What attracts Baltic sea grey seals to seal-safe cod pots and when do they attempt to attack fish in the pots?

Stavenow, Jasmine; Ljungberg, Peter; Kindt-Larsen, Lotte; Lunneryd, Sven Gunnar; Königson, Sara

Published in:
Journal of Ocean Technology

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

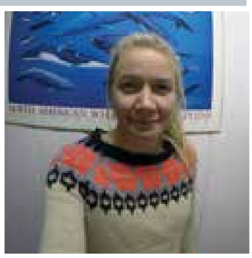
Link back to DTU Orbit

Citation (APA):
Stavenow, J., Ljungberg, P., Kindt-Larsen, L., Lunneryd, S. G., & Königson, S. (2016). What attracts Baltic sea grey seals to seal-safe cod pots and when do they attempt to attack fish in the pots? Journal of Ocean Technology, 11(4), 91-107.

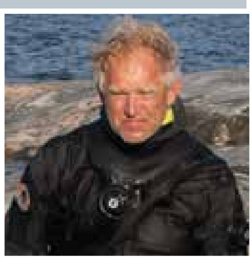
Candid camera

Jasmine Stavenow

Peter Ljungberg



Lotte Kindt-Larsen



Sven-Gunnar Lunneryd

Sara Königson

Stavenow, Ljungberg, Kindt-Larsen, Lunneryd, and Königson use underwater cameras to document the behaviour of grey seals visiting baited cod pots.

Who should read this paper?

Gear technologists and manufacturers with an interest in the development of passive fishing gears, as well as marine mammal ecologists.

Why is it important?

Grey seals demonstrate remarkable adaptability and cognitive capacity. In some areas of the world like the Baltic Sea, this can create conflict with commercial fishermen targeting Atlantic cod. Some have even called it an "arms race." The challenge at present is how do we develop effective and sustainable fishing methods for catching fish, while at the same time preventing damage caused by the attacks of grey seals. The answer partly lies in studying the behaviour of seals using underwater cameras. Why do seals attack cod pots? Are they truly hungry, or perhaps just curious?

This Swedish and Danish research team used underwater cameras to quantify the behaviour of attacking grey seals toward baited cod pots. They undertook three main objectives: i) describe the behavioural pattern of seals around cod pots, ii) investigate what variables might influence seal presence around cod pots, and iii) investigate what variables might influence attack behaviour around cod pots. They collected 218 hours of useable video footage near Gotland Island in the Baltic Sea. The behaviour of the seals was categorized into eleven groups and compared across different pot designs, twine material, time of day, and even whether the fish were dead or alive inside the pot.

About the authors

Jasmine Stavenow is a graduate student at the Swedish University of Agricultural Sciences working on the development of sustainable and seal-safe fishing gear. This paper is based on the results of her master's thesis. Peter Ljungberg works in the field of fishing gear development in small-scale, coastal fisheries, as a response to changing environments. Lotte Kindt-Larsen studies the interactions between fisheries and protected, endangered and threatened species. 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.

WHAT ATTRACTS BALTIC SEA GREY SEALS TO SEAL-SAFE COD POTS AND WHEN DO THEY ATTEMPT TO ATTACK FISH IN THE POTS?

Jasmine Stavenow[1], Peter Ljungberg[1], Lotte Kindt-Larsen[2], Sven-Gunnar Lunneryd[1], Sara Königson[1]

[1]Institute of Coastal Resources, Department of Aquatic Resources, Swedish University of Agriculture Sciences, Lysekil, Sweden

[2]National Institute for Aquatic Resources, Technical University of Denmark, Denmark

ABSTRACT

Seals and fishermen share the role of top consumers in the Baltic Sea, leading to inevitable competition. One aspect of this is that fishermen use fishing gear to catch fish and seals raid these fishing gear. The fisheries lose out in terms of fish catches and also bear the significant costs of damage to the gear. Researchers have been active for some years in developing 'seal-safe' fishing gear, which will be unattractive to seals and resistant to attacks. This study investigated the presence of grey seals (*Halichoerus grypus*) around cod pots and their attempts to take fish from them. Baited and camera-equipped cod pots of three designs including three netting types were set out close to a seal haul-out site east of the island of Gotland in the Baltic Sea. The behaviour of visiting seals filmed with underwater cameras was observed and analysed using a generalized linear model (GLM). As well as the cod pot characteristics, the variables used for modelling included the time of day, whether bait fish were alive or dead, and the quantity of fish in each pot. It was found that the most important cod pot-characteristic for both seal presence and 'attack behaviour' was the design of the cod pot. The design which attracted the most seal presence and the most fish-attacking behaviour had loose netting around the upper chamber, in contrast to the other two designs which had tightly stretched mesh. Neither mesh size nor material showed any correlation with seal presence or attack behaviour. It was also found that the most important overall factor for predicting attack behaviour was the time of day. There was individual variation in seal behaviour. The behaviour was categorized into eleven groups, of which 'investigation' was the most commonly observed. Most attack behaviours were targeted towards moving fish and no attacks occurred on dead fish. These results could suggest that seals are visiting cod pots because of curiosity and not primarily because of hunger.

KEYWORDS

Halichoerus grypus; Seal depredation; Seal-fishery conflict mitigation; Behaviour; Behavioural ecology

INTRODUCTION

In the early 20th century, the grey seal (*Halichoerus grypus*) population in the Baltic exceeded 88,000 individuals [Harding et al., 1999]. By the 1970s, the population had declined to 4,000 individuals [Harding et al., 1999; Österblom, 2006]. Today grey seal numbers are rapidly increasing again, with over 30,000 individuals being counted in 2016 [HELCOM, 2016]. In parallel with an increasing seal population, there is an ongoing seal-fisheries conflict in the Baltic Sea [Baltscheffsky, 1997; Westerberg et al., 2000; Lunneryd, 2001; Kauppinen et al., 2005], with seals reducing catches and damaging fishing gear, especially in the small-scale coastal fisheries. In 2014 the total costs of catch losses and gear damage due to seal predation in Sweden was estimated at over half a million Canadian dollars, a loss which has a considerable impact on the local economy in the coastal areas affected [Havs-och vattenmyndigheten, 2014]. The conflict can also be costly for the seals, due to the problem of by-catch. Vanhatalo et al. [2014] found that between 1,240 and 2,860 seals are caught in traps or gillnets in Sweden, Finland, and Estonia every year.

The most sustainable method for mitigating the seal-fisheries conflict is to develop and use seal-safe fishing gear [Königson, 2011]. The first seal-safe fish traps to be developed in Sweden were the pontoon traps, which rescued the inshore salmon fishery from collapse in the early 2000s [Lunneryd and Fjälling, 2004]. The research which led to their introduction established some important criteria. Seal-safe fishing gear should enclose and protect the caught fish (by making the fish chamber inaccessible to seals), it should withstand seal attacks (by using Dyneema™ instead of nylon), and it should also avoid attracting seals. For seal-safe fishing gear to be successfully adopted in practice, a few other criteria must also be met. Most importantly for the fishermen, the gear needs to be catch efficient, yielding at least the same catches as traditional fishing gear. It should also be practical to use; inshore fishermen often work alone, so any new fishing gear has to be easy to handle on a small boat. Finally, it should have a low environmental impact.

The gillnet fishery for cod (*Gadus morhua*) is a small-scale fishery with large economic value in the southern Baltic [Waldo et al., 2010]. According to Königson et al. [2009] this fishery has experienced an extensive surge in damage by grey seals during five years from 2004 until 2009. Gillnets are inherently difficult to make seal-safe. For the seals, it is like offering them a buffet table where they can come along and take a bite out of any fish they fancy, resulting in huge catch damage as well as direct losses. To replace gillnets in the cod fishery, efforts have been made to develop baited cod pots, where fish are caught in enclosed pots similar to lobster pots, making them much less accessible for the seals. Königson et al. [2015A] showed how cod pots could be a potential alternative to gillnets and longlines, giving commercial catches equal to traditional fishing gear during some seasons. Cod pots are compact baited pots, easy to handle and relocate if needed, and they can be used over large areas, which is how cod is typically fished using gillnets. Cod pots also have the advantage of keeping the catch alive and in good condition until the catch is collected, unlike gillnets, and have been shown to be catch efficient and selective in commercial fisheries [Ovegård et al., 2011; Königson et al., 2015B].

However, just as competition and conflicts of interest between species in nature force the competing parties to counter-adapt to the adaptation of the other, so with the seals and the fisheries an arms race has developed. Grey seals have proved their adaptability and cognitive capacity continuously during the development of seal-safe fishing gear [Varjopuro, 2011]. In fact, one could say that the seals' ability to learn has been the main obstacle in designing the ultimate seal-safe fishing gear. Therefore, an adaptive approach to changes in seal behaviour is essential. Studying the behavioural ecology of seals in relation to fishing gear is at least as important as the technical developments and the two areas of research must go hand in hand as we seek to resolve the seal-fisheries conflict.

In an ongoing project between the Swedish University of Agriculture Science (SLU) and the Danish Technical University (DTU), three new cod pot designs have recently been developed (the Drum, Pentagonal and Bell-tent). Pots were made in two different netting materials (nylon and Dyneema™). The Dyneema material had a mesh size of 30 mm and the nylon material had mesh sizes 20 and 30 mm. The new pot designs are all showing high catch efficiencies; however, their capacity to withstand seal attacks has not yet been tested.

In this study our aim is to analyse seal behaviour around the cod pots in relation to these newly developed cod pot designs. We have three main objectives: (i) to describe the behavioural pattern of the seals around the cod pots, (ii) to investigate what variables might influence seal presence around the cod pots, and (iii) to investigate what variables might influence attack behaviour around the cod pots.

METHODS

Field Site

The study was conducted between August 12 and September 30, 2015, close to the seal haul-out site of Rute Misslauper, east of Gotland Island in the Baltic Sea (Longitude: 57.461 E

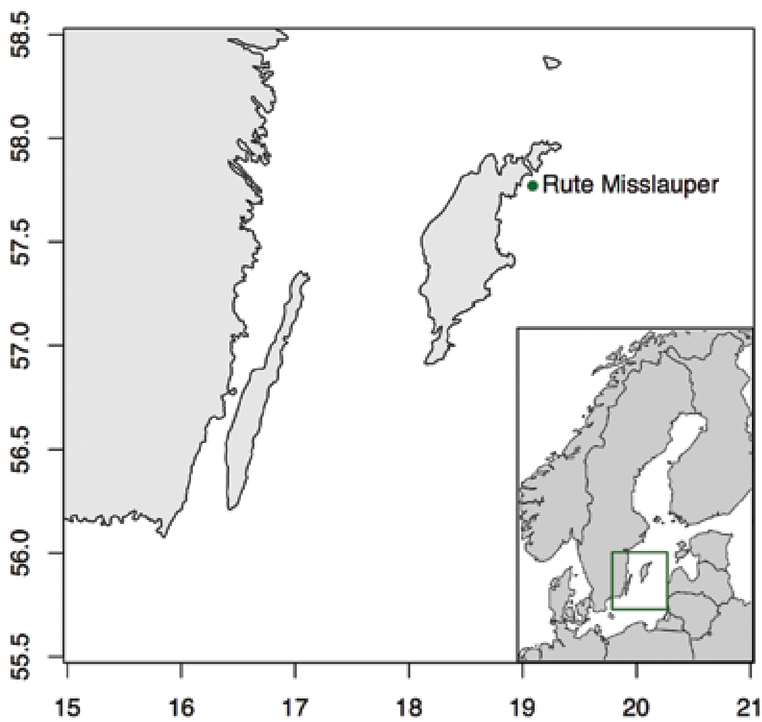


Figure 1: Position of the seal haul-out site, Rute Misslauper, where the study was conducted (green dot).

Latitude: 19.050 N) (Figure 1). Cod pots were baited with fish and equipped with underwater cameras so that seal behaviour close to cod pots could be observed.

Nine cod pot models, based on three designs and three netting types were tested. The designs were pentagonal (cubic with an extra triangular shape on one side, making the top and bottom faces five-sided), drum-shaped (like a squat cylinder), and bell-tent shaped (cylindrical with a conical top) (Figure 2), hereafter referred to as Pentagonal pots, Drum pots, and Bell-tent pots. Pentagonal pots are designed to be suspended about a metre from the bottom while both Drum and Bell-tent pots were designed to stand on the bottom. All pot types were equipped with one entrance chamber and one fish holding chamber, placed above the entrance chamber. The three netting types tested were 20 mm nylon mesh, 30 mm nylon mesh, and 30 mm Dyneema™ mesh (mesh measured between knots). For further details on the cod pot models used see Table 1.

In order to attract seals, live fish of various species and in varying quantities were placed in the cod pots prior to them being set out at the field site. We used cod as bait whenever possible; however, due to the low numbers of

Figure 2: The three cod pot designs, from left: Pentagonal, Drum and Bell-tent.

Model	Design	Netting type	Description of design
PN20	Pentagonal	Nylon 20mm	Floating two-chamber pot with one entrance, second chamber on top of first chamber. L= 120cm, W= 70cm, H= 55cm, V=1.52m³
PN30	Pentagonal	Nylon 30mm	
PD	Pentagonal	Dyneema 30mm	
DN20	Drum	Nylon 20mm	Large round bottom standing two-chamber pot with three entrances, second chamber on top of first chamber. D= 150cm, H= 86cm, V=0.39m³
DN30	Drum	Nylon 30mm	
DD	Drum	Dyneema 30mm	
BN20	Bell-tent	Nylon 20mm	Large round bottom standing two-chamber pot with three entrances, second chamber on top of first chamber. D= 150m, V=1.15m³
BN30	Bell-tent	Nylon 30mm	
BD	Bell-tent	Dyneema 30mm	

Table 1: Description and measurements of the nine cod pot models used.

cod in nearby areas, ide (*Leuciscus idus*), white bream (*Blicca bjoerkna*), turbot (*Scophthalmus maximus*), and tench (*Tinca tinca*) were also used. When several species of fish were used on the same occasion, species were evenly distributed between the cod pots. Studies have shown that seals' preference for different fish species varies between individuals, sexes, ages and seasons and all species used in the study are known to be eaten by seals [Lunneryd, 2001; Beck et al., 2007; Lundström et al., 2007; Lundström et al., 2010]. Therefore, an assumption was made that how the species were distributed and used in the pots would not affect seal behaviour. All cod pots set out had bait fish in them and the number of bait fish in cod pots varied in different trials due to fluctuations in fish availability. The number of fish in the trials varied from one to six and the mean number of fish in a cod pot was 3.9. To prevent bait fish from escaping, the entrances of the cod pots were sewn together. In three trials, dead fish were used as bait in order to see how this changed the seals' behaviour.

Experimental Set-up

In most trials, two waterproof cameras were used with each cod pot to record seal behaviour. Cameras used were GoPro 3s, equipped with 128 GB memory cards and two power pack batteries (12000-15000 mAh), placed inside a stainless steel underwater housing. One camera was suspended directly above the cod pot, giving an overhead view (Figures 3 and 4). The second camera was placed on the bottom to give a side view, using a specially built camera housing stand fixed at a distance of 1.5 m from the cod pot (Figures 3 and 4). The two cameras allowed for different perspectives on the ongoing activities and also provided redundancy if one camera failed or ran into technical issues. The total number of trials filmed was 21 and the longest recordings made were over 24 hours. The mean number of hours filmed per trial was 16 hours. The number of trials each cod pot model was given was adjusted to ensure that some recordings with seals present were obtained for each model. Cod pots were set out either at 09.00 hrs or at 15.00 hrs. Most often cod pots were deployed one at a time. When a lot of bait fish was available,

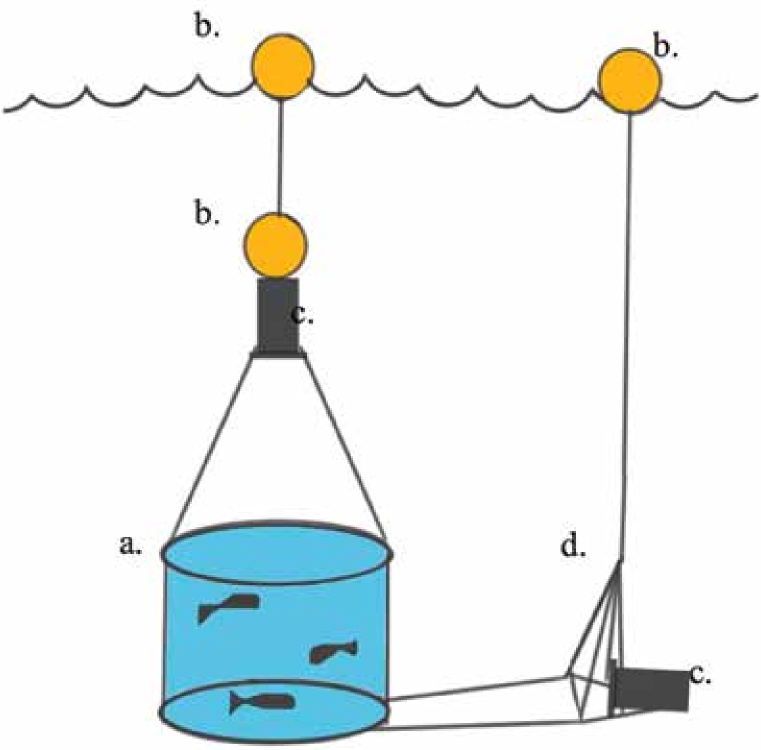


Figure 3: Set-up of camera housing (c), camera housing stand (d), and buoys (b) in relation to the cod pot (a).

we sometimes set out up to three cod pots simultaneously, in which case that counted as three trials. Cod pots were randomly placed within a radius of 500 m from the haul-out site (Figure 1) and at a minimum separation of 50 m from each other. They were placed at water depths of between 3 m and 7 m and were fixed with an anchor. For each trial the following parameters were noted: cod pot model, date, position, depth, time, whether one or two cameras were used, number of bait fish, if fish were alive, and fish species. On hauling the pots, any damage to fish or equipment was noted, as well as if any fish had gone missing.

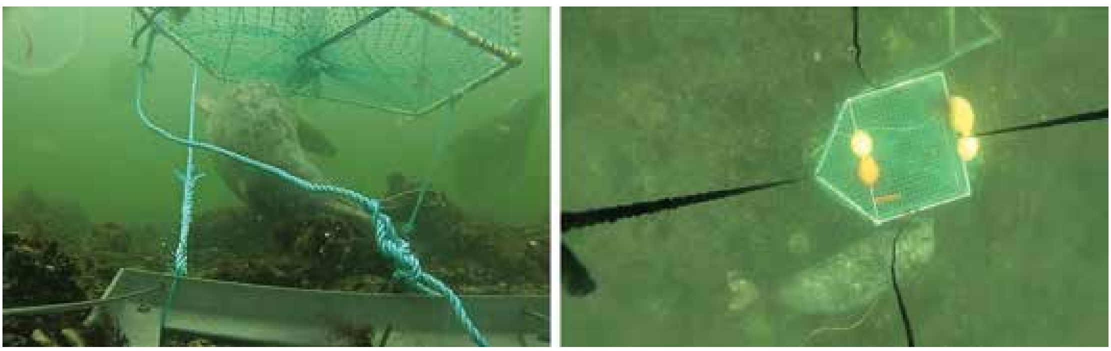


Figure 4: Left: view from the side camera. Right: view from the camera above the cod pot.

Wind speed and land temperature was recorded by the Swedish Institute of Meteorology and Hydrology (SMHI) at Fårösund, available at the SMHI website (www.smhi.se).

Data Analysis

Camera recordings were saved as 30 minute sequences. Sequences were viewed manually using VLC software. Daylight and clear view recordings were labelled as 'observable film time' (OFT), and within those sections, the times of seals entering and leaving the frame were recorded, giving several clips of 'seal presence time' (SPT) in each typical sequence. For the behavioural analysis, 11 types of seal behaviour were observed and defined as follows:

1. Swam by. Seal passed the camera's field of view, but paid no attention to either cod pot or bait.
2. Investigating. Seal touched, swam in close contact to or observed the cod pot and equipment visually, with an apparent focus on the cod pot and not the bait.
3. Resting on. Seal laid on top of the cod pot apparently having a nap. In that position the seal often had its eyes closed and a relaxed body position.
4. Guarding. Seal took up a position underneath the cod pot. When a seal did this, it was not resting; on the contrary, it often held its body stiffly and 'guarded' the cod pot against other seals.
5. Jabbed with nose. Seal pushed the cod pot with its nose, with a focus on the cod pot and not the bait.
6. Chewed equipment. Seal chewed on ropes or other equipment.
7. Chased fish. Seal had its focus on the bait and physically followed its movement in the cod pot.
8. Attack behaviour. Seal made an attempt to take fish from inside the cod pot, trying to grab them through the mesh.
9. Bit fish. Seal succeeded in its attack, and

actually bit a fish.
10. Aggression to seal. Seal chased away or attacked another seal.
11. Unclear behaviour. Seal, or part of a seal, was in view but its behaviour could not be identified.

Additionally, all instances of attack behaviour were reviewed to see whether the seals were responding to fish movements when they initiated an attack. A note was also made if several seals were present at once, along with any interactions observed between them.

The length of time seals were present as a proportion of the total time of each sequence was calculated from SPT/OFT. For the analysis of seal behaviour around the pots, seals' occurrence within each SPT clip was recorded and the relative proportions of each behaviour were calculated for each sequence (Figure 5). The SPT consisted of a number of shorter clips within the 30 minute sequences. For each clip, the specific types of behaviour seen were recorded, and these were presented for modelling as a percentage of the total number of behaviours observed within the whole sequence. One film sequence could, for instance, contain 12 hours of OFT within which there were four clips with seals present. Clip 1 could have featured behaviours 1 and 3; clip 2 behaviours 2, 3, and 4; clip 3 just behaviour 4; and clip 4 behaviours 3, 4, 5, and 6. Thus in the whole sequence, there were ten occurrences of the different behaviours. One out of ten was for behaviour 1, so this gets 10%. Three out of ten were for 3, so this gets 30%, and so on. Calculating the proportional occurrence of each behaviour was chosen as a relatively simple way of getting an overview of the seals' behavioural patterns from the mass of data we had.

To see whether the presence of seals and their attack behaviour were affected by

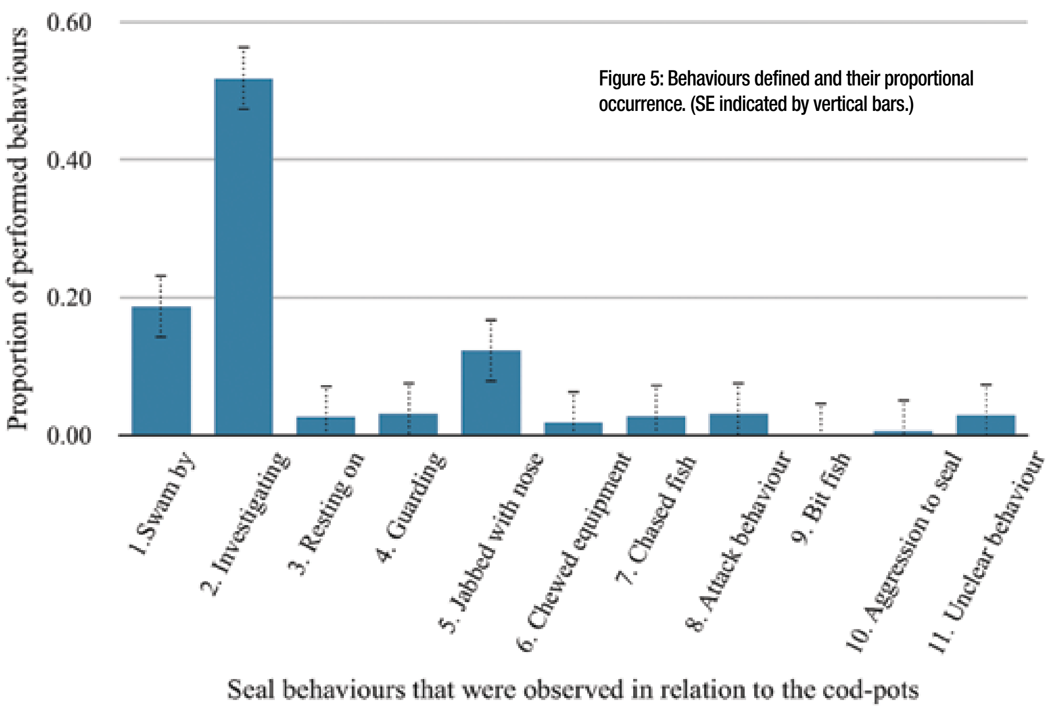


Figure 5: Behaviours defined and their proportional occurrence. (SE indicated by vertical bars.)

lighting conditions, the daylight hours were divided into five equal segments based on sunrise and sunset times: Morning, Pre-noon, Mid-day, Afternoon, and Evening. Due to variations in daylight hours during the field-period (early August to late September), a daytime segment did not contain the same number of hours from day to day. Night time was not included since it was too dark for the cameras to record any events.

To analyse which factors might have affected the attack behaviour and seal presence, generalized linear models (GLM) were used:

Seal presence:
presence~meshsize+codpotdesign+meshmaterial+livebait+numberofbait+outaloneornot+timeofday, family=bnomial

Attack behaviour:
attackornot~numberofbait+codpotdesign+meshmaterial+meshsize+ timeofday+ outaloneornot, family=binomial

When analysing seal presence, all OFT data was used. For attack behaviour analysis, only SPT was used, since by definition no attacks could occur when no seals were present. The response variables of the two models, seal presence and attack behaviour, were transformed from their continuous proportional data into binomial data prior to analysis. Transforming the data allowed it to be used in a GLM that is adapted for normally distributed data. Following each GLM, a stepwise function was used in order to find the model most relevant for the response variable. Environmental factors (wind speed, temperature, and water depth) were also analysed, using Spearman correlation analysis, for whether or not they affected seal presence and attack behaviour. All statistical analyses were made using the RStudio Version 0.99.489 software.

RESULTS

The 21 trials gave rise to a total of 463 hours 27 minutes recording time, of which 218 hours were observable film time (OFT). The Bell-tent cod pot showed the highest ratio of seal presence time to observable footage time (SPT/OFT), with the model BN30 having the highest recorded ratio of all (Tables 2 and 3). The design with the lowest proportion of seal time (SPT) was the Pentagonal and the models with the least seal presence recorded (zero) were PN30 and PN20 (Tables 2 and 3). The design with most attack behaviours recorded was the Bell-tent and the one with the fewest was DN30. The Pentagonal lost most fish whereas the Drum lost none (Table 3). The model with most recorded attack behaviours was BN20 and the one with most instances of fish going missing was PD (Table 2).

Environmental Factors

Using a Spearman correlation analysis, it was found that neither the water depth, wind speed nor air temperature at the study sites affected the proportion of seals present (P=0.98, P=0.29, P=0.86) nor the number of seal attacks (P=0.58, P=0.94, P=0.23).

Behaviour Around Cod Pots

The results showed that seals performed a variety of behaviours when around the cod pots (Figure 5). The most frequently observed category of behaviour was the ‘investigation’

Model	In water	OFT	SPT	SPT/OFT	Number of attack behaviours	Baits used	Bait/ cod-pot	Missing fish	Trials fish went missing	Trials
PN30	24h 0m	13h 55m	0h 0m	0.000	0	6	6	0	0	1
PN20	74h 10m	23h 57m	0h 0m	0.000	0	7	3.5	1	1	2
PD	144h 15m	46h 28m	1h 35m	0.034	18	11	2.8	5	1	4
DN30	70h 37m	24h 36m	0h 3m	0.002	0	15	5	0	0	3
DN20	66h 45m	17h 10m	1h 1m	0.059	30	3	1	0	0	3
DD	24h 0m	12h 11m	0h 12m	0.016	0	3	3	0	0	1
BN30	48h 0m	20h 34m	3h 34m	0.173	23	4	2	1	1	2
BN20	70h 19m	29h 6m	1h 27m	0.050	52	17	5.7	1	1	3
BD	47h 20m	24h 22m	0h 29m	0.020	33	16	8	1	1	2

Table 2: Cod pot model recordings along with parameters collected.

Design	In water	OFT	SPT	SPT/OFT	Number of attack behaviours	Baits used	Bait/ cod-pot	Missing fish	Trials fish went missing	Trials
Pentagonal	242h 25m	84h 20m	1h 35m	0.019	18	24	4.1	6	2	7
Drum	161h 22m	53h 57m	1h 17m	0.024	30	21	3	0	0	7
Bell-tent	165h 39m	74h 1m	5h 30m	0.074	108	37	5.2	3	3	7

Table 3: Cod pot design recordings along with parameters collected.

behaviour. The definition of 'investigating behaviour' in this study was when seals touched, swam in close contact to and observed the cod pot all around, with an apparent focus on the cod pot and not the bait inside. Importantly, 'attack behaviour' (lunging towards the fish in an attempt to catch them) was not the most common behaviour observed.

Seal Presence

The GLM produced a model with an Akaike Information Criterion (AIC) value of 370.9, residual deviance of 346.9, and 441 degrees of freedom. The cod pot-factor 'design' had the highest significance for seal presence, in that most seals visited the Bell-tent design and fewest the Pentagonal design (Table 4, Figure 6). Mesh size and material had no significant effect (Table 4). The number of fish and if they were alive had significance: live fish and pots baited with more fish correlated with higher seal presence (Table 4). The time of day also affected seal presence, with most seals present in the morning and fewest in the evening (Table 4, Figure 7).

Through a stepwise function, the most relevant model for the seal presence response was found to be:

Factor	P-value
Cod pot design	**<0.01**
Cod pot mesh size	0.71
Cod pot mesh material	0.61
Live bait	**<0.05**
Number of bait fish	**<0.001**
Out with other cod pot	0.30
Time of day	**<0.05**

Table 4: The GLM factors with seal presence as response variable.

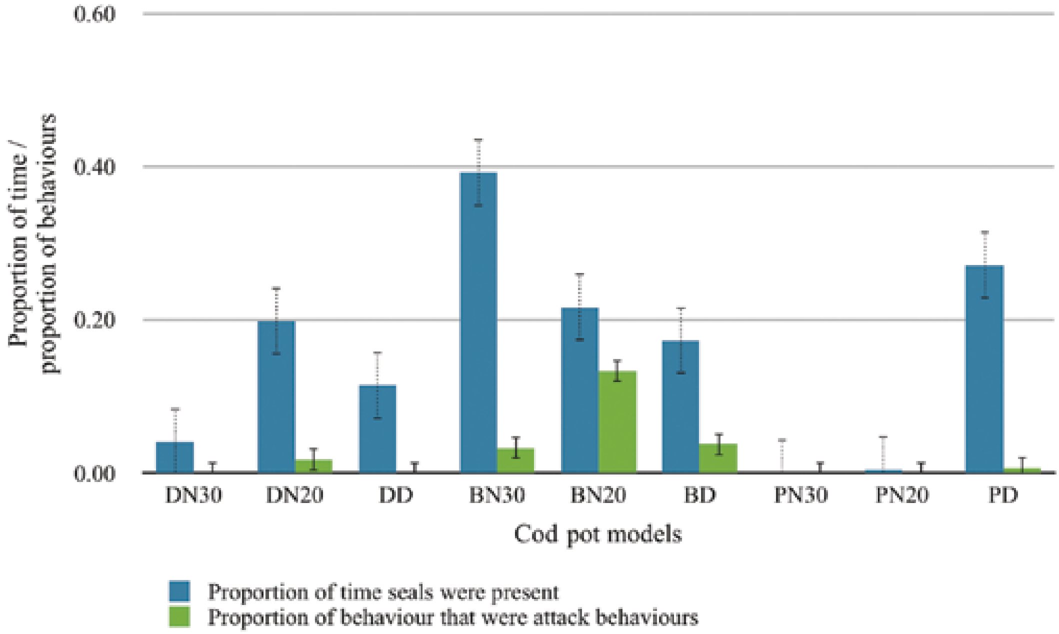


Figure 6: Proportion of time seals were present/proportion of behaviours that were attack behaviours, against cod pot models. (SE indicated by vertical bars.)

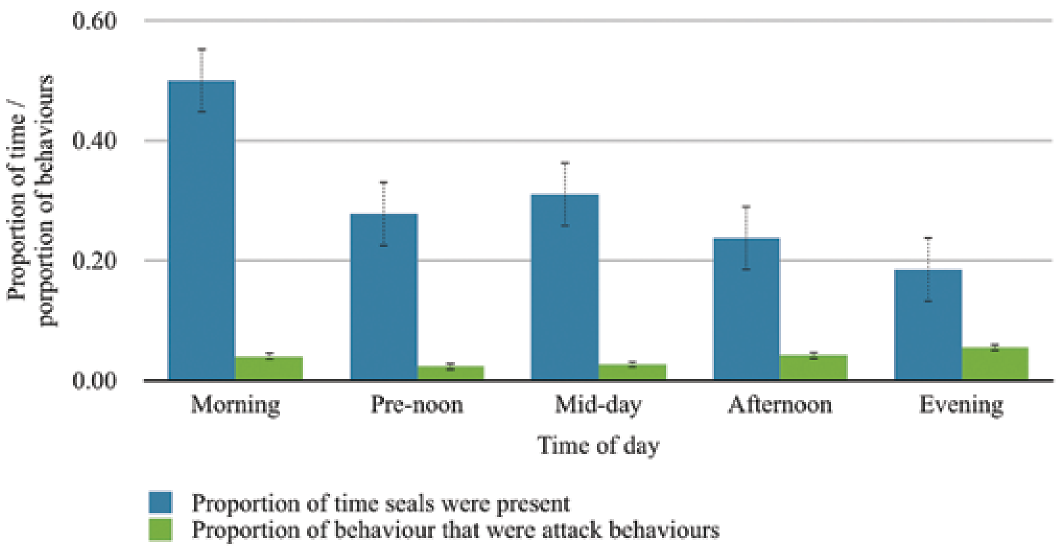


Figure 7: Proportion of time seals were present/proportion of behaviours that were attack behaviours, against time of day. (SE indicated by vertical bars.)

presenceornot~codpotdesign+livebait+number ofbaitfish+aloneornot+timeofday
with an AIC value of 367.7, residual deviance 347.7, and 441 degrees of freedom.

There was a significant relationship between the number of attempted attacks and the proportion of seal presence (Spearman correlation, $P<0.05$, $R^2=0.2224$). With seals present for longer time periods, more attacks occurred. However, the proportion of attack behaviour did not increase with an increased proportion of seal presence (P=0.768).

Attack Behaviour

The GLM for attack behaviour produced an AIC value of 66.1, residual deviance 44.1, and 46 degrees of freedom. Time of day was found to have the most significant correlation with attack behaviour with most attacks occurring during the evening and fewest in the Pre-noon (Table 5, Figure 7). Neither the number of bait fish nor whether the cod pot was alone or not were found to have any effect (Table 5). A strong tendency for the cod pot design to show a correlation was found, with a greater proportion of attack behaviours on the Bell-tent cod pot than on the others (Table 5, Figure 6). There was no significant effect of either mesh size or material (Table 5). The cod pot model with highest proportion of attack behaviour was the BN20 and those with the lowest were DD, DN30, PN30 and PN20 (Figure 6).

Through a stepwise function, the most relevant model for attack was found to be: *at tackornot~codpotdesign+timeofday* with an AIC value of 61.8, residual deviance 47.8 and 56 degrees of freedom.

One hundred fourteen of the 138 visible attacks were directed towards moving fish (83%) while 24 were directed at non-moving fish (17%). Attacks that were targeted towards fish which could not be observed are not included. Additionally, no attack behaviour at all was observed on cod pots that were baited with dead fish.

DISCUSSION

This study evaluated factors affecting seal presence and attack behaviour around cod pots. By taking our data from live underwater video recordings, we were able to get a different insight into these questions than previous studies which have relied on the material after-effects of seal damage. The results are of importance not only when considering fishing with cod pots, when and how to use them, and which designs to develop further, but also for understanding the behavioural ecology of the Baltic grey seal. Our results indicate that some cod pots attract more seals than others and that certain components of the pot were more prominent in having that effect. Cod pot design was the most important cod pot factor influencing seal presence, while neither mesh size nor material were found to be important.

The Bell-tent pot had the highest proportions both of seal presence and attack behaviour. In contrast to both the Pentagonal- and Drum-shaped pots, the Bell-tent design has loose netting on its cone-shaped top, while the first two have the netting firmly stretched all around the pot (Figure 2). This is an unavoidable feature of its design, which allows the Bell-tent

Factor	P-value
Number of bait fish	0.42
Cod pot design	0.09
Cod pot mesh material	0.43
Cod pot mesh size	0.48
Time of day	**<0.01**
Out with other cod pot	0.38

Table 5: Results from GLM with attack behaviour as response variable.

pot to be collapsed flat for ease of transport and storage. Previous studies have shown that loose netting may be correlated with a higher amount of seal attacks [Varjopuro and Salmi, 2006]. One explanation could be that loose netting allows seals to push it in further, letting them reach the fish through the netting. If fish are more reachable, seals are likely to be more attracted to the cod pot itself, hence the proportions of both seal presence and attack rate are likely to increase. As well as the loose netting, the Bell-tent pot is taller and could visually work as a 'flag,' making the cod pot stand out from the environment more than other designs. Thirdly, a cone-shaped top adds water volume for the fish to swim in. If this extra volume alters the fish behaviour, possibly making them swim around more, this could attract seals to the Bell-tent pot.

Neither mesh material nor size was found to affect seal presence or attack behaviour. The Dyneema™ material was only used in the larger regular mesh size, which makes it hard to establish the true effect of either mesh material or size in this study. On the other hand, we know that Dyneema™ is a very strong material compared to nylon [Suuronen et al., 2004]. With a stronger material, any attack attempts are predicted to be less successful, also less damage to pots is predicted. Although there were two mesh sizes used in this study, 20 mm and 30 mm, it is probable that 10 mm is too small a difference to detect an effect of the two types. A small mesh size will catch more fish but may catch them at a smaller size. Since small individuals are typically juveniles, hence not yet reproductively active, a small mesh size could be undesirable from an ecological perspective. On the other hand, a small mesh is harder for seals to pull fish out through and might therefore be a seal-safe alternative. Selection panels consisting of a larger mesh, which cod pots have, allow undersized fish to escape while still maintaining an overall small mesh size to keep the gear more seal-safe.

Time of day was found to be an important factor for seal presence. The highest proportion of seal visits was found in the early mornings and early afternoons. However, the biological reasons behind this pattern are not known. The temporal variation in seal presence could potentially correlate with times of resting, foraging or playing. Jessopp et al. [2013] found that grey seals in southwest Ireland performed pelagic dives at night time, suggesting these dives were due to foraging and that foraging behaviour was influenced by light levels. To observe and collect behaviours during the hours of darkness, night vision cameras would have been needed; these might have revealed a seal presence peak during low light levels in this population as well. If biological reasons as to why seals are present more at certain times were understood, then efforts both to mitigate the effects on fisheries and to develop seal-safe fishing gear could take that information into consideration.

Even though the results showed that in terms of time units, attack behaviour was not correlated to seal presence, there cannot be any attacks if no seals are present. Mitigation efforts should not only focus on making cod pots attack-resistant, but also on keeping seals away from the fishing area in the first place. If seals were kept away from the area, that would also lower the amount of the hidden losses, i.e., the invisible economic losses due to fish being scared away from the area, or eaten whole, thus leaving no trace [Königson et al., 2013A]. Results showed that seal presence, but not attack behaviour, was higher with more bait fish in the cod pots, which could suggest that moving fish work like a magnet for seals to stay around the gear after the initial approach, even if they do not actually attack the fish. One implication of this finding might be that emptying cod pots regularly would reduce their attractiveness to seals.

Attacks occurred to a higher extent on moving fish than on fish that were still, suggesting that fish movements trigger attack behaviour. Movement is likely perceived by the seals either visually or by sensing the movement of water through optic flow [Fjälling et al., 2007; Gläser et al., 2014]. It could be useful to find out which senses the seals are primarily using, as this could lead to the possibility of adapting fishing gear to make the fish in the fish chamber less visible or detectable to seals. Therefore, it would be a good idea in future research to consider which of the seals' senses are triggered most by fish movement in traps.

The results showed that seals perform a variety of behaviours around the pots, and that attack behaviour is not, in fact, a common one (Figure 5). Assuming that attack behaviour is mostly motivated by hunger, then the seals must be present for some other reason than simply hunger. The most common behaviour was the investigation behaviour, when seals were focused on the cod pot and not the fish inside, swimming around, sniffing the pot and touching it. This could suggest that seals are present around pots simply out of curiosity. To investigate that idea further, a study similar to ours, but without any bait fish, could be used. Comparing the sets of behaviours from this study with those from observing empty cod pots could help us to understand what motivates seals to take an interest in them. Empty cod pots could work as a novel object for the seals, instead of as a possible food source, and an animal's tendency to investigate a novel object is a measure of its curiosity [Réale et al., 2007].

When dead fish were used as bait, the seals were present all around the pots but did not attempt to grab the bait fish, even though they could easily have got at them since they were floating at the top of the fish chamber. This is perhaps not surprising, as seals prefer to eat live fish. But the question remains: what does attract seals to fishing gear if they don't get to dine out as a result? Is it the fish, is it the moving fish, or is it something about the pots themselves? If further studies show that there are certain materials, sounds or smells associated with different gear which seals find more or less interesting to investigate, we could perhaps use that information to entice seals away from cod pots.

It was found that the number of attacks, but not the proportion of attack behaviour in relation to other behaviours, increased with seal presence. This suggests that not only attack behaviour, but seal interactions in general will increase with more seal presence. Seals will not conduct a higher percentage of attacks the longer they are there. However, since the number of attacks increases with seal presence, a low seal presence is still preferred for a low amount of attack behaviour to occur. Moreover, having seals hanging around pots will hardly encourage fish to be active in the area and possibly to swim into the pots, even if the seals are not directly attacking the catch.

Studies have found that gear destruction and catch losses are not caused by all seals in a population, but rather by individuals that are specializing in raiding traps [Königson et al., 2013B; Oksanen et al., 2014; Kauhala et al., 2015]. Königson et al. [2013B] found that 1% of the seal population in their study area was responsible for 71% of the seal visits to the monitored fishing gear. Königson et al. [2013B] also observed that activity patterns of grey seal individuals were diverse and unpredictable, which is again supported by this study. Some seals stayed for a long time, lying on the cod pot as if resting. Others investigated the cod pot thoroughly by swimming around it upside-down, seemingly playfully, over and again. Some lay underneath the cod pot, in what seemed like a dominant manner, attacking any other seals swimming by. In general, seal behaviour varied between individuals; individual seals had their own techniques and ways of approaching and interacting with the cod pots and appeared to have different temperaments. So it is important not to generalize too much and to take this behavioural variability into account when considering mitigation methods.

CONCLUSION

This study aimed to gather data about seal presence and attack behaviour around cod pots in order to find solutions to the conflict between grey seals and the inshore cod fishery. The questions we raised and partly answered are not just about behaviour or about gear design but about the relationship between the two. We found that the design of the cod pot is of importance to seal presence, and that the models with loose netting attracted the most seals. Seal presence was found to be linked to the number of bait fish used, to whether they were alive or dead, and also to the time of day. As regards attack behaviour, the time of day was, in fact, found to be the most important factor. A large variety of other behaviours were observed, which could mean that seals are often visiting pots because of other reasons than simply hunger.

As usual, further research is indicated, but no matter why seals are attracted to cod pots, the 'arms race' that currently exists, in which fishermen and seals are trying to outsmart each other in competing for the same resources, is not productive. In nature, competing parties can only thrive in the same habitat if they each adapt to their own niche. By understanding seal behaviour better and at the same time using smarter technological solutions, we look forward to a situation in which seals and fishermen can co-exist peacefully.

ACKNOWLEDGMENTS

The authors would like to thank those involved at SLU AQUA and DTU AQUA. Also, fisherman Kurt Siltberg provided invaluable help throughout the fieldwork. Thanks to Anders Nissling at the AR Marine Laboratory for providing great advice, housing, and laboratory and field equipment. Claudia von Brömssen at SLU gave us valuable advice on the statistical analysis. Thanks to Rolf Gydemo who helped with test fishing for fish used as bait. The study was funded by Gotland County Administrative Board, Project Seals and Fisheries, and the Swedish Agency for Marine and Water Management.

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