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Explaining catch efficiency of cod pots using in situ behavioural studies

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Användning av beteendestudier för att förklara fångsteffektiviteten hos torskburar

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Abstract

The seal populations in the Baltic have been growing since the 1980s causing great economic losses for the fisheries since seals are using fishing gear as easy food sources. One solution to the seal and fishery conflict is the development of seal safe fishing gear. Pots are a possible solution in the cod (*Gadus morhua*) fishery. The success of pots depends on knowledge of the target species' behaviour in relation to the gear. There are few previous studies of cod pots relating behaviour of cod to catches of pots by filming the whole catch process.

This thesis aimed to investigate how the behaviour of cod affects the catch per unit effort (CPUE) of cod pots. Camera systems were used to record in situ behaviour of cod. The relationship between entries, exits and soak time was studied and predictors explaining entry rate were identified. Fishing trials were conducted of the east coast of Bornholm, Denmark.

Video analysis showed continuous entry and exit behaviour of cod during the soak time of a pot. A GAMM analysis was used to identify the predictors explaining CPUE and entry rate. Pot type was one important predictor and most fish entered large, round, bottom standing pots. When artificial light was used in pots, more fish were entering during night time than during the day, the artificial light being a possible explanation for this behaviour. When no light was used the entry rate decreased with soak time, possibly due to the bait loosing odour with time.

Populärvetenskaplig sammanfattning

Antalet sälar i Östersjön har ökat sedan 1980-talet. Detta innebär stora problem för det svenska kustfisket då sälarna skadar fångst och redskap vilket resulterar i stora ekonomiska förluster för fiskaren. För att lösa konflikten mellan sälen och fisket pågår en utveckling av sälsäkra redskap. Torskburar är ett alternativt och sälsäkert redskap under utveckling. Förutom att sälen har svårare för att komma åt fångsten i burar än i nät så är burar även mer selektiva och fångsten håller en bättre kvalité då den är levande vid vittjning. För att burar ska användas kommersiellt krävs en ökad fångsteffektivitet. Fångsteffektiviteten påverkas av en rad faktorer, exempelvis strömriktning, temperatur och födotillgång vilka i sin tur påverkar beteendet hos torsk. Tidigare studier har undersökt vilka faktorer som påverkar fångsteffektiviteten hos burar men få har relaterat fångsterna till beteende hos torsk. Målet med denna studie var därför att undersöka hur beteende hos torsk är relaterat till fångsteffektiveteten hos burar.

Ett provfiske med burar betade med sill utfördes utanför Bornholms kust. Ett antal olika burtyper testades för att se vilka burar som fiskar bäst. I samband med provfisket placerades kameror på burar för att filma beteendet hos torsk som simmade in i burarna. De specialbyggda kamerasystem som användes gjorde det möjligt att filma upp till 36 timmar vilket ger ett unikt datamaterial av torskens beteende i relation till redskapet under lång tid. I en del burar användes lampor för att få mer analyserbart videomaterial. Videomaterialet tittades igenom och beteenden hos den torsk som sågs registrerades.

Analyser av fångstdata visade att en stor, rund bottenstående burmodell fiskade bäst av de modeller som testades. Analyser av videomaterialet visade att torsk går in och ut ur burarna under hela den tid som filmats. Videomaterialet användes också för att se vad som påverkar om torsk går in eller inte i en bur. Faktorer som tros påverka kan exempelvis vara burmodell, ståtid, antal fiskar i buren och tid på dygnet. Det visade sig att burmodell och vilken tid det är på dygnet avgör hur mycket fisk som går in i buren. Fler fiskar gick in på natten vilket skulle kunna bero på att burarna var upplysta vilket attraherade torsken. Fler studier behövs för att utreda ljusets inverkan på torskens beteende. Då det inte var ljus i burarna gick färre fiskar per tidsenhet in ju längre tid buren stått ute. Detta kan bero på att betesdoften minskar med tiden och buren därmed inte lockar lika till sig fisk. Kunskapen om vilka faktorer som gör att fisk går in i buren är viktig för att kunna optimera fisket med burar ytterligare.

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Introduction

The conflict between seals and fisheries

In the Baltic there are three seal species; harbour seal (*Phoca vitulina*), ringed seal (*Pusa hispida*) and grey seal (*Halichoerus grypus*). The grey seal population is the largest and the one causing most damage in Baltic fisheries (Hemmingsson and Lunneryd, 2005). Since the end of the 19^{th} century the Baltic seal populations have been hunted to keep the numbers down. In the beginning of the 20^{th} century the estimated population of grey seals in the Baltic was 88 000-100 000 animals (Harding and Harkonen, 1999). During the 1970s a large proportion of the females were sterile due to pollution of the marine environment which lead to a dramatic decrease in population size (Harding and Harkonen, 1999). The grey seal population has now increased from an estimated 3000 (HAV, 2014) animals in the end of the 1980s to 30 000 counted individuals in 2015 (HAV, 2016). The counted number represent 60 - 80 % of the actual population (Hiby et al., 2007) which gives an estimate of 37 500 - 50 000 individuals in 2015.

The total number of active marine fishermen in Sweden has decreased by 50 % between 1995 and 2013 (Naturvårdsverket, 2014) due to a number of reasons one of them being the increasing seal populations (HAV, 2010). Seals cause great problems for the small scale coastal fishermen using traps, gillnets and longlines. Gillnets and longlines with caught cod (*Gadus morhua*) provide an easy food source for seals. The seal damaged catch and gear of all Swedish fisheries is valued at 35 million Swedish kronor each year, a number that does not include hidden losses (HAV, 2014). Hidden losses are catch taken by seals without them leaving any parts visible in the nets (HAV, 2014). The presence of seals around fishing gears is also scaring away potential catch and together with hidden losses causing even larger economical losses than the ones reported by the fishermen (Fjälling, 2005, Königson et al., 2010). Another problem causing economical losses in the fishing industry is parasites (Haarder et al., 2014, Lunneryd et al., 2015). Two species of parasites have seals as their final hosts, these are *Pseudoterranova decipiens* (Seal worm) and *Contracaecum osculatum.* Especially *Contracaecum osculatum* can cause mortality among the cod (Haarder et al. 2014). The seal worm occurs in the flesh of fish resulting in a less attractive product to the consumer. It can also cause infections in humans if fish is eaten raw.

The ongoing increase of the seal populations in the Baltic has resulted in increasing conflicts with the fisheries (Königson et al., 2009, Varjopuro, 2011). According to HELCOM (Helcom recommendation 27-28/2) seal populations in the Baltic Sea shall continue to grow to maximum carrying capacity. This means no large scale hunting of seals is possible in the Baltic countries hence today the only solution to the seal and fisheries conflict is the development of seal safe fishing gear.

Seal safe fishing gear

With the increasing seal fisheries conflict in the Baltic, the need for alternative fishing gear is growing. The small scale coastal fishing is threatened to disappear if no solution is found. The development of seal-safe gear have succeeded in the Swedish salmon fishery (Hemmingsson et al., 2008). When traditional trap nets for salmon were being subject to an increasing amount of seal attacks a new fish chamber was developed in the 1990s. The new rigid chamber had double netting which stopped seals from reaching caught fish. The eel fishery with fyke nets along the Swedish west coast also had increasing seal problems. By changing material to a stronger material in the fish bag, the compartment where the caught eels gather, catch losses and gear damage decreased (Königson et al., 2007). This fishery is very restricted today due to the vulnerable state of the eel population.

Finding a solution for the gillnet and longline cod fisheries is harder since the catch is more easy for the seals to access. The fishery is also spread over large areas compared to the trap fishery for salmon which is more restricted to river mouths. One alternative to gillnets and longlines is pots (Königson et al., 2015). Cod pots have been tested in different trials in Sweden since 2006 but are still at the experimental state. Pots are considered a form of LIFE fishing (Low Impact and Fuel Efficient fishing) (Suuronen et al., 2012). They can be made selective on species and size and they have minimal impact on the bottom substrate. Negative features listed are low catches and the risk of ghost fishing when lost (Suuronen et al., 2012). The problem with ghost fishing can however easily be avoided if a biodegradable thread is used when constructing the pot: pots will continue to fish for a while but once the thread is dissolved one side of the pot will open and they will stop fishing.

That fishing with pots would result in low catches is not always the case. A previous study by Königson et al. (2015) investigated the catch per unit effort (CPUE, there defined as number of cod per pot) of pots compared to gillnets. When looking at a yearly average there was no difference in CPUE between the two methods. On a monthly basis, gillnets had larger daily catches from April to June while pots constituted a better method from August until November. It is therefore suggested that pots can be a viable substitute to gillnet fisheries although this is also believed to be dependent on the location and fisherman.

Factors impacting catches of pots

Previous studies have investigated how environmental variables and different features of pots affect CPUE and the size and quality of the catch of cod (Bryhn et al., 2014, Furevik and Lokkeborg, 1994, Königson et al., 2015, Ovegård et al., 2011). CPUE of pots depend on many different factors, both biotic and abiotic. The biotic factors include abundance of target species and prey abundance in the surroundings. The abiotic factors are water temperature, speed of current, current direction, depth, topography, season, soak time, stimuli and different features of the pot. All these factors impact CPUE through their influence of behaviour of the target species (Stoner, 2004). The biotic and abiotic factors affect target species' activity level, feeding motivation and ability to detect, locate and consume the bait (Stoner, 2004).

The biotic and abiotic factors mentioned above impact the catch process at different times. The catch process of a pot can be divided into three steps (He, 2010):

1. Attract fish
2. Lure fish inside
3. Retain fish until hauled

Attracting and luring fish inside

Bait

When fishing with baited pots or other baited gear, the fishing area that the gear covers depends on its active space which is the area in which the odour from the bait is above the response threshold of the target species (Stoner, 2004). A study of cod's reaction to bait showed that the chemically mediated response in cod resulted in an increase in swimming speed (Lokkeborg, 1998). The attraction of the bait is believed to decrease with time since release rate of amino acids from bait decreases with soak time. It first decreases rapidly for 1.5 hours, then it keeps declining but at a lower rate (Lokkeborg, 1990). The optimal bait for cod has been tested both in Norway and Sweden. In the Baltic herring has been shown to result in higher catches than squid (Ljungberg, 2007) while the opposite was found in Norway (Furevik and Lokkeborg, 1994).

Light

Light is known to attract fish into different gear types (Ben-Yami, 1988, Marchesan et al., 2005). Preferred wavelengths and intensity vary among species and knowledge of this can help increase catches of the target species and reduce by-catches (Marchesan et al., 2005). Green led light (wavelength of 523 nm) has been used as stimuli in pots to attract cod (Bryhn et al., 2014). Control pots were baited with herring and test pots had both bait and green light. Results showed that pots with light had significantly higher catches of large cod (>38 cm) than pots with only bait.

Social interaction

Since the odour from bait declines with time this suggests that there are other factors attracting fish to pots and traps. Unbaited pots and traps may interest fish as hiding places, for curiosity, social behaviour where fish inside the pot attract more fish or predator-prey interaction (High and Beardsley, 1970, Renchen et al., 2012). Earlier studies in the Caribbean have found that unbaited pots have the same catches as baited pots (High and Ellis, 1973). Unbaited traps targeting gadoid species have not been as successful (Valdemarsen et al. 1977). A trap that contained one cod contained eight individuals after two weeks suggesting social interaction although it was concluded that bait was important in the initial phase (Valdemarsen et al. 1977). Caught fish can both decrease and increase the probability of fish that located the pot or trap to enter. The presence of one fish inside a cod pot decreased probability of capture of cod ≥ 45 cm while it increased the probability of capture for fish < 45 cm (Anders, 2015). One explanation for this being that smaller fish are subjects to higher predation pressure and they seek therefore predation protection they can get from shoaling inside a pot.

Retraining the fish

Entries and exits

Once the fish has located the pot the next step is to get fish to enter the pot. Knowledge of entry and exit behaviour in relation to soak time makes it possible to optimize CPUE (Bacheler et al., 2013, Cole et al., 2004). A study by Munro (1974) compared entry and exit rate, calculated as total number of entries of exits per day, between baited and unbaited pots. For baited pots the catch increased until bait was consumed and then entry rate decreased until it equalled the escape rate. For unbaited pots the entry rate was constant until saturation was reached and entry rate equals exit rate. The study also concluded that escape rate determined catches of Antillean fish traps. Knowing if entry rate or exit rate is the limiting factor is crucial to increase CPUE of pots (Munro, 1974).

Soak time

Optimal soak time vary with target species and fishing gear. Bacheler et al. (2013) found optimal soak time for black sea bass (*Centropristis striata*) of 50 min and Cole et al. 2004 suggests that numerous shorter sets are more effective than fewer longer deployments when fishing for blue cod (*Parapercis colias*). For cod pots Königson et al. (2015) found it to be 6 days while Furevik and Skeide (2003) conclude that catches of cod do not increase between 1-8 days probably due to decreasing effect of bait after 24 hours.

Design

A study (Furevik and Lokkeborg, 1994) concluded that cod pots should have two entrances, placed in line. The first one is wider and easy to enter while the second one is narrower and harder to escape. Larger pots are also more effective than small pots possibly since the risk of entering fish to be disturbed by caught fish is lowered (Furevik and Lokkeborg, 1994).

This thesis

This master thesis was conducted as a part of a larger collaborative project between the Danish National Institute of Aquatic resources (DTU Aqua) and the Swedish University of Agricultural Sciences (SLU). The purpose of the project which was called SEAL SAFE was to develop seal-safe and sustainable cod pots to diminish the increasing human-seal interaction in Danish waters. The project was financed by the Ministry of Environment and Food of Denmark, The Danish Agrifish Agency and Programme Seal and Fishery with funds from the Swedish Agency for Marine and Water Management.

Aim

All biotic and abiotic factors described in the introduction impact the behaviour of the target species. No previous studies on the behaviour of cod in relation to pots have filmed the catch process for more than a few hours. Hence it has not been possible to relate entry and exit behaviour to catches of cod.

This thesis aims to investigate how the behaviour of cod affects the CPUE of cod pots. Camera systems are used to record in situ behaviour of cod to get a better picture of the whole catch process of a cod pot. The specific objectives were:

1. Compare CPUE of different pot types.
2. Study the relationship between number of entries, number of exits and soak time.
3. Determine predictors explaining entry rate.

Method

Fishing trials

Two fishing trials with cod pots were conducted, one in September-November 2014 (trial1) and one in May 2015 (trial 2). Both trials took place off the east coast of Bornholm in Denmark in cooperation with a local fisherman using a small gill-net vessel (9.9m). In total six different pot types were constructed for the trials (Table 1). All pots were two chamber pots with one entrance chamber and one fish holding chamber. They were made of green 30 mm polyethylene (2.5 mm thread) equipped with 45 mm mesh square escape windows. Entrances were made of black knotless 20 mm nylon with a circular opening of 16 cm in diameter. One pot type (Carapax) was borrowed from another manufacturer (Carapax). The Carapax pot was made of black 27.5 mm nylon (1.2 mm thread) with 50 mm (45 mm in trial 2) mesh square escape window and a rectangular entrance (W= 15 cm, H= 24 cm).

Pots were deployed in sets of 4-6 attached to the same bottom line, defined as a string. Pots were baited with ~300 g of cut frozen herring (*Clupea harengus*) and set with a distance of 40 m resulting in stings with total lengths of 160 – 240 m. Date, time, position and depth was recorded for each string. Number and weight of cod above and below minimum landing size or conservation size was recorded for each pot. The minimum landing size of cod in the Baltic was 38 cm in 2014 (trial 1). Since 2015 there is a landing obligation of cod in the Baltic meaning all cod caught has to be landed independent of size. There is no longer a minimum landing size but instead a conservation size of 35 cm. Cod caught in trial 2 were counted and weighed in two size classes; ≥ 35 cm and < 35 cm. For each size class this resulted in a CPUE and weight per unit effort (WPUE) per pot which is defined as the total number (CPUE) or total weight (WPUE) of cod caught per pot and fishing occasion.

Trial 1

In 2014 four different pot types were used in the test fishery (table 1 and figure 2). One type was bottom standing and three were floating pots. The floating pots (Pentagonal L, Pentagonal M and Carapax) float 50 cm above the seabed allowing them to move with the current in order to place the entrance in line with the current which increases the chance of the cod to find it. The larger round pot (Round L) has a different design with three entrances and is therefore not dependent on a specific placement in the current. Therefore it is set on the bottom and only has floats to keep it in an upright position. One string consisted of one pot of each type to decrease the impact of location on catch efficiency. In total 40 pots were used, 10 of each type. Soak time varied between 1-2 days.

Trial 2

In 2015 six different pots were used in the test fishery, with two new pot types (table 1 and figure 3) along with the previous used ones. There was one new floating pot (Pentagonal S) and one bottom standing (Round M). Pentagonal S had a new design with the fish holding chamber in line with the entrance chamber instead of above it as in the other pot types. This pot was invented to try to find an ultimate position of the fish holding chamber in a pot. The Round M pot was of similar design as the Round L but a smaller version and it was built to test if the size of a pot impacts catch efficiency. The fish holding chamber of the Round L pot was modified in trial 2 so the diameter of the two chambers was equal (table 1 and figure 3). In total 60 pots were used in Trial 2, 10 of each type. Soak time varied between 1-3 days.

Table 1. *Names and description of pot types used in trial 1 and 2. L (Large), M (Medium) and S (Small) in the pot name indicate the size of the pot. Measures are in centimetres (cm).D= diameter, H = height, L = length, W= width.*

Name	Trial	Description
Round L	1 and 2	Round, bottom standing large two-chamber pot with three entrances. Fish holding chamber in angle in trial 1 and with same diameter as entrance chamber in trial 2. D= 150, H= 86
Pentagonal L	1 and 2	Floated two-chamber pot with one entrance. . L= 120, W= 70, H= 90
Pentagonal M	1 and 2	Floated two-chamber pot with one entrance, same type as Pentagonal L but smaller. L= 90, W= 70, H= 75
Carapax	1 and 2	Floated two-chamber pot with one entrance. L= 118, W= 78, H = 98
Round M	2	Small, round bottom standing two-chamber pot with three entrances. Fish holding chamber same diameter as bottom chamber. D= 95, H= 90
Pentagonal S	2	Floated two-chamber pot with one entrance, fish holding chamber in line with entrance chamber. L= 120, W= 70, H= 55

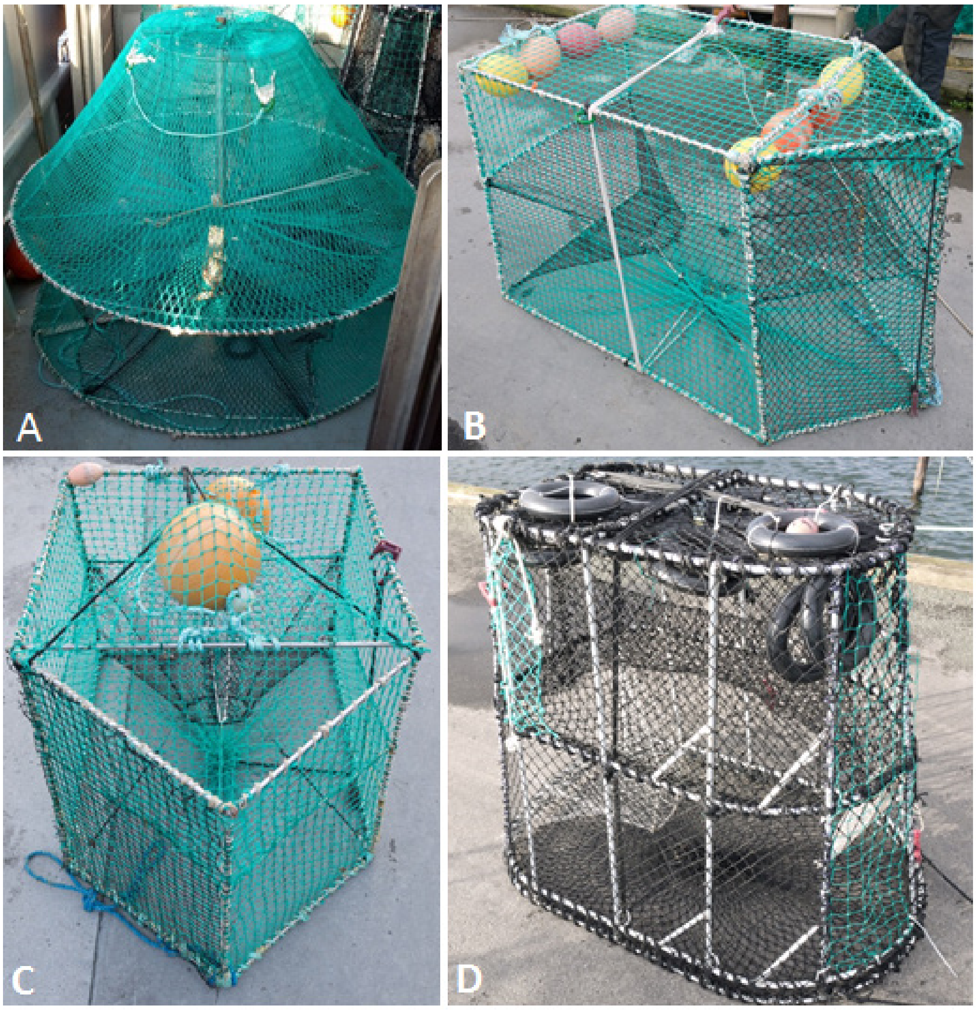

Figure 2. Pots used in trial 1. A: Round L. B: Pentagonal L. C: Pentagonal M. D: Carapax.

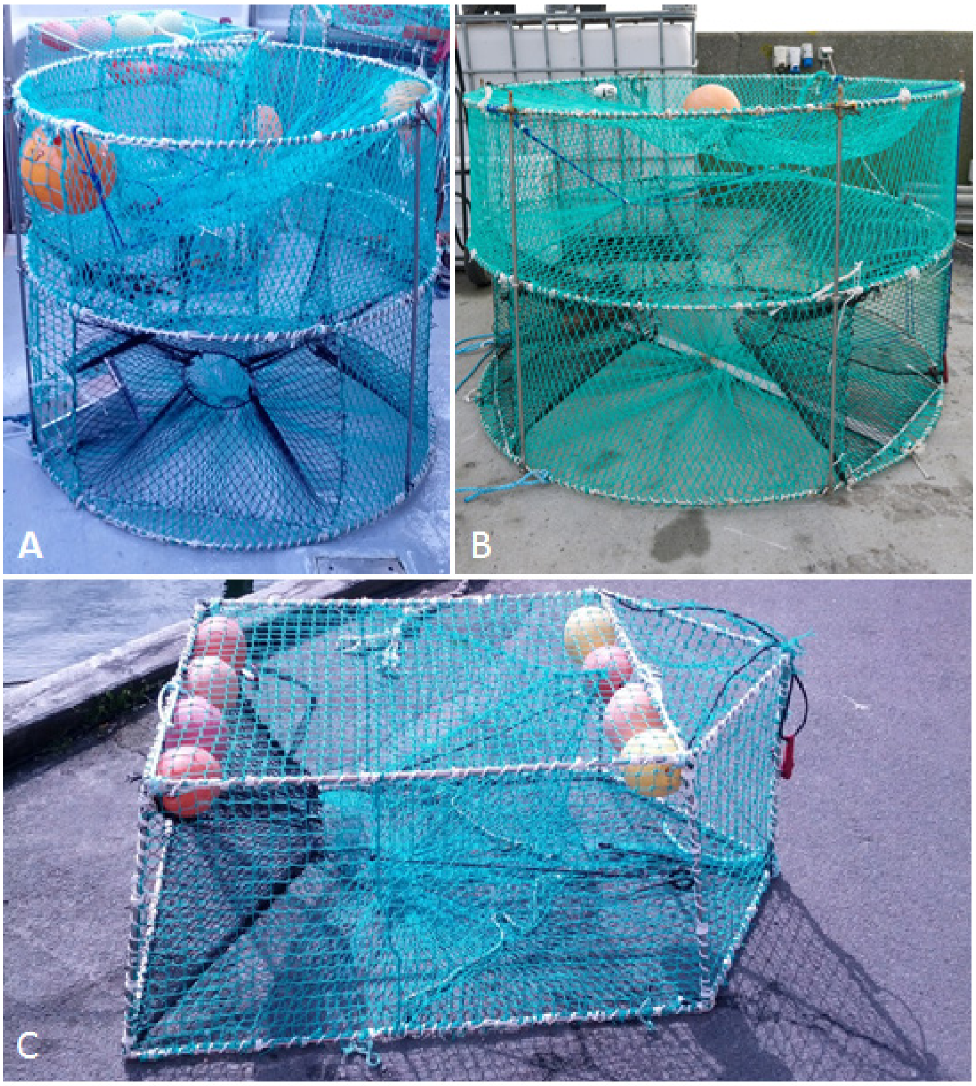

Figure 3. The two new pots and the modified Round L pot used in trial 2. A: Round M. B: Round L. C: Pentagonal S.

Camera systems and set up

During both fishing trials cameras were mounted on pots to record the catch process and behaviour of cod outside and inside pots. Cameras used were of the model GoPro Hero 3 White Edition. Underwater houses (figure 4) for cameras were custom made to be able to fit the camera and two power packs (12 000 - 15 000 mAh). With two power packs and a micro SD card with 128 GB memory the camera was able to film up to 36 hours. The camera house was placed inside the pot facing towards the entrance to record behaviour of approaching and entering individuals (figure 5).

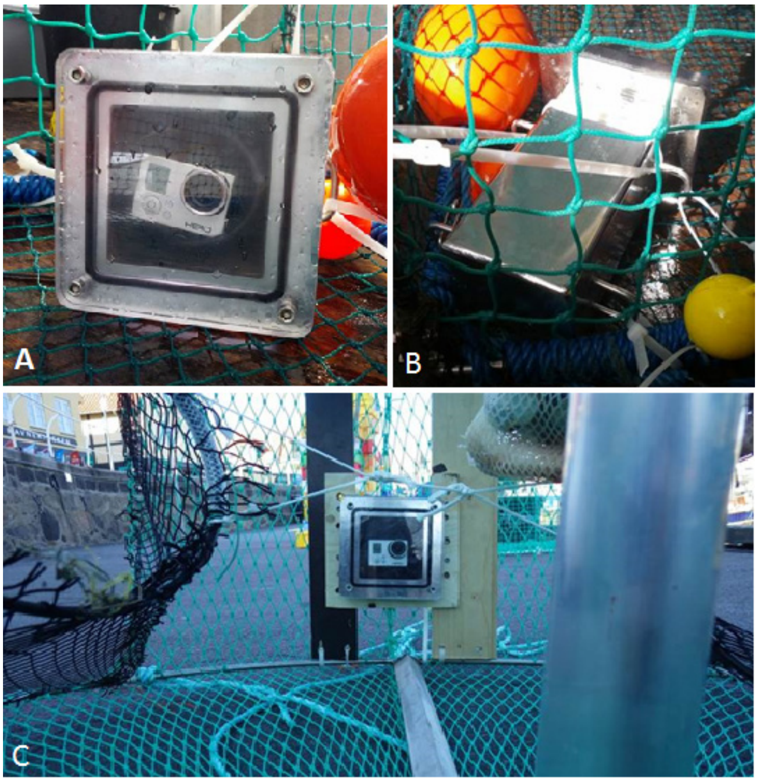

Figure 4. Custom made camera house set up in pot. A: The GoPro camera is attached to the lid of the camera house. B: Camera house is attached to pot with cable ties. C: Camera house is fixed to side of a Round L pot.

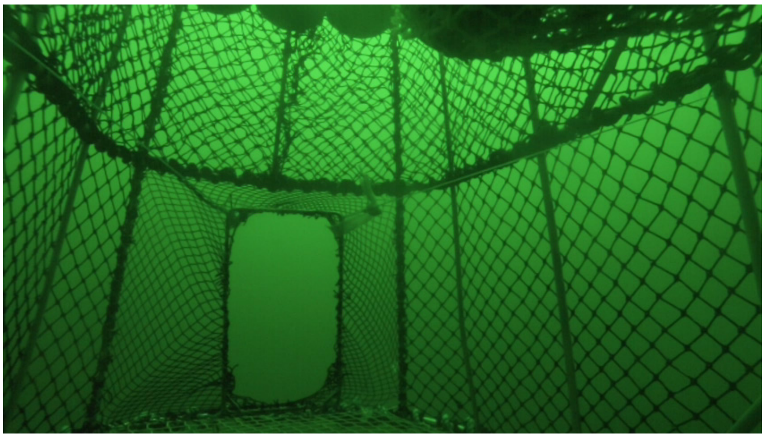

Figure 5. View of camera set up in a Carapax pot.

Due to poor light conditions at some fishing depths and many dark hours during the day and night of trial 1 lights were used to facilitate the filming process. Lights used were models Fisheye Fix Neo DX 800 (figure 6) and Fisheye Fish Neo DX 1200. The effect of the lights can be adjusted (in this study it was set to 12 %) and the aim was to have enough light for filming while not having too much light outside of the pot. This in reality proved to be very difficult. Majority of pots filmed in trial 1 had lamps while none of the filmed pots in trial 2 did. The reason no lamps were used in trial 2 was to eliminate artificial light as a factor possibly affecting behaviour of cod. In May, when trial 2 took place, there is also day light enough to film for more hours a day than in autumn.

Figure 6. Fisheye Fix Neo DX 800.

Video analysis

Recorded video material was analysed using the programs VLC media player and Movie maker. Videos were watched with playback speed of 1-16 times normal speed, depending on the presence of cod. Behaviour of other species than cod was not registered since presence of those was extremely rare. Codes in Excel were used to register fish entering the view of the camera and to register behaviours of individuals. Due to the setup of camera inside of the pot it was not possible to get a full picture of the pot. Main focus when viewing video material was entry and exit behaviour of fish. Size of cod was not possible to determine from video analysis.

Cameras used recorded videos in sequences of approximately 30 min. For each sequence the information in table 2 was registered. Current direction in relation to pot was also registered for each sequence since the chances of fish finding the entrance of a pot increases when the entrance faces in the direction of the current (Valdemarsen et al. 1977). It was noticed on video sequences that the floating pot types were lacking enough float and hence were standing on the bottom. Therefore it was of interest to record current direction in relation to pot to see possible impacts on behaviour. Other factors of interest were current speed and abundance of mysids since current speed impact the spreading of bait odour and cod have been seen feeding on mysids in and outside of pots. Unfortunately current speed and abundance of mysids were missing proper measurements due to lack of suitable methods and limited time for analysis, hence they were excluded from further analysis.

Table 2. *Behaviours registered through video analysis.*

	Behaviours	Definition
1	Enter view	An individual enter the camera view
2	Exit view	An individual exit the camera view
3	Turns away	An individual swims towards the entrance but turns away
4	Enter pot	An individual fully enter pot through entrance ring
5	Exit pot	An individual fully exit pot through entrance ring
6	Enter through net	An individual enter through netting of pot
7	Exit through net	An individual exit through netting of pot

Data analysis: catch per unit effort

The CPUE of the two trials were analysed separately. Catch was calculated as CPUE (number of cod caught per pot and occasion) above minimum landing size

(38 cm) in trial 1 and above conservation size (35 cm) in trial 2. The CPUE of the different pot types was compared using a generalized additive mixed model (GAMM) developed in the SEAL SAFE project. CPUE was the response variable and predictors included were pot type, soak time, depth, the pots place in the string(ns) and string id. This thesis focuses only on the impact of pot type on the CPUE, whereas the impact of the other predictors on CPUE is discussed in Kindt-Larsen et al. (manuscript). The model used:

$$\mathrm{CPUE} \sim \mathrm{Pot} + \mathrm{soak\,time} + \mathrm{ns} + \mathrm{depth} + \mathrm{s(string\,id, bs = "re")}$$

For the numerical predictors different smoothers can be chosen. A smoother is an algorithm producing a smooth curve of the predictor's impact on the response variable. String id is a combination of the string number and date and is treated like an independent random effect through the use of a random effect smoother. This predictor is used to account for spatial and temporal variations in cod abundance.

Data analysis: video data

Activity level

Registered entries and exits from video analysis were used to describe entry and exit behaviour during a part of the catching process. For all pots from trial 1 where the whole catch process had been filmed entries and exits were plotted together as number of fish in pot against soak time. Since all pots were not filmed for the same amount of time, a time limit of 20 hours was set to increase the number of replicates and to facilitate comparison of pots.

For further visualization and comparison between pots cumulative entries and exits in relation to soak time were calculated. Each pot was plotted separately to show variations in when entry and exit behaviours occur during soak time. Only data from trial 1 was used in the analysis since longer video sequences per pot was available due to the use of artificial light when filming.

Factors affecting entry rate

Entry rate was calculated for the 30 min film sequence. The time frame was set to 30 min since this was the length of each film sequence. It was also a way to increase the number of replicates while not collecting a dataset with too many zeros. Entry rate was calculated as number of entries minus the number of exits per 30 min resulting in a net number of fish entering the pot. Number of exits was subtracted from number of entries due to video analysis showing the same individual entering and exiting a pot several times during a short time span.

$$\text{Entry rate} = \text{Total number of entries} - \text{Total number of exits}$$

Since all pots were equipped with an escape window some of the fish that entered could exit the pot through that without being seen by the viewer. Since this was a possibility there was a risk that the total number of entries and exits would be over- or underestimated by fish entering through the escape window and exiting through the entrance or the other way around. To avoid this, the number of fish present in each pot was counted at the start and end of each film sequence. Placement of cameras inside the pot made the view limited and there was a possibility that the number of fish seen inside the pot did not represent the exact number present. However the fish caught tend to move around in the pot which increases chances of them being filmed and counted. The registered entries and exits were then adjusted to match the number of fish in the pot. For example if two entries were registered but there was three individuals inside the pot at the end of the sequence, one entry was added to the data. The same was done for number of exits where necessary. When calculating entry rate, a few occasions (< 3 %) had negative values which were then treated as zeros because the model could not handle negative values.

For trial 2 only 3 pot types (Round L, Round M and Pentagonal S) were included in the analysis of entry rate. The position of cameras in Pentagonal L and Pentagonal M during trial 2 had a different angle than in trial 1 which made it impossible to view any part of the fish holding chamber of pots which made any estimation of number of fish in the pot very uncertain. The behavioural data registered from those pots was therefore excluded from further analysis.

A GAMM was used to determine predictors (explanatory variables) affecting entry rate. Data from trial 1 and 2 was analysed separately due to more than one predictor differing between them. In trial 1 artificial light was used while in trial 2 filming was carried out without artificial light. The season also differed between the two trials. The predictors in table 3 were included in the first model for both trials.

Table 3. *Predictors used in the candidate GAMM model explaining entry rate of cod in trial 1 and 2.*

Predictor	**Description**
Pot	Pot type
Number in pot	The counted number of fish inside the pot at the end of the video sequence of which entry rate had been calculated for
Time	Time of the day at the end of the video sequence of which entry rate had been calculated for
Soak time	Hour since the pot had been deployed at the end of the video sequence of which entry rate had been calculated for
Current dir.	Direction of current in relation to the pot
String id	Date of deployment combined with ID of the string in which the pot was set.

GAMM was chosen to determine significant predictors since it has a number of advantages compared to GLM. A GAMM can include factorial and numerical predictors. Different smoothing factors were used for predictors. For time of day a cyclic penalized cubic regression smoother (s_1) was used to ensure that the response gets the same start and end point. String id (s_2 = random effect) was a combination of number of string and date equal to the predictor used in the catch analysis. Since the response variable was count data the distribution of data was determined to be either Poisson or negative binomial. Both distributions were tested for both start models and the one with lowest BIC value chosen for further analysis. The start model used for both fishing trials was the following:

Entry rate ~ Pot + s_1(time, bs= "cc") + current dir. + number in pot + soak time + s_2(string id, bs="re")

BIC (Bayesian Information Criterion) was used to determine which model best explained the variation in entry rate. Since many of the replicates are from the same set of pots there is a risk of pseudo replication leading to inflated degrees of freedom. This made BIC a better choice than AIC (Akaike Information Criterion) since AIC tends to prefer larger, more complex models.

Results

Catch per unit effort

Number of empties pots, total catches, CPUE and WPUE (weight per unit effort) for both trials is summarized in table 4. In trial 1, CPUE was significantly different between all pot types (figure 7). Round L pots had the largest CPUE and Carapax pots the lowest. The Round L pot was not emptied as many times as the other pot types during trial 1 because a few pots were still being constructed at the start of the fishing trial. In trial 2 the Round L pot had the highest CPUE and Pentagonal S and Pentagonal M pots the lowest (figure 8).

CPUE were larger for all pots during the second trial (table 4). Video material from trial 1 showed that the majority of floating pots were not floating properly and this could have affected catches. Before the second trial floats were adjusted and this could be one explanation for the larger CPUE in trial 2. Although new fishing spots and another season of the year may also have influenced CPUE.

Table 4. *Summary of catches from fishing trials. Minimum landing size was 38 cm in trial 1. In trial 2 conservation size was 35 cm.*

Pot	Number of emptied pots		Total catch Number of cod ≥ 38/ 35 cm		Mean CPUE ≥ 38/35 cm		Total kg ≥ 38/35 cm		Mean WPUE ≥ 38/ 35 cm	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Pentagonal M	343	195	536	315	1.56	1.62	373	260	1.09	1.34
Pentagonal L	345	174	444	433	1.29	2.49	307	299	0.89	1.73
Carapax	342	80	263	177	0.77	2.39	198	126	0.56	1.66
Round L	220	93	449	418	2.04	4.59	300	278	1.36	3.06
Round M	-	124	-	379	-	3.06	-	275	-	2.23
Pentagonal S	-	154	-	248	-	1.62	-	164	-	1.08

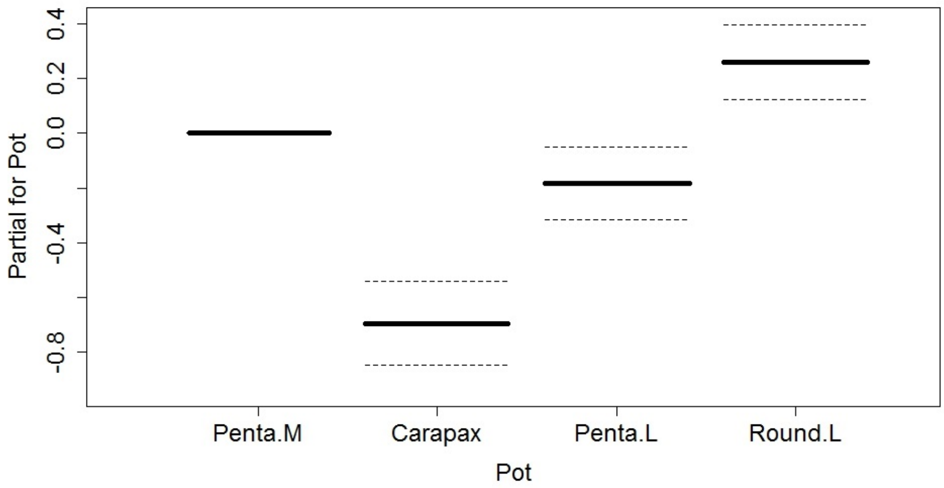

Figure 7. Partial effect of pot type on CPUE of cod over minimum landing size (≥ 38 cm) during trial 1. The effect of all pots is relative to the Pentagonal M pot, which is therefore without confidence intervals. Dotted line shows 95 % confidence intervals. The effect is on the log scale meaning CPUE of a Round L pot is exp(0.26) times higher than a Pentagonal M pot.

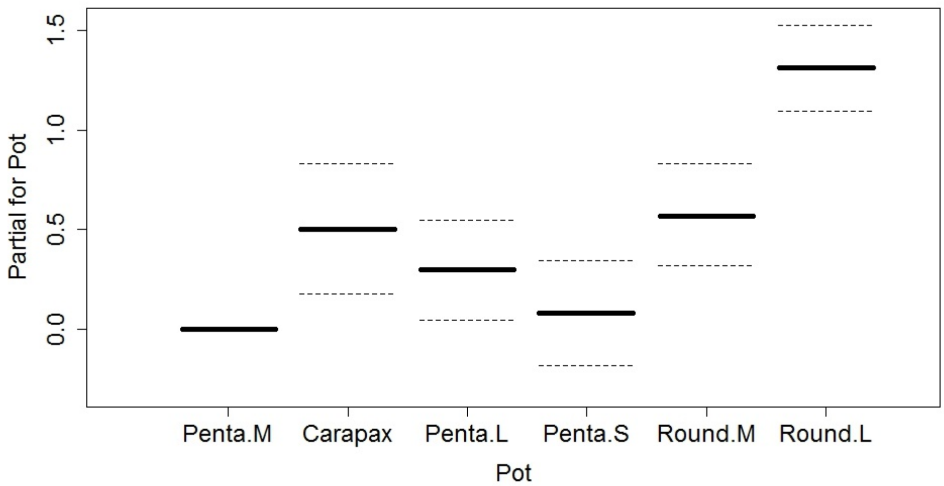

Figure.8. Partial effect of pot type on CPUE of cod above conservation size (≥ 35 cm) during trial 2. The effect of all pots is relative to the Pentagonal M pot, which is therefore without confidence intervals. Dotted line shows 95 % confidence intervals. The effect is on the log scale meaning CPUE of a Round L pot is exp(1.13) times higher than a Pentagonal M pot.

Video analysis

A total of 173 pots were filmed during the two fishing trials. Due to limitations in time and poor quality of films due to darkness or murky waters not all collected video material was analysed. The collected and analysed material for trial 1 and 2 is summarized in table 5.

Table 5. *Summary for video material analysed from trial 1 and 2.*

Pot	Pots filmed		Pots analysed		Hours analysed		Registered entries		Registered exits	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Pentagonal M	22	30	11	12	187:22:27	141:38:01	42	136	18	86
Pentagonal L	26	12	11	11	210:28:53	120:57:34	106	146	41	48
Carapax	19	0	10	0	200:29:14	0	133	0	91	0
Round L	17	16	8	10	129:01:37	120:42:03	143	118	37	56
Round M	-	15	-	11	-	129:54:51	-	36	-	20
Pentagonal S	-	16	-	11	-	208:56:36	-	17	-	5
Total	**84**	**89**	**40**	**55**	**727:22:12**	**722:09:05**	**424**	**453**	**187**	**215**

Activity level

Registered entries and exits from video analysis show that generally fish continuously enter and exit pots during 20 hours (figure 9). The largest amount of fish entering was registered in a Round L pot where there was a larger number of entries registered after 15 hours. An increase in entries after approximately 15 hours was also found in one of the Carapax pots. The plotted pots are examples from the video analysis. They do not indicate any pattern of decreasing entries with time which could otherwise have been expected since the bait odour decreases with time.

Cumulative entries and exits are shown in figure 10. The gap between the two lines (entries – exits) in each plot indicates the catch at that time in the pot.

For many of the pots there is a larger amount of entries than exits in the beginning of the soak time. Then the cumulative entries and exits seem to increase at the same rate which can be explained by one individual entering and exiting the same pot multiple times. For the plotted Round L pots cumulative entries seem to keep increasing at a higher rate than exits.

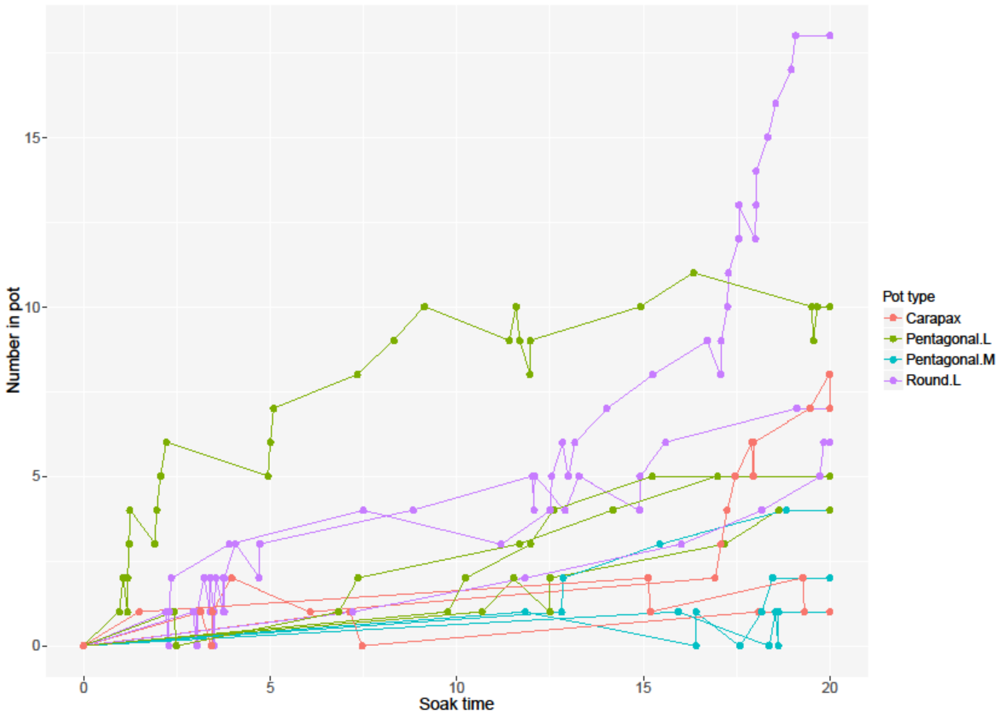

Figure 9. Number of fish in pot in relation to soak time. The pots plotted are examples from trial 1. Each colour represents one pot type and each line represents a setting of a pot. Each dot represents a fish either entering or exiting the pot.

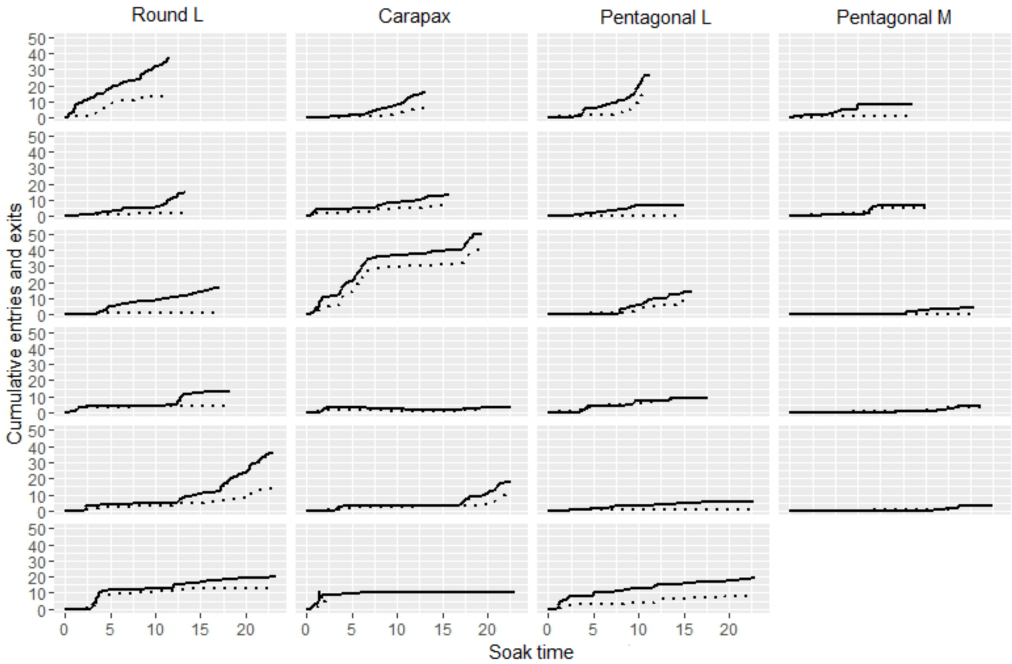

Figure 10. Cumulative entries (solid line) and exits (dashed line) in relation to soak time. The pots plotted are examples from trial 1. Each plot represents one setting of one pot. The gap between the two lines show the number of fish in the pot.

Factors affecting entry rate

Trial 1

The GAMM showed that variations in entry rate could be explained by the predictors pot type, time of day and string id. Deviance explained was 21.8 % (n= 795). The different models with their respective BIC value are presented in table 6.

There was a significant difference between the Round L pot and the other pots with the highest entry rate found in the Round L pot (table 7 and figure 11). There was no significant difference between the other pots. There was a positive effect of time of the day on entry rate between approximately 20 in the evening and 8 in the morning (figure 12), the entry rate was higher than the mean between those hours. The effect of time of the day on each pot type was not tested due to a low number of replicates, low overlap of pots in the same string and risk of overfitting the data.

Table 6. *The models tested for entry rate trial 1. Final model in bold.*

Model entry rate	BIC
gamm(entry rate ~pot + time + current dir. + number in pot + soak time + string id)	1040.9
gamm(entry rate ~pot + time + current dir. + number in pot + string id)	1032.9
gamm(entry rate ~pot + time + current dir. + string id)	1026.1
gamm(entry rate ~pot + time + string id)	**1014.6**

Table 7. *Entry rate of each pot in relation to Carapax.*

Pot	*reference pot Carapax	± confidence interval
Pentagonal M	0.7	1.31
Pentagonal L	0.73	1.17
Round L	2.28	3.51

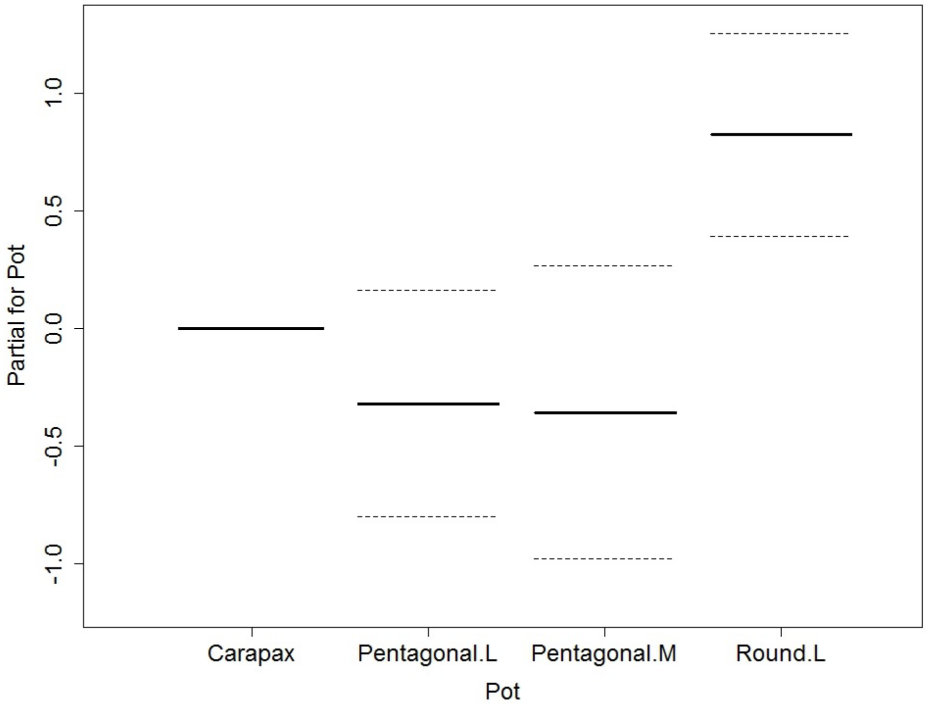

Figure 11. Partial effect of pot type on entry rate during trial 1. The effect of all pots is relative to the Carapax pot, which is therefore missing confidence intervals. Dotted line shows 95 % confidence intervals. The effect is on the log scale.

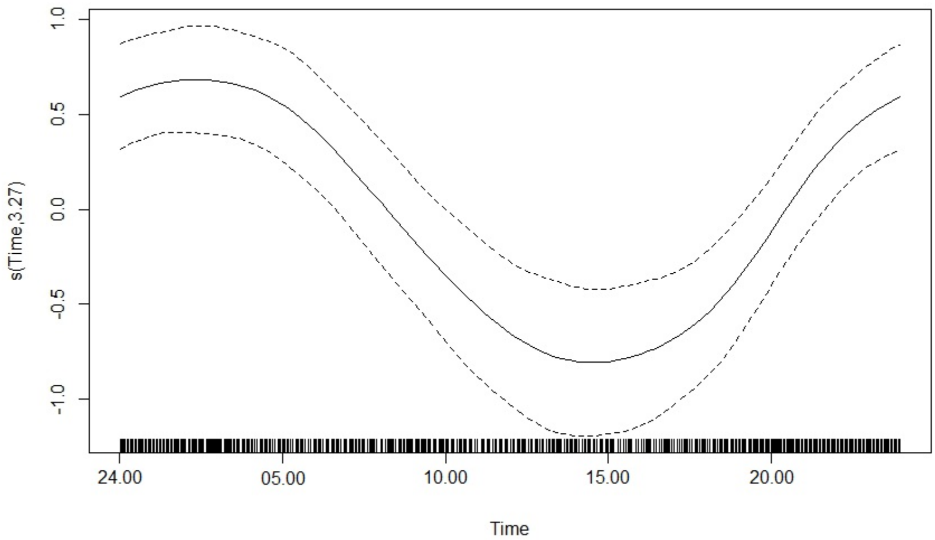

*Figure 12.*Partial response curve for entry rate in relation to time of the day for trial 1. Values above 0 indicate a positive effect of time of the day on entry rate compared to the mean. The effect is on the log scale.

Trial 2

The different models with their respective BIC value for trial 2 are presented in table 8. The significant predictors are pot type and soak time. Deviance explained was 16.1 % (n= 330). There was a significant difference between the Pentagonal S pot and the two round pots, Pentagonal S had significantly lower entry rate (table 9 and figure 13). There was no significant difference between the other two pots. There was a negative effect of soak time on entry rate (figure 14). There is limited data of a soak time between 13 and 21 hours. These hours coincides with the dark hours of night where video sequences were too dark to be analysed. The effect of soak time on each pot type was not tested due to a low number of replicates, low overlap of pots in the same string and risk of overfitting the data.

Table 8. *The models tested for entry rate trial 2.Final model in bold.*

Model entry rate	BIC
gamm(entry rate ~pot + time + current dir. + number in pot + soak time + string id)	293.9
gamm(entry rate ~pot + time + number in pot + soak time + string id)	287.6
gamm(entry rate ~pot + time + number in pot + soak time)	287.6
gamm(entry rate ~pot + number in pot + soak time)	287.6
gamm(entry rate ~pot + soak time)	**283.0**

Table 9. *Entry rate of each pot in relation to Pentagonal S.*

Pot	* reference pot Pentagonal S	± confidence interval
Round M	3.11	8.78
Round L	4.83	11.9

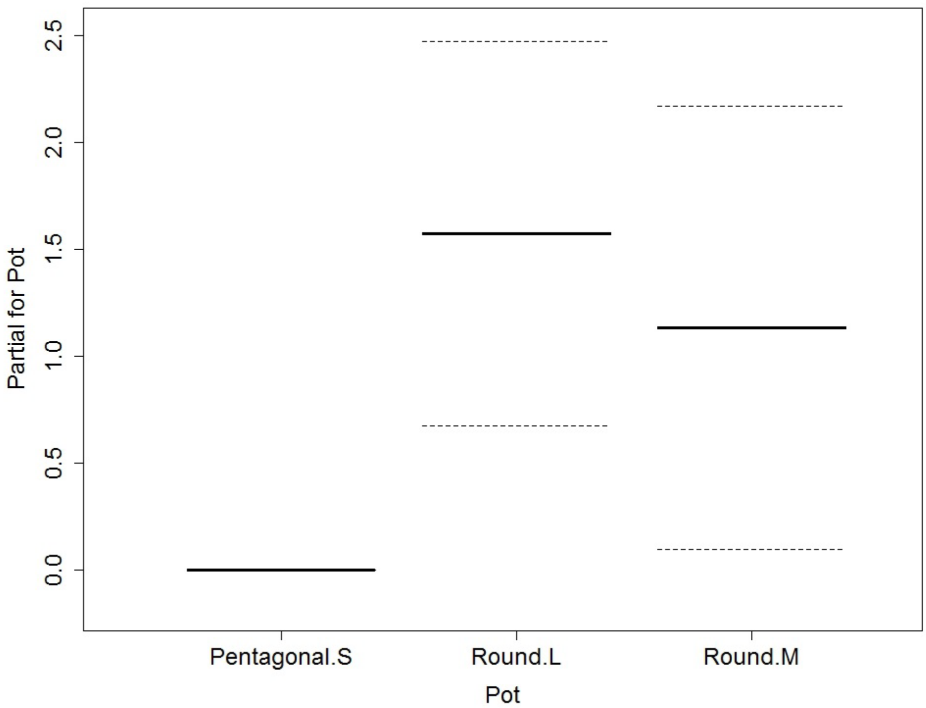

Figure 13. Partial effect of pot type on entry rate during trial 2. The effect of all pots is relative to the Pentagonal S pot, which is therefore missing confidence intervals. Dotted line shows 95 % confidence intervals. The effect is on the log scale.

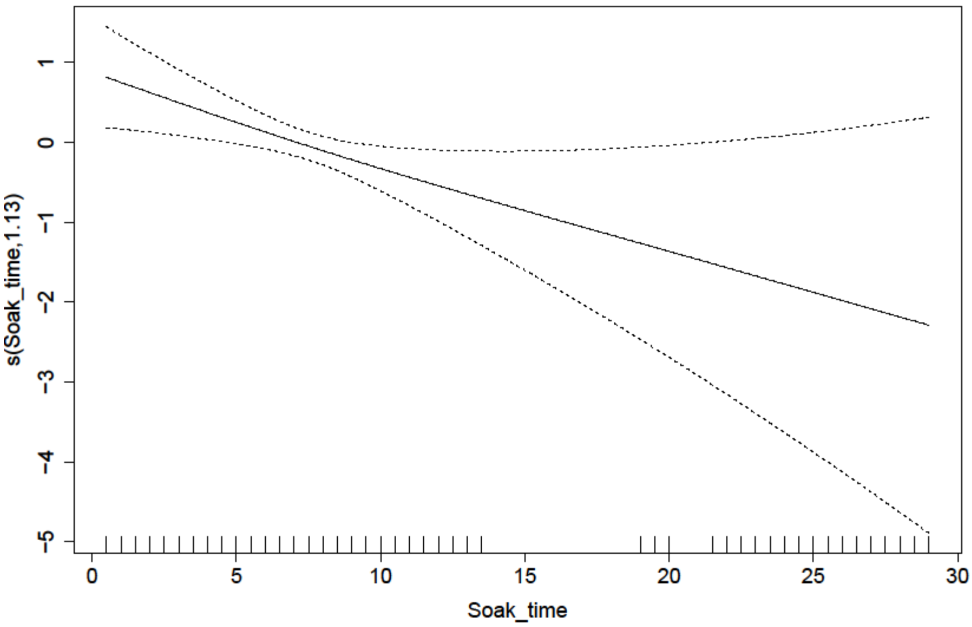

Figure 14. Partial response curve for entry rate in relation to soak time (hours) for trial 2. Values above 0 indicate a positive effect of soak time on entry rate compared to the mean. The effect is on the log scale.

Discussion

To fully understand the catch process of pots it is important to look at behaviour of the target species (Renchen et al., 2012, Stoner, 2004). This study is unique since it has used camera systems with the ability to record for more than 24 hours to study cod behaviour in relation to pots. Our knowledge of the full catching process of cod pots is now improved. Analysis showed continuous entry and exit behaviour during the whole set time and increased entry rate during night time when artificial light is used.

Catch per unit effort

Analysis of CPUE showed that Round L had the largest catches during both fishing trials. The results are in line with previous studies (Furevik and Lokkeborg, 1994) finding that larger pots resulted in larger catches and so did pots with two entrances compared to pots with one entrance. The catch efficiency of floating pots versus bottom standing pots was tested by Furevik et al. (2008) and results showed that floating pots had a higher CPUE. The bottom standing pots used in the study by Furevik had two entrances thus there was a risk that none of the entrances would face the direction of the current and chances of cod finding it would decrease. The round pot types in this thesis had three entrances which ensure that one is always facing the right direction; this may explain the higher CPUE of the Round L pot compared to the floating pots. Size, number of entrances and that the pot was bottom standing were all traits of Round L that differed from the other types. Hence it could not be concluded if it is one of these traits or a combination of them which increases CPUE. Video analysis of pots from trial 1 showed that many of the floating pots were standing on the bottom. This could have negatively impacted the catches of the floating pot types during trial 1. The low catches of the Carapax pot may also be due to a larger mesh size of the escape window than the other types. A 50 mm mesh side escape window, as the one in the Carapax pot, allows 50 % of cod of 42 cm in length to escape (Ovegård et al., 2011). In trial 2 all pots hade the same mesh side in escape windows.

Mean catches of all pot types were larger in the second fishing trial. Some of the floating pots had additional floats during trial 2 to assure them to be in the right position in the current with the entrance facing downstream. This most likely increased the catches. However, the higher CPUE in the bottom standing Round L pots suggest that there were other factors affecting catches. Season of the year is one factor that impacts CPUE (Königson et al., 2015). The traits of the pot types in this study and their catch efficiency is further described and discussed in a paper by Kindt-Larsen et al. (manuscript).

Video analysis

Divers and video systems have been used to record and analyse behaviour of fish around pots and traps (Anders 2015, Bacheler et al., 2013, Cole et al., 2004, High and Ellis 1973). The majority of previous studies have filmed for a few hours but some solutions have been tested to film for longer making it possible to follow the whole catching process of a pot or trap (Jury et al., 2001, Renchen et al., 2012). For some fisheries saturation occurs after a few hours hence the set times are not as long as in this study (Bacheler et al., 2013). The camera system used had the capacity to film up to 36 hours although lack of enough and reliable batteries meant this was not always achieved. Norwegian studies (Anders 2015, Olsen 2014) have filmed the behaviour of cod around pots but this study is unique in the sense that it has covered catch processes for > 24 hours. Further development of the systems is underway with new camera models and batteries being tested for filming at least 70 hours. The use of artificial light made it possible to watch the full catch process although the light may have impacted natural behaviour. Renchen et al (2012) used red light to decrease the impact of light on behaviour but in night time the light was not enough to light up the whole pot hence the material was not analysed. Another disadvantage with red light is that red filter needs stronger light effect and therefore the battery of the light does not last as long as the camera.

Activity level

Analysis of entries and exits showed continuous entry and exit behaviour in all pot types. Caught individuals have been seen exiting and re-entering a pot numerous times resulting in similar increases of cumulative entries and exits. For some pots the number of exits was as high as the number of entries resulting in no catch. Conversely, in the Round L pot the cumulative entries increased more than exits all through the set time. The exits in relation to entries seem to be lower in the Round L pot which can explain the higher CPUE. This may be due to its large volume which then prevents saturation.

Factors affecting entry rate

Trial 1

The Round L pot had significantly higher entry rate than the other pot types. There was no difference in entry rate between the other pot types while CPUE was significantly different between all types. The mismatch in CPUE and entry rate may be due to filmed pots having artificial light while pots without light were included in the CPUE analysis. The mismatch can also be because entry rate included all sizes of cod while CPUE only included cod ≥ 38 cm.

String id was also a significant predictor which indicates that date and/or string which the pot was set in impacts entry rate, probably through the spatial or temporal differences in abundance of cod between strings.

The most interesting finding was that time of the day had a significant impact on entry rate. The artificial light used may explain the higher entry rate during night time. A study of activity of cod showed that the chances of cod finding available bait is higher in day time. Cod also use vision to locate bait and the absence of light may be the explanation of the low activity and location of bait during night time (Lokkeborg and Fernö, 1999). Although another study by Furevik and Skeide (2003) found more activity of cod around pots at night time than during the day. The use of light in our study may favour search for prey during night time and hence increase entry rate. The increase in entry rate during night time could explain the higher catches in pots with lights found by Bryhn et al. (2014). It has been suggested that pots are set later in the day so that the maximum odour from bait coincides with most available cod (Furevik and Skeide 2003). When analysing video material a large number of mysids have been noticed and cod have been seen feeding on them. This could explain why cod is attracted to pots with artificial light. Further studies combining catch and stomach analyses of cod could reveal if cod are feeding inside the pots.

The analysis did not find a saturation effect since number of individuals present in pots did not have an effect on entry rate. This was further strengthen by analysis of cumulative entries which did not show any consistent plateaus indicating saturation. It can also be concluded that there was no effect of social interaction since neither a positive nor negative effect of presence of conspecifics inside pots on entering individuals was found. A previous study of behaviour of cod found that the entry rate of large cod (≥45 cm) peaked with one fish in the pot and then decreased with additional cod present in the pot (Anders 2015). This was not strengthened by the results of this thesis since the number of cod present in the pot was not a significant predictor for entry rate, although few individuals were larger than 45 cm. However since entry rate was calculated as number of entries minus number of exits it is possible that number of cod present in the pot impacted both entries and exits keeping the entry rate constant. In the study by Anders (2015) the effect of present conspecifics inside pots was different when individuals were smaller than 45 cm, the chances of capture increased until four individuals were caught. Since it was not possible to determine size of individuals from video analysis it is possible that size specific impacts on entry rate was missed in the present thesis. It is also possible that there are saturation effects when the catches are higher than those in this thesis.

Trial 2

The new Pentagonal S pot had significantly lower entry rate than the other pot types. The total number of registered entries and exits of Pentagonal S was low indicating that fish did not enter pot in the first place.

The other significant predictor of entry rate was soak time which had a negative effect on the entry rate, i.e. entry rate decreased with soak time. A previous study (Lokkeborg, 1990) found a decrease in bait odour with soak time and this could explain the decrease in entry rate in this thesis. The effect of soak time on entry rate was not seen in trial 1 which was probably due to the attraction of light having a positive impact on entry rate during night time.

There was no effect of time of the day on entry rate in the second trial. Since no artificial light was used when filming the second trial no behaviours were recorded during night time and it is therefore possible that the effect of time of the day was missed. However the effect of time of the day seen in trial 1 could be due to the artificial light attracting cod at night time. This attraction was lacking in trial 2 hence time of the day was not a significant predictor. String id was not a significant predictor either which may be due to the trial period being shorter than trial 1 thus the abundance of cod varied less. The number of fish in the pot did not impact entry rate meaning no saturation effect was found. Although soak time is a predictor that can be assumed to correlate with saturation since bait odour decreases with soak time and likelihood of saturation increases with soak time. It is therefore possible that there is a hidden saturation effect not found by the model.

Limitations and potential sources of error

All pots used were equipped with escape windows to reduce bycatch of cod < 38 cm. Due to this it was possible for individuals to enter and exit pots through the escape window without being noticed on video sequences. It is therefore possible that both total number of entries and exits are over- or underestimated. A fish may enter through the escape window and then exit though the entrance resulting in one registered exit but no registered entry, the opposite may also occur. This problem was dealt with by counting all individuals inside a pot at the end of each film sequence. The number inside the pot was compared with the registered number of entries and exits and if they did not match the number of entries and exits was adjusted.

When analysing video material the size of cod could not be determined. Due to this there might be size dependent effects of present individuals inside the pot on entry rate that was missed in this study.

Due to set up of cameras inside pots it was not possible to get a full picture of abundance of cod outside pots. A previous study (Anders, 2015) calculated entry rate as the proportion of fish outside the pot that enter. Since that was not possible with the video material available for this thesis, entry rate was instead calculated as the net entries per half hour. Due to this my results are not comparable with the previous study (Anders, 2015).

Since string id was also included as a factor in GAMM analyses for CPUE and entry rate, the fish abundance around that string and at that day was accounted for in the model. However, one weakness of the model is that it does not include the interaction between pots in the same string. For example if abundance of cod increases in the area of a string the entry rate of a pot in that string is likely to increase and it is also more likely to increase in other pots of the same string. This means that there is a possible correlation between pots in the same string which should have been included in the model. Another weakness of the model for entry rate is that it does not handle negative values. When calculating entry rate, a few occasions (< 3 %) had negative values which were then treated as zeros. If there had been many negative data points this would have impacted the results but since these occasions were few the risk was minimal.

Conclusion

Catches vary widely between pot types hence it is important to test different traits of pots to be able to develop a pot which is easy for fish to enter and difficult to exit. There were differences in CPUE and entry rate between the different pot types with the largest CPUEs and entry rate found in the Round L pot.

Three entrances and a large size seem to have resulted in more registered entries than the other pot types but not a proportional increase in exits which then results in higher catches. When applying this knowledge in the fishery it is important to not only consider the CPUE of a pot type but also take into account that larger pots may have longer handling time than smaller pot types. Future studies of different pot types should include analysis of handling times to be able to further optimize the use of cod pots.

The artificial light may explain the higher entry rate during night time in trial 1. Although season is also a factor that impact environmental variables which change the behaviour and possibly the willingness of fish to enter pots (Stoner, 2004). The effect of light needs to be further investigated to see if the increase in catch when light is used is due to increases in entry rate during night time or other unknown factor. It is also of interest to determine if it is the light itself that attract cod to the pot or if light attract other species that are of interest for the cod as prey.

That entry rate increases during night time with artificial light is useful knowledge when planning a fishery with pots. Future studies should test at what time of the day pots should be set to maximize the effect of bait and light. It is possible that they should be set in the afternoon so the greatest attraction effect of bait and light would coincide. Alternatively they should be set in the morning, then the bait would first attract fish and when the bait odour decreases the light will continue to attract fish. Ultimately the attraction of light should be combined with a bait construction that omits odour for a longer period of time.

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References

Anders, N., 2015. The effect of pot design on behaviour and catch efficiency of gadoids. Thesis in Master of Science in Fisheries Biology and Management. Department of Biology, University of Bergen.

Bacheler, N. M., Schobernd, Z. H., Berrane, D. J., Schobernd, C. M., MitchellI, W. A. & Geraldi, N. R. 2013. When a trap is not a trap: converging entry and exit rates and their effect on trap saturation of black sea bass (Centropristis striata). Ices Journal of Marine Science, 70, 873-882.

Ben-Yami, M. 1988. Attracting fish with light. FAO training series, 14.

Bryhn, A. C., Königson, S. J., Lunneryd, S. G. & Bergenius, M. A. J. 2014. Green lamps as visual stimuli affect the catch efficiency of floating cod (Gadus morhua) pots in the Baltic Sea. Fisheries Research, 157, 187-192.

Cole, R. G., Alcock, N. K., Tovey, A. & Handley, S. J. 2004. Measuring efficiency and predicting optimal set durations of pots for blue cod Parapercis colias. Fisheries Research, 67, 163-170.

Fjälling, A. 2005. The estimation of hidden seal-inflicted losses in the Baltic Sea set-trap salmon fisheries. Ices Journal of Marine Science, 62, 1630-1635.

Furevik, D. M. & Lokkeborg, S. 1994. Fishing trials in Norway for torsk (Bromse bromse) and cod (Gadus morhua) using baited commercial pots. Fisheries Research, 19, 219-229.

Furevik, D.M. & Skeide, R.L. 2003. Fishing for cod (Gadus Morhua), ling (Molva, molva) and tursk (Bormse, bromse) using two-chamber pots along the Norwegian coast. Institute of Marine research .

Furevik, D.M., Humborstad, O.B., Jorgensen, T., Lokkeborg, S. 2008. Floated fish pot eliminates bycatch of red king crab and maintains target catch of cod. Fisheries Research, 92, 23-27.

Haarder, S., Kania, P. W., Galatius, A. & Buchmann, K. 2014. Increased Contracaecum osculatum infection in Baltic cod (Gadus morhua) livers (1982-2012) associated with increasing grey seal (Halichoerus gryphus) populations. Journal of Wildlife Diseases, 50, 537-543.

Harding, K. C. & Harkonen, T. J. 1999. Development in the Baltic grey seal (Halichoerus grypus) and ringed seal (Phoca hispida) populations during the 20th century. Ambio, 28, 619-627.

HAV, 2010. Småskaligt kustfiske. Regeringsuppdrag att beskriva det småskaliga kustnära fisket i Sverige. [swedish]

HAV, 2014. Sälpopulationernas tillväxt och utbredning samt effekterna av sälskador i fisket. [swedish]

HAV, 2016. Havet 2015/2016. Havs- pch vatten myndigheten, Havsmiljöinsitituet och Naturvårdsverket. [swedish]

He, P. 2010. Behaviour of marine fishes: Capture Processes and Conservation Challenges.

Hemmingsson, M., & Lunneryd, S.G. 2005. Inventering av sälskadesituationen i

Västerbottens- och Norrbottens län. Report to the Project Seals and Fisheries. [swedish]
Hemmingson, M., & Lunneryd, S.G. 2007. Pushup-fällor i Sverige - Introduktionen av ett nytt sälsäkert fiskeredskap. Fiskeriverket. [swedish]
Hemmingsson, M., Fjälling, A. & Lunneryd, S.-G. 2008. The pontoon trap: Description and function of a seal-safe trap-net. Fisheries Research, 93, 357-359.
Hiby, L., Lundberg, T., Karlsson, O., Watkins, J., Jussi, M., Jussi, I. & Helander, B. 2007. Estimates of the size of the Baltic grey seal population based on photo-identification data. NAMMCO Scientific Publications, 6, 163-175.
High, W.L. and Beardsley, A.J. 1970. Fish behaviour studies from an undersea habitat. Comm. Fish. Rev, 31,7.
High, W.L. & Ellis. I.E. 1973. Underwater observations of fish behaviour in traps. Helgolländer Wiss. Meeresunters., 24, 341-7.
Jury, S. H., Howell, H., O'Grady, D. F. & Watson, W. H. 2001. Lobster trap video: in situ video surveillance of the behaviour of Homarus americanus in and around traps. Marine and Freshwater Research, 52, 1125-1132.
Kindt-Larsen L., Berg, C., Hedgärde, M., Larsen, F., Ljungberg, P. Månsson, M. and Königson, S. Development new technology to avoid grey seal depredation: Increasing catch rates in Atlantic cod pots in the Baltic Sea. (Manuscript)
Königson, S., Hemmingsson, M., Lunneryd, S. G. & Lundström, K. 2007. Seals and fyke nets: An investigation of the problem and its possible solution. Marine Biology Research, 3, 29-36.
Königson, S., Lunneryd, S. G., Sundqvist, F., and Stridh, H. 2009. Grey seal predation in cod gillnet fisheries in the central Baltic Sea. Journal of North Atlantic Fisheries Science, 42: 41–47.
Königson, S., Lunneryd, S. G., Stridh, H. & Sundqvist, F. 2010. Grey Seal Predation in Cod Gillnet Fisheries in the Central Baltic Sea. Journal of Northwest Atlantic Fishery Science, 42, 41-47.
Königson, S. 2011. Seals and Fisheries, A Study of the Conflict and Some Possible Solutions. Ph D thesis at Göteborg University.
Königson, S. J., Fredriksson, R. E., Lunneryd, S. G., Strömberg, P. & Bergström, U. M. 2015. Cod pots in a Baltic fishery: are they efficient and what affects their efficiency? Ices Journal of Marine Science, 72, 1545-1554.
Ljungberg, P., 2007. Evaluation of baited pots in the fishery for cod, (Gadus morhua) within the southeast Baltic. Master's Thesis in Marine Biology, Department of Biology, Lund University.
Lokkeborg, S. 1990. Rate of release of potential feeding attractants from natural and artificial bait. Fisheries Research, 8, 253-261.
Lokkeborg, S. 1998. Feeding behaviour of cod, Gadus morhua: activity rhythm and chemically mediated food search. Animal Behaviour, 56, 371-378.
Lokkeborg, S., Bjordal, A. & Fernö, A. 1989. Responses of cod (Gadus Morhua) and haddock (Melanogrammus aeglefinus) to baited hooks in the natural environment. Canadian Journal of Fisheries and Aquatic Sciences, 46, 1478-1483.
Lokkeborg, S. & Fernö, A. 1999. Diet activity pattern and food search behaviour in cod, Gadus morhua. Environmental Biology of Fishes, 54, 345-353.
Lunneryd, G.G., Boström, M.K. and Aspholm P.E. 2015. Sealworm (Pseudoterranova decipiens) infection in grey seals (Halichoerus grypus), cod (Gadus morhua) and shorthorn sculpin (Myoxocephalus scorpius) in the Baltic Sea. Parasitology Research, 114, 257-264.
Maclennan, D. N. 1992. Fishing gear selectivity – an overview. Fisheries Research, 13, 201-204.
Marchesan, M., Spoto, M., Verginella, L., Ferrero, E.A. 2005. Behavioural effects of artificial light on fish species of commercial interest.
Munro, J.L. 1974. The mode of operation of Antillean fish traps and the relationships between ingress, escapement, catch and soak. J. Cons. Int. Explor. Mer, 35(3), 337-50.

Naturvårdsverket. 2014. http://www.miljomal.se/Miljomalen/Alla-indikatorer/Indikatorsida/?iid=142&pl=1

Olsen, L., 2014. Baited pots as an alternative fishing gear in the Norwegian fishery for Atlantic cod. Master's thesis in Fisheries- and Aquaculture Science, The Arctic University of Norway.

Ovegård, M., Königson, S., Persson, A. & Lunneryd, S. G. 2011. Size selective capture of Atlantic cod (Gadus morhua) in floating pots. Fisheries Research, 107, 239-244.

Punsly, R. & Nakano, H. 1992. Analysis of variance and standardization of longline hook rates of bigeye (Thunnus obesus) and yellowfin (Thunnus albacares) tunas in the eastern Pacific Ocean during 1975-1987. Inter-American Tropical Tuna Commission Bulletin, 20, 167-184.

Renchen, G. F., Pittman, S. J. & Brandt, M. E. 2012. Investigating the behavioural responses of trapped fishes using underwater video surveillance. Journal of Fish Biology, 81, 1611-1625.

Stoner, A. W. 2004. Effects of environmental variables on fish feeding ecology: implications for the performance of baited fishing gear and stock assessment. Journal of Fish Biology, 65, 1445-1471.

Suuronen, P., Chopin, F., Glass, C., Lokkeborg, S., Matsushita, Y., Queirolo, D. & Rihan, D. 2012. Low impact and fuel efficient fishing-Looking beyond the horizon. Fisheries Research, 119, 135-146.

Valdemarsen, J.W., Fernö, A., Johannessen, A. 1977. Studies on the behaviour of some gadoid species in relation to traps.

Varjopuro, R. 2011. Co-existence of seals and fisheries? Adaptation of a coastal fishery for recovery of the Baltic grey seal. Marine Policy, 35,450-456.