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Explaining the catch efficiency of different cod pots using underwater video to observe cod entry and exit behaviour

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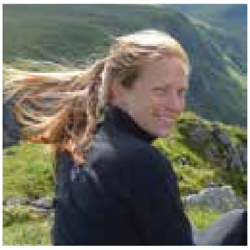
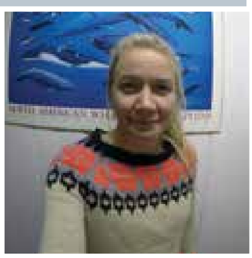
Coming and going



Maria Hedgärde

Casper Willestofte Berg



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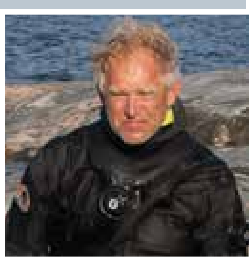

Sven-Gunnar Lunneryd

Sara Königson

Hedgärde, Berg, Kindt-Larsen, Lunneryd, and Königson investigate how pot design affects the entry and exit rates of Atlantic cod in baited pots.

Who should read this paper?

People with an interest in the development of sustainable and seal-safe fishing gear as well as people interested in fish behaviour and new video techniques.

Why is it important?

The pursuit of low impact and fuel efficient fishing operations and techniques has received growing attention in developed countries over the last decade in response to the undesirable impacts of commercial fishing on marine ecosystems. Yet the development of sustainable fishing technologies is rarely revolutionary. Rather it is more often a systematic iterative approach in which novel innovations are evaluated through comparative fishing experiments and behavioural observations of animals using underwater cameras. This study is a good example of how both these techniques can be used together to improve fishing gear design and operation.

In this paper, the authors test the performance of six different pot designs for targeting Atlantic cod. Four pot designs were floating concepts with one entrance, and two were bottom standing concepts with three entrances. Fishing experiments and camera observations were conducted off the east coast of Bornholm in Denmark. Entry and exit rates of cod were observed using underwater cameras. Soak time, number of fish in the pots, and artificial light were all found to affect entry and exit rates of fish from the pots. This Swedish and Danish research team hopes to use the results to inform the design of additional prototypes.

About the authors

Maria Hedgärde is a marine biologist working on the development of sustainable and seal-safe fishing gear to mitigate the growing seal-fishery conflict in the Baltic Sea. Casper Berg works mainly with statistical models for fish populations. This involves the analysis of catch data from scientific research vessels as well as samples from commercial landings. Lotte Kindt-Larsen studies the interactions between fisheries and protected, endangered and threatened species. Her work focuses on gear development to avoid by-catch in fisheries, increase catch rates in pot fisheries and protect fish catches in fyke, pot and net fisheries against seal depredation. Sven-Gunnar Lunneryd is the project leader/senior scientist at the Institute of Coastal Research, working with different aspects of the conflict between man and marine mammals and birds. Sara Königson studies marine mammal and fisheries interactions. She works with fishing gear development for small-scale fisheries with a focus on sustainable and seal-safe fishing gear.

EXPLAINING THE CATCH EFFICIENCY OF DIFFERENT COD POTS USING UNDERWATER VIDEO TO OBSERVE COD ENTRY AND EXIT BEHAVIOUR

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ABSTRACT

Cod pots are considered seal-safe fishing gear and are proposed as a solution to mitigate the ongoing seal-fisheries conflict in the Baltic Sea. This study examined various factors which could affect the entry and exit behaviour of cod in relation to cod pots. Statistical modelling was used to determine which of these factors most affected the pots' catch per unit effort (CPUE). Two fishing trials were conducted off the coast of Bornholm, Denmark, using six pot types with different design features, equipped with underwater camera systems to record the behaviour of the cod in relation to the pots. Four pot types were floating pots with one entrance and two were bottom standing with three entrances.

Different pot types showed significantly different CPUEs and the pot type was an explanatory factor for entry and exit rates for both trials. In trial 1 artificial light was used for filming and results showed an increase in entry rates during the night time, suggesting that lights attract fish to the pot when the dark surroundings make the effect of the light more noticeable. Exit rates in trial 1 increased with an increasing number of fish in the pot while they decreased with soak time. In trial 2, when no artificial light was used, a saturation effect was found in that the probability of cod entering the pot lessened as the number of cod already in the pot increased. However, the exit rates in trial 2 also decreased with increasing number of fish in the pot. The study offers greater depth to the understanding of CPUE results by examining fish behaviour around the pots and not just the raw catch data. This in turn contributes to the ongoing search for the most favourable pot designs.

KEYWORDS

Cod; Pot; Behaviour; Saturation; CPUE; Attraction

INTRODUCTION

In the Baltic Sea region, small-scale fisheries are important, both economically and socially [Bruckmeier and Larsen, 2008; Waldo et al., 2010]. In recent decades, the grey seal (*Halichoerus grypus*) population in the Baltic Sea has increased significantly, resulting in a growing conflict between seals and small-scale fisheries [Lunneryd et al., 2005; Varjopuro, 2011]. The grey seal population has not only increased in numbers, it has also expanded its range further south [Härkönen et al., 2013] resulting in increased grey seal depredation in cod gillnet and longline fisheries in the central and southern Baltic Sea, which are fisheries with great economic value [Königson et al., 2009].

The most sustainable method for mitigating seal depredation is to develop and use seal-safe fishing gear [Königson, 2011; Königson and Lunneryd, 2012]. Therefore research efforts have focused on the development of pots. Königson et al. [2015] showed that cod (*Gadus morhua*) pots could indeed be a seal-safe alternative to gillnets in the southern Baltic.

Pots are also considered to be a low impact and fuel efficient type of gear [Suuronen et al., 2012]. Pots can be made species- and size-selective, they are passive fishing gear, do not consume fuel while fishing, and they have minimal impact on the bottom substrate. However, even though pots have been shown to be a commercially viable alternative to gillnets and longlines, they need to be further developed, since their current catch efficiencies can be low compared to those of traditional gear [Königson and Lunneryd, 2012; Furevik, 1997; Furevik and Hågensen, 1997; Furevik and Skeide, 2003].

The catch efficiency of baited fishing gear, here described as catch per unit effort (CPUE), depends on both biotic and abiotic factors. Biotic factors include the abundance of the target species and the abundance of suitable prey for them. Abiotic factors can include water temperature, current speed and direction, underwater topography, soak time, stimuli provided to attract the fish (bait or light) and various features of the pot design (size, number of entrances, etc.). All these factors may impact CPUE through their impact on the behaviour of the target species [Stoner, 2004]. These different factors may affect target species' activity levels, feeding motivation and ability to detect, locate and consume the bait [Stoner, 2004] and they impact the catch process at different stages. The catch process of a pot can be divided into three steps: attracting the fish to the pot, luring the fish inside, and retaining the fish until the pot is hauled [He, 2010]. Bait is almost always used to attract cod to the pot but studies have shown that light can also be used for this purpose [Bryhn et al., 2014].

Fish are initially attracted by smelling the bait in the current, but when approaching the pot, their behaviour is influenced by short-range senses such as vision and lateral line stimulation [He, 2010]. The entry behaviour, when fish swim into the pot, and the exit behaviour, when fish swim out of the pot again, can both depend on many different factors. The net effect of these factors can be quantified in terms of entry and exit rates, defined as the total number of fish entering or exiting a pot during a given time span. One factor affecting entry and exit rates is the pot's size and appearance, both with regards to the entrance of the pot and to the shape and colour of the pot itself [Furevik and Løkkeborg, 1994; Munro, 1974]. Larger pots are more effective than small pots, possibly because the risk of fish entering being disturbed by fish already caught is lowered [Furevik and Løkkeborg, 1994]. The exit rate is also inversely proportional to the volume of the pot [Munro, 1974]. Furevik and Løkkeborg [1994] found that when pots are equipped with a wider entrance, the entry rate increases but so does the exit rate.

Pilot studies of cod approaching baited pots have shown that the pots' position in relation to the current is of importance to the fishes' entry behaviour [Valdemarsen et al., 1977]. Pots tested in this study included bottom standing pots and also pots suspended in the water column some metres off the bottom, defined as floating pots. These floating pots have one entrance. Since fish most likely follow the bait odour in order to locate the pot, it is preferable that the entrance is in line with the current, making it easy for a fish to locate the entrance. The suspension arrangement of a floating pot includes a crowfoot attached to one of the short sides, allowing the pot to orient itself into the right position in the current at all times. Bottom standing pots are equipped with multiple entrances since the pot cannot change position once it is set. Floating two-chamber pots tested in Norway achieved larger catches than bottom standing pots [Furevik et al., 2008]. However, bottom standing pots can be an alternative to floating pots if they have more than one entrance, making them independent of a certain position in the current.

The number of fish inside a pot may also affect the entry behaviour through the so-called saturation effect, where entry rates decrease when fish inside the pot reach a certain density [High and Beardsley, 1970; Bacheler et al., 2013]. It has been shown that the presence of cod inside a pot has different impacts on conspecifics of different sizes [Anders, 2015]. The presence of one fish inside a cod pot decreases the probability of capturing cod ≥ 45 cm while it increases the probability of capturing cod <45 cm [Anders, 2015]. One explanation for this is that smaller fish are subject to higher predation pressure and are more willing to shoal together than larger fish which tend to disperse away from each other.

Another factor impacting entry behaviour is the time of day. One study of cod activity [Løkkeborg and Fernö, 1999] showed that the chances of cod finding available bait are higher in day time than at night. Cod also use vision to locate prey so the absence of light may be the explanation of the low activity and bait detection at night time [Løkkeborg and Fernö, 1999].

Knowledge of how entry and exit behaviours change with soak time is also valuable to be able to optimize the CPUE. For cod pots, Königson et al. [2015] got the highest catches at soak time of six days while Furevik and Skeide [2003] concluded that catches of cod do not increase between one and eight days, probably due to the decreasing attractive effect of the bait after 24 hours.

There are additional factors affecting entry and exit behaviour but the ones mentioned above (the pot's size and appearance, pot's position in relation to the current, number of fish inside the pot, time of the day and soak time) are the ones which are measurable through in-situ studies. In-situ studies are a key requirement for studying fish behaviour in relation to the catch process. It is clear that understanding fish behaviour around the pots is fundamental to increasing their catch efficiency and to reducing by-catch [He, 2010], but there are surprisingly few in-situ studies that actually quantify the behaviour related to the capture process [Anders, 2015; Jones et al., 2003; Laurel et al., 2007; Stewart and Beukers, 2000]. Behavioural studies are an essential part of the process of developing catch efficient and seal-safe fishing gear, which is why we have addressed them in this study.

When studying fish behaviour, it is most desirable to do so in the natural habitat. Environmental factors that can affect cod behaviour such as currents, visibility or presence of other fish cannot be controlled as can the conditions in a lab. Nevertheless, new low-cost video technology does now enable us to learn a lot about fish behaviour in the wild [Anders, 2015; Jones et al., 2003; Laurel et al., 2007; Stewart and Beukers, 2000].

In this study the aim was to examine the cod pot entry and exit behaviour of free-swimming wild cod and to compare the factors affecting it. Finding out what factors have the most impact on entry and exit behaviour can explain different types of pots' CPUEs and help to improve their performance in future. This was done by (1) comparing the CPUEs of different pot types, (2) observing and measuring entry and exit rates using underwater video cameras, (3) using statistical modelling to determine which of the factors described above best explained entry and exit rates, and (4) relating the results of the behavioural study to the CPUEs of the different pot types.

METHOD

Experimental Set-Up

Two fishing trials using different types of pots were conducted, from September 19 to November 8, 2014 (Trial 1) and May 3-27, 2015 (Trial 2). Both trials took place off the east coast of Bornholm in Denmark (Figure 1) in collaboration with a local fisherman using a small gillnet vessel (9.9 m long). During both fishing trials, cameras were mounted inside individual pots to record the catch process and the behaviour of the cod inside the pots and just outside the entrances.

Fishing Trials

Pots were deployed in sets of 4-6 and attached to the same bottom line, defined as a string. Pots were baited with ~300 g of frozen herring (*Clupea harengus*) placed in white bait bags in the entrance chamber of the pot. They were set with a distance of 40 m between them, resulting in strings with total lengths of 160 m-240 m. Dates, times, positions and depths of all set and hauled strings were recorded. The catch was separated into cod above and below minimum landing size (38 cm in 2014 and 35 cm in 2015) and the number caught in each pot and the total weight per pot was recorded for both size classes.

Six pot types were used in the study and all, except the Carapax pot, were made of the same material (structure of 8 mm stainless steel and green polyethylene 2.5 mm thread),

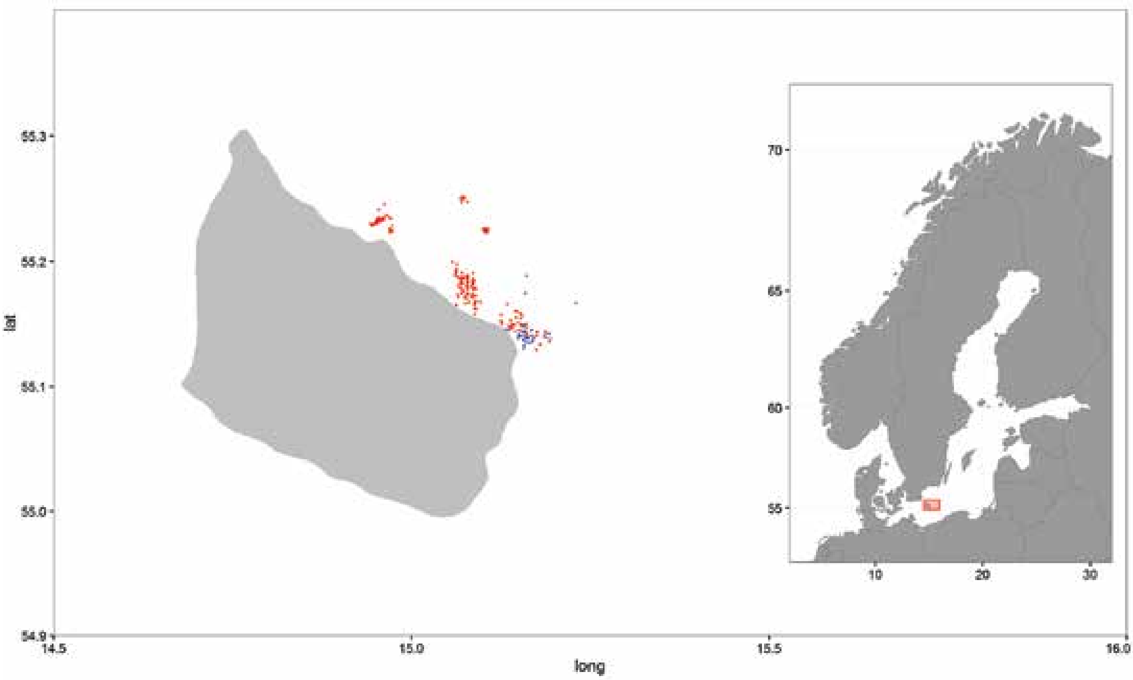

Figure 1: Pot string positions off the east coast of Bornholm, Denmark. Red circles indicate pot string positions in trial 1 and blue stars indicate pot string positions in trial 2.

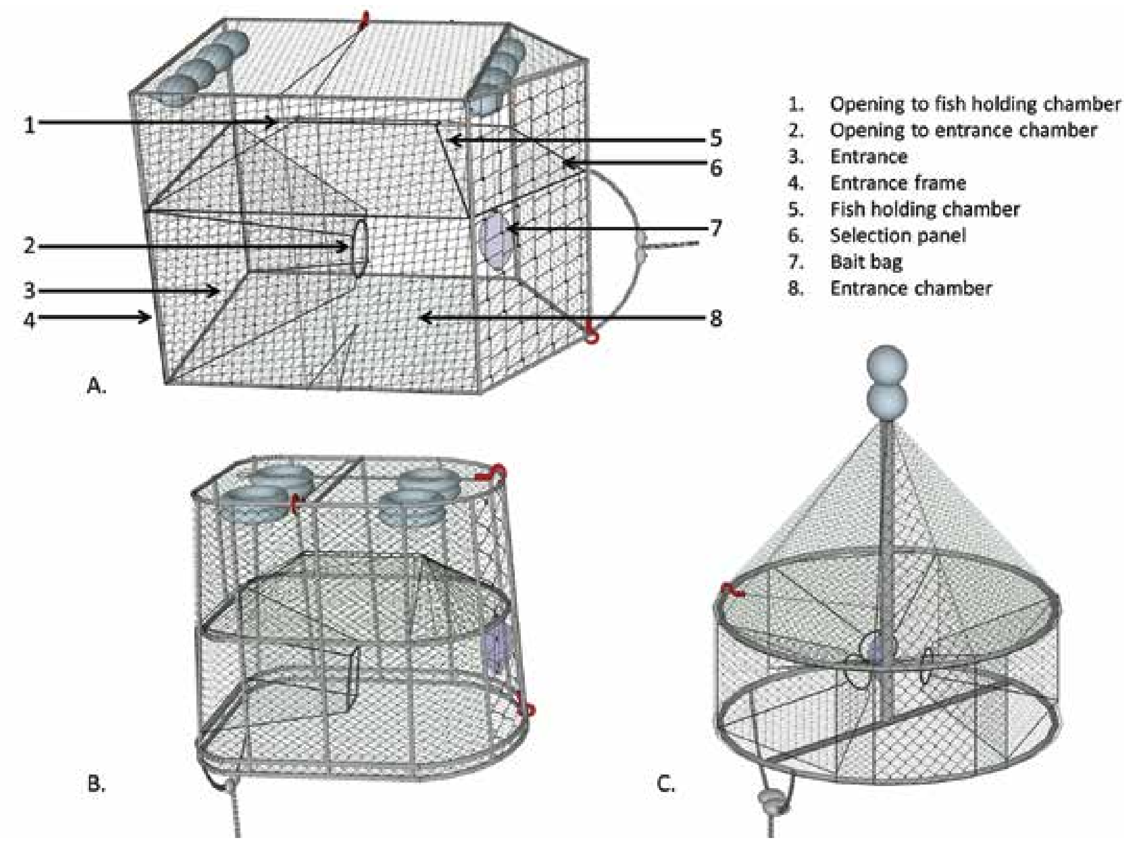

Figure 2: Pots used in trial 1. A: Pentagonal M and L; B: Carapax; and C: Round L. The different parts of the pot are defined to the upper right.

Name	Trial	Description	Pot frame	Entrance frame	Selection panels
Round L	1 and 2	Large round bottom standing two-chamber pot with three entrances. Fish holding chamber conical in trial 1 and cylindrical in trial 2.	D= 150, H= 86	H= 55, W= 80	H= 86, W= 42
Pentagonal L	1	Floated two-chamber pot with one entrance.	L= 120, W= 70, H= 90	H= 55, W= 70	H= 90, W= 45
Pentagonal M	1	Floated two-chamber pot with one entrance, same type as Pentagonal L but smaller.	L= 90, W= 70, H= 75	H= 50, W= 70	H= 75, W= 45
Carapax	1	Floated two-chamber pot with one entrance.	L= 118, W= 78, H= 98	H= 44 W= 55	H= 98, W= 30
Round M	2	Small, round bottom standing two-chamber pot with three entrances. Upper fish holding chamber same diameter as bottom chamber.	D= 95, H= 90	H= 50, W= 60	H= 90, W= 42
Pentagonal S	2	Floated two-chamber pot with one entrance, fish holding chamber horizontally in line with entrance chamber.	L= 120, W= 70, H= 55	H= 55, W= 70	H= 55, W= 45

Table 1: Names and description of pot types used in trial 1 and 2. D= diameter, H= height, L= length, W= width. Measurements are in centimetres (cm).

30 mm mesh size (distance between knots) and had the same diameter circular opening to the entrance chamber (16 cm). The Carapax pot was borrowed from the manufacturer Carapax® while the other models were custom-made for us by a supplier of fishing gear on Bornholm. All pots were two-chamber pots, with one entrance chamber and one fish holding chamber (Figure 2). The entrance sides of the custom-made pots were made of black knotless 20 mm mesh size nylon. The pots were equipped with 45 mm mesh size selection panels, covering one whole side of both the entrance chamber and the fish holding chamber. In previous trials, similar selection panels were found to allow 50% of cod of 38 cm length to escape [Ovegård et al., 2011]. The 45 mm mesh size was chosen to optimize catch retention of cod of 38 cm and above due to a minimum landing size of 38 cm in 2014. The Carapax pot was made of 1.2 mm black nylon thread, using a 27.5 mm mesh size and with 50 mm (45 mm in trial 2) mesh size selection panels. In previous trials, similar selection panels were found to allow 50% of cod of 42 cm length to escape [Ovegård et al., 2011]. The opening to the entrance chamber was rectangular (W= 15 cm, H= 24 cm) and the entrance sides were made of monofilament.

In trial 1, four different pot types were used (Table 1, Figure 2): three floating pots (Pentagonal M, Pentagonal L and Carapax) and one bottom standing (Round L). The floating pots had one entrance and were suspended 50 cm above the seabed. They were free to rotate in the water column, allowing the entrance to line up with the current. The round pot (Round L) had a different design, with three entrances, and was therefore not dependent on a specific placement in the current. It was also larger than the other pot types. Ten strings of pots were set daily whenever the weather permitted, with soak times varying from one and two days. Each string consisted of four pots, one of each type in random order.

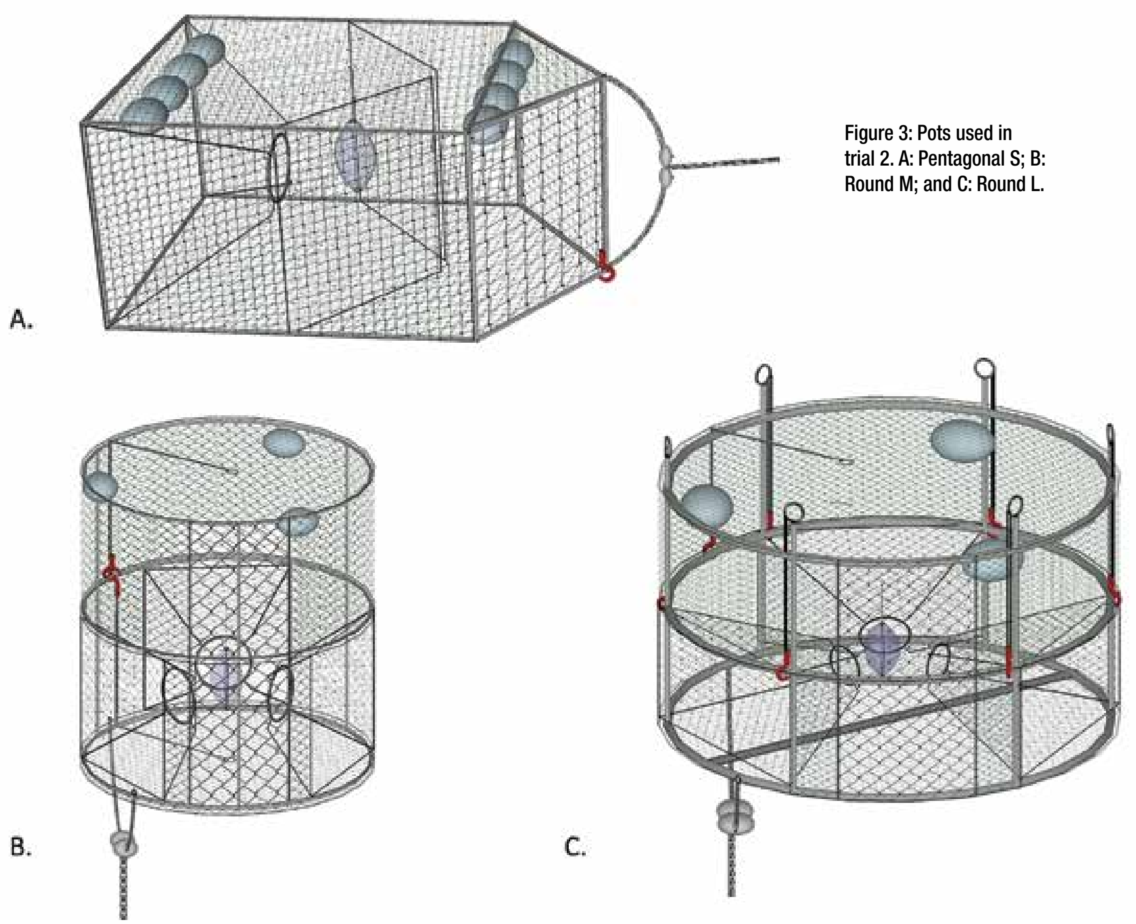

Figure 3: Pots used in trial 2. A: Pentagonal S; B: Round M; and C: Round L.

In trial 2, three different pot types were used (Table 1, Figure 3). Two types were bottom standing (Round L and Round M) and one was floating (Pentagonal S). The Round L pot was fitted with a different fish holding chamber (cylindrical instead of conical) during the second trial (Figure 3) in order to make it collapsible and easier to handle. Round M was a smaller version of Round L, made to investigate whether pot size alone would impact on the CPUE. Pentagonal S had a new design with a fish holding chamber horizontally in line with the entrance chamber instead of above it as in the other pot types. In total 30 pots were used, 10 of each type, in 10 strings of pots, and the soak time varied between one and three days. Each string included one of each of the three pot types, placed in random order. The strings also included one to three extra pots of other pot types which are not included in the analysis mainly because these pot types were not filmed.

Video Analysis

Of the ten strings of pots set in the fishing trials, 1-2 strings were fitted with cameras in 1-4 pots in each string. The cameras were used to record the catch process and cod behaviour around the pots. Cameras (GoPro Hero 3 White Edition) in underwater housings were mounted inside each pot. Underwater housings (Figure 4) for the cameras were custom-made to fit two power packs (12000 - 15000 mAh) as well as the cameras. With the additional power packs and micro SD cards (128 GB memory), the cameras were able to film up to 36 hours continuously. Cameras recorded videos in 30 minute sequences. The camera housings were fixed inside the pots, facing towards the entrances. Due to poor daylight conditions at some fishing depths and poor visibility at all depths during the hours of darkness, underwater video lights were used in all pots in trial 1. The lights used were Fisheye Fix Neo DX 800 and Fisheye Fish Neo DX 1200. The lights were set to 12% of their full power output, which enabled them to last for up to 30 hours. One light was used in each pot, placed on top of the camera housing facing towards the entrance of the pot (or towards the middle of the entrance chamber in the case of the Round models).

Videos were watched at a playback speed of up to 16x, depending on cod activity. For each 30 minute film sequence, four aspects of the fishes' interactions with the pot were observed and recorded: swimming in, either through the entrance or the sides of the pot, and swimming out, also either through the entrance or sides. In addition to entry and exit records, the current direction in relation to the pot was registered, since the chances of fish finding the entrance of a pot increase when the entrance faces in the direction of the current [Valdemarsen et al., 1977]. Current direction was determined by observing the movement of suspended particles in relation to the pot. The direction of the current in relation to the floating pots also indicated whether these pots were positioned as intended in the water column. The time of the day for each record was also registered, since this can affect the level of activity around cod pots [Furevik and Skeide, 2003] and the ability of the cod to find the bait [Løkkeborg and Fernö, 1999].

Statistical Analysis

Catch Data Analysis: CPUE
Catches were presented as CPUEs, i.e., the number of cod over minimum landing size caught per hauled pot. CPUEs were

Figure 4: Custom-made camera housing.

analysed separately for the two trials due to the differences in minimum landing sizes. The distribution of data was tested using the Kolmogorov-Smirnov test for normality, showing that data was not normally distributed ($p<0.01$). To compare CPUEs between different pot types, a Randomized (Complete) Block Design was used. Each block, i.e., one hauled and emptied string, contains a complete set of treatments, in this case 'type of pot.' With this set-up, differences in CPUE between blocks are not due to the types of pots, since these are the same in each block. CPUEs of the different pot types were thereafter compared using a Friedman test. Post-hoc comparisons, when necessary, were conducted using the Wilcoxon signed rank test.

Video Data Analysis: Factors Affecting Entry and Exit Rate

A generalized additive mixed model (GAMM) was used to determine the explanatory variables affecting entry and exit rates. A GAMM was chosen over a generalized linear model because a GAMM can include non-linear relationships and account for random variations between blocks (strings).

Entry and exit rates were calculated for each 30 minute video sequence. Since cameras were mounted inside the pots facing the entrance, fish could pass through the selection panel without being observed on the video. This meant that the overall entry and exit rates could be over- or underestimated due to fish entering through the selection panel and exiting through the entrance or the other way around. To avoid this, the numbers of fish present in each pot were counted at the start and end of each video sequence. The numbers of recorded entries and exits were then adjusted to match the number of fish in the pot. For example, if two entries were recorded but there were three fish inside the pot at the end of the sequence, one entry was added to the data. The same was done for the number of exits where necessary.

For a few recorded video sequences, the direction of the current was not determined. In the GAMM, the current direction was then assumed to be the most commonly observed direction in the other sequences. In total this was done for 32 data points in the analysis of entry rates in trial 1 and 14 data points in the analysis of entry rates in trial 2.

Data from trial 1 and 2 were analysed separately due to more than one predictor differing between them. In trial 1, artificial light was used, while no artificial light was used in trial 2. The two trials were also carried out in different seasons of the year. The predictors in Table 2 were included in the candidate models for both trials.

The candidate models for entry rate (1) and exit rate (2) for both trials:

$$log(Entry\ rate) \sim Pot + s_1(Time) + current\ dir. + s_2(number\ in\ pot) + soak\ time + s_3(string\ id) \quad (1)$$

$$log(Exit\ rate) \sim Pot + s_1(Time) + current\ dir. + s_2(number\ in\ pot) + soak\ time + s_3(string\ id) + log(number\ in\ pot) \quad (2)$$

Different smoothing functions (smoothers) were chosen for the predictors. A smoother is an algorithm producing a smooth curve of the

Predictor	Description
Pot	Pot type. Categorical variable.
Number in pot	The counted number of fish inside the pot at the end of the video sequence.
Time of day	Time of the day at the end of the video sequence.
Soak time	Hours since the pot had been deployed at the end of the video sequence.
Current direction	Direction of current in relation to the pot at the end of the video sequence. Categorical variable with four levels: cross, mix, opposite and right.
String ID	Date of deployment combined with ID of the string in which the pot was set. Categorical variable.

Table 2: Predictors used in the candidate GAMM model explaining entry and exit rates of cod in trials 1 and 2. All predictors are recorded for each 30 minute video sequence.

predictor's impact on the response variable. Smoothness selection was carried out with the marginal likelihood method [Wood, 2011]. For time of day a cyclic penalized cubic regression smoother (s_1) was used to ensure that the curve had the same start and end point. A thin plate regression spline was used for s_2. String id was a combination of the string number and setting date and is treated like an independent random effect through the use of a random effect smoother (s_3). This predictor is used to account for spatial and temporal variations in cod abundance. In the exit rate model the logarithm of the number of fish in the pot was added as a model offset (i.e., with an assumed regression coefficient of one). This was done in order to be able to interpret estimated exit rates as individual rates rather than having only an overall exit rate for the whole pot. The distribution of data was assumed to be either Poisson or negative binomial due to data being count data. Both distributions were tested for both start models and the one with the lowest Bayesian Information Criterion (BIC) value was chosen for further analysis. BIC 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 Akaike Information Criterion (AIC) since AIC tends to prefer larger, more complex models. Backward stepwise model selection was used to build a final model. At each step, the least significant variable was dropped until an increase in BIC was obtained.

RESULTS

Catch Data Analysis: CPUE

In trial 1 a total of 213 strings with four pots in each (one of each pot type) were hauled, resulting in 852 emptied pots. There was a significant difference in CPUEs between pot types (Friedman test, $p < 0.001$) (Figure 5). Round L and Pentagonal M had significantly higher catches than Carapax and Pentagonal L (Wilcoxon signed rank, $p < 0.001$). Round L had 2.7 times higher mean CPUE than Carapax and 1.7 times higher than Pentagonal L. Pentagonal

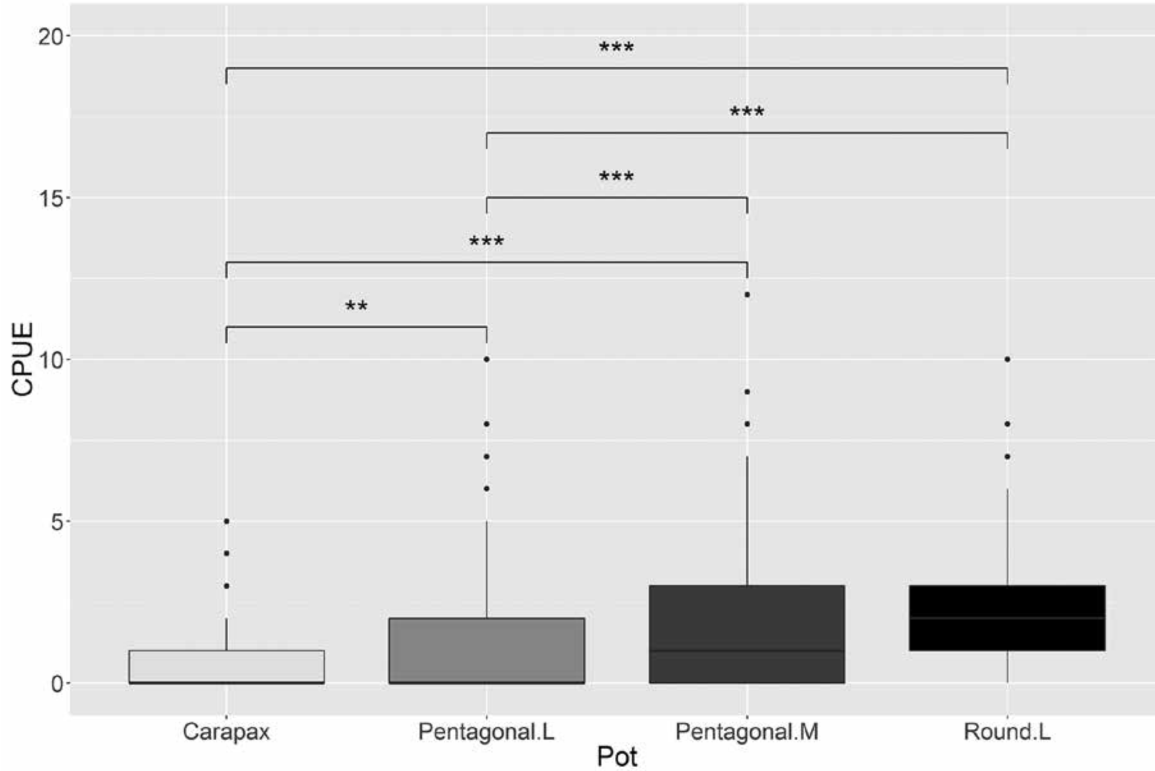

Figure 5: Median CPUE of cod above minimum landing size (38 cm) for the different pot types in trial 1. The bottom of a box represents the first quartile and the top the third quartile. The whisker is drawn from the top of the box to the largest value within 1.5 times the interquartile range and the same from the bottom. Dots represent outliers. Asterisks show significance level, where ** indicates $p<0.01$ and *** indicates $p<0.001$.

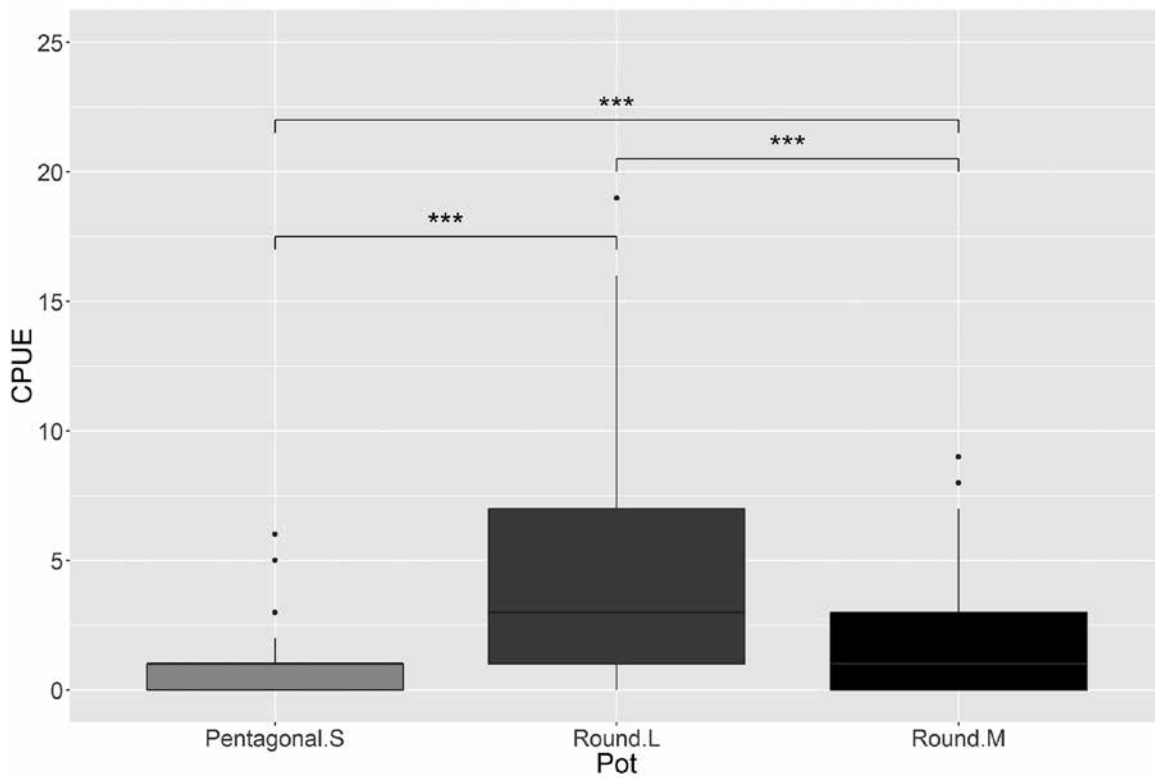

Figure 6: Median CPUE of cod above minimum landing size (35 cm) for the different pot types in trial 2. The bottom of a box represents the first quartile and the top the third quartile. The whisker is drawn from the top of the box to the largest value within 1.5 times the interquartile range and the same from the bottom. Dots represent outliers. Asterisks show significance level, where *** indicates $p<0.001$.

Pot	Pots analysed	Hours analysed	Observable film time	Mean length analysed recording (±SD) per pot	Registered entries	Registered exits
Pentagonal.M	7	89:50:27	87:01:15	12:25:54 (06:48:22)	42	22
Pentagonal.L	7	110:59:13	110:59:13	15:51:19 (05:28:46)	75	36
Carapax	7	139:04:28	127:10:32	18:10:05 (05:32:40)	90	52
Round.L	7	112:16:23	112:16:23	16:02:20 (06:42:58)	128	25
Total	**28**	**452:10:31**	**437:27:23**	**15:37:24 (06:11:05)**	**335**	**135**

Table 3: Summary of video material analysed from trial 1.

Pot	Pots analysed	Hours analysed	Observable film time	Mean length analysed recording (±SD)	Registered entries	Registered exits
Round.L	7	83:40:23	60:28:23	10:04:44 (06:27:44)	51	27
Round.M	3	32:07:17	32:07:17	10:42:26 (02:09:47)	25	16
Pentagonal.S	6	151:28:38	95:57:53	15:59:39 (04:52:52)	13	7
Total	**16**	**267:16:18**	**188:33:33**	**12:15:36 (04:30:08)**	**89**	**50**

Table 4: Summary of video material analysed from trial 2.

M had 2.2 times higher mean CPUE than Carapax and 1.4 times higher than Pentagonal L. Pentagonal L had 1.6 times higher mean CPUE than Carapax, which was significant (Wilcoxon signed rank, $p<0.01$). There was no significant difference between Round L and Pentagonal M (Wilcoxon signed rank, $p= 0.067$).

In trial 2 a total of 49 strings including at least three pots in each (one of each pot type) were hauled, resulting in 149 emptied pots. There was again a significant difference in CPUEs between pot types (Friedman test, $p <0.001$) (Figure 6). CPUE was significantly lower in the Pentagonal S pot than in the Round L (Wilcoxon signed rank, $p<0.001$) and Round M pots (Wilcoxon signed rank, $p<0.01$). Round L had significantly higher catches than Round M (Wilcoxon signed rank, $p<0.001$). Round L had 5.5 times higher mean CPUE than Pentagonal S and 2.4 times higher than Round M. Round M had 2.3 times higher mean CPUE than Pentagonal S.

Video Data Analysis: Factors Affecting Entry and Exit Rates

Tables 3 and 4 provide an overview of the video data collected and analysed. In total, 452 hours were analysed from trial 1 and 267 hours were analysed from trial 2. In trial 1, 437 hours were observable film time (OFT) meaning recordings with good quality video where behaviours could be observed. In trial 2, 188 hours were OFT.

The different models for entry and exit rates with their respective BIC values are presented in Table 5. Some splines were almost completely eliminated from the models for trial 2 during the automatic smoothness selection, leading to identical BIC values, in which case the simpler model was chosen.

Trial 1

Entry rate in trial 1 could best be explained by 'pot,' 'time of day,' and 'string ID' (Figure 7). Deviance explained by these factors was 26.3%. The differences in entry rates between pots are presented in Table 6. The Round L pot had a significantly higher entry rate than Pentagonal L and Carapax but not significantly higher than Pentagonal M. There was no difference between Pentagonal M, Pentagonal L and Carapax. There was a positive effect of 'time of day' on entry rate between approximately 9 p.m. and 8 a.m., i.e., the entry rate was higher than the mean entry

Model entry rate trial 1, n = 763	df	BIC
entry rate ~pot + time + current dir. + number in pot + soak time + string id	21.0	1287.8
entry rate ~pot + time + current dir. + number in pot + string id	20.1	1282.0
entry rate ~pot + time + current dir. + string id	19.8	1278.0
entry rate ~pot + time + string id	**16.6**	**1270.8**
Model exit rate trial 1, n = 532		
exit rate ~pot + time + current dir. + number in pot + soak time + string id	17.4	611.6
exit rate ~pot + time + number in pot + soak time + string id	14.9	607.0
exit rate ~pot + number in pot + soak time + string id	**12.8**	**605.1**
Model entry rate trial 2, n = 330		
entry rate ~pot + time + current dir. + number in pot + soak time + string id	10.8	446.9
entry rate ~pot + time + number in pot + soak time + string id	6.0	411.8
entry rate ~pot + number in pot + soak time + string id	6.0	411.8
entry rate ~pot + number in pot + soak time	6.0	411.8
entry rate ~pot + number in pot	**5.0**	**407.4**
Model exit rate trial 2, n = 162		
exit rate ~pot + time + current dir. + number in pot + soak time + string id	14.3	218.7
exit rate ~pot + time + current dir. + number in pot + string id	8.1.	194.5
exit rate ~pot + time + number in pot + string id	6.3	185.9
exit rate ~pot + number in pot + string id	6.3	185.9
exit rate ~pot + number in pot	**6.3**	**185.9**

Table 5: The models tested for entry and exit rates with their degrees of freedom (df) and BIC values. The final model in bold.

rate between those hours. For example, the entry rate was 5.5 times higher at 5 a.m. than at 3 p.m. (the difference is about 1.7 in Figure 7B, which shows the effect on the log(rate), hence a factor of exp(1.7) = 5.5).

Exit rates in trial 1 were best explained by 'pot,' 'number in pot,' 'soak time,' and 'string ID' (Figure 8). Deviance explained was 21.4%. The differences in exit rates between pots are presented in Table 6. Round L had significantly lower exit rates than Carapax and Pentagonal M. Pentagonal L had significantly lower exit rates than Carapax. The exit rate increased with the number of fish in the pot: it was three times higher when 15 cod were in the pot than when there were only two. Due to the use of a model offset on the number of fish in the pot, the exit rate related to 'number in pot' is to be interpreted per individual fish. The soak time had a negative impact on the exit rate. The exit rate was four times higher after five hours than after 15 hours.

Trial 2

The variation in entry rate in trial 2 was best explained by 'pot' and 'number in pot' (Figure 9). The deviance explained was 19%. There was no significant difference in entry rates between Round L and Round M, but they both had significantly higher entry rates than Pentagonal S. Round L had 9.9 times higher and Round M 7.6 times higher entry rate than Pentagonal S (Table 6). The entry rate decreased with an increasing number of fish in the pot, being twice as high with one fish in the pot as with four fish.

Exit rates in trial 2 are best explained by 'pot' and 'number in pot' (Figure 10). The

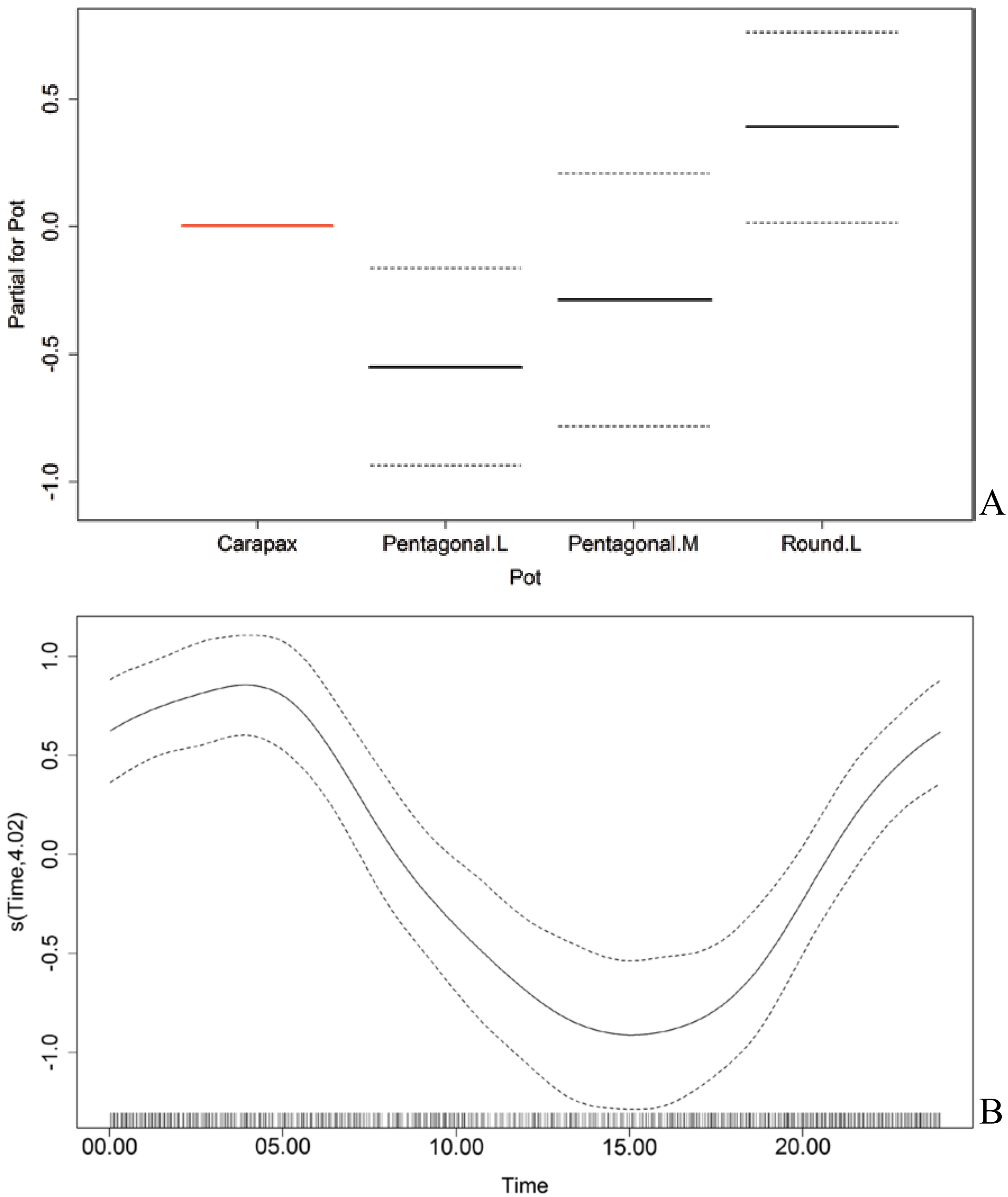

Figure 7: Predictors for entry rate trial 1. Dotted lines show 95% confidence intervals. The effect is on the log scale. A) Partial effect of 'pot.' The effect of all pots is relative to the Carapax pot (red line), which is therefore missing confidence intervals. B) Partial response curve of 'time of day.' Values above zero indicate a positive effect of time of the day on entry rate compared to the mean.

deviance explained by the model was 14%. The differences in exit rates between pots are presented in Table 6. Round L had a significantly higher exit rate than Pentagonal S. There was no difference in exit rate between Round M and Round L and no difference between Round M and Pentagonal S. Exit rates decreased with the number of fish in the pot.

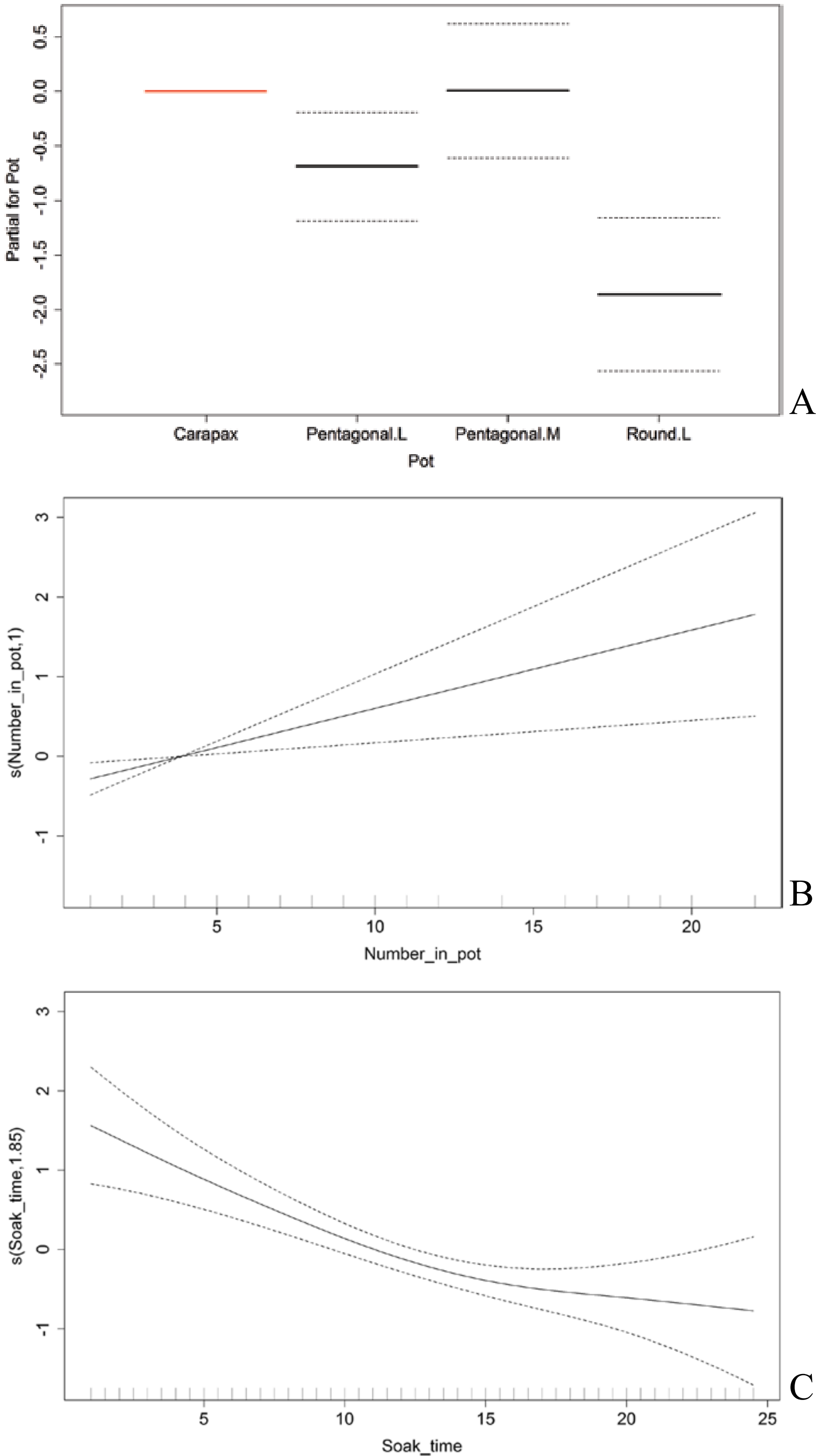

Figure 8: Predictors for exit rate trial 1. Dotted lines show 95% confidence intervals. The effect is on the log scale. A) Partial effect of 'pot.' The effect of all pots is relative to the Carapax pot, which is therefore missing confidence intervals. B) Partial response curve for individual exit rate in relation to number of fish in the pot. Values above zero indicate a positive effect of 'number in pot' on exit rate for individual fish compared to the mean. C) Partial response curve for 'soak time.' Values above zero indicate a positive effect of soak time on exit rate compared to the mean.

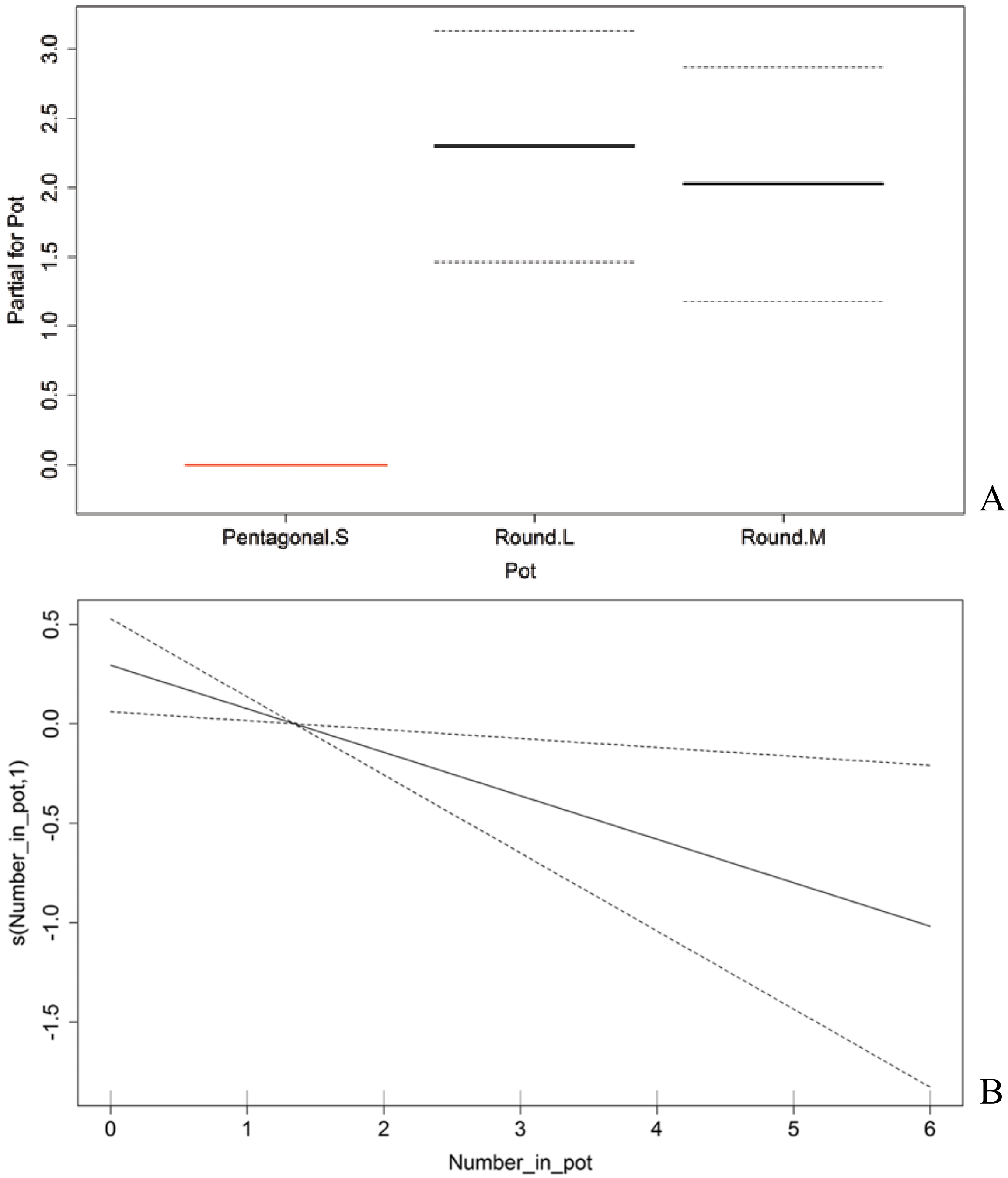

Figure 9: Predictors for entry rate trial 2. Dotted lines show 95% confidence intervals. The effect is on the log scale. A) Partial effect of 'pot.' The effect of all pots is relative to the Pentagonal S pot (red line), which is therefore missing confidence intervals. B) Partial response curve for number of fish in the pot. Values above zero indicate a positive effect of 'number in pot' on entry rate compared to the mean.

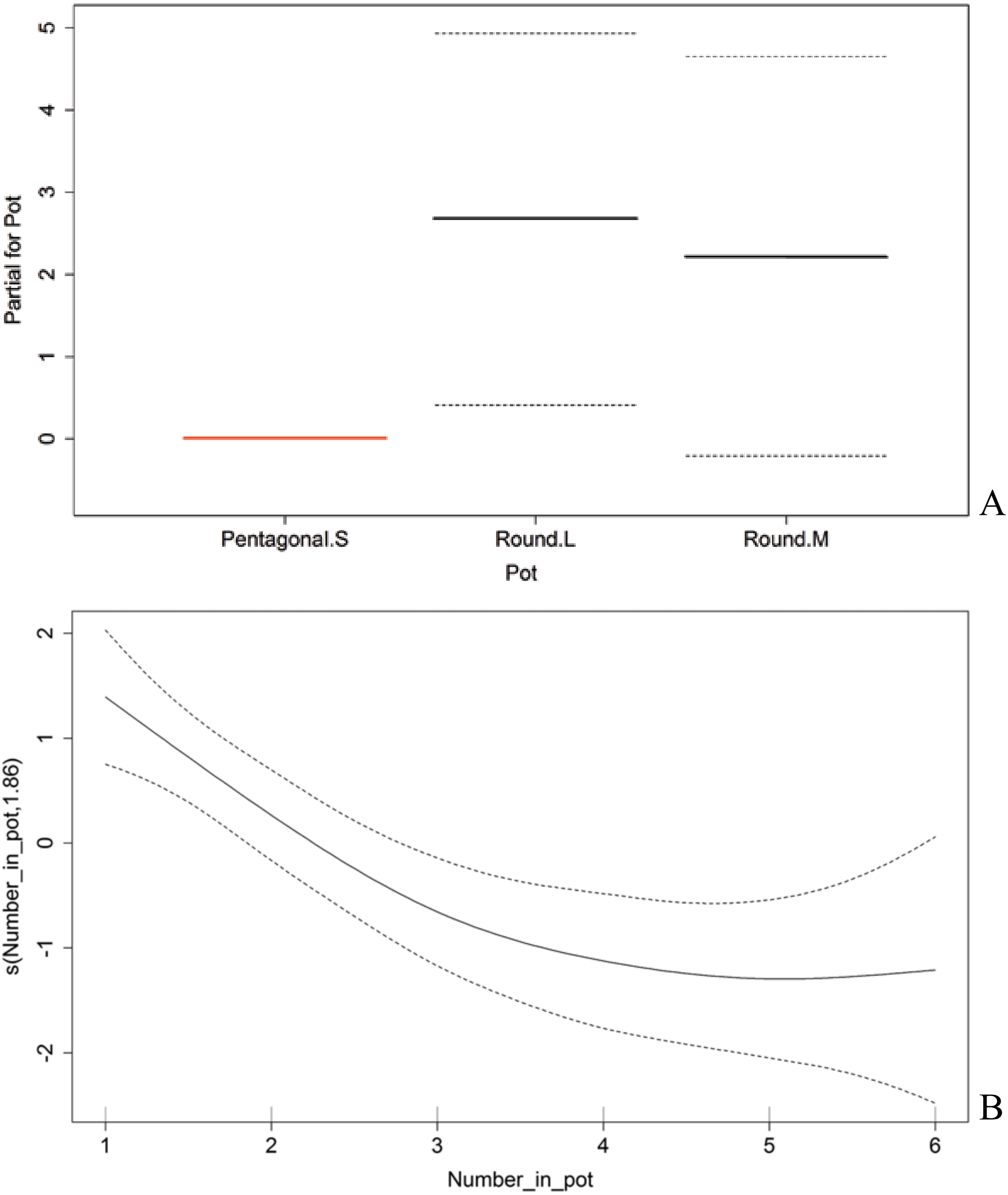

Figure 10: Predictors for exit rate trial 2. Dotted lines show 95% confidence intervals. The effect is on the log scale. A) Partial effect of 'pot.' The effect of all pots is relative to the Pentagonal S pot (red line), which is therefore missing confidence intervals. B) Partial response curve for individual exit rate in relation to number of fish in the pot. Values above zero indicate a positive effect of 'number in pot' on exit rate for individual fish compared to the mean.

Model	Pot	Estimated rate relative to the reference pot (equals one)
Entry rate trial 1	Carapax	1
	Pentagonal L	0.58
	Pentagonal M	0.75
	Round L	1.47
Exit rate trial 1	Carapax	1
	Pentagonal L	1.47
	Pentagonal M	1.005
	Round L	0.16
Entry rate trial 2	Pentagonal S	1
	Round L	9.94
	Round M	7.58
Exit rate trial 2	Pentagonal S	1
	Round L	14.47
	Round M	9.23

Table 6: The relative impact of pot type on entry and exit rates for all models. Values are in relation to a reference pot, Carapax in trial 1 and Pentagonal S in trial 2, with an entry or exit rate of 1.

As in trial 1 the model offset means this should be interpreted per individual fish. This means the likelihood of an individual fish exiting a pot decreases with an increasing number of fish present in the pot. For example, the exit rate is 3.5 times higher with two fish in the pot than with four fish in the pot.

DISCUSSION

The behaviour of fish around pots and traps has previously been recorded for analysis both by divers and by underwater video systems [Anders, 2015; Bacheler et al., 2013; Cole et al., 2004; High and Ellis, 1973]; however, cod behaviour around fishing gear has only been observed for a few hours continuously. This study is unique because it covered the catch processes of trapping cod in a pot over a 24-hour period. By analysing more than 1,100 hours of video material, our understanding of the full catching process of cod pots has been much improved.

In trial 1, the Round L and Pentagonal M pot had higher CPUEs than Carapax and Pentagonal L and Round L also had a higher entry rate than Carapax and Pentagonal L. A previous study [Furevik and Løkkeborg, 1994] found that larger pots resulted in larger catches and so did pots with two entrances compared to pots with one entrance. This is in line with our finding that the largest pot we tested, Round L, also gave the highest CPUE. 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. This is confirmed by the CPUE of Pentagonal M which is just as high as the Round L even though Round L has a larger volume and more entrances. Surprisingly, Pentagonal L had significantly lower CPUE than Pentagonal M even though it had a larger volume. Video analysis of pots from trial 1 showed that many of the floating pots were standing on the bottom instead of being suspended just above the bottom. Due to this, the entrance was not in line with the current all the time which probably made it more difficult for fish to locate the entrance. This could have negatively impacted the catches of the floating pot types during trial 1, especially Pentagonal L since it is heavier than Pentagonal M due to its larger size and was therefore harder to maintain at the correct depth.

The Carapax pot had a higher entry rate than the Pentagonal L and there was no difference in entry rate between Carapax and Pentagonal M. However, Pentagonal M had a higher CPUE probably due to the Carapax pot having a selection panel with larger mesh size than the other pot types, resulting in a high exit rate as well as a high entry rate.

Time of the day had a significant impact on entry rates in trial 1 as more cod entered the pots during the night. The higher entry rate was probably due to the use of artificial light. Cod are normally more active in the daytime, when they also have a better chance of finding the prey as they hunt using their vision [Løkkeborg and Fernö, 1999]. The use of light in our study may have favoured their search for prey during the night time and hence have increased entry rates into the cod pots. Bryhn et al. [2014] found a higher CPUE in pots equipped with green light in areas where fishing was conducted in deep waters but a lower CPUE in pots equipped with the same green light when used in shallower waters. One explanation was that deeper waters are darker and the light then has a greater power of attraction. When analysing our video material, cod were observed to feed on large number of mysids. This could explain why cod are attracted to pots fitted with artificial lights. A lot of the cod seen in the video analysis were probably below minimum landing size, since pots with artificial light have been reported to catch more juvenile cod than pots without lights (Königson et al., personal communication).

An open entrance in a pot is also an open exit so it might be thought that having more entrances would increase the chances for a fish to find its way out. However, the exit rate in trial 1 was significantly lower in the Round L pot, which had three entrances, than in the other pot types, suggesting that having more entrances does not in fact increase exit rates. The artificial light used in trial 1 could also explain the low exit rate in the Round pot. Cod feeding on mysids attracted to the light inside the pot may not have been motivated to try to get out, due to the available food source inside the pot. However, the chance of finding the entrance to escape through is also related to the volume of the pot [Munro, 1974], so the exit rate could also be low in the Round L pot due to its size. Round L had more than twice as much volume as Pentagonal L and triple the volume of Pentagonal M. The design of the fish holding chamber may also have helped to prevent fish from escaping.
The exit rate increased with the number of fish present in all pot types, which indicates that the pot was too crowded for cod to benefit from the protective effect of being with other individuals. Exit rates decreased with soak time which can be explained by more cod finding the fish holding chamber as time passed, resulting in decreased chances of finding the entrances to exit the pot. String ID was significant for entry and exit rates during trial 1 due to spatial and/or temporal differences in the abundance of cod.
In the second trial the CPUE of Pentagonal S was significantly lower than the two round pot

types. Pentagonal S was the only floating pot type in trial 2 and video analysis showed that it floated properly. The design of Pentagonal S, with the fish holding chamber in a horizontal line with the entrance chamber, probably impacted the CPUE since fish were seen moving freely between the two chambers. In line with the low CPUE results, the Pentagonal S pot also had significantly lower entry rates than the other pot types. There was no significant difference in entry rates between Round L and Round M even though Round L had significantly higher catches. In trial 2, pots were not filmed for their entire soak time since no artificial light was used. In hours not recorded, there could have been a chance of saturation effect in the Round M due to its smaller size compared to Round L. This could explain the significantly higher CPUE in the Round L.

The entry rate in trial 2 decreased with an increasing number of cod present in the pot, indicating a saturation effect, which confirmed that the probability of cod entering the pot was negatively dependent on cod density in the pot [High and Beardsley, 1970]. This is in line with a previous study [Anders, 2015] on cod behaviour in relation to baited pots, which found that the entry rate of large cod (>45 cm) peaked with one fish in the pot and then decreased. However, for fish smaller than 45 cm, chances of capture increased until four individuals were caught. In our study, the size of individuals could not be determined from the video analysis.

Soak time did not appear to impact entry rate. A previous study [Løkkeborg, 1990] found a decrease in bait odour with soak time. The decreasing attractiveness of the bait would have been expected to reduce the entry rate. However, it is possible that the true effect of soak time was not found by our model since soak time was correlated with the number of fish present in the pot. Any effects of soak time might have been hidden by that factor. For GAM models this phenomenon is known as concurvity [Amodio et al., 2014], a generalization of collinearity which occurs when some smooth term in the model could be approximated by other smooth terms in the model. This is often the case when a time smoothing is applied along with covariates that also vary smoothly in time, in our case the number of fish in the pot and the soak time.

There was no effect of ‘time of day’ on entry rates in the second trial, which may be due to the fact that no artificial light was used. String ID was not significant in the second trial, probably since the trial was shorter and strings with cameras were not spread out over such large areas, so cod abundance would have been more constant.

Pot type and the number of fish present in the pot explained the exit rate well in trial 2. Round L had a significantly higher exit rate than Pentagonal S. The low exit rate of Pentagonal S was probably due to a low entry rate, thus few cod were present in the pot to start with. In contrast to trial 1, exit rates in trial 2 decreased with an increasing number in the pot. It could be that an increasing number of fish in the pot are related to an increasing soak time. The activity of caught cod decreases with soak time [Furevik, 1994], hence fish will be less likely to exit the pot as time goes on. Also the number of fish present in the pot in trial 2 did not reach the amounts present in trial 1, thus cod would have been less inclined to exit due to overcrowding.

In summary, this study shows that the analysis of behavioural data from field trials can be used as a complement to strengthen the analysis of CPUEs. In-situ behavioural data can reveal limitations of pot constructions and how entry and exit behaviour is related to catch levels. Our results show that entry and exit rates observed in in-situ studies can accurately describe CPUEs in pots. Depending on the number of entries, one or two days' video observation could be enough to predict catch levels when testing a new type of pot. Pot types can affect both exit and entry rates. The large bottom-standing pot with three entrances had higher entry rates as well as exit rates when no light was used than did the floating pot types with one entrance. The number of cod inside the pot also affected entry rates, indicating a possible saturation effect. Furthermore, the use of artificial lights affect the pot entry and exit behaviour of cod, so these should be avoided in future studies of the natural behaviour of cod.

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