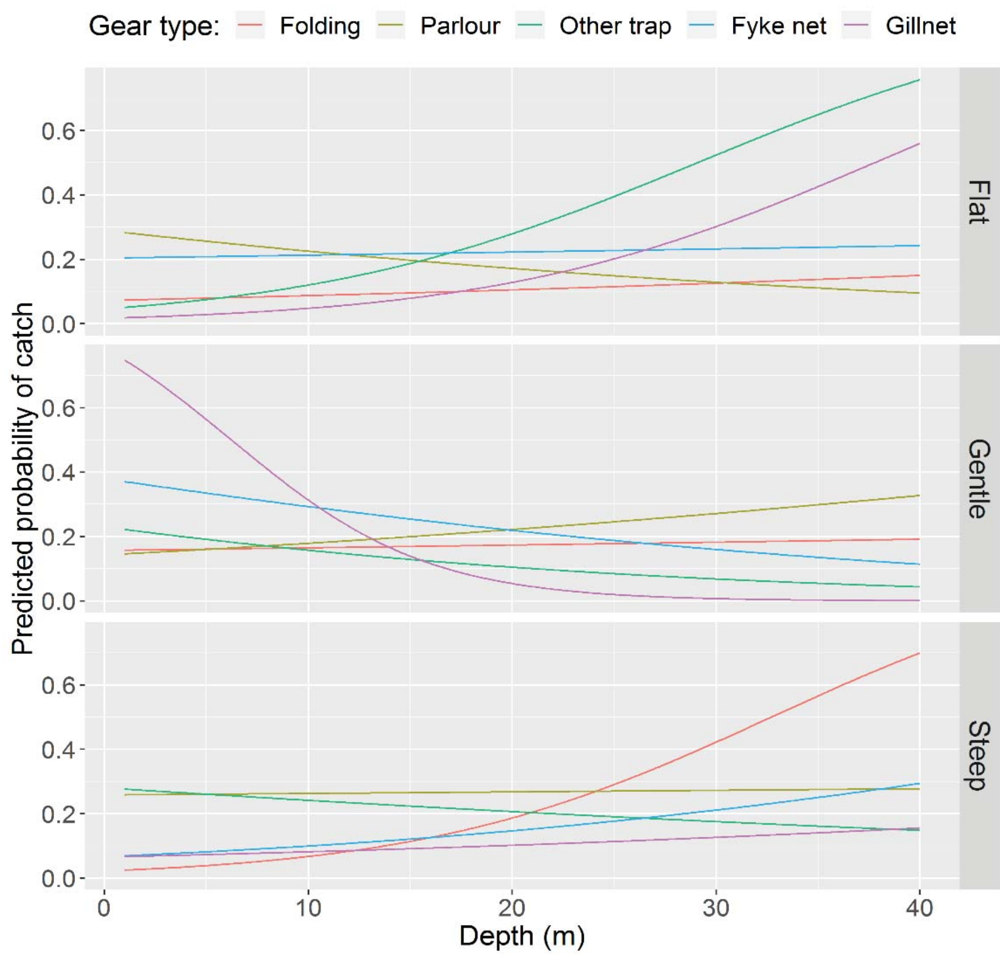


Figure 12: A) Predicted number of fish (Y=count) captured by lost gear as an effect of gear type, bottom slope, substrate and depth (log-scaled). Predictions were estimated from the most supported ZIP-model provided in Appendix, Table 6. B) Predicted probability of catch (1-Pr (0)) of the most supported ZIP model.

4 Discussion

This thesis evaluated the quantity and spatial extent of lost fishing gear, represented mostly by traps, and the ghost fishing catch of lobsters, crabs and fishes inhabiting shallow (>80 m) habitats along the Norwegian coast during the period 2015-2018. Lost gear were widely distributed along the coast with "hot spots" accumulations of gear found at the south-eastern region. A large number of gear types were retrieved during clean-up efforts, in which traps accounted for the largest proportion. Ghost catch was reported for all gear, although, with varying catch and catch composition between gear types. Ghost fishing were observed for all animal groups, in particular crabs. Catch of lobsters was estimated to be influenced by several factors such as trap type, substrate, bottom slope and depth. The catch of crabs and fish were also influenced by most of these factors, although the animal groups responded differently in terms of catch as a function of these factors.

The analysis of this study is based on citizen science data, hence it is important to review some of the aspects of using such data to explain ecological patterns. Citizen science projects have the advantage of collecting a large amount of data across vast areas over a longer time period and is a cost-effective method to obtain a lot of data that can support both research and management (Bonney et al., 2009). Studies have reported that the involvement of volunteers in research provides a unique opportunity for scientists to study ecological patterns at large geographic scales (Dickinson et al., 2010). Hence, it may increase scientific knowledge and raise public awareness of biological issues (Jordan et al., 2011). However, the large quantities of data collection may often compromise with the quality of the data, which is a common problem for citizen science projects (Bonney et al., 2009). Poor data quality may create challenges for analyses and interpretation of data. As the analyses of this present study is based on citizen science data, there might be several potential sources of error that may have biased the analysis. The results should therefore be interpreted with caution, as they might not be representative to the real world. The analysis of catch of lobsters, crabs and fish showed that all ZIP-models had relatively low R-squared values, in which 22-30 % of the observed variation in catch rate could be explained by the models, which reflects the large amount of noise in the data. Citizen science data often contain a higher level of noise than those collected through a standardized scientific procedure, which could be the result of variation among reporters in how to collect data, uneven distributions of data in space and time (Sullivan et al., 2014) or due to randomness and sampling errors. This is most likely the case in this present study, as data was collected on diver report forms submitted by a large number of divers, reporting from different locations and periods of time. Another potential source of error that could have biased the results is outliers in the data. For example, the catch rate of fyke nets increased remarkably after 20 m on flat bottom slope (Figure 9A). This was probably the result of sampling errors and/or few individual observations that led to a skewed distribution pointing in this direction. Furthermore, it is likely that the combination of extrapolation of data and large amount of noise could have led to an overdispersion of data beyond the expected true observation, which probably resulted in a high predicted catch rate of lobsters in folding traps (Figure 8A). For these reasons, the prediction models should be evaluated carefully as the results may not be representative to the true condition. Despite the weaknesses of the data, the result of this study shows clear tendencies that lost fishing gear continue to catch and that the ghost fishing catch rate is dependent on gear type and environmental variables. Standardized sampling instructions (e.g. video, posters, talks) and training of volunteers on how and what to record, could be a step in the right direction to obtain good quality of data from citizen science programs.

4.1 Extent and geographical distribution of gear

The analysis of the extent and geographical pattern of lost gear revealed that a total of 4128 lost fishing gear were retrieved along the Norwegian coast during the period 2015-2018. A number of different gear types were recovered during retrieval surveys, of which traps represented the largest part (84%), followed by fyke nets (11%) and gillnets (5%). The large number of gear may explain that the surveyed areas are commonly used fishing grounds and have a long history of intensive fishing. Hence, these areas more exposed to boat traffic which may have large impacts on the frequency of gear loss, increasing the likelihood of gear conflicts and propel strikes that could cut off the marker buoys, which is one of the main sources of gear loss (Bullimore et al., 2001; Gilman et al., 2015). The dominance of traps could also indicate that traps are more commonly used and frequently lost by fishers in the surveyed areas. Although, there little information on catch and efforts in these coastal areas (Kleiven et al., 2012).

Furthermore, folding traps was the most frequently found gear type accounting for 44 % of the total gear retrieved and 52 % (1791 out of the 3456) of traps reported, followed by other traps (21 %) and parlour traps (19 %). The dominance of folding traps is expected considering the light-weight structure and simple design, which would increase the risk of gear loss, particularly at sites that are more exposed to physical forces (i.e. storms, strong currents). In contrast, a lower number of parlour traps were found during retrieval surveys. Parlour traps are heavier and more costly to the fishers, both in terms of handling time, effort and prize, supporting the theory that the rate of pot loss is related to the type of gear and gear design (Breen, 1989). It has been suggested that the incentives of fishers to retrieve lost gear is related to the value of gear, as well as the probability of recovery and the alternative costs of fishing (Brown et al., 2005). This might explain the dominance of the low-priced folding traps, implying that these fishing gear have less financial value to the fisher and thus more likely to get intentionally abandoned or discarded at sea.

Another important aspect is that for every lost gear retrieved by a diver, a reward was given to the corresponding diving club. Different rewards could have biased the results. Although, there are no current surveys investigating fisher's experiences of gear loss. Nevertheless, there is a lack of information on the numbers and proportion of gear that is set for fishing in these areas, as well as estimates of the frequency of gear loss is scarce. Additionally, there might be several factors affecting the quantity and proportion of lost gear that have not been included in this study. For example, physical conditions, location, whether the gear was intentionally set for fishing or unintentionally lost at sea, gear design, fishing traditions and methods, as well as the fisher's experience (Breen, 1989). Furthermore, gear loss as a result of unskilled handling by recreational fishers have been reported in Santa Catarina, Brazil (Adelir-Alves et al., 2016). These theories require further investigations to better understand the extent and distribution of gear loss along the Norwegian coast. Furthermore, it is important to note that the extent and spatial pattern of lost gear is only a subset of the real extent of lost gear and that the estimates provided here might be conservative, not accounting for the total numbers of gear. Furthermore, the total number of gear presented in this study only reflects sites that has been explored by divers and only the sites where gear has been found. Therefore, it is likely that the number and geographical distribution of lost gear reported here is an underestimation of the actual numbers of lost gear along the coast.

Further studies are necessary to make accurate estimates of the extent and geographical distribution of lost gear along the Norwegian coast. It would also be of further interest to investigate potential explanatory factors influencing the extent and spatial pattern of lost gear to better understand the sources of gear loss and which mechanism that drives this pattern.

The analysis of geographical distribution of retrieved gear was significantly different among regions, with larger proportions of gear retrieved from the south-eastern coast. This suggests that this region might be a "hotspot" for accumulation of gear loss. Accumulation of lost fishing gear has been reported in several nearshore coastal areas (Boland & Donohue, 2013; Macfadyen et al., 2009; Uhrin et al., 2014). Several factors could influence the concentrated accumulation of these debris, such as size (e.g. length of rope), bottom type, physical processes (e.g. tides, circulation patterns), weather conditions, fishing effort and the level of boat trafficking (Uhrin et al., 2014). Areas exposed to a higher level of boat traffic and fishing intensity is expected to have a greater proportion of lost gear caused by gear conflicts or propel strikes (Bilkovic et al., 2014). It is important to note that the regional "hotspots" of accumulation of gear presented here, may only be an indicator of the differences in the level of efforts among the diving clubs, meaning that some diving clubs retrieved more fishing gear than others. For these reasons, estimates of the extent and geographical distribution should be made with caution. Additionally, it is important to note that gear may have dispersed from adjacent habitats by prevailing environmental conditions (i.e. storms, currents, wind), thus the true geographical pattern of lost gear may not be accurate.

To date, there have been no studies investigating the spatial pattern of lost fishing gear along the Norwegian coast. As such, further studies should be undertaken to better understand the geographical distribution of lost gear. It would also be of further interest to investigate the factors influencing the geographical pattern of lost fishing gear along the Norwegian coast.

4.2 Ghost fishing catch and catch composition

The analysis of ghost fishing catch rate showed that 29 % of all lost fishing gear (n=1428) contained animals. In total, 3779 crabs, 1406 fish and 160 lobsters were caught by different gear types, with mean catch ranging from 0.62-3.09 animals/per gear. Several other studies have reported similar ghost fishing impacts by lost fishing gear (Anderson & Alford 2014; Bilkovic et al., 2014; Bullimore et al., 2001; Smolowitz 1979). For example, a study of ghost fishing by derelict fishing gear in the Virginia waters of Chesapeake Bay, estimated that 28-38 % of retrieved blue crab traps were actively ghost fishing, in the period 2008-2012 (Bilkovic et al., 2014), which is consistent with the findings in this study. In contrast, another study on derelict crab traps in coastal Louisiana, a citizen science program revealed that 65% of 3607 recovered traps were actively ghost fishing (Anderson & Alford, 2014), which is significantly greater than those reported by other studies, including this study. Moreover, the estimated crab catches varied between 2.4-3.5 crab/pot, which corresponds to the results. A more recent study investigating lost lobster traps in Kosterhavet National Park in Sweden, Toivio (2017) found that 15 % contained animals, and estimated a lower average number of animals (0.5 animals per gear), than those presented here. This could indicate that the estimated catch provided here is greater than expected.

Other studies investigating catch rates in deliberately lost traps, have also reported relatively low catch numbers, concluding that the low catch rate was a result gear design and their potential to escape (Godøy et al., 2003; Guillory, 1993; High & Worelund, 1979; Parrish and Kazama, 1992; Pawson, 2003). For example, an estimated 40-85 % escapement rate is estimated in lost crab pots (Guillory, 1993). Moreover, Adey et al., (2008) reported a high escapement rate and low mortalities of animals captured by lost creels in the Norway lobster fishery. It was concluded that the low ghost fishing catch rate was due to the design of the creels, in which escapement mechanisms allowed both target species and non-target species to escape easily. As animals may enter and escape lost gear frequently, it is likely that the estimated catches presented here may not be representative of the actual numbers. Furthermore, since animals are expected to die and decay over time, it is possible that the total ghost fishing catch might be even higher. However, considering the previous investigations suggest that the ghost fishing activity of lost gear may be greater than expected.

Overall, there were great differences in catch and catch composition among gear types, which is consistent with previous knowledge that the ghost fishing potential of lost gear vary according to gear type. Furthermore, parlour traps accounted for the largest proportion of catch, in which 52 % contained animals. With the highest mean catch of all gear (3.09 animals/pot), this pot type dominated the catch of lobsters and fish, in which one lost parlour pot caught an average of 0.12 lobster, 2.09 crabs and 0.88 fish per pot. These findings suggest that parlour traps may have a greater impact on animals than other gear. This is observed by Smolowitz (1978), who investigated mortality rates of the American lobster (*Homarus americanus*) in parlour traps. He reported that 12-25 % of the animals died, probably as a consequence of the entrances preventing them to re-entering the traps. High catch rates in parlour traps has also been reported by other studies on ghost fishing. For example, Bullimore et al., (2001) investigated ghost fishing of deliberately lost parlour traps off the coast of Wales in UK. In a fleet of 12 parlour traps, he observed an annual catch rate of 6.06 brown crabs per pot and 0.44 lobsters per pot. He also concluded that these traps were capable of fishing for long periods of time. Although, their estimates are significantly greater than those presented in this study, it appears that lost parlour traps may be species-specific capturing large numbers of crabs and lobsters, which is expected as the pot is designed to catch crustaceans. The relatively low average numbers of crustaceans in folding traps, however, indicates that the catch is irrespective of the target organism, as both of these traps are designed to catch crustaceans. The relatively low catch of lobsters is expected and consistent with the presumably low population size of this species (Bakketeig et al., 2017). Furthermore, parlour traps dominated the catches of fish. Consequently, there is a reason to believe that parlour type-traps may be less selective, meaning that this gear type may have a greater ghost fishing impact on animals when lost. Another possible explanation could be related to the behaviour pattern of animals. For example, Bullimore et al., (2001) suggested that trapped fish may function as a source of bait, and hence attract more crabs and lobsters into the pot, in which eventually become trapped themselves. This could explain the large catch and composition of animals in parlour traps. It is also possible that a proportion of lobsters may have been attracted to the pot alone, as it may provide a good shelter from predators (Adey et al., 2008)

The second most hazardous gear type in this study was gillnets, in which 41 % contained animals. Furthermore, gillnets caught the most crabs of all gear (2.27 crabs per net), indicating that crabs are most vulnerable to being caught by this fishing gear. Despite the relatively low numbers of gillnets reported, these findings suggest that they have a greater impact on animals. Correspondingly, gillnets have been described as one of the most damaging methods of fishing, and described a significant problem causing severe impacts on marine species (Adey et al 2008). For example, Humborstad et al., (2003), found that lost gillnets in the Greenland halibut (*Reinhardtius hippoglossoides*) fishery in Norway caught a substantial number of animals and concluded that nets could continue to fish for several years. Since gillnets are normally made of synthetic materials, they can persist for several years may continue to catch and kill animals for a long period of time (Smolowitz, 1989). In Washington, High (1985) observed lost gillnets over a period of 6 years and concluded that nets continued to catch crabs, fishes and even birds over 3 years. Another study investigating ghost catches in set net fishery in Wales, UK, found that dead and decomposing fish in lost nets acted as a source of bait, attracting scavenging crabs which also became trapped in the netting, and concluded that lost nets could continue to catch crustaceans for up to 9 months after loss (Kaiser et al., 1996). Further, given the net structure and the characteristics of crabs they are also more likely to become entangled. This is likely to explain the large catch of crabs in gillnets.

Despite that folding traps were the most frequently found gear type along the coast, these traps had the lowest mean catch rate of all (0.62 animals/traps), in which 15 % contained animals. This might explain the fragile structure of folding traps, that makes them less resistant compared to parlour traps, which are made of more solid materials. Accordingly, the pot may have a higher risk of breakage exposed to harsh weather conditions (i.e. strong currents, storm) that may cause the pot to collapse and lose its capture function (Matsouka et al., 2005). Although, few studies have compared the catch efficiency of gear types in the coastal fishery in Norway. However, a study of ghost fishing in a blue swimmer crab (*Portunus pelagicus*) fishery in Australia, found that the rigid traps covered with wire meshing caught significantly more crabs than collapsible traps, which is comparable with the large and low catch of parlour and folding pot, respectively (Campbell & Sumpton, 2009). This was observed after the bait was exhausted, suggesting that the number of catches was more related to gear type instead of the presence of bait, which contradicts with previous research that catch declines with the decreasing odour of the bait making the pot no longer attractive to enter (Matsouka et al., 2005). It is important to note that there are many uncertainties when estimating the catches and catch composition by lost fishing gear, which is consistent with the lack of estimates in literature. The instantaneous estimates of catches presented here is likely to be an underestimation of the actual catch, as dead animals will eventually decay over time or get eaten by predators or other trapped animals (Adey et al., 2008; Campbell & Sumpton, 2009). Moreover, body parts of dead animals may have been lost during hauling of the gear to the surface, thus the estimated catches might be conservative. Several other factors may also affect the ghost fishing potential of lost gear, including gear design, gear size, abundance of organisms, location, physical exposure, environmental conditions, auto-rebaiting mechanisms, intended mode of capture, as well as the condition and age of the gear (Adey et al., 2008; Anderson & Alford, 2014; Breen 1978; Brown et al., 2005). Future studies are necessary to investigate the relationship between the ghost catch and these factors, to fully understand the ghost fishing potential of lost fishing gear.

4.3 Factors affecting ghost catch on lobster

In the analysis of factors influencing the ghost fishing catch of lobster, crabs and fish, different models were favoured for all animal groups. However, all models included gear type, bottom slope, substrate and depth, indicating that they all influenced the catch rate of these animals. Overall, the analysis showed that ghost fishing catch by gear vary depending on animals and that external factors may affect the ghost fishing potential of lost gear. Differences between the expected catch rate and the probability that a gear could catch (given no occupants), may indicate that catch rate is dependent on the presence of other occupants that may be already be trapped in the gear. Although, these differences will not be discussed any further for the overall comparison of animals.

For the analysis of lobster catch, there were no significant interaction effects between the various types of variables. However, the analyses showed that many of these were interacting and should therefore be discussed jointly. Nevertheless, the factors influencing lobster catch have been reviewed separately, as this compromised the literature. Environmental variables that clearly interact will be emphasized where it is particularly relevant.

4.3.1 The effect of gear type

The estimates for the effect of gear type on the catch of lobsters indicated that lost folding traps caught a higher number of lobsters compared to parlour and other traps. The model predicted maximum catches of 4 lobsters in folding traps. Although the estimated catch only reflects traps that contained animals, the low probability of catch suggests that this result may not be representative to the true catch rate and is probably due to low catch ratio in folding traps which creates noise in the data. However, the predictions from the model may indicate that the catch of lobster is dependent on the trap's ability to catch. In terms of gear type, this indicates that folding traps could have a larger catch than other gear types given that the pot is occupied. While an empty parlour pot may have a higher probability of catch compared to folding and other traps given no occupants. This indicates that the ghost fishing catch of lobsters depends on gear type, but also that the catch may depend on the presence of occupants. Trap-dependency has also been reported, meaning that the capture of species is dependent on previous captured animals or future captures. For example, a capture-mark-recapture study by Moland et al., (2003) from the South-eastern coast of Norway, reported that lobsters were "trap happy" and would return to traps as they associate traps with bait. This indicates that previously caught lobsters could have a higher recapture probability in areas with higher trap densities, as lobsters will be attracted to the trap and recaptured. Lobsters could also be attracted to a trap by the presence of other animals (Zimmer-Faust et al., 1989) or to the trap itself as they may function as shelters, which is crucial for this species (Smolowitz, 1978).

Gear type is a significant explanatory factor determining the species and size-specific ghost fishing catch rates by lost gear (Brown et al., 2005). Research shows that gear type is one of the main factors affecting ghost fishing. For example, parlour type-traps have been seen to cause greater mortalities of the American lobster (*Homarus americanus*) (Smolowitz, 1978). The author concluded that 12-25% of the trapped lobsters died due to starvation and injuries, as a result of the lack of escape routes preventing the escapement. Although, the study reported significantly greater catches than this present study, it could explain that parlour traps generally have a greater probability of catch compared to other gear types. One possible explanation for the low probability of catch in folding traps, could be related to their lightweight structure and simple design, as gear types with fragile structure may also have a greater risk of breakage. This is equivalent with the "collapsible" attributes of this gear type. A broken pot may lose its capture function and hence the ability to ghost catch. This may explain why the probability that a lost folding pot would catch was relatively low compared to the others. According to the predicted catch on lobsters, folding traps could capture a maximum of four lobsters, given that the pot contained lobster. This could indicate that the catch depends on the behaviour responses, and that there might be some social interactions between conspecifics, where animals may attract more animals into the pot. This is consistent with observations made in the spiny lobster (*Panilirus interruptus*) fishery in California, where lobsters released chemicals that attracted more lobsters to enter (Zimmer-Faust et al., 1989). In contrast, Smolowitz (1978) found that lobsters might be attracted to the pot alone, as they may function as good shelters protecting them from predators. Similar study described that the size and shape of the pot may influence ghost fishing catch, where larger traps would catch a higher number of animals. Moreover, the gear design and materials are important factors determining the ghost fishing catch rate. This was observed by Putsa et al., (2016), who compared ghost fishing catch rates in collapsible crab traps and found that traps varied depending on escape vents. Although, details on gear design or escape vents were not included in this study, this is likely a part of the explanation for the differences revealed by the models and should be further investigated. Different models were favoured for predicted catch and probability of catch, which made the interpretations difficult. However, this may indicate that the catch depends on gear type, but also depending on the presence of occupants.

Other important factors are gear selectivity and the efficiency of escapement mechanisms in preventing escapement (Adey et al., 2008; Putsa et al., 2016). Whether the gear remains intact as an efficient piece of fishing gear may also determine its ability to catch, which is coupled with exposure to physical forces, age and condition of the gear (Smolowitz, 1978). To distinguish these factors apart and determine their effect on the ghost fishing catch, more studies are needed. This could be done by monitoring deliberately lost traps under controlled conditions. For example, two traps of the same gear type with different ages, could be placed under similar environmental conditions to investigate whether the catch rate varied as a function of age.

4.3.2 The effect of depth

Overall, predictions from the model indicated that there were great variations in the predicted number of lobsters as a factor of depth, suggesting that ghost fishing is highly depth-dependent. The depth at which the lost gear occurs has been reported as a significant explanatory factor determining the ghost fishing ability of lost gear (Brown et al., 2005). Furthermore, depth has been suggested to affect the species-specific selectivity of ghost gear (Brown & Macfadyen, 2007). The predicted catch of lobsters was greatest in gear at mid-depths of approximately 10-20 meters on boulder and rock substrate, as well as towards shallower depths on soft substratum (Figure 10A). These results are representative of those habitats preferred by the lobster. For example, Galparsoro et al., (2009) predicted that the most suitable habitat for the European lobsters was rocky bottoms with steep slopes, ranging at depths between 25-30 meters, which is consistent with the findings of this study. This is further evidenced by Moland et al., (2011), who found that lobsters consumed more time within a depth range of 15 to 35 meters, in a study investigating the activity pattern of European lobster in a coastal marine reserve in Skagerrak, southern Norway. Therefore, higher catch rates at middle depths, could explain a higher abundance of lobsters and greater catch availability in these habitats. However, there are no current estimates of frequencies and/or the spatial distribution of lobsters that could confirm this. Another possible explanation is that the majority of gear retrieved in this study, were found at shallower water depths, as these areas are more accessible for the use of scuba diving gear. This could potentially have biased the results, as divers provided most of the data collection.

Ghost fishing in shallow waters are poorly investigated in pot fisheries and little is known about the impacts of ghost fishing on European lobster. Most studies has been carried out in shallow waters by experiments of simulated lost gear and underwater observations by diving (Baeta et al., 2009; Bullimore et al., 2001; Carr et al., 1992; Erzini et al., 1997; Humborstad et al., 2003; Kaiser et al., 1996; Sancho et al., 2003; Tschernij and Larsson, 2003). However, one study has been performed on Bullimore et al., (2001) reported catches of the European lobsters in deliberately lost traps deployed at a depth of 15 meters, which is consistent with the findings of this study. It is suggested that lost gear in shallow waters are more affected by bad weather conditions and other physical forces that could alter the catch characteristics of gear (Humborstad et al., 2003). Moreover, another study investigating lost gillnets in shallow waters, Erzini et al., (1997) found that gillnets are more exposed to light penetration and overgrowth by algae in shallow waters, which makes them more visible to animals, consequently reducing their catch efficiency.

On the contrary, the predicted probability of catch increased towards greater depths for all gear types and were greatest in deeper waters around 40 m (Figure 8B), which contradicts with previous knowledge of lobster habitat preference. Large catches have been observed in lost gillnets in Norwegian waters by Humborstad et al., (2003), who found the nets lost in deeper waters may continue to fish Greenland halibut for prolonged periods, as biofouling organisms and crabs are absent at greater depths, which tends to slow down the degradation rate of the net. Although, the study mentioned above was conducted at far greater depths, it could explain the greater probability of lobster catch towards deeper waters, as traps in deeper water may extend their fishing capabilities (Bullimore et al., 2001). As this study does not include data on the characteristics or condition of gear, it is difficult to determine the isolated depth-effect on lobster catch by lost gear, as several factors may be important. Further studies are needed to determine whether depth has an effect on the catch rate of lobsters.

4.3.3 The effect of substrate

Generally, the model predicted that the catch of lobsters differed between all levels of substrates, suggesting that the ghost fishing catch is also depends on substrate. Along with several other factors, the substrate material is one of the foremost factors affecting the potential of lost fishing gear to ghost fish (Brown et al., 2005). Furthermore, the predicted lobster catch was slightly greater on boulder and rocky substratum than soft substratum, with maximum catches in folding traps at boulder substrate. These habitat types are representative of those fished by recreational fishermen targeting lobsters. This corresponds to the findings of Krone and Schroder (2011), who found that the European lobster usually prefer rocky substrates and boulder fields, which is further evidenced by Smith et al., (2001). Similarly, another study on ghost fishing off the coast of Wales in the UK, reported catches of *H. gammarus* at grounds composed of boulders and bedrock (Bullimore et al., 2001). This indicates the effects of substrate on lobster catch depend on the habitat preference, however, this cannot be confirmed as the abundance and distribution of lobsters is unknown (as for the depth effect). Moreover, fisheries operating on rocky grounds is expected to have a greater loss of gear as these habitats are more exposed to harsh weather conditions such as storms and strong currents, as well as gear are more likely to get snagged on the seabed (Adey et al., 2008). However, it is likely that the catch of lobsters is greater at sites were lobster traps are usually set for fishing, which is consistent with the findings in this study.

Generally, the probability of catch increased with greater depths, irrespective of gear type (Figure 8B). Although, the probability of catch was slightly greater in gear found on boulder and rocky substratum, which is consistent with previous literature, as well as the findings provided by the count model. However, as the model predicts different outcomes for the count- and zero model, it is difficult to interpret the effect of substrate. A possible explanation could be that this predictor variable may be a poor indicator for the true condition. For these reasons, it is important to note that predictions should be interpreted with caution. Further investigation is needed to determine if these predictions are accurate, in order to evaluate whether the effect of substratum is a good predictor to estimate the ghost fishing catch on lobster.

4.3.4 The effect of bottom slope

Predictions from the model indicated that the catch of lobsters also differed as a function of bottom slope, predicting slightly greater catches for gear that were found in areas with gentle bottom slope, which indicates that traps lost at this elevation may catch more efficiently. The seabed structure, in which a fishing gear is lost has been reported as a significant variable that may influence the ghost fishing ability of lost gear (Brown et al., 2005). Furthermore, among depth and other environmental factors, the seabed structure may alter the physical exposure on lost gear that could potentially alter the catch efficiency of gear (Macfadyen et al., 2009). This could be the case in areas with steeper slopes, predicting very low catches. However, since there are no available data on any physical forces (i.e. wave exposure, currents, biofouling), this cannot be confirmed. The low numbers of lobsters at these bottom types could also be explained by the availability of the target species in these areas. In a study investigating the home range of lobster within a lobster reserve on the Skagerrak coast in Norway, Moland et al., (2011) found that the majority of lobsters were found on boulder fields with steeper slopes, which is inconsistent with this study. Another possible explanation of the low numbers of lobsters caught at steep slopes, is that that few traps were retrieved from these elevations. Possibly as these areas were less accessible for divers. This may also indicate that less traps are set for fishing at these elevations, probably as fishers tends to avoid deploying traps in locations that are more exposed to physical forces that would lead to gear loss (Pawson, 2003; Macfadyen et al., 2009). Therefore, one would expect fishers to deploy gear in more sheltered areas, which is consistent with the higher numbers of lobsters caught at flat and gentle bottom slopes.

Overall, the predicted probability of catch showed that there were no large differences between level of bottom slope, although the catch was slightly higher for gear found on rocky and flat substrate, which indicates higher catches at these habitats. There are currently few studies that have investigated the direct effect of bottom slope on ghost catch. Most traps may function as habitat enrichment and provide refuges for several animals in habitats with little structure (Valdemarsen & Suuronen, 2003). In similarity to artificial reefs, traps may attract species. Furthermore, the model indicates that the probability of lobster catch was predicted to zero for gears found on soft substrate and steep bottom type, irrespective of depth. This is likely the result of lack of data at this particular combination of substrate and depth a bottom slope. However, the number of studies investigating this effect on ghost fishing catches appears to be very scare. Therefore, more research is needed.

4.3.5 Comparison of animal groups

The prediction model of crabs showed significant interaction effects between gear type, bottom slope and depth, indicating an overall effect on the crab catch. The fish model revealed significant interaction effects between bottom slope, substrate and depth, while there was no significant interaction effect for lobster, which is probably due to insufficient data (n = 160). The many interaction effects between variables indicates that the combinations of these factors are important influencing the ghost fishing catch rates. Furthermore, the effect of gear type on catch indicated that parlour traps caught most lobster, while gillnets and other traps caught the most fish, in contrast to the catch of crabs that was relatively constant between the gear types with slightly higher catches (0-10 crabs/gear) than lobster and fish. A particularly high catch rate was observed for crab in fyke nets, which is probably due to outliers in the data, which is also the case for the high catch rate of fish on flat slope substrates. Previous research suggests that lost fishing gear is selective and that the catch efficiency depends on both design and abundance of target species (Smolowitz, 1989). This corresponds to the findings of Adey et al., (2008), who observed that more of the Norway lobster (*Nephros norvegicus)* retained in lost creels, while the non-target species escaped. He concluded that this was related to the creel design, which is consistent with the larger catch of lobster in folding traps. This is also equivalent to the dominant fish catch in other traps, which is mostly represented by fish traps. The predictions for the effects of the environmental factors substrate, bottom slope and depth varied between the animal groups. The depth effect on lobster catch and fish catch showed preference for optimum depth at medium depth and a descending catch rate towards zero at increased depth. For crabs, on the other hand, the catch was relatively constant at different depths, with the exception of some increase in catch with increased depth for all traps. The location where the gear was lost including other location-dependent factors such as depth, bottom conditions and habitat has been reported as an important factors that can affect the ghost fishing potential for lost gear (Al-Masroori et al., 2004; Brown et al., 2005; Humborstad et al., 2003; Pawson, 2003; Smolowitz, 1987;). Furthermore, the ghost fishing catch rate may vary depending on the availability of organisms (Anderson & Alford, 2014). Although there is a lack of estimates of the abundance of these organisms in the study area, it is possible that these differences could explain their availability and different habitat preferences.

5 Further studies

The data used in these analyses was based on the divers' own experiences on sites of which lost fishing gear occurred and areas that allowed for the retrieval of gear. As the data was collected only where gear occurred this indicates that the estimates provided here only represent a subset of the real extent of lost gear and ghost fishing impact. To increase the sample size and achieve more accurate estimations more systematic sampling should be carried out. For example, standardized quantitative methods such as underwater transect surveys by divers, could be a more appropriate method of mapping the extent and details of lost fishing gears. A strip transects sampling method, in which one observer moves along a path and records the occurrences (e.g. lost gear) would enable "in situ" observations of lost gear and enmeshed animals. This would provide us with more accurate estimates on the density of lost fishing gear (e.g. number of traps per unit area) and record important data such as gear type. Underwater technology such as underwater drones and ROV cameras may also be useful tools for future ghost fishing studies, scanning the seabed for lost gear and conduct video transects which can be used for further analysis.

The results of this study showed that different fishing gear varied in catch rates and catch composition and that gear type had an effect on catch rates. However, divers did not report details of trap designs, which most likely would have affected the ghost fishing potential of fishing gear. More comprehensive data could be obtained through by changing the design of diver report forms. For example, it would be interesting to collect data on the number of traps with cotton wire attached, to determine whether this preventative measure has been an effective solution reducing the ghost fishing catch rate of lost gear.

6 Conclusion

The present study found that a total of 4128 lost fishing gear were retrieved along the Norwegian coast during underwater clean-up efforts in the period 2015-2018. Many gear types were retrieved including traps, gillnets and fyke nets, in which traps represented the largest proportion. The clear dominance of traps was expected, since the clean-up efforts aimed at removing these. Folding traps was the most frequently found gear type, which indicates that this trap type might be more prone to become lost, probably as a result of its fragile structure, simple design and light weight. It could also be a result of the reluctance of fishers to retrieve this gear, as they represent a smaller economic loss than for example parlour traps. These theories should be further investigated through questionaries of fishers, to increase our understanding of the cause of loss and frequency of gear loss.

The geographical distribution of retrieved fishing gear was significantly different among regions, with larger proportions of gear retrieved from the south-eastern coast, indicating that this region might be a "hot spot" for accumulation of gear loss. This may be coupled with the higher level of boat traffic and fishing activity in this region, increasing the risk of gear conflicts and propel strikes. However, the significantly differences in gear distribution is most likely the result of variations in retrieval efforts among the diving clubs.

The analysis of ghost fishing catch revealed that 29 % of the retrieved gear contained animals. This suggest that lost fishing gear may actively ghost fishing in the shallow waters along the Norwegian coast. In total, 3779 crabs, 1406 fish and 160 lobsters were caught by different gear types, with mean catch ranging from 0.62-3.09 animals/per gear. With more than half of all retrieved parlour traps containing animals, this pot type represented the largest proportion of catch and had an average catch of 2.09 crabs, 0.12 lobster and 0.88 fish per trap. This suggested that parlour traps were less selective and caught large numbers of lobsters, crabs and fish, suggesting that these traps have a greater impact on animals, both capturing target and non-target organisms. Although, gillnets were less represented in numbers, they accounted for a large proportion of the crab catch. These findings suggest that these gear types may have a greater impact on organisms, which is supported by the literature and other studies on ghost fishing. This emphasize the importance of removing these gear types, as well as the need for preventative measures to avoid the loss. Despite the large proportion of retrieved folding traps, only 15 % contained animals, suggesting that these are more of a source of marine litter than a ghost fishing problem. In order to reduce the damages on animal groups due to ghost fishing, it would be necessary to aware fishers about the appropriate use of fishing gear according to the target species.

The analysis of factors influencing the ghost fishing catch rate showed clear differences among lobsters, crabs and fish in catch rates depending on gear type, depth, substrate and bottom slope. This could imply that gear types are selective of their target organisms and that the ghost fishing catch rate by lost gear is influenced by environmental factors. These results may reflect the location where gear is found, availability of the organisms in the area, gear selectivity and whether the gear contains animals or not. According to the magnitude of literature on ghost fishing, other factors may also be crucial including gear condition, causes of loss, time from loss to retrieval, whether the bait is still intact, weather conditions and other physical exposures on the gear. In order to provide a comprehensive picture of the ghost fishing problem, it would be necessary to collect more data on these variables.

The analysis of lobster catch showed that the catch rate differed depending on gear type and environmental factors. Folding traps had the largest predicted catch with a maximum a catch rate of 3-4 lobsters peaking at middle depths of 10-20 m on boulder and nearly 30 m on rock substratum. Although, the maximum catch rate is likely to be overpredicted, the predictions of depth and substrate type could reflect their habitat preference for middle depths and boulders and rock substratum and therefore the locations where lobster traps are usually set for fishing. Supporting this theory, interaction effects were detected between substrate and depth, which suggests that the depth effect was dependent on the level of substrate, yet this was not statistically significant. Furthermore, the probability of catch (given no occupants) was nearly 90 % in parlour traps found on rock substrate and flat slope, while folding traps had a low probability of catch. Differences between the predicted catch and probability makes it difficult to conclude, but could indicate that the ghost catch of lobsters also depends on the presence of occupants. However, these theories cannot be concluded with due to the contradicting results between the predicted catch rate and probability of catch, which is probably the result of noise in the data. It is important to note that the prediction models should be interpreted with caution, as they might not be representative to the real world.

Despite the weaknesses of the data that potentially could have biased the results, this study shows clear tendencies that lost fishing gear continue to catch animals and that the ghost fishing catch rate vary depending on gear and environmental variables. This study provides a good basis for future studies of ghost fishing in coastal fisheries in Norway. To assess the ghost fishing problem, studies should investigate the causes and frequencies of gear loss. To increase the credibility of citizen science data, clearer collection protocols should also be introduced, as well as training and instruction of divers. Further, other methods of data collection should also be considered such as underwater transect surveys using both divers and new technology, which can provide a more accurate picture of the magnitude of lost gear and their effects on marine life.

7 References

Adelir-Alves, J., Rocha, G. R. A., Souza, T. F., Pinheiro, P. C., & Freire, K. D. M. F. (2016). Abandoned, lost or otherwise discarded fishing gears in rocky reefs of Southern Brazil. *Brazilian Journal of Oceanography*, *64*(4), 427-434.

Adey, J. M., Smith, I. P., Atkinson, R. J. A., Tuck, I. D., & Taylor, A. C. (2008). 'Ghost fishing'of target and non-target species by Norway lobster Nephrops norvegicus creels. *Marine Ecology Progress Series*, *366*, 119-127.

Akaike, H. (1974). A new look at the statistical model identification. In *Selected Papers of Hirotugu Akaike* (pp. 215-222). Springer, New York, NY.

Al-Masroori, H., Al-Oufi, H., McIlwain, J. L., & McLean, E. (2004). Catches of lost fish traps (ghost fishing) from fishing grounds near Muscat, Sultanate of Oman. *Fisheries Research*, *69*(3), 407-414.

Anderson, D. A., Burnham, K. P., Anderson, D. A., & Burnham, K. P. (1998). Model selection and inference: a practical information-theoretic approach.

Anderson, J. A., & Alford, A. B. (2014). Ghost fishing activity in derelict blue crab traps in Louisiana. *Marine Pollution Bulletin*, *79*(1-2), 261-267.

Baeta, F., Costa, M. J., & Cabral, H. (2009). Trammel nets' ghost fishing off the Portuguese central coast. *Fisheries Research*, *98*(1-3), 33-39.

Bakketeig I.E., Hauge M. & Kvamme C. (ed.). 2017 Havforskningsrapporten 2017. Fisken og havet, særnr. 1–2017.

Bilkovic, D. M., Havens, K., Stanhope, D., & Angstadt, K. (2014). Derelict fishing gear in Chesapeake Bay, Virginia: Spatial patterns and implications for marine fauna. *Marine Pollution Bulletin*, *80*(1-2), 114-123.

Boland, R. C., & Donohue, M. J. (2003). Marine debris accumulation in the nearshore marine habitat of the endangered Hawaiian monk seal, Monachus schauinslandi 1999–2001. *Marine Pollution Bulletin*, *46*(11), 1385-1394.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*(11), 977-984.

Breen, P. A. (1987). Mortality of Dungeness crabs caused by lost traps in the Fraser River Estuary, British Columbia. *North American Journal of Fisheries Management*, *7*(3), 429-435.

Breen, P. A. (1989, April). A review of ghost fishing by traps and gillnets. In *Proceedings of the second international conference on marine debris* (Vol. 2, p. 571p).

Brown, J., & Macfadyen, G. (2007). Ghost fishing in European waters: Impacts and management responses. *Marine Policy*, *31*(4), 488-504.

Brown, J., Macfadyen, G., Huntington, T., Magnus, J., & Tumilty, J. (2005). Ghost fishing by lost fishing gear. Final Report to DG Fisheries and Maritime Affairs of the European Commission. Fish/2004/20. *Institute for European Environmental Policy/Poseidon Aquatic Resource Management Ltd joint report*, *151*.

Bullimore, B. A., Newman, P. B., Kaiser, M. J., Gilbert, S. E., & Lock, K. M. (2001). A study of catches in a fleet of" ghost-fishing" pots. *Fishery Bulletin*, *99*(2), 247-247.

Burnham, K. P., & D. R. Anderson. 1998, Model Selection and Inferences. New York, Springer Verlag.

Campbell, M. J., & Sumpton, W. D. (2009). Ghost fishing in the pot fishery for blue swimmer crabs Portunus pelagicus in Queensland, Australia. *Fisheries Research*, *95*(2-3), 246-253.

Carr, H. A. (1985). Underwater survey of simulated lost demersal and lost commercial gill nets off New England. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris 26-29 November 1984 Honolulu Hawaii* (pp. 438-447).

Carr, H. A. (1992). A study of ghost gillnets in the inshore waters of southern New England. In *Proceeding of Marine Technology Society'92 Conference. Marine Technology Society, Washington DC*.

Carr, H. A., & Harris, J. (1997). Ghost-fishing gear: Have fishing practices during the past few years reduced the impact?. In *Marine Debris* (pp. 141-151). Springer, New York, NY.

CNO (2017a). Clean Nordic Oceans. [Online]. Retrieved from http://cnogear.org/news/english/successful-retrieval-survey-along-the-coast-of-norway-copy

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., ... & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), 291-297.

Directorate of Fisheries (DOF). (2017). Fritidsfiske (Version 4.5.0) [Mobile application software]. Retrieved from www.fiskeridir.no/Fritidsfiske/Appen-Fritidsfiske

Erzini, K., Bentes, L., Coelho, R., Lino, P. G., Monteiro, P., Ribeiro, J., & Gonçalves, J. (2008). Catches in ghost-fishing octopus and fish traps in the northeastern Atlantic Ocean (Algarve, Portugal). *Fishery Bulletin*, *106*(3), 321-327.

Erzini, K., Monteiro, C. C., Ribeiro, J., Santos, M. N., Gaspar, M., Monteiro, P., & Borges, T. C. (1997). An experimental study of gill net and trammel net\'ghost fishing\'off the Algarve (southern Portugal). *Marine Ecology Progress Series*, *158*, 257-265.

FAO (Food and Agriculture Organization of the United Nations). (1995). Code of Conduct for Responsible Fisheries. FAO, Rome. 41 p.

Forskrift om utøvelse av fisket i sjøen. (2009). Tap av redskap og orden på høstingsfelt (FOR-2019-03-13-224). [Online]. Retrieved from https://lovdata.no/dokument/SF/forskrift/2004-12-22-1878#KAPITTEL_19

Forskrift om utøvelse av fisket i sjøen. (2018) Vedlegg 8. Krav til rømningshull (FOR-2004-12-22-1878). [Online]. Retrieved from https://lovdata.no/dokument/SF/forskrift/2004-12-22-1878

Fox, J., & Weisberg, S. (2011). Car: companion to applied regression Available at: http://CRAN. *R-project. org/package= car Accessed*, *20*.

Galparsoro, I., Borja, Á., Bald, J., Liria, P., & Chust, G. (2009). Predicting suitable habitat for the European lobster (Homarus gammarus), on the Basque continental shelf (Bay of Biscay), using Ecological-Niche Factor Analysis. *Ecological modelling*, *220*(4), 556-567.

Gilman, E. (2015). Status of international monitoring and management of abandoned, lost and discarded fishing gear and ghost fishing. *Marine Policy*, *60*, 225-239.

Gilman, E., Chopin, F., Suuronen, P., & Kuemlangan, B. (2016). Abandoned, lost and discarded gillnets and trammel nets: methods to estimate ghost fishing mortality, and the status of regional monitoring and management. *FAO Fisheries and Aquaculture Technical Paper*, (600), I.

Godøy, H., Furevik, D. M., & Stiansen, S. (2003). Unaccounted mortality of red king crab (Paralithodes camtschaticus) in deliberately lost pots off Northern Norway. *Fisheries Research*, *64*(2-3), 171-177.

Grimaldo, E., Herrmann, B., Vollstad, J., Su, B., Moe Føre, H., Larsen, R. B., & Handling editor: Michael Pol. (2018). Fishing efficiency of biodegradable PBSAT gillnets and conventional nylon gillnets used in Norwegian cod (Gadus morhua) and saithe (Pollachius virens) fisheries. *ICES Journal of Marine Science*, *75*(6), 2245-2256.

Guillory, V. (1993). Ghost fishing by blue crab traps. *North American Journal of Fisheries Management*, *13*(3), 459-466.

Guillory, V., McMillen-Jackson, A., Hartman, L., Perry, H., Floyd, T., Wagner, T., & Graham, G. (2001). *Blue crab derelict traps and trap removal programs* (pp. 1-10). Ocean Springs, Mississippi: Gulf States Marine Fisheries Commission.

Gule sider. (2017). [Online]. Retrieved from https://kart.gulesider.no/

Hébert, M., Miron, G., Moriyasu, M., Vienneau, R., & DeGrâce, P. (2001). Efficiency and ghost fishing of snow crab (Chionoecetes opilio) traps in the Gulf of St. Lawrence. *Fisheries Research*, *52*(3), 143-153.

Hidalgo-Ruz, V., & Thiel, M. (2015). The contribution of citizen scientists to the monitoring of marine litter. *Marine anthropogenic litter*, 433-451.

High, L. H. (1985). Some consequences of lost fishing gear. In *Proc. Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu Hawaii*.

High, W. L. & Worlund. D. (1979). Escape of king crab, Paralithodes camtschatica, from derelict pots. Technical report NMFS SSRF 734. National Oceanic and Atmospheric Administration, Washington, D.C.

Huse, I. (2003). *A Desk-study of Diverse Methods of Fishing when Onsidered in Perspective of Responsible Fishing, and the Effect on the Ecosystem Caused by Fishing Activity*. Nordic Council of Ministers.

Jackman, S., Tahk, A., Zeileis, A., Maimone, C., Fearon, J., Meers, Z., ... & Imports, M. A. S. S. (2017). Package 'pscl'. *See http://github. com/atahk/pscl*.

Jennings, S., & Kaiser, M. J. (1998). The effects of fishing on marine ecosystems. In *Advances in marine biology* (Vol. 34, pp. 201-352). Academic Press.

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., & Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen‐science programs. *Conservation Biology*, *25*(6), 1148-1154.

Kaiser, M. J., Bullimore, B., Newman, P., Lock, K., & Gilbert, S. (1996). Catches in\'ghost fishing\'set nets. *Marine ecology progress series*, *145*, 11-16.

Kimker, A. (1994). Tanner crab survival in closed pots. *Alaska Fishery Research Bulletin*, *1*(2), 179-183.

Kleiven, A. R., Olsen, E. M., & Vølstad, J. H. (2011). Estimating recreational and commercial fishing effort for European lobster Homarus gammarus by strip transect sampling. *Marine and Coastal Fisheries*, *3*(1), 383-393.

Kleiven, A. R., Olsen, E. M., & Vølstad, J. H. (2012). Total catch of a red-listed marine species is an order of magnitude higher than official data. *PLoS One*, *7*(2), e31216.

Krone, R., & Schröder, A. (2011). Wrecks as artificial lobster habitats in the German Bight. *Helgoland marine research*, *65*(1), 11.

Kruse, G. H., & Kimker, A. (1993). *Degradable escape mechanisms for pot gear: a summary report to the Alaska Board of Fisheries* (p. 23). Alaska Department of Fish & Game, Division of Commercial Fisheries.

Laist, D. W. (1997). Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In *Marine Debris* (pp. 99-139). Springer, New York, NY.

Laist, D. W., & Wray, T. (1995). Marine debris entanglement and ghost fishing: a cryptic and significant type of bycatch. *Solving Bycatch: Considerations for Today and Tomorrow, University of Alaska*.

Lambert, D. (1992). Zero-inflated Poisson regression, with an application to defects in manufacturing. *Technometrics*, *34*(1), 1-14.

Macfadyen, G., Huntington, T., & Cappell, R. (2009). *Abandoned, lost or otherwise discarded fishing gear* (No. 523). Food and Agriculture Organization of the United Nations (FAO).

Matsuoka, T., Nakashima, T., & Nagasawa, N. (2005). A review of ghost fishing: scientific approaches to evaluation and solutions. *Fisheries Science*, *71*(4), 691.

Mazerolle, M. J. (2017). AICcmodavg-model selection and multimodel inference based on (q) aic (c), R package.

Moland, E., Olsen, E. M., Andvord, K., Knutsen, J. A., & Stenseth, N. C. (2011). Home range of European lobster (Homarus gammarus) in a marine reserve: implications for future reserve design. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*(7), 1197-1210.

Moland, E., Ulmestrand, M., Olsen, E. M., & Stenseth, N. C. (2013). Long-term decrease in sex-specific natural mortality of European lobster within a marine protected area. *Marine Ecology Progress Series*, *491*, 153-164.

Nagelkerke, N. J. (1991). A note on a general definition of the coefficient of determination. *Biometrika*, *78*(3), 691-692.

Nelms, S. E., Coombes, C., Foster, L. C., Galloway, T. S., Godley, B. J., Lindeque, P. K., & Witt, M. J. (2017). Marine anthropogenic litter on British beaches: a 10-year nationwide assessment using citizen science data. *Science of the Total Environment*, *579*, 1399-1409.

Norges Geologiske Undersøkelse (NGU). (Version 4.5.0) [Online]. Retrieved from http://geo.ngu.no/kart/marin_mobil/).

Parrish, F. A. (1992). Evaluation of ghost fishing in the Hawaiian lobster fishery. *Fish. Bull.*, *90*, 720-725.

Pawson, M. G. (2003). The catching capacity of lost static fishing gears: introduction.

Pecci, K. J. (1978). Ghost fishing of vented and unvented lobster, Homarus americanus, traps. *Mar. Fish. Rev.*, *40*, 9-43.

Putsa, S., Boutson, A., & Tunkijjanukij, S. (2016). Comparison of ghost fishing impacts on collapsible crab trap between conventional and escape vents trap in Si Racha Bay, Chon Buri province. *Agriculture and Natural Resources*, *50*(2), 125-132.

Sætre, R. (Ed.). (2007). *The Norwegian coastal current: oceanography and climate*. Akademika Pub.

Sancho, G., Puente, E., Bilbao, A., Gomez, E., & Arregi, L. (2003). Catch rates of monkfish (Lophius spp.) by lost tangle nets in the Cantabrian Sea (northern Spain). *Fisheries Research*, *64*(2-3), 129-139.

Santos, M. N., Saldanha, H. J., Gaspar, M. B., & Monteiro, C. C. (2003). Hake (Merluccius merluccius L., 1758) ghost fishing by gill nets off the Algarve (southern Portugal). *Fisheries Research*, *64*(2-3), 119-128.

Sheldon, W. W., & R. L. *Dow*. (1975). Trap contribution of losses in the American lobster fishery. *Fish. Bull.*, *73*, 449-451.

Smith, I. P., Jensen, A. C., Collins, K. J., & Mattey, E. L. (2001). Movement of wild European lobsters Homarus gammarus in natural habitat. *Marine Ecology Progress Series*, *222*, 177-186.

Smolowitz, R. J., Corps, L. N., & Center, N. F. (1978). Lobster, Homarus americanus, trap design and ghost fishing. *Marine Fisheries Review*, *40*(5-6), 2-8.

Stevens, B. G. (1996). Crab bycatch in pot fisheries. *Solving bycatch: considerations for today and tomorrow*, 151-158.

Sullivan, B. L., Aycrigg, J. L., Barry, J. H., Bonney, R. E., Bruns, N., Cooper, C. B., ... & Fink, D. (2014). The eBird enterprise: an integrated approach to development and application of citizen science. *Biological Conservation*, *169*, 31-40.

Sullivan, B. L., Wood, C. L., Iliff, M. J., Bonney, R. E., Fink, D., & Kelling, S. (2009). eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation*, *142*(10), 2282-2292.

Team, R. C. (2013). R development core team. *RA Lang Environ Stat Comput*, *55*, 275-286.

Toivio, S. (2017). Factors influencing the geographical pattern of lobster fishing and gear loss in Kosterhavet National Park.

Tschernij, V., & Larsson, P. O. (2003). Ghost fishing by lost cod gill nets in the Baltic Sea. *Fisheries Research*, *64*(2-3), 151-162.

Uhrin, A. V., Matthews, T. R., & Lewis, C. (2014). Lobster trap debris in the Florida Keys National Marine Sanctuary: distribution, abundance, density, and patterns of accumulation. *Marine and Coastal Fisheries*, *6*(1), 20-32.

Valdemarsen, J. W., & Suuronen, P. (2003). 19 Modifying Fishing Gear to Achieve Ecosystem Objectives. *Responsible Fish. Mar. Ecosyst*, 321.

Vegter, A. C., Barletta, M., Beck, C., Borrero, J., Burton, H., Campbell, M. L., ... & Gilardi, K. V. (2014). Global research priorities to mitigate plastic pollution impacts on marine wildlife. *Endangered Species Research*, *25*(3), 225-247.

Vuong, Q. H. (1989). Likelihood ratio tests for model selection and non-nested hypotheses. *Econometrica: Journal of the Econometric Society*, 307-333.

Wagh, Y. S., & Kamalja, K. K. (2017). Comparison of methods of estimation for parameters of generalized Poisson distribution through simulation study. *Communications in Statistics-Simulation and Computation*, *46*(5), 4098-4112.

Wickham, H., & Wickham, M. H. (2007). The ggplot package.

Zeileis, A., Kleiber, C., & Jackman, S. (2008). Regression models for count data in R. *Journal of statistical software*, *27*(8), 1-25.

Zimmer-Faust, R. K. (1989). The relationship between chemoreception and foraging behavior in crustaceans. *Limnology and Oceanography*, *34*(7), 1367-1374.

8 Appendix

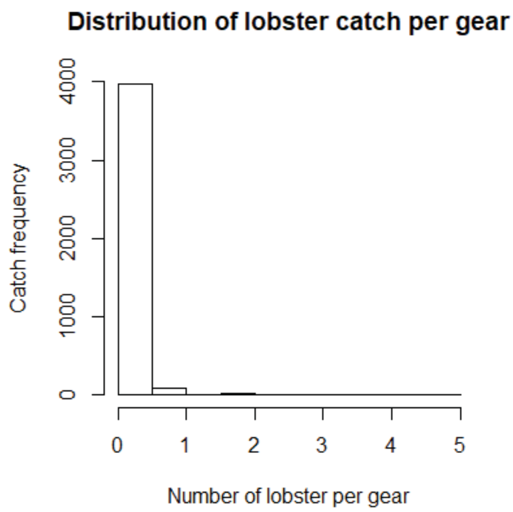


Figure 1: Catch frequency of lobsters per gear showing excess zero observations in the data

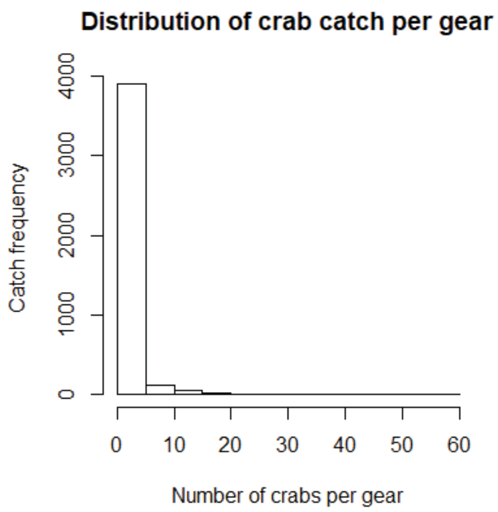
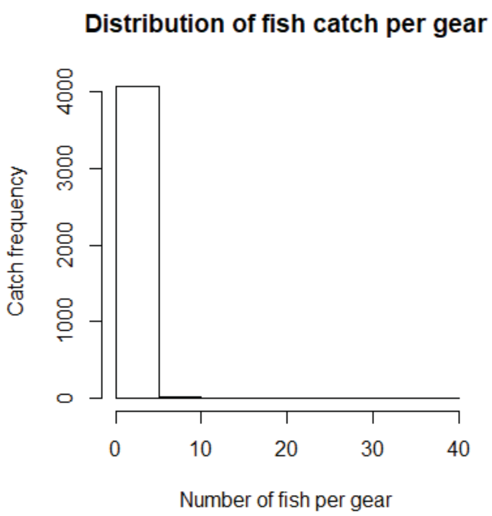


Figure 2: Catch frequency of crabs per gear amount of showing amount of excess zero observations in the data



.

Figure 3: Catch frequency of fish per gear showing amount of excess zero observations in the data.

Table 1: Complete model selection table for ZIP models predicting the lobster catch as a function of geartype, depth, substrate and bottom slope, retrieved along the Norwegian coast in 2015-2018. General model structure: Y=count | Pr (y=0). K: number of parameters; AICc: corrected for Akaike's information criterion; ΔAIC: deviation relative to the most supported model; ModelLik: model likelihood among the candidate models; AICcWt: AICc-weight (the model's AICc support); LL: loglikelihood-value.

<table>
<tr><th>Model structure</th><th>K</th><th>AICc</th><th>ΔAICc</th><th>ModelLik</th><th>AICcWt</th><th>LL</th></tr>
<tr><td>geartype + Bottom.slope + Substrate * Depth2 | geartype + Bottom.slope * Substrate + Depth</td><td>25</td><td>844,15</td><td>0,00</td><td>1,00</td><td>0,37</td><td>-396,87</td></tr>
<tr><td>geartype + Bottom.slope + Substrate * Depth | geartype + Bottom.slope * Substrate + Depth</td><td>22</td><td>844,30</td><td>0,14</td><td>0,93</td><td>0,34</td><td>-399,99</td></tr>
<tr><td>geartype + Bottom.slope + Substrate * Depth2 | geartype + Bottom.slope * Substrate + Depth2</td><td>26</td><td>845,38</td><td>1,23</td><td>0,54</td><td>0,20</td><td>-396,46</td></tr>
<tr><td>geartype + Bottom.slope + Substrate + Depth | geartype + Bottom.slope * Substrate + Depth</td><td>20</td><td>848,09</td><td>3,94</td><td>0,14</td><td>0,05</td><td>-403,91</td></tr>
<tr><td>geartype * Bottom.slope + Substrate * Depth | geartype + Bottom.slope * Substrate + Depth</td><td>26</td><td>849,59</td><td>5,44</td><td>0,07</td><td>0,02</td><td>-398,57</td></tr>
<tr><td>geartype * Bottom.slope + Substrate + Depth | geartype + Bottom.slope * Substrate + Depth</td><td>24</td><td>852,53</td><td>8,38</td><td>0,02</td><td>0,01</td><td>-402,07</td></tr>
<tr><td>geartype + Bottom.slope + Substrate | geartype + Bottom.slope * Substrate + Depth</td><td>19</td><td>853,12</td><td>8,97</td><td>0,01</td><td>0,00</td><td>-407,44</td></tr>
<tr><td>geartype + Depth * Substrate | geartype + Bottom.slope * Substrate + Depth</td><td>20</td><td>854,98</td><td>10,82</td><td>0,00</td><td>0,00</td><td>-407,35</td></tr>
<tr><td>geartype * Bottom.slope + Substrate | geartype + Bottom.slope * Substrate + Depth</td><td>23</td><td>857,65</td><td>13,50</td><td>0,00</td><td>0,00</td><td>-405,65</td></tr>
<tr><td>geartype + Bottom.slope + Depth | geartype + Bottom.slope * Substrate + Depth</td><td>18</td><td>858,67</td><td>14,52</td><td>0,00</td><td>0,00</td><td>-411,23</td></tr>
<tr><td>geartype + Depth + Substrate | geartype + Bottom.slope * Substrate + Depth</td><td>18</td><td>859,01</td><td>14,86</td><td>0,00</td><td>0,00</td><td>-411,39</td></tr>
<tr><td>geartype * Bottom.slope + Depth | geartype + Bottom.slope * Substrate + Depth</td><td>22</td><td>860,69</td><td>16,54</td><td>0,00</td><td>0,00</td><td>-408,18</td></tr>
<tr><td>geartype + Depth | geartype + Bottom.slope * Substrate + Depth</td><td>16</td><td>863,27</td><td>19,12</td><td>0,00</td><td>0,00</td><td>-415,55</td></tr>
<tr><td>geartype * Depth * Substrate | geartype + Bottom.slope * Substrate + Depth</td><td>30</td><td>864,14</td><td>19,98</td><td>0,00</td><td>0,00</td><td>-401,77</td></tr>
<tr><td>geartype * Depth + Substrate | geartype + Bottom.slope * Substrate + Depth</td><td>20</td><td>864,70</td><td>20,54</td><td>0,00</td><td>0,00</td><td>-412,21</td></tr>
<tr><td>geartype * Depth | geartype + Bottom.slope * Substrate + Depth</td><td>18</td><td>865,93</td><td>21,78</td><td>0,00</td><td>0,00</td><td>-414,85</td></tr>
<tr><td>geartype * Bottom.slope * Depth | geartype + Bottom.slope * Substrate + Depth</td><td>30</td><td>872,93</td><td>28,78</td><td>0,00</td><td>0,00</td><td>-406,16</td></tr>
<tr><td>geartype + Substrate | geartype + Bottom.slope * Substrate + Depth</td><td>17</td><td>967,95</td><td>123,80</td><td>0,00</td><td>0,00</td><td>-466,88</td></tr>
<tr><td>geartype * Bottom.slope | geartype + Bottom.slope * Substrate + Depth</td><td>21</td><td>969,19</td><td>125,03</td><td>0,00</td><td>0,00</td><td>-463,44</td></tr>
<tr><td>geartype * Substrate | geartype + Bottom.slope * Substrate + Depth</td><td>21</td><td>973,48</td><td>129,32</td><td>0,00</td><td>0,00</td><td>-465,59</td></tr>
<tr><td>geartype | geartype + Bottom.slope * Substrate + Depth</td><td>15</td><td>986,33</td><td>142,17</td><td>0,00</td><td>0,00</td><td>-478,09</td></tr>
</table>

Table 2: Complete model selection table for ZIP models predicting the crab catch as a function of geartype, depth, substrate and bottom slope, retrieved along the Norwegian coast in 2015-2018. General model structure: Y=count | Pr (y=0). K: number of parameters; AICc: corrected for Akaike's information criterion; ΔAIC: deviation relative to the most supported model; ModelLik: model likelihood among the candidate models; AICcWt: AICc-weight (the model's AICc support); LL: loglikelihood-value.

<table>
<tr><th>Model structure</th><th>K</th><th>AICc</th><th>ΔAICc</th><th>ModelLik</th><th>AICcWt</th><th>LL</th></tr>
<tr><td>geartype * Bottom.slope * Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>61</td><td>8539,34</td><td>0,00</td><td>1,00</td><td>1,00</td><td>-4207,63</td></tr>
<tr><td>geartype + Bottom.slope * Substrate * Depth2 | geartype + Bottom.slope * Substrate * Depth2</td><td>62</td><td>8634,14</td><td>94,80</td><td>0,00</td><td>0,00</td><td>-4254,00</td></tr>
<tr><td>geartype + Bottom.slope * Substrate * Depth2 | geartype + Bottom.slope * Substrate * Depth2</td><td>62</td><td>8634,14</td><td>94,80</td><td>0,00</td><td>0,00</td><td>-4254,00</td></tr>
<tr><td>geartype + Bottom.slope * Substrate * Depth2 | geartype + Bottom.slope * Substrate * Depth2</td><td>62</td><td>8634,14</td><td>94,80</td><td>0,00</td><td>0,00</td><td>-4254,00</td></tr>
<tr><td>geartype * Bottom.slope * Substrate | geartype + Bottom.slope * Substrate * Depth2</td><td>76</td><td>8634,18</td><td>94,84</td><td>0,00</td><td>0,00</td><td>-4239,48</td></tr>
<tr><td>geartype + Bottom.slope * Substrate * Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>53</td><td>8734,85</td><td>195,51</td><td>0,00</td><td>0,00</td><td>-4313,65</td></tr>
<tr><td>geartype + Bottom.slope * Substrate * Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>53</td><td>8734,85</td><td>195,51</td><td>0,00</td><td>0,00</td><td>-4313,65</td></tr>
<tr><td>geartype + Bottom.slope * Substrate + Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>45</td><td>8741,86</td><td>202,52</td><td>0,00</td><td>0,00</td><td>-4325,37</td></tr>
<tr><td>geartype * Bottom.slope + Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>47</td><td>8766,97</td><td>227,63</td><td>0,00</td><td>0,00</td><td>-4335,87</td></tr>
<tr><td>geartype * Bottom.slope + Substrate * Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>51</td><td>8768,76</td><td>229,42</td><td>0,00</td><td>0,00</td><td>-4332,66</td></tr>
<tr><td>geartype + Bottom.slope * Substrate | geartype + Bottom.slope * Substrate * Depth2</td><td>44</td><td>8778,06</td><td>238,72</td><td>0,00</td><td>0,00</td><td>-4344,49</td></tr>
<tr><td>geartype * Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>41</td><td>8799,82</td><td>260,48</td><td>0,00</td><td>0,00</td><td>-4358,44</td></tr>
<tr><td>geartype * Substrate + Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>47</td><td>8810,49</td><td>271,14</td><td>0,00</td><td>0,00</td><td>-4357,63</td></tr>
<tr><td>geartype * Bottom.slope + Substrate | geartype + Bottom.slope * Substrate * Depth2</td><td>48</td><td>8811,18</td><td>271,83</td><td>0,00</td><td>0,00</td><td>-4356,95</td></tr>
<tr><td>geartype + Bottom.slope * Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>41</td><td>8814,20</td><td>274,86</td><td>0,00</td><td>0,00</td><td>-4365,63</td></tr>
<tr><td>geartype * Bottom.slope | geartype + Bottom.slope * Substrate * Depth2</td><td>46</td><td>8817,76</td><td>278,42</td><td>0,00</td><td>0,00</td><td>-4362,29</td></tr>
<tr><td>geartype + Bottom.slope + Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>39</td><td>8821,12</td><td>281,77</td><td>0,00</td><td>0,00</td><td>-4371,13</td></tr>
<tr><td>geartype + Bottom.slope + Substrate + Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>41</td><td>8823,70</td><td>284,36</td><td>0,00</td><td>0,00</td><td>-4370,38</td></tr>
<tr><td>geartype + Bottom.slope + Substrate * Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>43</td><td>8826,70</td><td>287,36</td><td>0,00</td><td>0,00</td><td>-4369,83</td></tr>
<tr><td>geartype + Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>37</td><td>8833,16</td><td>293,82</td><td>0,00</td><td>0,00</td><td>-4379,20</td></tr>
<tr><td>geartype + Substrate + Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>39</td><td>8833,80</td><td>294,46</td><td>0,00</td><td>0,00</td><td>-4377,48</td></tr>
<tr><td>geartype + Substrate * Depth | geartype + Bottom.slope * Substrate * Depth2</td><td>41</td><td>8836,93</td><td>297,59</td><td>0,00</td><td>0,00</td><td>-4377,00</td></tr>
<tr><td>geartype * Substrate | geartype + Bottom.slope * Substrate * Depth2</td><td>46</td><td>8849,88</td><td>310,54</td><td>0,00</td><td>0,00</td><td>-4378,35</td></tr>
<tr><td>geartype + Bottom.slope + Substrate | geartype + Bottom.slope * Substrate * Depth2</td><td>40</td><td>8870,92</td><td>331,58</td><td>0,00</td><td>0,00</td><td>-4395,01</td></tr>
<tr><td>geartype + Substrate | geartype + Bottom.slope * Substrate * Depth2</td><td>38</td><td>8871,42</td><td>332,08</td><td>0,00</td><td>0,00</td><td>-4397,31</td></tr>
</table>

Table 3: Complete model selection table for ZIP models predicting the fish catch as a function of geartype, depth, substrate and bottom slope, retrieved along the Norwegian coast in 2015-2018. General model structure: Y=count | Pr (y=0). K: number of parameters; AICc: corrected for Akaike's information criterion; ΔAIC: deviation relative to the most supported model; ModelLik: model likelihood among the candidate models; AICcWt: AICc-weight (the model's AICc support); LL: loglikelihood-value.

<table>
<tr><th>Model structure</th><th>K</th><th>AICc</th><th>ΔAICc</th><th>ModelLik</th><th>AICcWt</th><th>LL</th></tr>
<tr><td>geartype + Bottom.slope * Substrate * Depth2 | geartype * Bottom.slope * Depth</td><td>61</td><td>3676.50</td><td>0.00</td><td>1.00</td><td>1.00</td><td>-1776.21</td></tr>
<tr><td>geartype + Bottom.slope * Substrate * Depth | geartype * Bottom.slope * Depth</td><td>52</td><td>3704.87</td><td>28.38</td><td>0.00</td><td>0.00</td><td>-1799.69</td></tr>
<tr><td>geartype * Bottom.slope + Substrate * Depth | geartype * Bottom.slope * Depth</td><td>50</td><td>3741.57</td><td>65.07</td><td>0.00</td><td>0.00</td><td>-1820.09</td></tr>
<tr><td>geartype + Bottom.slope + Substrate * Depth2 | geartype * Bottom.slope * Depth</td><td>45</td><td>3758.36</td><td>81.87</td><td>0.00</td><td>0.00</td><td>-1833.62</td></tr>
<tr><td>geartype + Bottom.slope + Substrate + Depth2 | geartype * Bottom.slope * Depth</td><td>41</td><td>3768.13</td><td>91.63</td><td>0.00</td><td>0.00</td><td>-1842.60</td></tr>
<tr><td>geartype + Bottom.slope + Substrate * Depth | geartype * Bottom.slope * Depth</td><td>42</td><td>3772.00</td><td>95.50</td><td>0.00</td><td>0.00</td><td>-1843.51</td></tr>
<tr><td>geartype * Bottom.slope * Depth | geartype * Bottom.slope * Depth</td><td>60</td><td>3772.98</td><td>96.48</td><td>0.00</td><td>0.00</td><td>-1825.49</td></tr>
<tr><td>geartype + Bottom.slope + Substrate + Depth | geartype * Bottom.slope * Depth</td><td>40</td><td>3794.35</td><td>117.85</td><td>0.00</td><td>0.00</td><td>-1856.73</td></tr>
<tr><td>geartype * Substrate + Depth | geartype * Bottom.slope * Depth</td><td>46</td><td>3804.11</td><td>127.62</td><td>0.00</td><td>0.00</td><td>-1855.47</td></tr>
<tr><td>geartype + Substrate * Depth | geartype * Bottom.slope * Depth</td><td>40</td><td>3817.23</td><td>140.73</td><td>0.00</td><td>0.00</td><td>-1868.17</td></tr>
<tr><td>geartype + Bottom.slope + Depth | geartype * Bottom.slope * Depth</td><td>38</td><td>3822.89</td><td>146.39</td><td>0.00</td><td>0.00</td><td>-1873.04</td></tr>
<tr><td>geartype + Bottom.slope * Depth | geartype * Bottom.slope * Depth</td><td>40</td><td>3826.79</td><td>150.30</td><td>0.00</td><td>0.00</td><td>-1872.95</td></tr>
<tr><td>geartype + Substrate + Depth | geartype * Bottom.slope * Depth</td><td>38</td><td>3841.58</td><td>165.09</td><td>0.00</td><td>0.00</td><td>-1882.39</td></tr>
<tr><td>geartype * Depth | geartype * Bottom.slope * Depth</td><td>40</td><td>3858.59</td><td>182.10</td><td>0.00</td><td>0.00</td><td>-1888.85</td></tr>
<tr><td>geartype + Depth | geartype * Bottom.slope * Depth</td><td>36</td><td>3859.08</td><td>182.58</td><td>0.00</td><td>0.00</td><td>-1893.18</td></tr>
</table>

Table 4: Parameter estimates for the most supported lobster ZIP model (Table 3 and Figure 8) based on model structure with the lowest AIC value. The model predicts the catch of lobster as a function of gear type, depth, bottom slope and substrate. Levels = Pa: Parlour trap; Fl: Flat bottom slope; Bo: Boulder substrate; Ro: rock substrate; Ge: gentle slope. SE = standard error. R^2= 0.22

Count model (Poisson with log link)			
Term	Levels	Estimate	SE
Intercept	Pa.Fl.Bo	-0.168	1.457
Geartype	Folding	0.969	0.605
Geartype	Other	-0.171	0.361
BottomSlope	Ge	0.293	0.499
BottomSlope	Steep	-2.414	0.823
Substrate	Rock	-6.398	3.379
Substrate	Soft	-0.298	1.789
Depth		0.042	0.106
$Depth^2$		-0.001	0.002
Substrate*Depth	Rock	0.384	0.259
Substrate* $Depth^2$	Soft	-0.065	0.124
Substrate*Depth	Rock	-0.006	0.004
Substrate* $Depth^2$	Soft	0.001	0.002

Zero-inflated model (binominal with logit link)			
Term	Levels	Estimate	SE
Intercept	Pa.Fl.Bo	2.810	0.897
Geartype	Folding	3.698	0.638
Geartype	Other	0.818	0.473
BottomSlope	Ge	0.486	0.638
BottomSlope	Steep	-2.337	1.281
Substrate	Rock	-3.550	1.064
Substrate	Soft	-1.062	0.774
Depth		-0.055	0.034
BottomSlope*Substrate	Ge.Ro	3.561	1.152
BottomSlope*Substrate	Steep.Ro	5.738	1.801
BottomSlope*Substrate	Ge.Soft	0.215	0.713
BottomSlope*Substrate	Steep.Soft	15.290	668.604

Tabell 5: Parameter estimates for the most supported crab ZIP model (Table 4 and Figure 9) based on model structure with the lowest AIC value. The model predicts the catch of crabs as a function of gear type. depth. bottom slope and substrate. Levels = Pa: Parlour traps; Fo: Folding trap; Fy: Fyke nets Ot: Other traps; Gi: Gillnets; Ge: Gentle slope. Fl: Flat slope; St: Steep slope. SE = standard error. R^2=0.30

Count model (Poisson with log link)			
Term	Level	Estimate	SE
Intercept	Fo.Fl	0.634	0.220
Geartype	Fyke net	-2.835	0.456
Geartype	Gillnet	2.328	0.328
Geartype	Other trap	0.216	0.276
Geartype	Parlour	0.541	0.251
BottomSlope	Gentle	0.955	0.287
BottomSlope	Steep	0.037	0.394
Depth		0.010	0.014
Geartype*BottomSlope	Fy.Ge	4.521	0.517
Geartype*BottomSlope	Gi.Ge	0.133	0.395
Geartype*BottomSlope	Ot.Ge	1.124	0.349
Geartype*BottomSlope	Pa.Ge	1.103	0.323
Geartype*BottomSlope	Fy.St	1.303	0.876
Geartype*BottomSlope	Gi.St	-2.359	0.569
Geartype*BottomSlope	Ot.St	0.199	0.503
Geartype*BottomSlope	Pa.St	0.353	0.441
Geartype*Depth	Fyke net	0.206	0.022
Geartype*Depth	Gillnet	0.046	0.018
Geartype* Depth²	Other trap	0.026	0.015
Geartype* Depth²	Parlour	0.020	0.014
BottomSlope*Depth	Gentle	0.052	0.015
BottomSlope*Depth	Steep	0.009	0.019
Geartype*BottomSlope*Depth	Fy. Ge	0.253	0.025
Geartype*BottomSlope*Depth	Gi.Ge	0.004	0.020
Geartype*BottomSlope*Depth	Ot.Ge	0.060	0.017
Geartype*BottomSlope*Depth	Pa.Ge	0.055	0.016
Geartype*BottomSlope*Depth	Fy.St	0.179	0.029
Geartype*BottomSlope*Depth	Gi.St	0.061	0.025
Geartype*BottomSlope*Depth	Ot.St	0.013	0.021
Geartype*BottomSlope*Depth	Pa.St	0.001	0.020

Zero-infl model (Binomial with logit link)			
Term	Level	Estimate	SE
Intercept	Fo.Bo.Fl	0.635	0.801
Geartype	Fyke net	0.946	0.160
Geartype	Gilnet	-1.253	0.183
Geartype	Other	0.745	0.125
Geartype	Parlour	-1.491	0.122
BottomSlope	Gentle	1.856	0.981
BottomSlope	Steep	1.167	1.086
Substrate	Rock	2.175	2.141
Substrate	Soft	1.597	0.685
Depth		0.135	0.108
$Depth^2$		0.005	0.003
BottomSlope*Substrate	Ge.Ro	-4.212	2.293
BottomSlope*Substrate	St.Ro	0.597	3.279
BottomSlope*Substrate	Ge.So	-1.857	0.871
BottomSlope*Substrate	St.So	0.908	1.091
Bottomslope*Depth	Ge.Depth	0.173	0.123
Bottomslope*Depth	St.Depth	0.089	0.137
Bottomslope*$Depth^2$	Ge.$Depth^2$	0.005	0.004
Bottomslope*$Depth^2$	St.$Depth^2$	0.003	0.004
Substrate*Depth	Ro.Depth	0.089	0.239
Substrate*Depth	So.Depth	0.167	0.096
Substrate*$Depth^2$	Ro.$Depth^2$	0.000	0.006
Substrate*$Depth^2$	So.$Depth^2$	0.005	0.003
BottomSlope*Substrate*Depth	Ge.Ro.Depth	0.313	0.253
BottomSlope*Substrate*Depth	St.Ro.Depth	0.027	0.307
BottomSlope*Substrate*Depth	Ge.So.Depth	0.171	0.110
BottomSlope*Substrate*Depth	St.So.Depth	0.005	0.125
BottomSlope*Substrate*$Depth^2$	Ge.Ro.$Depth^2$	0.005	0.006
BottomSlope*Substrate*$Depth^2$	St.Ro.$Depth^2$	0.001	0.007
BottomSlope*Substrate*$Depth^2$	Ge.So.$Depth^2$	0.005	0.003
BottomSlope*Substrate*$Depth^2$	St.So.$Depth^2$	0.003	0.004

Table 7: Parameter estimates for the most supported fish ZIP model (Table 5 and figure 10) based on model structure with the lowest AIC value. The model predicts the catch of fish as a function of gear type, depth, bottom slope and substrate Levels = Pa: Parlour traps; Fo: Folding trap; Fy: Fyke nets Ot: Other traps; Gi: Gillnets; Ge: Gentle slope. Fl: Flat slope; St: Steep slope. SE = standard error. R^2=0.22

Count model (Poisson with log link)			
Term	Level	Estimate	SE
Intercept	Fo.Bo.Fl	7.352	2.328
Geartype	Fyke net	1.620	0.232
Geartype	Gillnet	1.090	0.387
Geartype	Other trap	1.794	0.226
Geartype	Parlour	1.090	0.242
BottomSlope	Gentle	-8.640	2.433
BottomSlope	Steep	-8.471	2.369
Substrate	Rock	-5.239	2.365
Substrate	Soft	-8.238	2.334
Depth		-1.364	0.350
$Depth^2$		0.053	0.012
BottomSlope*Substrate	Ge.Ro	4.338	2.640
BottomSlope*Substrate	St.Ro	5.318	2.411
BottomSlope*Substrate	Ge.So	8.278	2.433
BottomSlope*Substrate	St.So	8.442	2.460
BottomSlope*Depth	Ge.Depth	1.408	0.363
BottomSlope*Depth	St.Depth	1.410	0.352
BottomSlope*$Depth^2$	Ge.$Depth^2$	0.055	0.012
BottomSlope*$Depth^2$	St.$Depth^2$	0.054	0.012
Substrate*Depth	Ro.Depth	0.681	0.340
Substrate*Depth	So.Depth	1.424	0.351
Substrate*$Depth^2$	Ro.$Depth^2$	0.033	0.011
Substrate*$Depth^2$	So.$Depth^2$	0.055	0.012
BottomSlope*Substrate*Depth	Ge.Ro.Depth	0.599	0.367
BottomSlope*Substrate*Depth	St.Ro.Depth	0.704	0.342
BottomSlope*Substrate*Depth	Ge.So.Depth	-1.459	0.363
BottomSlope*Substrate* $Depth^2$	St.So. $Depth^2$	-1.517	0.353
BottomSlope*Substrate*$Depth^2$	Ge.Ro.$Depth^2$	0.031	0.012
BottomSlope*Substrate*$Depth^2$	St.Ro.$Depth^2$	0.033	0.011
BottomSlope*Substrate*$Depth^2$	Ge.So.$Depth^2$	0.057	0.012

Zero-infl model (Binomial with logit link)			
Term	Level	Estimate	SE
Intercept	Fo.Fl	2.554	0.545
Geartype	Fyke net	-1.190	0.797
Geartype	Gilnet	1.524	1.428
Geartype	Other	0.483	0.701
Geartype	Parlour	-1.657	0.814
BottomSlope	Gentle	0.870	0.710
BottomSlope	Steep	1.236	1.309
Depth		0.020	0.032
Geartype*BottomSlope	Fy.Ge	0.002	1.049
Geartype*BottomSlope	Gi.Ge	-4.504	2.079
Geartype*BottomSlope	Ot.Ge	0.958	0.928
Geartype*BottomSlope	Pa.Ge	1.767	1.035
Geartype*BottomSlope	Fy.St	0.043	1.606
Geartype*BottomSlope	Gi.St	-2.652	2.310
Geartype*BottomSlope	Ot.St	-3.331	1.440
Geartype*BottomSlope	Pa.St	-1.078	1.508
Geartype*Depth	Fy.Depth	0.015	0.046
Geartype*Depth	Gi.Depth	0.087	0.054
Geartype*Depth	Ot.Depth	0.084	0.038
Geartype*Depth	Pa.Depth	0.054	0.043
BottomSlope*Depth	Ge.Depth	0.014	0.040
BottomSlope*Depth	St.Depth	0.095	0.067
Geartype*BottomSlope*Depth	Fy.Ge.Depth	0.030	0.062
Geartype*BottomSlope*Depth	Gi.Ge.Depth	0.302	0.114
Geartype*BottomSlope*Depth	Ot.Ge.Depth	0.137	0.051
Geartype*BottomSlope*Depth	Pa.Ge.Depth	0.075	0.054
Geartype*BottomSlope*Depth	Fy.St.Depth	0.057	0.079
Geartype*BottomSlope*Depth	Gi.St.Depth	0.179	0.100
Geartype*BottomSlope*Depth	Ot.St.Depth	0.220	0.072
Geartype*BottomSlope*Depth	Pa.St.Depth	0.059	0.074

Table 8: ANOVA table for the most supported model predicting the number of lobsters captured by lost gear retrieved along the Norwegian coast in 2015-2018. Df = degrees of freedom

Term	Df	Chisq	P-value
Geartype	2	3.190	0.203
Bottom.slope	2	15.232	0.000
Substrate	2	10.206	0.006
$Depth^2$	2	9.032	0.011
$Substrate*Depth^2$	4	4.615	0.329

Table 9: ANOVA table for the most supported model predicting the number of crabs captured by lost gear retrieved along the Norwegian coast in 2015-2018. Df = degrees of freedom

Term	Df	Chisq	p-value
Geartype	4	280.579	< 2.2e-16
Bottom.slope	2	14.305	0.0007829
Depth	1	55.716	8.373e-14
Geartype*Bottom.slope	8	97.514	< 2.2e-16
Geartype*Depth	4	49.752	4.068e-10
Bottom.slope*Depth	2	4.107	0.1282639
Geartype*Bottom.slope*Depth	8	140.132	< 2.2e-16

Table 10: ANOVA table for the most supported model predicting the number of fish captured by lost gear retrieved along the Norwegian coast in 2015-2018. Df = degrees of freedom.

Term	Df	Chisq	p-value
Geartype	4	87.658	< 2.2e-16
Bottom.slope	2	98.560	< 2.2e-16
Substrate	2	89.211	< 2.2e-16
$Depth^2$	2	406.913	< 2.2e-16
Bottom.slope*Substrate	4	34.961	4.731e-07
Bottom.slope*$Depth^2$	4	482.533	< 2.2e-16
Substrate*$Depth^2$	4	39.707	4.977e-08
Bottom.slope*Substrate*$Depth^2$	8	38.451	6.214e-06

RAPPORTERINGSSKJEMA FOR SPØKELSESREDSKAP

NORGES DYKKEFORBUND

Dykkeklubb (må være medlemsklubb av NDF)	Askøy Sportsdykkerklubb		
Klubbens kontonummer	36302065246		
Navn på dykkeleder under dykket	Morten Gjellestad		
Navn på dykker som har fylt ut skjema	Morten Gjellestad		
Dato og kommune dykket fant sted	10.1.2016		
Sted (gjerne stedsnavn og koordinater)	Engeviken 60.39700,5.20101		
Dybde, på hvilket dyp fant du redskapen?	20 meter		
Bunnforhold på funnsted (kan merke mer enn en)	Store steiner/ knauser ☐	Fjellbunn ☐	sand/mudder ☑
	Bratt skråning ☐	Litt skråning ☑	Flatt ☐
Hvilken tilstand var teinen i? Hel ☑	Noen hull ☐	Mange hull ☐	Helt ødelagt ☐
Er tilstanden til teina slik at den fortsatt kan fange fiske og skalldyr?	Ja ☑	Nei ☐	Usikker ☐
Var det noe dødt i teina/redskapen? Skriv hva og antall (hummer, krabbe, fisk etc)	nei		
Var det noe levende i teina? Skriv hva og antall (hummer, krabbe, fisk etc)?	nei		
Var det fortsatt teinetau på teina/redskapen?	Ja ☑	Nei ☐	ca. meter: 10
Hvis ja: Var det en blåse i enden av teinetauet?	Ja ☐	Nei ☑	
Hvordan var begroingen på teina/redskapen?	Lite begrodd ☐	Noe begrodd ☑	Mye begrodd ☐
Vurdering av hvor lenge den har vært tapt	Under 1 år ☐	1-2 år ☑	3 år eller mer ☐

Andre kommentarer
Liten hjemmelaget trekantet teine

[Morten Gjellestad] — **Signatur Klubbleder**

[Morten Gjellestad] — **Signatur Dykker**

Følgende bilder er vedlagt (kryss av):

- ☐ Undervannsbilde der den ble funnet (hvis mulig)
- ☑ Oversiktsbilde når den er kommet på land
- ☐ Nærbilde av begroing
- ☐ Nærbilde av skader på teina (hull etc.)

***Utfylt og signert skjema samt bilder som vedlegg sendes på mail til** dykking@nif.idrett.no*

Figure 5: Diver report form used to report data of retrieved gears.

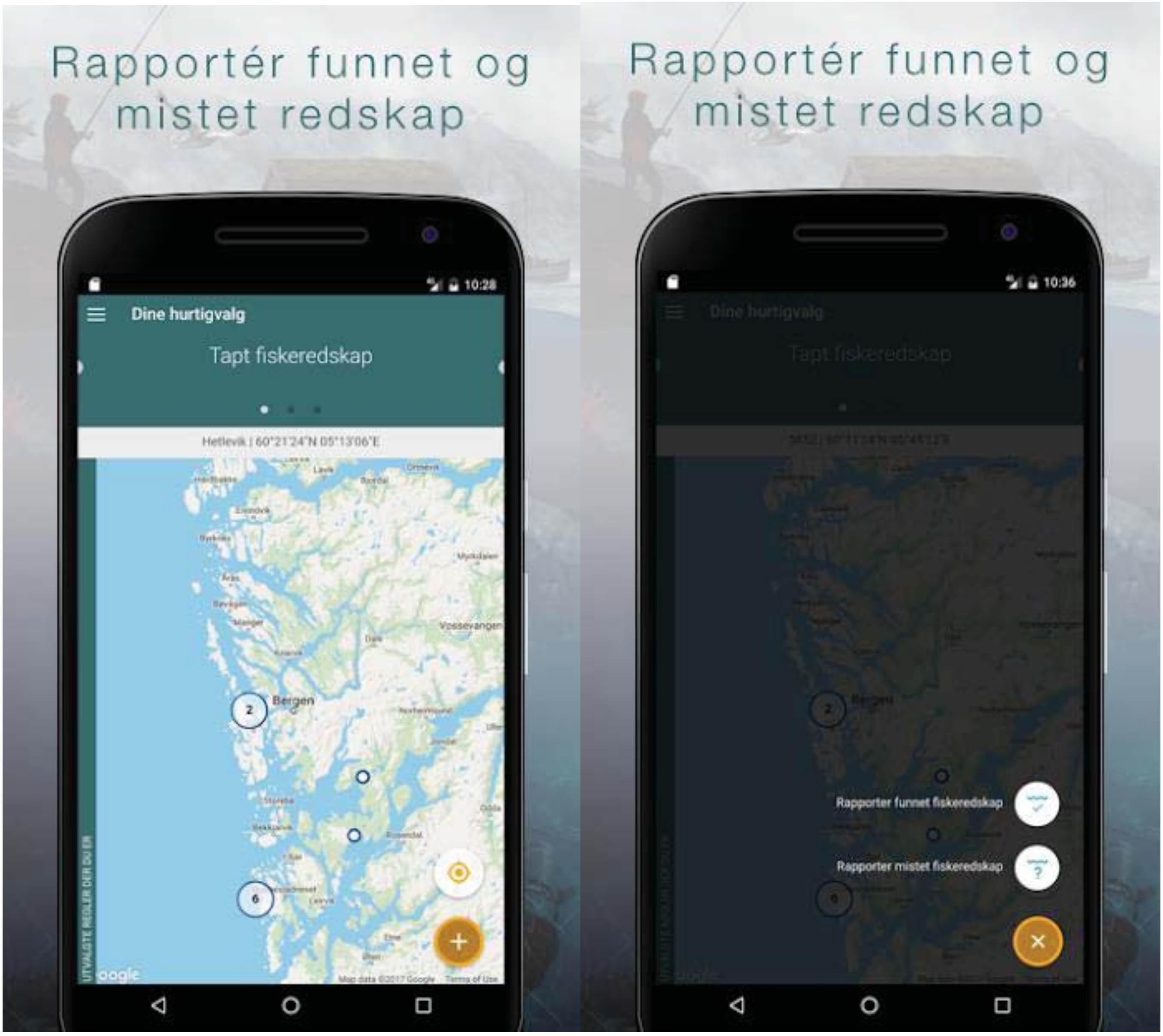


Figure 6: «Fritidsfiske» app used to report lost and found fishing gear from the recreational fishery in Norway. (www.fiskeridir.no/Fritidsfiske/Appen-Fritidsfiske)

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway