Sveriges lantbruksuniversitet
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Faculty of Natural Resources and Agricultural Sciences

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– A search for seal-safe cod-pots in the Baltic sea

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Department of Aquatic Resources
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Abstract

The seals and the fishery are forced to share the role as top-predators in the Baltic waters since they both depend on the same fish stocks, which leads to an unavoidable competition. Seals are raiding traps, leading not only to costly damaged fishing gears and loss in fish catch but also to the seals themselves getting caught and drowned in the gears as by-catch. In order to solve the conflict research is working on developing 'seal-safe' fishing gears, which are well-working fishing gears that also are unattractive to seals and that are resistant to attacks.

This study investigated seal presence and attack behavior of grey seals in relation to cod-pots in the Baltic sea. Baited camera-equipped cod-pots of three shapes and mesh types were set out in the vicinity of a seal colony outside the east coast of the Swedish island Gotland, and the behavior of the visiting seals caught on tape was observed and analysed.

It was found that the most important cod-pot component for both seal presence and attack behavior was the shape. The shape with most attack behavior and seal presence had an upper part of loose netting, in contrast to the other two shapes. Neither mesh size nor material showed any significance for seal presence or attack behavior. It was also found, through a Generalized Linear Model, that the most important factor for proportion seal presence was time of the day, where the morning had greatest proportion. Furthermore it was found that the proportion seal presence was not affected by if the bait fish were dead or alive, at the same time as no attack behavior on dead bait fish could be found. This could suggest that seals are present because of curiosity and not because of hunger.

This study provides insight in how grey seals behave around different cod-pots and what factors that might affect their behavior. It shows that cod-pot-components but also factors such as the time of the day can effect the behavior of the seal.

Populärvetenskaplig sammanfattning (Swedish)

Östersjön står idag inför många påfrestningar, flera på grund av att människans framfart hamnar i konflikt med naturens. En av konflikterna i Östersjön som blir värre, är konkurrensen mellan gråsäl och det kustnära fisket, som båda är beroende av samma fiskbestånd. Sälen är en mycket smart och nyfiken art, som har visat sig både förstöra redskap samt stjäla fångst från det kustnära fisket. Både sälen och fisket förlorar på konflikten dem emellan. Sälen fastnar i fiskeredskapen och drunknar som bifångst medan det kustnära fisket lider stora ekonomiska förluster på grund av de förstörda redskapen och minskade fångsterna. Sälen och det kustnära fisket tvingas dela på rollen som topp-rovdjur i Östersjön, och då säl-populationerna växer, och det kustnära fisket minskar, blir konkurrensen värre och en lösning måste hittas. Fiskeförlusten på grund av säl delas ofta in i antingen synliga eller gömda förluster. Synliga förluster är de förluster man kan se, exempelvis fiskrester i maskor i nät, eller halva fiskar i burar, direkta effekter av attacker. Gömda förluster är de förluster som inte går att se med ögat, dvs de fiskar som äts upp hela, eller som inte fastnar i redskapen alls på grund av en hög sälnärvaro. En möjlig lösning för att minska sälinteraktioner kan vara att få fram så kallade sälsäkra redskap, dvs väl fungerande fiskeredskap men som inte attraherar sälar och som har motståndskraft mot attacker.

Som ett led i att ta fram sälsäkra fiskeredskap undersöktes sälbeteende i relation till torskburar på Gotlands östra kust, på en plats som heter Rute Misslauper vid en sälkoloni. Det gjordes genom att tre olika former på torskburar, med tre olika masktyper, betades med fisk och sattes ned i vattnet utanför sälkolonin och filmades. Filmerna observerades i efterhand och sälarnas beteende och närvaro-mönster noterades. Beteendet och närvaron analyserades sedan i relation till olika faktorer såsom torskburs-komponenter, fisk-betesinformation samt tidsaspekt.

Det som hittades var att den enskilda faktorn som var mest viktig för en hög proportion sälnärvaro var tid på dygn, där morgonen hade högst proportion. Detta är viktigt eftersom det kan visa på effekter av sälens biologi som påverkar. Även burform visade sig ha en signifikant effekt på proportion sälnärvaro, där en rund bur med löst nät från en ”topp” (sk. Circus-bur) var den form med högst proportion. Samma burform gav även högst proportion attackbeteende vilket skulle kunna tyda på att sälen uppfattar ett lösare nät som lättare att fånga fisk genom, och därigenom uppmuntrar till att stanna kvar längre stunder samt försöka attackera. Varken maskstorlek eller maskmaterial visade sig ha någon effekt på vare sig sälnärvaro eller attackbeteende. Inga attackbeteenden alls skedde vid de tillfällena då torskburarna var preparerade med död betesfisk. Däremot var det ingen skillnad alls på sälnärvaron fast fisken var död. Detta skulle kunna tyda på att sälen befinner sig runt burarna i stor grad på grund av nyfikenhet, och inte för att den är ute efter att äta. Däremot kan en retning, som att fisken rör sig, ändå trigga attack-beteende vilket även resultaten visade på, då 83% av attackerna skedde på fisk som rörde sig.

Studien visade sammanfattningsvis på att det finns flera faktorer att ta hänsyn till i utvecklingen av sälsäkra fiskeredskap. Sälarna visade sig hellre besöka vissa burformer och även under vissa tider och resultaten visade även på att nyfikenhet kan vara en av de drivande motivationerna för att besöka burarna. Genom att fortsätta förstå sälarnas biologi och beteenden, och fortsätta utforma burar för att överlista dessa, så kan man förhoppningsvis hitta en lösning på den infekterade konflikten mellan sälar och det kustnära fisket.

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Prologue

The Baltic sea, the sea that relies on diverse and abundant marine foods webs, thriving fish-stocks, a viable and healthy seal population in combination with a flourishing coastal fishery. What today may seem as an unreachable utopia, is a goal set by the Baltic Sea Action Plan (HELCOM 2007). Today that goal is unfortunately far from reality. The commercially exploited fish stocks are not what they once were, the situation of seals is very problematic and the fisheries are having problems surviving. Not only have the three components just mentioned, the fish stocks, seals and coastal fishery problems to deal with one by one, they are together entangled in a vicious circle of problems where none of them is the absolute winner.

Introduction

The situation of the Cod (*Gadus morhua*)

The cod (*Gadus morhua*) population stocks of the Baltic sea have been undergoing great changes in the latest mid-century. In the 1950s a great inflow of salt water made accumulated phosphorus from the deep sediments mobilize, which stimulated nitrogen fixation (Österblom 2006). In combination with increasing anthropogenic nutrient loads, this led to rapidly increased primary production and thus a change from an oligotrophic to a eutrophicated state (Österblom 2006). This state stimulates fish production, but at the same time reduces biodiversity (Österblom 2006). In the 1980s the populations of cod started to decline rapidly, likely due to over-fishing, which in turn caused the main prey species, herring and sprat, to increase dramatically in the early 1990s (Österblom 2006, Köster 2000, MacKenzie and Köster 2004). Since those prey species to a great extent feed on cod egg and larvae the decline of adult cod individuals led to a shift in dominating species (Österblom 2006, Köster and Möllman 2000). Before the cod population regulated the herring and sprat populations, thereafter the situation became the opposite, herring and sprat regulate cod (Köster and Möllman 2000) and reversing the change can be difficult if not impossible (Beisner *et al*. 2003, Folke *et al.* 2004). Meanwhile the cod populations declined, the grey seal (*Halichoerus grypus*) populations increased, even though the events have not been found to correlate (Österblom 2006). On the other hand the recent study by Cook and Trijoulet (2016) found that the recovery of the cod stocks - at least in the Scottish waters - is fragile and sensitive to small increases in both fishery and seal predation.

The situation of the Grey seal (*Halichoerus grypus*)

The grey seal population in the Baltic sea have also been undergoing changes both historically and nowadays which have been and is causing effects through the intertwined food webs. The grey seal is a top-predator in the Baltic waters and thus has an important role to play. The traditional role of a top-predator is that it regulates the trophic level below its own, thus creating a so called ”trophic cascade” by increasing the populations in the trophic level two steps under itself (Frank *et al*. 2005, Bowen 1997). This is what is generally called the top-down effects. However, since the grey seal is an opportunistic feeder, the top-down effects can be hard to fully establish and are likely to occur in many parts of the food-webs. As a matter of fact, the ultimate top-down effects of top predator marine mammals is not yet fully understood (Bowen 1997). In the early 20th century, the grey seal were abundant in the Baltic sea and the population exceeded 88,000 individuals (Österblom 2006, Harding and Härkönen 1999). In the 1970s the population declined and was estimated to 4000 individuals. This caused the top-down control to be lowered, which in turn led to increasing fish stocks (Harding and Härkönen 1999, Österblom 2006). Today the number of seals is increasing rapidly, and in 2014 as many as 32240 individuals were counted (Havs- och vattenmyndigheten 2015). It was also found that the increase is much greater in the southern sea which means that the seals are dispersing south.

Even though the population of grey seals today is large and viable there are a few threats to the grey seal population and individual seals, both in longer terms and today, such as climate change and by-catch. The threat of climate change is a long-term population threat that is not considered a major threat for individual seals (Jüssi 2008). The problem lies primarily in that grey seals alternate between land and ice breeding, depending on ice coverage where breeding success and pup survival has been shown to be greater from breeding sites on ice (Jüssi 2008). A warmer climate would threaten the viability of the seal population in longer terms because of the resulting lower population growth rate and an increased infection rate during the breeding period (Harding *et al*. 2007, Jüssi 2008, Havs- och vattenmyndigheten 2015).

Another threat for the seal population, and especially for individual seals, is the problem of by-catch. Seals are attracted to fishing gear and fishing vessels which leads to them getting entangled, injured and often drown. Exactly to which extent the whole population of grey seals is affected by by-catch is not yet fully known but in the study by Vanhatalo *et al*. (2014) it was established that the yearly number of seals by-catched by trap or gillnet in Sweden, Finland and Estonia was with 90% probability between 1240 and 2860 individuals. The fishing gears that are causing the most problems with accidental by-catch are bag nets and fish traps which makes the magnitude of the by-catch problem vary with type of fishery (Lunneryd and Westerberg 1997).

The situation of the coastal fishery

The coastal fisheries have an important role in the Baltic sea, both economically and socially. More than 80 million people are living in the coastal region around the sea which makes the fisheries affect the possibilities for people to settle, and also if companies and industries can depend on the coastal resources (Waldo *et al.* 2010). Because of the vast dependence on the resources the coastal fishery is relying on, the economical consequences of a coastal fishery is profound. Socially, a so called ”living harbour” with a viable coastal fishery is important not only for attracting tourists, but also for cultural and historical traditions (Waldo *et al*. 2010).

The fisheries which are subjected to the seal-fisheries conflict to the greatest extent is the small-scale and coastal fisheries. Coastal fisheries are widely scattered along the Swedish coastline and they are of great importance to the local populations. In addition to facing damage caused by seals, these fisheries tend to suffer from diminishing fish stocks and structural problems such as difficulties distributing the catch.

The problem at hand

The coastal fishery and the grey seal population are forced to share the role as top-predator in the Baltic sea and are thus competing for the same stocks of fish which is causing a serious and expensive conflict. A decrease fish stocks in combination with a rapidly increasing grey seal population leads the competition towards a tipping point where the presence of seals is causing huge economical losses for the fishery. In 2014 it was estimated that the cost for damage on catches by seals and repairing and replacing the fishing equipment costs as much as € 3.56 million per year, not even including the so called hidden losses (Havs- och vattenmyndigheten 2015). Nearly half of these costs have been from seal damage in the southern Baltic sea where the seal population is increasing the most.

These economic losses, caused by seals interacting with fishing gear, are due to both the literal losses of fish but also gear destruction. The literal losses in fish catch are typically divided into either so called visible or hidden losses. Visible losses are fish, you can visibly see, damaged by seals. This would for example be fish that are halfway eaten or fish-parts that are left in gillnets or traps. In the study by Königson *et al.* (2010) they found that 76% of the cod-fishing trips had visible losses. The hidden losses are the negative effects of seal presence that cannot be observed. This is for example the fish that are eaten whole from the nets, thus leaving no traces of seal presence, or fish that are scared of the gears before they even are caught. In Königson *et al.* (2013) nets were baited with marked fish and 95% of the baited marked fish went missing. This gives us an idea of the amount of hidden losses in the cod fishery, and thus the magnitude of the problem.

Other than damage to the catch, there are damages on fishing gear caused by the raiding seals. Repairing damaged gears is expensive and time consuming. Additionally, the life span of a fishing gear is also shortened with any seal interaction. Damage to the fishing gear is also likely to lead to loss in catch, since the fish is more likely to escape after being caught.

The number of seals are increasing, and the number of coastal fisherman is declining, but the relative damage because of seals is increasing (Havs- och vattenmyndigheten 2015).

The development of 'seal-safe' fishing gear

The costly consequences of seals interacting with fishing gear are in need of solutions, and a lot of research in constructing 'seal-safe' fishing gear have been made to moderate the competition between the seals and the fishery. Seal-safe fishing gear are those that attract few seals and that withstands the attacks of those that do interact with the gear. However, prior to constructing seal-safe fishing gear there are few criteria that first must be met; they have to be catch efficient, have low environmental impact and also be practical at sea. Research on catch efficiency have not only been focusing on how much fish each gear is able to catch, but also which factors that are causing them to be efficient and how to develop those factors further. Those factors varies with different types of fishery and thus have to be targeted for specific prey species. A low environmental impact fishing gear can be reached by for example employ size selectivity on fishing gear and reduce factors that can be linked to by-catch of marine mammals and birds (Lundin *et al*. 2011, Königson *et al.* 2015). Passive fishing gears, such as traps or pots are generally less environmentally damaging than active ones such as trawls (Suuronen *et al.* 2012). Since coastal fishermen often work alone it is of special importance that the gears are easy to handle on a small boat and effortlessly can be put in and taken out of the water. If the gears are not practical to use, it is probable that it will not be used instead of other alternatives, even if it is catch efficient and environmentally friendly.

Arms race

When the above described criteria are met the fishing gear can be further developed to become seal-safe. However, just as competition and conflicts of interest between species in nature forces the competing parties to counter-adapt to the adaptation of the other, the seal and the fishery does as well, creating a so-called ”arms race”. Grey seals have proven their adaptability and mental capacity continuously during the developments of seal-safe fishing gears (Varjopuro 2011). In the development of the pound net in salmon fishing the fish bag had to be further developed since the seals bit their way through it. The standard nylon mesh was exchanged to the very strong newly developed material of Dyneema® (Kauppinen *et al*. 2004, Suuronen *et al*. 2004). Due to the strong material the problem was thereby solved, but the finding did not significantly reduce the amount of fish taken. The reason was that when the seals were not able to bite through the mesh anymore their new solution for taking fish was to swim inside the fish bag through the entrance, take the fish and then swim out again (Varjopuro and Salmi 2006). The counter-adaptation by the gear-developer's was then to prevent seals from entering the fish bag by having metal bars in front of the entrance. The bars were after trial and error further developed to not be too thick, because that scared away the fish and was too heavy, and not too thin, because the seals then could bend it. The best solution was found to be steel wire (Varjopuro and Salmi 2006). The seals ability to learn has been a main obstacle in designing the ultimate seal-safe fishing gear, therefore an adaptive approach to changes in behavior of seals is of major importance.

The seal-safe 'push-up trap'

The pontoon trap, or 'push-up trap' is an example of a fishing gear that have been proven to both be catch efficient and seal-safe by having specific components in its design (Hemmingsson *et al*. 2008, Lunneryd and Fjälling 2004). The gear was primarily developed for salmon (*Salmo salar*) fishing but is now used in whitefish (*Coregonus lavaretus*) fishing and have been further developed for herring (*Clupea harengu*s), vendace (*Coregonus albula*) and most recently for cod. The fish chamber, where the fish gather, is a large cylinder divided into two parts. The first part have a single layer firmly stretched Dyneema mesh. In front of the entrance to the second part, the holding chamber, there is stainless steel vertically across the opening. The holding chamber has a double wall of firmly stretched mesh of Dyneema. In order to be easily handled in rough sea conditions, the trap is raised from the sea bottom to the surface by pumping air into large tubules that the fish chamber is attached to, hence the name push-up trap. The gear have shown great success in fishing salmon while being seal-safe and several hundreds of them are now being used in Swedish waters (Hemmingsson *et al*. 2008). At the time of writing these traps are now also being tested for cod-fishing, due to an increasing conflict with seals in cod-fishing.

The development of cod-pots

The push-up trap is working well in terms of being catch efficient and seal-safe, however due to its size and ungainly design it is troublesome to bring up on boats and relocate. This is a problem when it comes to cod-fishing since the traditional way of fishing cod is over large areas, using gillnets. The team of 'Seals and Fishery' is now developing small, sturdy traps, called 'cod-pots', that are easily handled, relocated, can be used over large areas and be used in both small and large scale fishery. They are baited with a prey species of cod, for example herring, thus attracting the cod which is then kept alive and in good condition in the cod-pot until emptying.

The best design for these smaller traps in terms of both being seal-safe and catch-efficient is not yet fully established. Studies have shown that cod-pots can be catch-efficient (Königson *et al*. 2015) but how seal-safe they are have not been tested prior to the present study. There are a few different shapes that have been developed and proven to be catch efficient, three of them are the Sara-, Lotte- and Circus-shape, which are the shapes that was used in this study.

Aim of this study

As a part of the 'Seals and Fishery' project the overall goal of this study was to increase the knowledge about what makes a cod-pot seal-safe, with the aim of easing the seals-fishery conflict. This study was focused on testing cod-pots with two main objectives (i) to describe the pattern of seal presence around the cod-pots, and (ii) to investigate what is causing the attack behavior of the seal.

Nine cod-pots models were tested and they were made of three shapes and three mesh types. The shapes were Sara, Lotte and Circus and mesh types were of two mesh sizes in nylon and Dyneema in larger mesh size.

Using Generalized Linear Models it was tested which factors that affected the proportion seal presence and proportion attack behavior the most. The factors used were cod-pot components of shape, mesh size and material and time of the day for the proportion seal presence response. The factors of number of bait fish, cod-pot model and seal presence was tested fot the proportion attack behavior response.

It was also statistically tested whether other factors affected seal presence and attack behavior. For proportion seal presence response the factors of cod-pot model, the time of the day and if bait fish were alive were factors. For the attack behavior response it was tested whether the shape, mesh size or material of the cod-pot had any effect. The mobility of the fish during the attacks and the effect of dead bait fish was described.

Similar studies comparing the same type of cod-pots have not been made prior to the present study, therefore the outcome of the experiment was troublesome to hypothesize. However, one of the most apparent difference between the shapes of the cod-pots is that the Circus-shape has an upper part of loose netting in contrast to both the Lotte- and Sara-shape. Since loose netting could possibly simplify for seals to catch fish from further inside the cod-pot, it was hypothesized that the least seal-safe shape would be the Circus-shape. Therefore, it was believed that either the Sara- or Lotte-shape would prove to be most seal-safe, which means attract the fewest seals and attack behaviors.

Methods

What was done

Cod-pots modified to resist attacks from seals were baited with fish and placed in the vicinity of a seal colony. To be able to quantify the pots resistance against seals the pots where filmed continuously for up to 30 hours under water and the behavior patterns of the seals were observed, noted and later on statistically tested in relation to the components of the cod-pots, time of the day and other factors of interest.

Field site

The field work for this study was conducted on the east coast of the Swedish island, Gotland, around the very small islands called Rute Misslauper (Longitude: 57.461 Latitude: 19.050) in the late summer and fall of 2015 (Figure 1). Rute Misslauper is a haul-out site for a large grey seal colony. The field work occurred from August 12th 2015 to September 30th 2015.

Figure 1. Map showing the position of Rute Misslauper (circled), the small islands outside the east coast of Gotland where the field work for this study was conducted.

Bait fish

In order to attract seals to the cod-pots, living fish were placed into pots to be used as bait. The fish were caught in a near-by push-up trap, cod-pots or gillnet prior to the performed experiment. After fishing they were either transported and placed into fish tanks in a lab, (primarily in the beginning of the field period when the sea water was too temperate) or placed in a sink by the sea. In the beginning of the field period we exclusively aimed for fishing cod as bait, however due to the low number of cod in nearby waters we decided to include other species as well. The species except for cod that was included were ide *(Leuciscus idus)*, white bream *(Blicca bjoerkna)*, turbot (*Scophthalmus maximus*) and tench *(Tinca tinca).* The experienced fisherman Kurt Siltberg who supported the field work greatly, concluded that those species were all known to attract seals. The number of fish in each cod-pot differed due to how many fish that were available. In three cod-pots, fish were used as bait even though they had died. This was again, due to the low number of bait fish caught in the beginning of the field period. The mean number of bait fish in a cod-pot simultaneously were 3,9. When several species of bait fish were used together, they were evenly distributed between the cod-pots. An assumption that species did not affect the behavior of the seals was made, based on that the species used were all known to attract seals, that they were placed together and evenly in cod-pots, and that species preference of seals varies between individuals, sexes, ages and seasons (Beck *et al*. 2007, Lunneryd 2001).

The cod-pot models

There were nine cod-pot models that were tested. They had three shapes and of three mesh types. The shapes were: quadrangular with a triangular tip (Sara-shape), cylindrical (Lotte-shape) and cylindrical with a tip (Circus-shape) (Figure 2). The three mesh types tested were: nylon with regular mesh size (30mm), nylon with small mesh size (20mm) and Dyneema with regular mesh size (30mm). Prior to the experiment cod-pot entrances were sewn together to prevent bait fish from escaping.

Throughout the paper the cod-pot models will be referred to with a letter combination reflecting shape and mesh type, for example CN. The first letter reflects the shape, Lotte (L), Sara (S) or Circus (C). The second and third letter reflects the mesh type, nylon regular mesh size (N), nylon small mesh size (N2) or Dyneema regular mesh size (D). CN would therefore be the model with Circus-shape and nylon regular mesh size.

Figure 2. The three cod-pot shapes. To the left, the Sara-shape, in the middle, the Lotte-shape, to the right, the Circus-shape.

The set-up and how the cod-pots were filmed

The total replicate of number of cod-pots filmed were 21. The number of times each type of cod-pot was tested was depending on how well the cameras worked in combination with how much seal visits they recorded. The cod-pots were most often set out in the morning around 9.00 but depending on weather and other factors they were sometimes set out in the afternoon around 15.00, and the order of the models were randomly decided. At the most there were three cod-pots out at the same time, but most often they were alone, due to a lack of bait-fish. They were randomly placed at the field site, in a radius of ~500m, but a minimum of 50m from each other. The cod-pots were placed at depths from 3 to 7m and were fixed on the spot with an anchor. An assumption that if cod-pots were set out together or alone did not affect the seal behavior was made. The reasoning was that several cod-pots could possibly attract more seals, but would make it more apparent which of the cod-pots they preferred. When cod-pots were set out together the bait fish number and species they were prepared with was the same and they were deployed at about the same time.

In addition to the cod-pot, two waterproof camera houses, a camera house stand and three buoys were part of the equipment (Figure 3). The camera houses were each equipped with one GoPro camera, a 128GB memory card and a pair of extra batteries in order for the camera to record over 24 hours. The first camera house was placed over the cod-pot, in line with the buoy, and the second was placed perpendicular to the cod-pot using a special built cam12era house stand (Figure 4, left). Two cameras for each cod-pot were helpful since it gave us two perspectives of the events that occurred around the cod-pot and also worked as an insurance when one of the cameras stopped working (Figure 5).

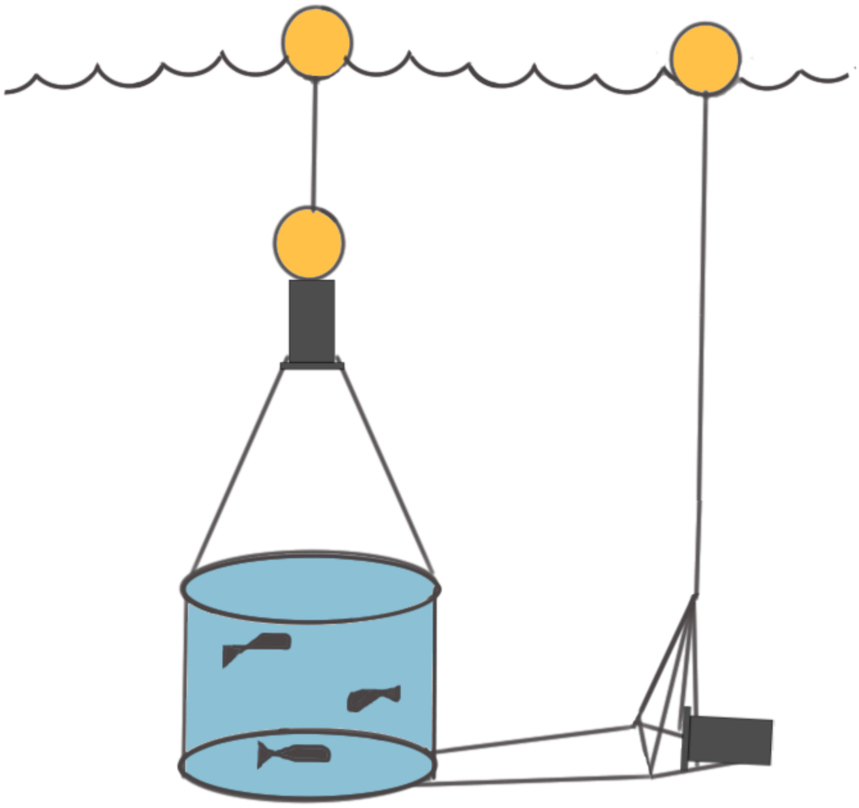

Figure 3. Figure illustrating the set-up of how the cod-pots were placed in the water in relation to the two camera houses and the buoys.

Figure 4. The two camera houses attached to the cod-pots. To the left, the camera house attached perpendicular to the cod-pot and to the right the camera house attached above the cod-pot.

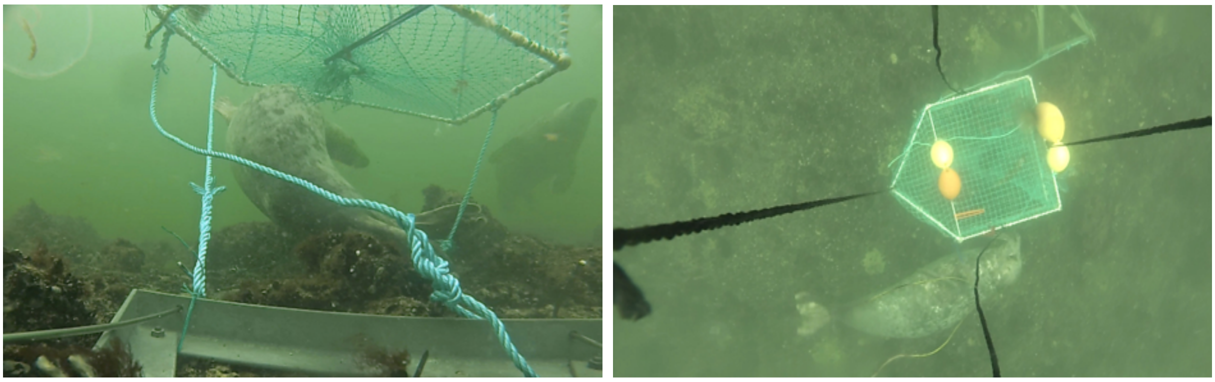

Figure 5. The two perspectives from the cameras attached to the cod-pots. To the left, the view from the perpendicular camera house perspective. To the right, the view from the camera above the cod-pot.

Protocol

For every cod-pot replicate the following parameters were noted in a protocol: the sequence of the cod-pot, date, position, depth, time, which camera houses that were attached, number of fish that were put in and taken out, if the fish were alive, fish species, damage on fish and if there were any equipment damage. The windspeed and land temperature recorded by SMHI at Fårösund, available at the SMHI-website, were noted in the same protocol for further analysis.

Data analysis

The cameras on the cod-pots were in best cases recording over 24h for each replicate. Film from one camera was saved into 30 minute sequences. These film sequences were viewed manually and during the so called ”observable film time” (when it was daytime and clear view to watch the film) the events around the cod-pot could be observed. The following events were noted as they appeared: the entering and leaving times of the seal, and its behavior (Table 1). Which specific behaviors that was performed was noted, but not how many times each behavior occurred, in the time frame when the seal was present. The only instance when the number of times a behavior occurred was noted, was at the times of attack behavior, when also the movement pattern of the targeted fish was noted.

When a seal entered the camera view when another seal was already present, entering and leaving times for the new seal and its behavior were noted, together with a mark that there already was a previous seal.

Table 1. The 14 behaviors that were noted when observing the seal behavior around the cod-pots.

	The seal behavior that was observed and noted
1	Swam by and passed cod-pot
2	Swam around cod-pot
3	Investigated cod-pot
4	On top of cod-pot
5	Underneath cod-pot
6	Jabbed cod-pot with nose
7	Chewed on equipment
8	Hunted fish inside cod-pot
9	Attacked fish inside cod-pot
10	Succeeded taking fish from cod-pot
11	Caused damage on equipment
12	Chased another seal away
13	Aggressive behavior towards another seal
14	Behavior is not visible/clear

For every film sequence the proportion of specific behaviors and seal presence were calculated. In a film sequence the proportion could for example be 50% behavior 2 (swimming around the cod-pot) and 50% behavior 3 (investigating the cod-pot). The proportion of seal presence was calculated by dividing the time when seals were present, with the total observable film time for that film sequence.

To be able to investigate if the presence of seals and the attack behavior were affected by the time of day, the sun-hours (observable film time) recorded were grouped into the following daytime-categories: morning, forenoon, mid-day, afternoon and evening. Because of the variation of sun-hours over the field-period (early august to late september) a daytime-category did not always contain neither the same number of hours nor the same specific times.

The groupings were therefore calculated based on the specific time of sunrise, mid-day and sunset of the date the cod-pot was put out.

Prior to the statistical analysis, the data from the cod-pots with dead bait fish was taken out of the data-sheets for the analysis. This was done since it was found that no attack behaviors at all happened when the fish was dead. In order to be able to find which factors that was linked to the attack behavior, that factor had to be taken out. However, the data from the cod-pots with dead fish were used in relation to seal presence.

Statistical analysis

The statistical analysis were focused on which cod-pots and which cod-pot components that are most important for the gear to be seal safe, what factors that are affecting seal presence and that leads to attack behavior. All statistical analyses were made using the software RStudio Version 0.99.489. Calculations prior to analysis were made using Numbers Version 3.2.2.

When testing the proportion seal presence and proportion attack behavior with factors of categorical data the Kruskal-wallis test was used. The factors of cod-pot shape, mesh size and material, cod-pot models, time of the day, number of fish and if fish were dead or alive were tested using this test.

When testing the proportion seal presence and proportion attack behavior with factors of numerical data a correlation coefficient and spearman correlation analysis were used. These factors were environmental factors of temperature, wind speed and depth, number of attacks, the proportion of attack behavior and the proportion of seal presence.

In order to analyze which factors that affected attack behavior and seal presence the most Generalized Linear Models (GLM) were used. The first GLM had proportion seal presence in the film sequences as a response variable and the cod-pot components of shape, mesh size, mesh material and the time of the day as factors. The second GLM had the proportion attack behavior in the film sequences as a response variable and the factors of proportion seal presence, number of bait fish and cod-pot model as factors.

The response variables of the two models described above, proportion seal presence and proportion attack behavior, were both transferred into binomial data instead of continuos data prior to analysis. The film sequences with seal presence, respectively attack behavior were given the number one and the film sequences with no seal presence respectively attack behavior were given the number 0. This was done since the model of interest, GLM, is adapted for normally distributed data, which was not the case for our data. By transforming the numerical data to binomial data the model could be used with accuracy, and the most important factor for the responses could still be found.

Results

During the field period a total of 21 replicates of cod-pots in the water were conducted and a total film time of 2 weeks, 5 days, 7 hours and 27 minutes was recorded through the two cameras. Of that time 1 week, 2 days and 2 hours were so called observable film time from one camera. Observable film time refers to the part of the film where there was a possibility to have a clear view due to ex. night time, position of cameras, light, weather or other possible explanations for unclear sight.

The Circus-shape had most recorded seal time (5h 30m) and the specific model with greatest time of seals recorded was the CN (3h 34m) (Table 2, Table 3). The shape with least recorded seal film time (ST) was the Lotte-shape (1h 17m) and the models with shortest time seal presence recorded was the SN, SN2 and LN (0h 0m) (Table 2, Table 3). The shape with most attacks recorded was the Circus-shape (108) and the fewest (where seals were present) LN (0). The shape with most missing fish was the Sara-shape (6). No fish at all went missing using the Lotte-shape (Table 2). The specific model with most attacks recorded was the CN2 (52) and the model with most fish missing was the SD (6) (Table 3). Missing fish are the number of fish counted when the cod-pot was taken up from the water.

Table 2. The shapes of the cod-pots used and the field data of time in water, observable film time (OFT), time with seal, bait fish information and the replicate number for each shape.

Shape	In water	OFT	Seal time	Attacks	Total fish used	Fish/ cod-pot	Missing fish	Times fish went missing	Total times used
Sara	10d 2h	84h 20m	1h 35m	18	24	4,1	6	2	7
Lotte	6d 17h	53h 57m	1h 17m	30	21	3	0	0	7
Circus	6d 22h	74h 1m	5h 30m	108	37	5,2	3	3	7

Table 3. Cod-pot models used and the data of time in water, observable film time (OFT), time with seal, bait fish information and number of replicates for each model. The first letter of the name stands for the shape, Lotte (L), Sara (S) or Circus (C). The second and third letter stands for the mesh type, nylon regular mesh size (N), nylon small mesh size (N2) or Dynemaa regular mesh size (D).

Model	In water	OFT	Seal time	Attacks	Total fish used	Fish/ cod-pot	Missing fish	Times fish went missing	Total times used
SN	1d 0h	13h 55m	0h 0m	0	6	6	0	0	1
SN2	3d 2h	23h 57m	0h 0m	0	7	3,5	1	1	2
SD	6d 0h	46h 28m	1h 35m	18	11	2,8	5	1	4
LN	2d 23h	24h 36m	0h 3m	0	15	5	0	0	3
LN2	2d 19h	17h 10m	1h 1m	30	3	1	0	0	3
LD	1d 0h	12h 11m	0h 12m	0	3	3	0	0	1
CN	2d 0h	20h 34m	3h 34m	23	4	2	1	1	2
CN2	2d 22h	29h 6m	1h 27m	52	17	5,7	1	1	3
CD	1d 23h	24h 22m	0h 29m	33	16	8	1	1	2

Environmental factors

Using the spearman correlation analysis it was found that neither the depth of the water at the location, the wind speed nor the air temperature at the study site affected the proportion of seals present or the number of attacks that the present seals performed (p>>0.05).

Seal presence

The cod-pot models

The cod-pot model with the greatest proportion of seal presence was the CN and the models SN and SN2 had the lowest (Figure 6).

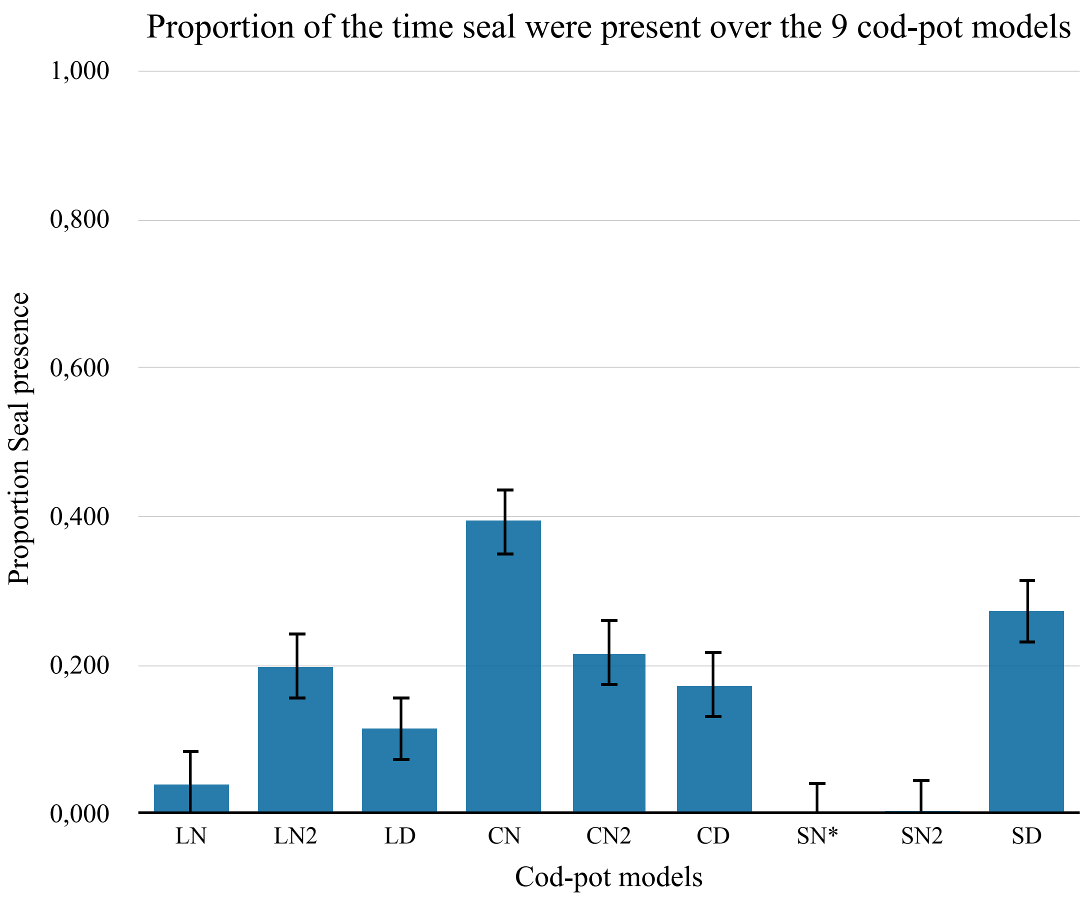

*Figure 6. The proportion of the time seals were present on the y-axis and the cod-pot models on the x-axis. *No seals present*

The effect of dead fish

To test if the proportion of time seals were present was affected by dead bait fish a Kruskal-wallis test was used. It was found that the seal presence was not dependent on if the bait fish were alive or not (p>>0.05).

The time of the day

It was tested if there were significant differences in proportion of time seals were present depending on the times of the day, grouped into either morning, forenoon, mid-day, afternoon or evening. Through the Kruskal-wallis test it was found that the proportion seal presence was differed significantly with time of day ($p=0.005$). The greatest seal presence was found in the morning, lowest in the evening (Figure 7).

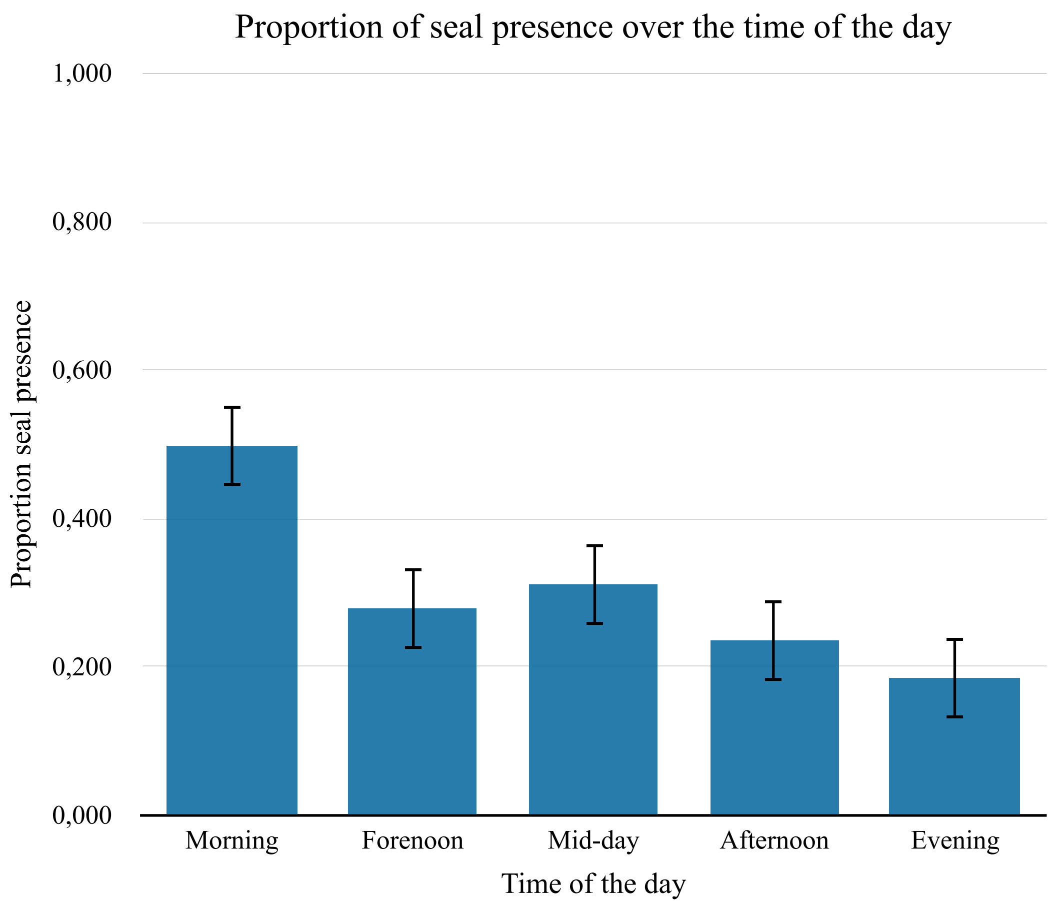

Figure 7. Histogram showing the dispersion of seal presence over the different times of the day. Morning had significantly most seals and evening the fewest.

Generalized Linear Model I - Cod-pot components and time of the day

In the first GLM that was made the aim was to find which factors that affected the proportion seal presence the most. Proportion seal presence (translated as a binomial-response as described in the methods section) was set as response variable and the cod-pot components of shape, mesh size and mesh material, and the time of the day as factors. It was found that the time of day affected the proportion seal presence the most ($p=0.008$), and the shape of the cod-pot second most ($p=0.050$). It was also found that mesh size and material affected the least ($p>>0.05$, $p>>0.05$). A significant difference in proportion seal presence between the Circus-shape and the Sara-shape was found ($p=0.017$). The Sara-shape had the lowest proportion and the Circus-shape the greatest. No significant difference between the Lotte-shape and the Circus-shape was found ($p>0.05$).

Attack behavior

Cod-pot components and cod-pot models

To test whether attack behavior occurred on cod pots of specific components the proportion attack behavior data from each film sequence was used with the components shape, mesh size and material and cod-pot model. It was the cod-pot shape (p=0.003) and the model (p=0.008) had significance. The Circus-shape had the greatest proportion attack behavior, the Sara-shape the least (Figure 8). The cod-pot model with greatest proportion attack behavior was the CN2 and the lowest LD, SN and SN2 (Figure 9). A trend that the mesh size affected was found (p=0.057), where the smaller mesh size had the greater proportion of attack behavior. No significant effect of the mesh material was found (p>>0.05).

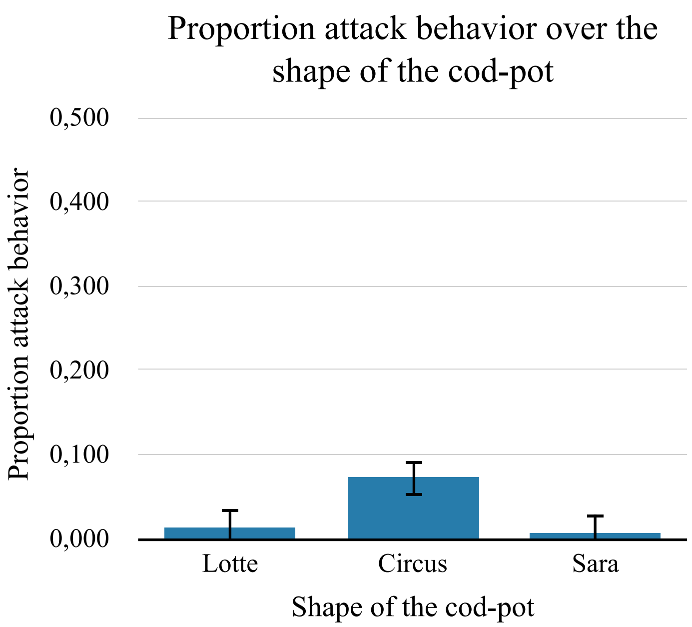

Figure 8. The proportion of the behaviors that were attacks on the y-axis and the cod-pot shapes on the x-axis. The Circus-shape displayed the greatest proportion, the Sara-shape the lowest.

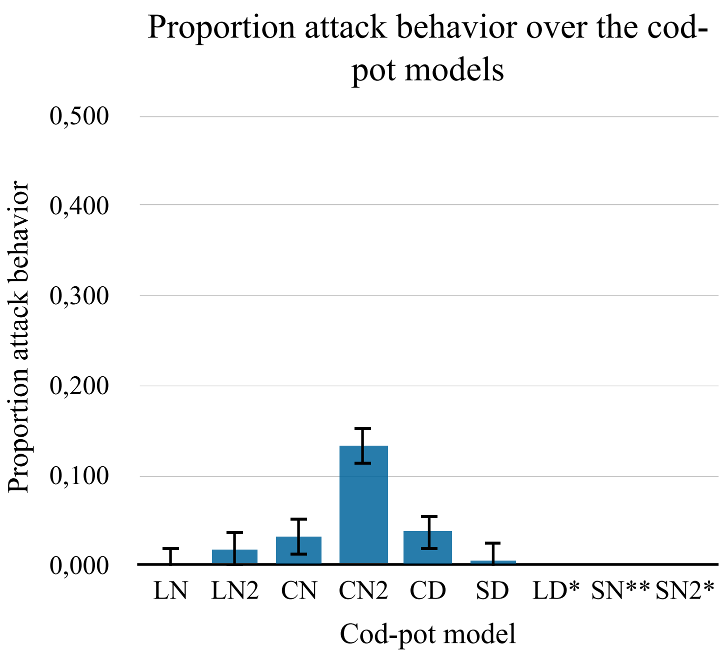

*Figure 9. The proportion of the behaviors that were attack behavior on the y-axis and the cod-pot shapes on the x-axis. *No attacks recorded **No seals present*

The mobility of fish

The number of attacks that occurred on moving respectively non-moving fish were graphed (Figure 10). It can be seen that 114 of the attacks were directed towards moving fish (83 percent) respectively 24 on non-moving fish (17 percent). The attacks that were targeted towards fish that could not be observed is not included.

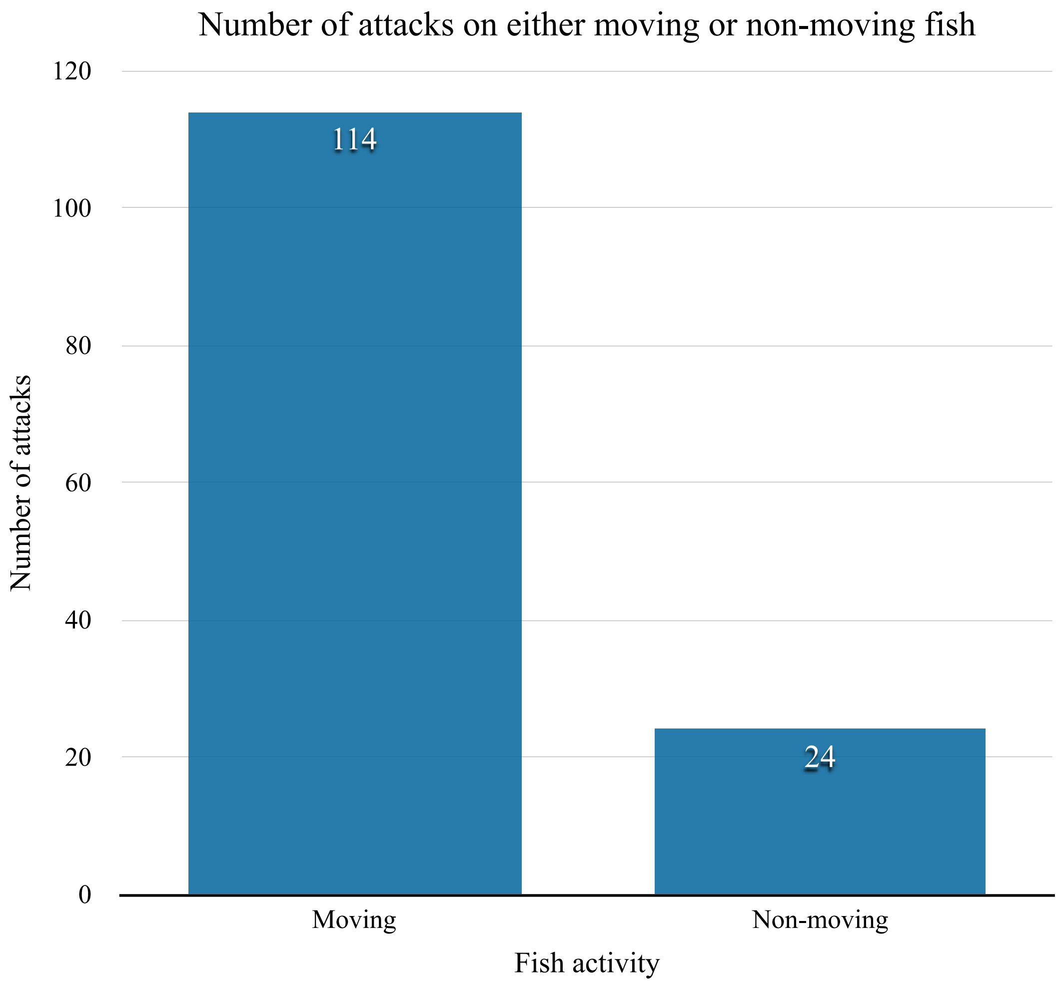

Figure 10. Histogram illustrating the dispersion of the attacks aimed either towards moving or non-moving fish. 114 attacks were targeted towards moving fish whereas 24 attacks were targeted towards non-moving fish.

The effect of dead fish

No attack behavior at all could be observed on the cod-pots that were prepared with dead fish.

Number of bait fish

The number of bait fish used had a significant effect on the proportion attack behavior ($p=0.027$). The greatest proportion of attack behavior were found when there were 6 bait fish used, and lowest when 3 bait fish were present (Figure 11).

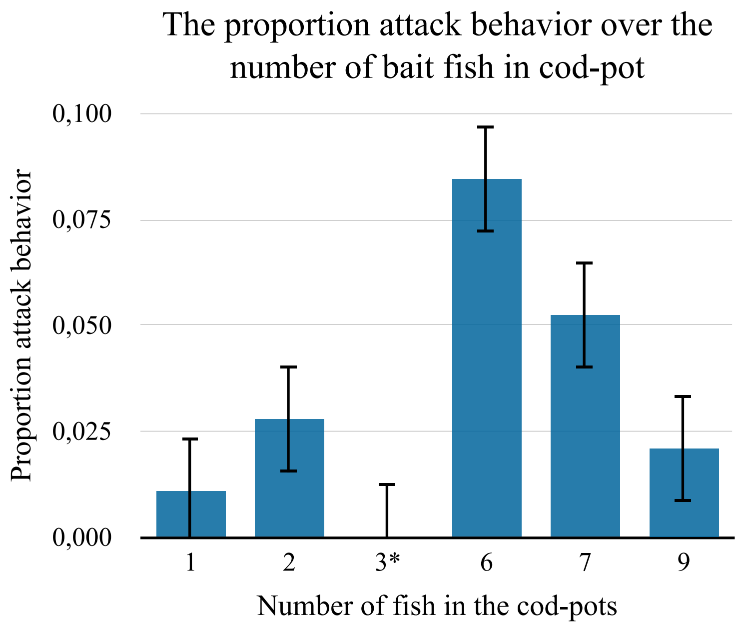

*Figure 11. Histogram showing the proportion of attack behavior over the number of bait fish in cod-pots. Greatest attack proportion happened when there were 6 bait fish and fewest when there were 3. *No attacks recorded*

The time of the day

No significant effect of time of the day, morning, forenoon, mid-day, afternoon or evening with proportion attack behavior was found ($p>>0.05$) (Figure 12).

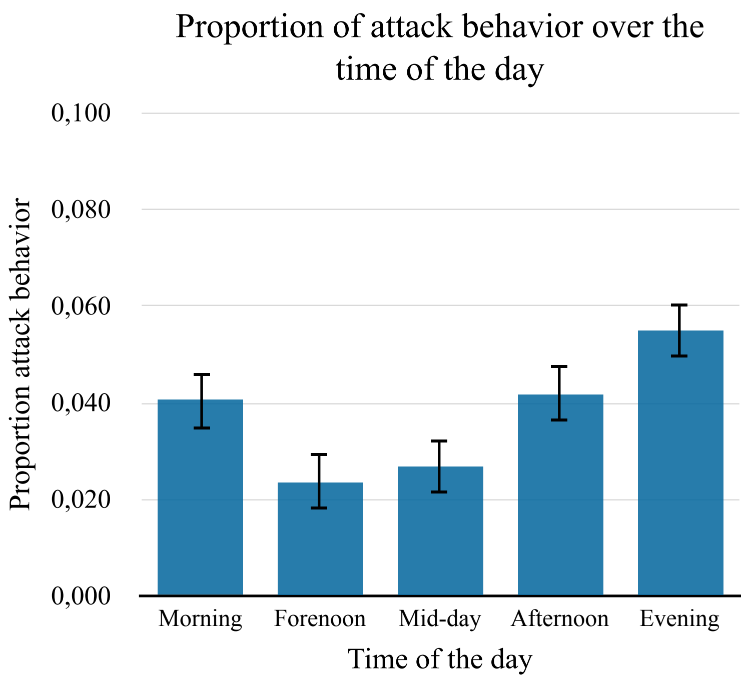

Figure 12. Histogram showing the proportion attack behavior over the different times of the day. No significant correlation could be found.

Seal presence

A significant relationship were found using the spearman correlation analysis with the number of attacks and the proportion seal presence (p=0.031, r=0.472). The greater proportion seal presence, the more number of attacks occurred (Figure 13). However, it was also found that the proportion of attack behavior did not increase with an increased proportion seal presence (p>>0.05).

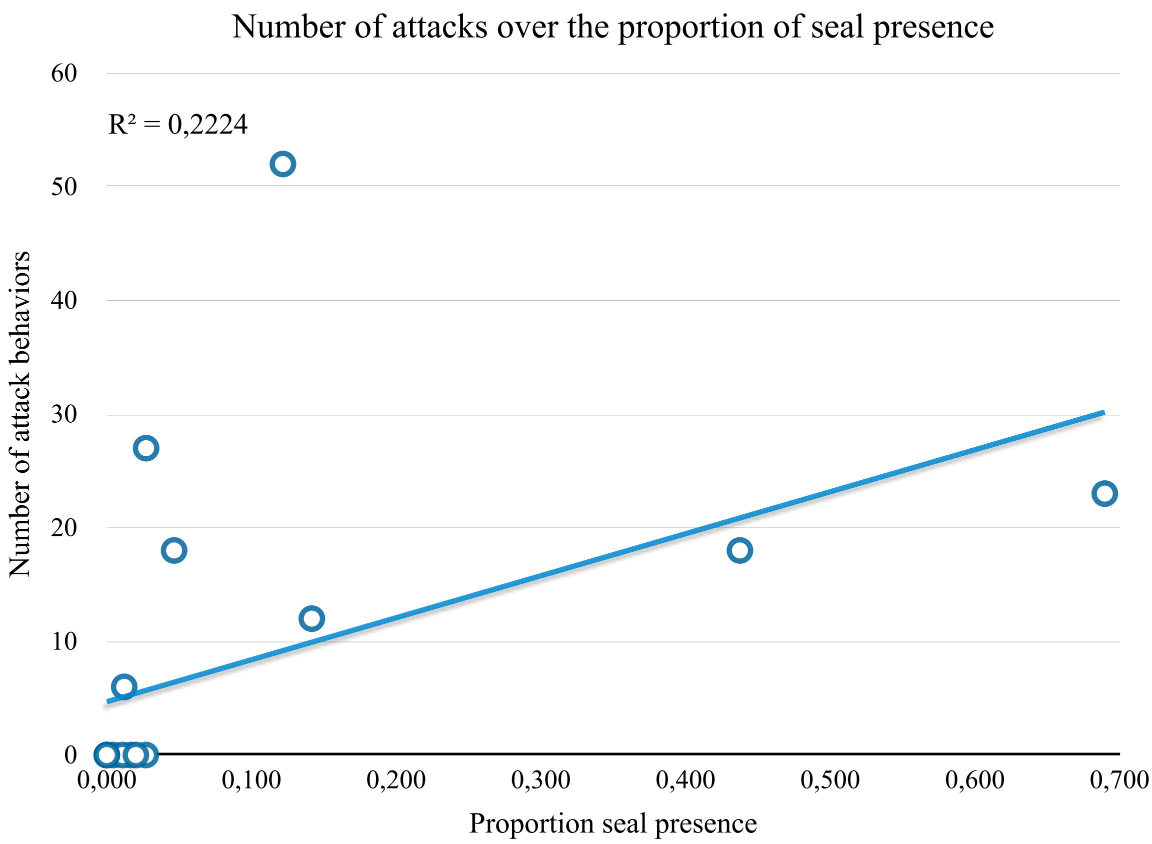

Figure 13. Graph illustrating the number of attack behaviors over the proportion seal presence. The number of attacks is positively correlated with increasing seal proportion.

Generalized Linear Model II- Seal presence, bait fish and cod-pot models

In the second GLM that was made, the proportion attack behavior (translated as a binomial-response as mentioned in the methods section) was the response variable and the proportion seal presence, number of bait fish and cod-pot model were factors. Through the model it was found that the seal presence around the cod-pot were the most important factor for the proportion attack behavior response (p=0.002). A strong trend that the cod-pot model had an effect was also found (p=0.076). The number of bait fish were found to affect the proportion attack behavior response the least (p=0.639).

Discussion

The infected conflict between seals and fishery is in need of solutions. A cod-pot that is both catch-efficient, easily handled, cheap and above all seal-safe could be part of that solution. In order to create the most seal-safe cod-pot research regarding the pots' resistance against seal attacks is needed, but also about the behavior of the seals around the cod-pots. The goal of this study was to increase the knowledge about what makes a cod-pot seal-safe. In order accomplish that goal this study was focused on testing different cod-pots with two main objectives (i) to describe the pattern of seal presence around the cod-pots, and (ii) to investigate what is causing the attack behavior of the seal.

In order for a cod-pot to be classified as seal-safe it needs to fulfill some criteria. Firstly, it needs to be unattractive to seals, so that both seal presence and seal attack rate is low. The presence of seals can, even without attack behaviors, lead to loss in fish catch, through for example previously mentioned hidden losses. Additionally, the cod-pots needs to be sturdy enough to withstand the possible attacks and also to keep the fish safe from the visiting seals.

The presence of the grey seals

Which factors that are causing a greater presence of seals are important to know for many reasons. If seals are abundant in the area around the cod-pots this could lead to the previously mentioned hidden losses such as seals scaring fish away from the fishing area.

It was found through the first GLM that the most important factor for the proportion of seal presence was the time of the day. The greatest proportion of seals visited the cod-pots in the early morning and in the early afternoon. Since it was found that the time of the day was such an important factor this knowledge is important to dig into further. The information about the seal presence peaks could biologically mean a lot of different things. It could for example describe when the energy level peaks for the seals, the time when they are most hungry or going hunting, or when they are most playful or resting. More research focused on the reasons for the seal presence peaks would be useful and important, since the reasons could outline how the cod-pots could be further developed. There might be mitigation efforts that could be developed if the biological reasons to why the seals are present is known.

The number of seals on the rocks on the field site of Rute Misslauper varied greatly from day to day. In the beginning of the field period, in early August, the number of seals seen on the rocks were estimated to as many as 70 individuals. In the late field period sometimes no seals at all could be observed. Also, number of observed individuals, both on the rocks and in the water, varied from day to day, where on days with nice clear weather more individuals could be seen than on the days with a lot of wind. Since the number of already present seals seemingly varied over the field season it is a possibility that it affects how much seals that were present around the cod-pots. On the other hand, the seals might as likely be in the water around the area even if they are not seen on the rocks. Therefore, the estimation of the seals on the rocks should not be given too much value.

Some of the cod-pots in the study were prepared with dead fish as a bait. Through the analysis it was found that seal presence did not significantly differ from those with living bait. In combination with result that no attack behavior were recorded on those cod-pots, it is interesting because it could suggest that the seals present at the times were there for curiosity and not because they were hungry. If the seals are present around the cod-pot primarily because of curiosity that could be of interest when developing cod-pots. Studies about what objects, colors or cod-pot factors a grey seal shows more or less curiosity in could be useful.

The attack behavior

The presence of seals may as mentioned, lead to hidden losses, but the visible losses are the results of the attack behavior. The Generalized Linear Model showed that the most important factor for attack behavior to occur is the seal presence. This means that mitigation efforts should not only focus on how to improve the cod-pots themselves, but also, how to keep the seals away from the fishing area. On the other hand, this study found that the seal presence, that the attack behavior is dependent upon (if there are no seals present, there can be no attacks), is affected by the shape of the cod-pot. Therefore, by developing as unattractive cod-pots as possible, from a seals point of view, the attacks can be lowered.

It was also found that the attacks that occurred happened on moving fish to a larger extent than on still fish. This suggests that the movement of the fish is triggering the attack behavior, through sensory stimuli. The movement is likely perceived by the seal either through visual stimuli or by movement of water through for example optic flow, motion elicited on the retina (Gläser *et al*. 2014, Fjälling *et al*. 2007). Therefore, research considering which of the seals senses that are most triggered by movement is important to conduct and thereafter adaptations on fishing gear, making fish for example either less visible or detectable through water movement could be considered.

Additionally, no attack behavior at all could be observed when dead fish were used as a bait, even though the seal presence were the same as when the fish were alive. The bait fish floated on the upper side of the pot, where they easily could have been caught by the seals. This suggests that they could be present around the cod-pots because of curiosity. If the seals are indeed more curious than hungry when visiting cod-pots, that could be useful information for further studies. For example, knowing what materials, sounds or smells the seals find most exciting could entice them away from the cod-pots. It is also a probability that they did not attack because of the lack of movement or due the dead fish-smell. However, previous studies have shown that even several days old fish used as a bait did not affect if they were eaten or not (Lunneryd 2001).

Also it was found that the number of attacks, but not the proportion of attack behavior increased with greater seal presence. This suggests that seal interactions in general increased with increasing seal presence, not only the attack behavior. This would mean that a seal will not conduct a greater percentage of attacks the longer it is there but perform the same ratio of other behaviors as well. But since the number of attacks is increasing with a greater proportion of seal presence, a low seal presence is still preferred for a low amount of attack behavior to occur.

In the analysis it was also found that the number of fish seemed to affect the attack behavior. The mean number of bait fish was 3,9 and the greatest attack rate happened on cod-pots with 6 baits. It was also found that the observed attacks happened more often on moving fish than on the non-moving fish. When there are more fish in a cod-pot it is more likely that some of the fish will be mobile. Therefore, one theory why attack behavior seems to increase when more fish are in a cod-pot could be because more mobile fish is together, creating a greater visual stimulus for attacking.

The most important cod-pot components

The results from the statistical analysis suggests that some cod-pots might be attracting more seals than others and that certain cod-pot components were more prominent in having that effect. It was found that the shape of the cod-pot was the most important cod-pot component in how much proportion seal presence the cod-pots recorded. Neither the size nor the material of the mesh were found to be important factors in both how much proportion seal presence the cod-pots had. Additionally, the shape was also found to be the only cod-pot component that had a significant effect on proportion attack behavior. Neither the mesh size nor material were found to have an effect.

The shape of the cod-pots

The shape of the cod-pot that had both the greatest seal presence and attack proportion was the Circus-shape. The Circus-shape can therefore in this study be concluded as the least seal-safe shape. What distinguishes the Circus-shape design most from the other two shapes used in this study, is its loose netting from a tip on the cone-shaped top. Both the Sara- and the Lotte-shape have firmly stretched netting all around the pot, and no cone-shaped tip (Figure 2). Also, the round design differentiates the Circus-shape from the quadrangular Sara-shape.

Previous studies have shown that loose netting could be correlated with more attacks from seals (Varjopuro and Salmi 2006). A reason why this might be is that a loose netting makes the seals able to push the mesh further, meaning that they can bite the fish through the netting. If the seals perceives the fish to be more attainable, they are likely to be more attracted to the cod-pot itself, hence the proportion of both seal presence and attack rate is likely to increase. Also, the cone-shaped tip could possibly work visually as a ”flag”, making the cod-pot stand out more in the environment than the other two shapes. The cone-shaped tip also adds additional volume for bait fish to swim in. If this extra volume alters the fish behavior, maybe making it move more, that could make the fish more attractive to the seals.

The cod-pot shape with the lowest seal presence, the Sara-shape, has a sturdy, firmly stretched design of the mesh. Using the same reasoning as described above, the firm mesh makes it hard to steal fish from, thus it might be more unattractive to seals, hence having lower seal presence and fewer attacks.

The mesh material and size

There are different benefits with having a small or large mesh size. A small mesh size catches more fish but catches them at a younger age as well (Varjopuro and Salmi 2006). This is bad from an ecological and conservationists perspective since those individuals might not have been reproductively active yet. On the other hand, a small mesh is harder for seals to pull out fish through and might therefore be a seal-safe alternative. A larger mesh size allows size selection for the fish and is thus better from an environmental point of view. A larger mesh size have also been shown to be effective in lowering the seal attack rate, at least in push-up traps (Lunneryd *et al*. 2003). The larger mesh size was shown to allow chased panicking fish to escape through the mesh, while the calm individuals still would be guided towards the chamber. Since the fish could escape when being chased, the attack success rate of the seals was lowered and thus the interest of the traps themselves was lowered. In the last example the gear themselves would be seal-safe but it would also be in conflict with the fisherman’s interest in having a large catch.

In the present study neither the mesh material nor size affect neither the seal presence nor the attack behavior. However, the Dyneema material was only used in the larger regular mesh size. This makes it hard to establish the true effect of both mesh material and the size in this study. On the other hand, previous studies have shown that Dyneema is a much stronger material than nylon (Suuronen *et al.* 2004). A much stronger material would mean that the attack attempts that do occur are less successful and that the damage on the pots would be smaller.

Individual behaviors

In order to take the most correct necessary actions in managing the seal populations one has to take the behaviors of the individual seals in consideration. From a fisherman's perspective an easy way of solving the problem would be to decrease the population by for example culling of seals. However, studies such as Königson *et al*. (2013) found that the theft of fish and the gear damage is not caused by the populations as a whole, but rather there are specific individuals that are specializing in raiding traps. They found that only 1 percent of the seal population was responsible for 71 percent of the seal visits and that the individuals most prone to causing problems were the large male seals.

In the study by Königson *et al.* (2013) it was observed that the activity-patterns of grey seal individuals are diverse and does not follow a straight line. That is also what could be observed in the present study. One individual stayed for a long time, laying on the cod-pot resting. Another investigated the cod-pot very thoroughly by swimming around it upside-down again and again. A third one wanted to lay underneath the cod-pot, in what seemed like a dominant manner, attacking any other seals swimming by. Since the problem is caused by specific individual seals, to have most effective results from culling, it should be targeted towards those problematic individuals raiding fishing gear. In the study by Königson *et al*. (2013) culling of the raiding individuals was tested as a mitigation effort and proven to be a successful way to reduce the impacts of seals on fishing gear

Conclusion - a seal-safe cod-pot

This study aimed to find answers in order to find solutions to the conflict between grey seals and the coastal fishery, that is a complicated problem in the Baltic sea. The main question to solve was to find which cod-pots that are most seal-safe, and what components of the trap that was having that effect. In order to solve that question the seal presence and attack behavior were studied.

It was found that the most seal-safe cod-pots were having either the Lotte- or Sara-shape, since they were the ones that attracted the least seals and attack behaviors. The material of Dyneema as mentioned earlier, is an very strong material, and is thus important in keeping the gear from being damaged and fish from getting caught. The size of the mesh is also of interest but further research is needed of which specific mesh sizes that should be used, and if the advantages of the Dyneema mesh is worth the extra costs, to fully establish the best cod-pot mesh.

The research in the area of the seal-fishery conflict is an ongoing project and the work is far from finished, but every part on the way is one important step further. This study has brought some new information about which shapes of cod-pots that are most attractive and unattractive for seals to visit. It has also brought information about which factors that are important for the seal presence and attack behavior to happen. Hopefully these findings are pieces in solving the infected seals-fishery competition. The conflict is not only between the seals and the fishery, the fish stocks are affected as well. Only when the seal-fishery conflict is so small that it is negligible it is possible that we will reach the ultimate goal of the Baltic sea. A sea that relies on diverse and abundant marine food webs, thriving fish-stocks, a viable and healthy seal population in combination with a flourishing coastal fishery.

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A huge thank you to the fishermen that helped us, particularly Kurt Siltberg for helping me every single say at the field site at Gotland with driving boats, carrying stuff everywhere and all the time, and helping me and teaching me the art of fishing. Additionally, thank you Claudia von Brömssen for helping us with the statistics, so that everything in the end made sense.

Another huge thank you to 'My Pack', Jesper the human and Xavi the Mighty dog for being there for me in the most stressful of times and giving me reasons to smile when my world outside of this thesis fell apart in the fall. Thank you my family, mom, dad, Vanessa and Melanie, for making me feel at home wherever you are and for always being just a phone-call away.

At last, but not least, I would like to dedicate this thesis and the greatest 'thank you' to all of the conscious beings that participated in this study. Without statistical analysis, I am ratther significantly sure that the seals very voluntarily took part so they are not the ones that I am most grateful to. The 82 bait fish that participated, and the countless of other fish and marine organisms that died in the proceedings, as baits, as by-catch, through handling and for other reasons, did not choose to dedicate their lives to be a part of my study and I am them very thankful. I hope that my work now and in the future will make up their involuntary sacrifices by contributing to a better environment for their fellow marine relatives, neighbors and earthlings.

References

Beck CA, Iverson SJ, Bowen WD, Blanchard W. 2007. Sex differences in grey seal diet reflect seasonal variation in foraging behaviour and reproductive expenditure: evidence from quantitative fatty acid signature analysis. *Journal of Animal Ecology* **76**:490-502

Beisner BE, Haydon DT, Cuddington K. 2003. Alternative stable states in ecology. *Frontiers in Ecology and the Environment* **1**:376-382

Bowen WD. 1997. Role of marine mammals in aquatic ecosystems. *Marine Ecology Progress Series* **158**:74

Cook R, Trijoulet V. 2016. The effects of grey seal predation and commercial fishing on the recovery of a depleted cod stock. *Canadian Journal of Fisheries and Aquatic Sciences*

Fjälling A, Keiner J, Beszczyńska M. 2007. Evidence that grey seals (Halichoerus grypus) use above-water vision to locate baited buoys. *NAMMCO Scientific Publications* **6**:215-227

Folke C, Carpenter S, Walker B, Scheffer M, Elmqvist T, Gunderson L, Holling CS. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics* 557-581

Frank KT, Petrie B, Choi JS, Leggett WC. 2005. Trophic cascades in a formerly cod-dominated ecosystem. *Science* **308**:1621-1623

Gläser N, Mauck B, Kandil FI, Lappe M, Dehnhardt G, Hanke FD. 2014. Harbor Seals (Phoca vitulina) Can Perceive Optic Flow under Water. *PLoS ONE* 9:e103555

Havs- och vattenmyndigheten. 2014. Sälpopulationernas tillväxt och utbredning samt effekterna av sälskador i fisket. *Havs- och vattenmyndighetens rapport* 2014-12-30 [swedish]

HELCOM. 2007. The HELCOM Baltic Sea Action Plan. Helsinki Commission. Available at: www.helcom.fi

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

Harding KC, Härkönen T, Helander B, Karlsson O. 2007. Status of Baltic grey seals: Population assessment and extinction risk. *NAMMCO Scientific Publications* **6**:33-56

Harding KC, Karin C, Tero J, Härkönen T. 1999. Development in the Baltic Grey Seal (Halichoerus grypus) and Ringed Seal (Phoca hispida) Populations during the 20th Century. *AMBIO* **28**:619-627

Jüssi M, Härkönen T, Helle E, Jüssi I. 2008. Decreasing ice coverage will reduce the breeding success of Baltic grey seal (Halichoerus grypus) females. *AMBIO* **37**:80-85

Kauppinen T, Siira A, Suuronen P. 2005. Temporal and regional patterns in seal-induced catch and gear damage in the coastal trap-net fishery in the northern Baltic Sea: effect of netting material on damage. *Fisheries Research* **73**:99-109

Königson S, Fjälling A, Berglind M, Lunneryd S-G. 2013. Male gray seals specialize in raiding salmon traps. *Fisheries Research* **148**:117-123

Königson S, Fredriksson RE, Lunneryd S-G, Stromberg P, Bergstrom UM. 2015. Cod pots in a Baltic fishery: are they efficient and what affects their efficiency? *ICES Journal of Marine Science* **72**:1545-1554

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, Lövgren J, Hjelm J, Ovegård M, Ljunghager F, Lunneryd S-G. 2015. Seal exclusion devices in cod pots prevent seal bycatch and affect their catchability of cod. *Fisheries Research* **167**:114-122

Köster F. 2000. Trophodynamic control by clupeid predators on recruitment success in Baltic cod? *ICES Journal of Marine Science* **57**:310-323

Köster F, Möllmann C. 2000. Trophodynamic control by clupeid predators on recruitment success in Baltic cod?. *ICES Journal of Marine Science* **57**:310-323

Lundin M, Calamnius L, Hillström L, Lunneryd SG. 2011. Size selection of herring *(Clupea harengus membras)* in a pontoon trap equipped with a rigid grid. *Fisheries Research* **108**:81-87

Lunneryd S-G. 2001. Fish preference by the harbour seal (Phoca vitulina), with implications for the control of damage to fishing gear. *ICES Journal of Marine Science* **58**:824-829

Lunneryd S-G, Fjälling A. 2004. Lyckad introduktion av stormaskefällan och pushup fiskhuset. *Yrkesfiskaren* **13**:12-14 [swedish]

Lunneryd S-G, Fjälling A, Westerberg H. 2003. A large-mesh salmon trap: a way of mitigating seal impact on a coastal fishery. *ICES Journal of Marine Science* **60**:1194-1199

Lunneryd S-G, Westerberg H. 1997. By-catch of and gear damages by grey seal (Halichoerus grypus) in Swedish waters. *ICES Annual Science Conference* **11**:10

MacKenzie BR, Köster FW. 2004. Fish production and climate: sprat in the Baltic Sea. *Ecology* **85**:784-794

Suuronen P, Chopin F, Glass C, Løkkeborg S, Matsushita Y, Queirolo D, Rihan D. 2012. Low impact and fuel efficient fishing—looking beyond the horizon. *Fisheries Research* **119**:135-146

Suuronen P, Siira A, Ikonen E, Riikonen R, Kauppinen T. 2004. Mitigation of seal damages by improved fishing technology and by alternative fishing strategies

Vanhatalo J, Vetemaa M, Herrero A, Aho T, Tiilikainen R. 2014. By-catch of grey seals (Halichoerus grypus) in Baltic fisheries—A Bayesian analysis of interview survey. *PloS One*, 9(11), e113836.

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

Varjopuro R, Salmi P. 2006. Complexities in keeping the seals away from the catch: building a "seal-proof"fishing gear. *Maritime Studies* **5**:61-86

Waldo S, Paulrud A, Jonsson A. 2010. A note on the economics of Swedish Baltic Sea fisheries. *Marine Policy* **34**:716-719

Österblom H. 2006. Complexity and change in a simple food web: studies in the Baltic Sea. *Department of Systems Ecology*, Stockholm university, Stockholm.

Attachment I - The protocol

Date	Cod-pot #	Model	Depth	Put down	Taken out	In water	Above-camera	Side-camera	Above-camera observable	Side-camera observable	Sel presence/ observable
12/8-13/8	0	LN	5,2	13:43	14:10	-1d 0h 27n	yes	yes	10h 19m 24s	12h 24m 39s	0,0045
19/8-20/8	1	CN	5,4	20:00		1d	yes	no	4h 55m 40s	0h	0,6897
21/8-22/8	2	LD	5,2	18:00		1d	yes	yes	12h 10m 34s	2h 7m	0,0168
21/8-22/8	3	CN	5,2	18:00		1d	yes	yes	2h 5m 25s	15h 37m 51s	0,0110
25/8-26/8	4	SD	6,6	12:30	10:55	-22h 25m	yes	yes	0h	14h 8m 22s	0,0270
27/8-29/8	5	SD	5,8	13:10		2d	yes	yes	1h 18m	2h 43m 31s	0,4376
2/9-3/9	6	SD	5,6	11:20	11:00	-23h 40m	yes	yes	14h 35m	7h 52m	0,0000
3/9-5/9	7	SD	5,7	11:20	13:30	-2d 2h 10n	yes	no	15h 1m 19s	0h	0,0004
3/9-5/9	8	SN2	5,7	11:20	13:30	-2d 2h 10n	yes	no	18h 18m 13s	0h	0,0002
5/9-7/9	9	SN2	5,2	13:50	?	1d	yes	no	5h 39m 9s	0h	0,0000
22/9-23/9	10	LN2	5,3	16:35	17:50	-1d 1h 15n	yes	yes	2h 40m 26s	2h 24m 23s	0,1417
23/9-24/9	11	LN2	5,3	17:53	10:40	-16h 47m	yes	no	1h 19m 37s	0h	0,0201
24/9-25/9	12	LN2	5,3	10:45	11:28	-1d 0h 43n	yes	no	13h 9m 54s	0h	0,0465
26/9-27/9	13	CN2	6,0	10:45	09:50	-23h 5m	yes	yes	5h 36m 46s	11h 12m 14s	0,0000
26/9-27/9	14	LN	5,4	11:20	09:30	-22h 10m	yes	no	10h 38m 47s	0h	0,0000
27/9-28/9	15	LN	5,6	09:40	09:40	-1d	yes	no	1h 33m 3s	0h	0,0000
27/9-28/9	16	CN2	5,2	16:00	15:39	-23h 39m	yes	no	11h 55m 58s	0h	0,1217
27/9-28/9	17	CD	3,4	16:10	16:00	-23h 50m	yes	yes	0h	12h 12m 52s	0,0121
28/9-29/9	18	SN	5,6	15:47		1d	yes	no	13h 54m 30s	0h	0,0000
29/9-30/9	19	CN2	7	9:50	9:25	-23h 35m	yes	no	11h 33m 14s	0h	0,0000
29/9-30/9	20	CD	5,8	10:00	9:30	-23h 30m	yes	yes	11h 24m 15s	12h 9m 8s	0,0272

Seal presence time	Number of attacks	Number of bait fish put in	Is bait alive	Bait fish after the trial	Alive after the trial	Cod	Turbot	Ide	Tench	White bream	Gear damage
3m 21s	0	3	yes	3	3	3					no
203m 56s	23	2	yes	2	2	2					no
12m 15s	0	3	no	3	0	3					no
10m 19s	0	2	no	2	0	2					no
22m 52s	0	1	yes	0*			1				no
71m 33s	18	6	yes	2	1			6			no
0m 0s	0	2	yes	2	2	2					no
0m 20s	0	2	yes	2	2	2					no
0m 10s	0	5	no	5	0	5					no
0m 0s	0	2	yes	2	1	2					no
22m 44s	12	1	yes	1	1			1			no
1m 36s	0	1	yes	1	1			1			no
36m 44s	18	1	yes	1	1			1			no
0m 0s	0	6	yes	6	6			3	3		no
0m 0s	0	6	yes	6	6			3	3		no
0m 0s	0	6	yes	6	6			3	3		no
87m 9s	52	6	yes	6	5			2	2	2	no
8m 50s	6	9	yes	9	8			2	4	3	no
0m 0s	0	6	yes	6	6			3	3		no
0m 0s	0	5	yes	5	5			1	2	2	no
19m 49s	27	7	yes	7	7			2	3	2	no

**The fish escaped*