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Pingers:

avoiding seals for a porpoise

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1 Abstract

Bycatch in fishing gear is a global issue that affects numerous species worldwide, including the critically endangered Baltic Sea population of harbour porpoises. Acoustic deterrent devices or pingers have been shown to be very effective at reducing bycatch of harbour porpoises, and are currently widely used, but may have a serious negative side effect in aggravating seal depredation caused by the so-called "dinner bell" effect. This project consisted of two parts, the first one looked at the possible presence of a "dinner bell" effect in seals in three different pingers (Banana pinger from Fishtek, Netguard dolphin pinger from Future Oceans and a custom-configured PAL pinger from F^3 Maritime Technology) all claimed to be seal-safe. This was tested by deploying baited stations, with and without pingers, at random locations near a seal haul-out site in the Blekinge County archipelago, Sweden. No evidence of a "dinner bell" effect was found, but the low seal engagement rate did not allow for high certainty in these results. The second part of this project looked at the effectiveness of these pingers (except the custom-configured PAL) at reducing porpoise bycatch in small-scale commercial fisheries on the Swedish West coast. For this, volunteer fishermen set their gillnets both with and without pingers and entered bycatch information in logbooks. An onboard, semi-autonomous two-camera monitoring system was also installed on their boats. The film and logbook data were compared, and the possible effect of the pingers on bycatch was investigated. The FO pinger was found to be effective at reducing porpoise bycatch, while the banana pingers in one area reduced bycatch, but in another had more bycatch than the control nets without pingers.

Keywords: bycatch, dinner bell effect, gillnet fishery, grey seal, harbour porpoise, pingers

2 Introduction

In the Baltic Sea, grey seal (*Halichoerus grypus*) populations have increased considerably in recent decades, leading to growing conflict between seals and various human activities, including coastal fisheries (Harding et al., 2007; Cosgrove et al., 2016; Galatius et al., 2020). Seals are known to not only use auditory and underwater visual cues, but also use above-water vision to detect fishing gear (Fjälling et al., 2007; Westerberg et al., 2008), which can lead to depredation and bycatch (Fjälling, 2006; Read et al., 2006). Several different approaches have been developed to mitigate seal-fishery conflicts, the most important one being the development of seal-safe fishing gear (Westerberg et al., 2008).

The harbour porpoise (*Phocoena phocoena*) is listed as “Least concern” in the IUCN Red List of Threatened Species, however, the Baltic Sea population is considered “Critically endangered” (Hammond *et al.*, 2008; Benke *et al.*, 2014). Currently, the main threats to the Baltic Sea population include pollution and interactions with fisheries, the latter taking the form of depleting food sources and a direct threat through entanglement in nets, particularly gillnets (Tonay & Öztürk, 2003; Read et al., 2006; Hammond *et al.*, 2008). Gillnets, as the name suggests, are nets suspended vertically from the bottom of the sea so that fish get trapped by their gills. Reducing fishery bycatch of harbour porpoises in the Baltic Sea, particularly in gillnet fisheries, is a vital conservation effort to protect this endangered population (Dolman et al., 2021).

There are a few hypotheses that try to explain why harbour porpoises get entangled in fishing nets, but it remains unclear which one or ones most accurately explain what happens. The net may be undetectable, or detectable but not perceived as a threat. It may also be that the weak sonar echo from the net is masked by the stronger echo from nearby living or dead organisms, especially if they have been caught in the net (Larsen *et al.*, 2007). Regardless of the exact explanation, harbour porpoises are amongst the cetaceans that have the most difficulty to detect nets in time to avoid entanglement (Kastelein et al., 2000). Several different mitigation measures have been proposed, developed, and tested, mostly with the aim of increasing detectability of the net or alerting the porpoises towards this possible danger. The most widespread mitigation measure is acoustic deterrent devices (“pingers”), though gillnets reinforced to produce a stronger echo have also been tested (Larsen *et al.*, 2007), among others.

Pingers are small, elongated devices, generally shorter than 20cm in length including the protective case, that can be attached to the net’s float line at specified intervals (depending on the model and manufacturer instructions). The ones used in this study emit ultrasonic frequency sounds that can be heard by dolphins and porpoises from large distances and alert them to the presence of the net. Numerous studies have already been carried out around the globe on the possible effectiveness of different models of pingers on reducing cetacean bycatch. Most evidence points towards pingers being an effective way of reducing porpoise bycatch (Gearin *et al.*, 1994; Kraus *et al.*, 1997; Carlström *et al.*, 2009; Gönener & Bilgin, 2009; Crosby *et al.*, 2013; Larsen & Eigaard, 2014; Zaharieva *et al.*, 2019; Omeyer *et al.*, 2020) and bottom set gillnets are especially important candidates for pinger use (Northridge *et al.*, 2013).

Thus far, there is little evidence of habituation to the pinger sounds (Cox *et al.*, 2001; Carretta & Barlow, 2011; Omeyer *et al.*, 2020), meaning that they remain effective in the long term. However, there have been concerns that they may disturb important habitats and migration routes (Carlström *et al.*, 2009; Omeyer *et al.*, 2020). Habituation is not necessarily a problem, as the pingers may still alert the porpoises to the presence of nets and reduce possible habitat exclusion (Kindt-Larsen *et al.*, 2019). Some authors have suggested that faulty or too sparsely placed pingers could be worse than no pingers at all, as it has resulted in higher bycatch rates than nets that were deployed with no pingers (Carretta & Barlow, 2011; Dawson *et al.*, 2013). On the other hand, for the harbour porpoise, bycatch reduction with the Aquamark 100 pinger remained unaffected when the spacing between pingers on the net was doubled from 200m to 400m (Larsen *et al.*, 2013). Catch rates of target species are also largely unaffected by pinger sounds (Gönener & Bilgin, 2009; Larsen & Eigaard, 2014; Zaharieva *et al.*, 2019).

One main difficulty regarding pinger use in the Baltic Sea is if they can be heard by seals. Phocid seals have an upper hearing limit of around 60kHz (Nedwell *et al.*, 2004) and many pingers emit sounds that are within this hearing range. This can lead seals to associate the pinger's sounds with the presence of easily accessible food in the net (generally referred to as the "dinner-bell" effect), which might, in turn, increase depredation and bycatch of seals (Gearin *et al.*, 1994; Stridh, 2008; Carretta & Barlow, 2011). More recent models of pingers claim to be "seal-safe", meaning they are claimed to be inaudible to seals while remaining effective at deterring porpoises, but these have so far not been extensively tested.

2.1 Goals and objectives

This project was divided into two main parts, one focusing on testing whether these pingers may provide acoustic cues to seals and therefore produce a "dinner bell" effect and the other part focusing on the effectiveness of a few of these "seal-safe" pingers at reducing porpoise bycatch. The goals of each part were as follows:

1. "Dinner bell" effect in grey seals: Evaluate whether commercial "seal safe" pingers produce a "dinner bell" effect in grey seals. This was achieved by comparing rate of fish removal by seals in baited stations with and without pingers.
2. Fishery bycatch: Evaluate whether commercial "seal safe" pingers reduce porpoise bycatch rates. This was achieved by comparing bycatch rates in gillnets with pingers with gillnets without pingers.

3 Materials and methods

3.1 Types of pingers

Three different types of "seal safe" pingers were tested in this project: the "Porpoise & dolphin deterrent pinger" from Fishtek, the "Netguard" Dolphin Pinger from Future Oceans, and a custom-configured "Porpoise-PAL" from F^3 Maritime Technology (Figure 1).

Figure 1. Pictures of the pingers in their casings. The Banana pinger from Fishtek (left), the Netguard Dolphin Pinger from Future Oceans (center) and the PAL pinger (right).

The Porpoise & dolphin deterrent pinger from Fishtek (www.fishtekmarine.com), generally referred to as the banana pinger due to the shape and colour of its casing (Figure 1), emits slightly different semi-randomised multi-harmonic 300ms pings with frequencies between 50-120 kHz and with a nominal source level of 145dBp-p re. 1 µPa at 1 m (Figure 2). The inter-ping interval is semi-random between 4s and 15s. A slightly altered version of this pinger was also used, where the only change was that the lower frequency limit was raised to 59 kHz. This experimental version of the banana pinger, was called the "seal-safe banana pinger" (or SSB) for convenience purposes, even though the original banana pinger is already claimed to be "seal-safe". The spacing between these pingers on a net should be about 200m according to the manufacturer.

The "Netguard" Dolphin Pinger from Future Oceans (www.futureoceans.com), here referred to as the FO pinger (Figure 1), emits 300ms pings with a fixed peak frequency at 65-69kHz and with weaker harmonics at 118-130kHz (Figure 3). The nominal source level is 145dBp-p re. 1 µPa at 1 m. The inter-ping interval is semi-random between 4s and 6s. Like the banana pinger, it should have a spacing of about 200m between pingers on the net.

The custom-configured “Porpoise-PAL” from F^3 Maritime Technology, here referred to as just PAL, emits multi-harmonic pings with a frequency range of 40 - 156 kHz and with a nominal source level of 145dB re. 1 µPa at 1 m (Figure 4). The inter-ping interval is semi-random between 4s and 31s. This pinger was only used for the “dinner bell” effect part of this project and only a single unit was available, as this was specifically configured for this study. The spacing on a net for this pinger should be 190-200m.

Both the Banana and the FO pingers should, according to their manufacturers, last for about 12 months with a 50% usage rate (12h in the water and 12h out of the water, every day), when powered by a 1.5V alkaline C cell. Durability may change depending on water temperature and other factors. Some FO pingers were noticed to run out of battery much quicker than expected, so a pinger battery life test was carried out with 10 Banana and 10 FO pingers.

This battery test consisted in submerging the pingers in water and leaving them on continuously. All pingers have a mechanism that automatically turns them on when submerged and off when they are taken out of the water and so leaving them submerged ensures that they are working continuously. Their battery status was checked almost weekly, both through the pinger’s status light that turns on when the pinger is removed from the water and with the help of a bat detector, that make their high frequencies audible to the human ear. Given that the pingers should have a battery durability of 12 months when being used for 50% of the time, it would be expected for them to have a durability of five to six months when continuously submerged and in operation.

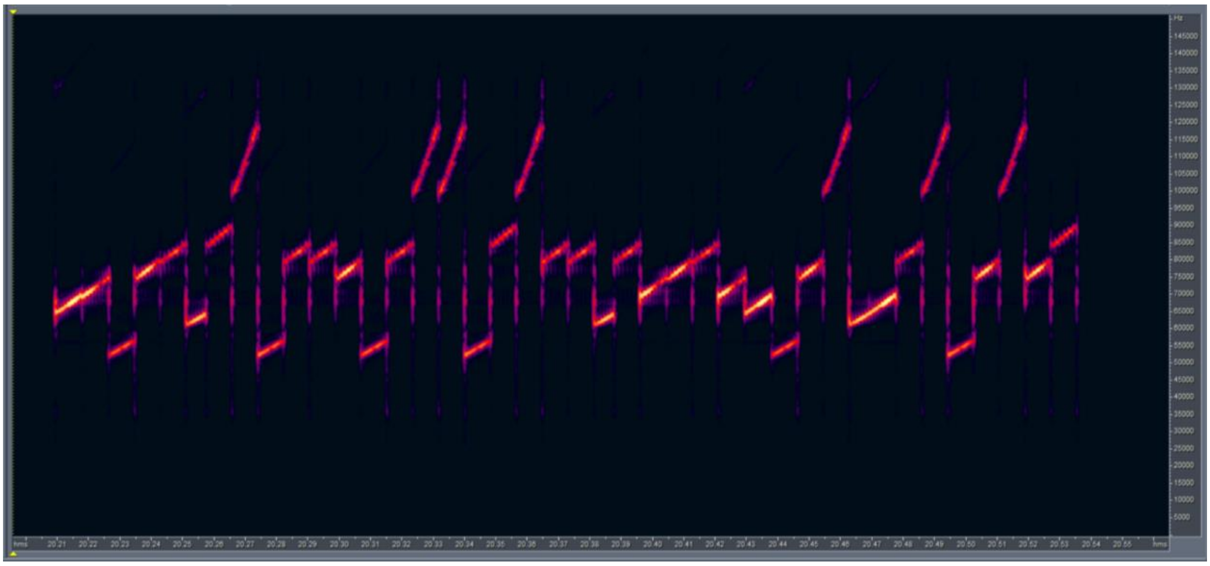

Figure 2. Spectrogram of a Banana pinger sound. The vertical frequency axis ranges up to 150kHz. The duration of the ping is around 300ms.

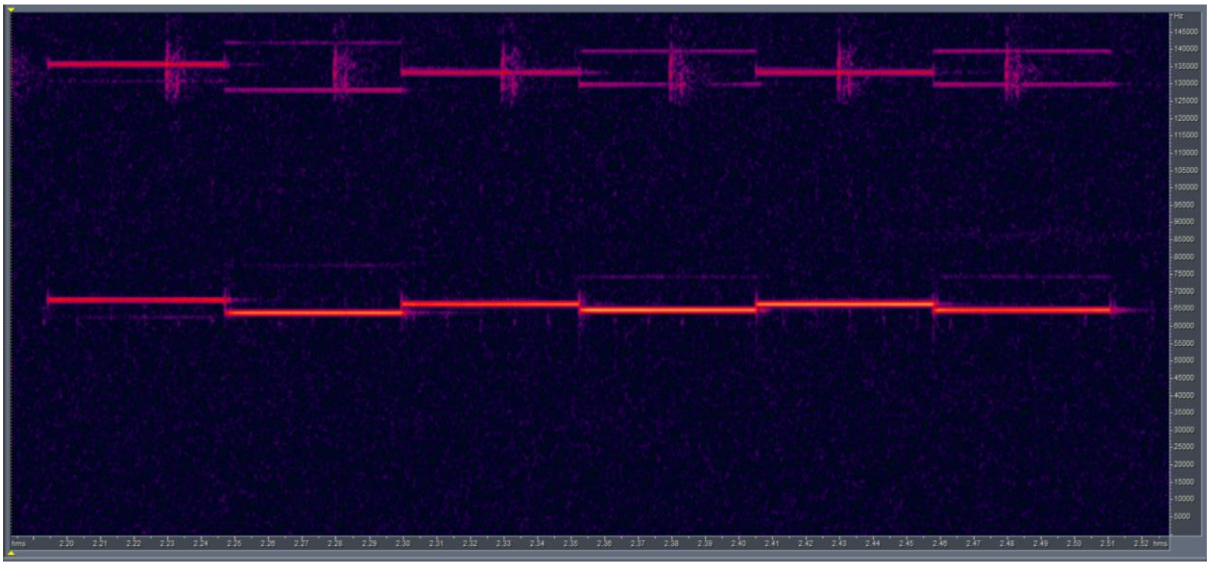

Figure 3. Spectrogram of a Future Ocean pinger sound. The vertical frequency axis ranges up to 150kHz. The duration of the ping is around 300ms.

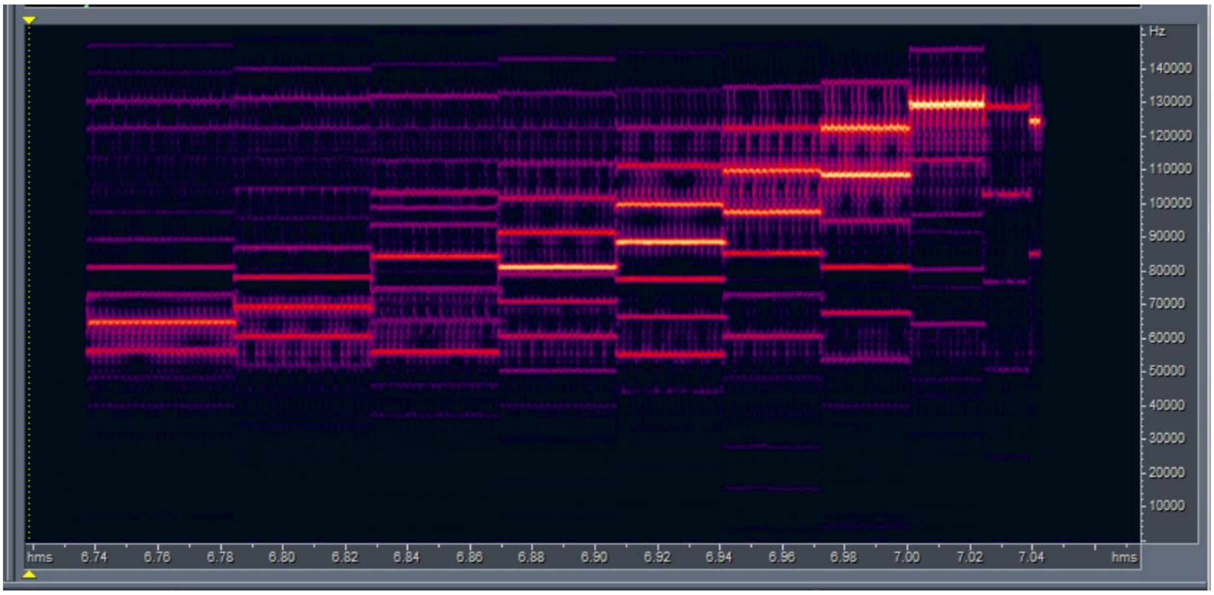

Figure 4. Spectrogram of the custom-configured sound from the PAL pinger. The vertical frequency axis ranges up to 150kHz. The duration of the ping is around 300ms.

3.2 “Dinner bell” effect in grey seals

3.2.1 Experimental setup

The data collection was carried out between June 2nd and June 19th of 2021, at Utklippan, Sweden (55.9552° N, 15.7033° E; Figure 5) located in a nature reserve which is protected under the EU Bird directive (SPA) and the Species and Habitats Directive (SCI; see map tool at Skyddad natur (naturvardsverket.se)). This location was chosen because it is a grey seal haul out site, meaning a location where seals come to rest on skerries around the Utklippan islands;

the period of the study also coincided with the annual moulting when the seals gather in this site.

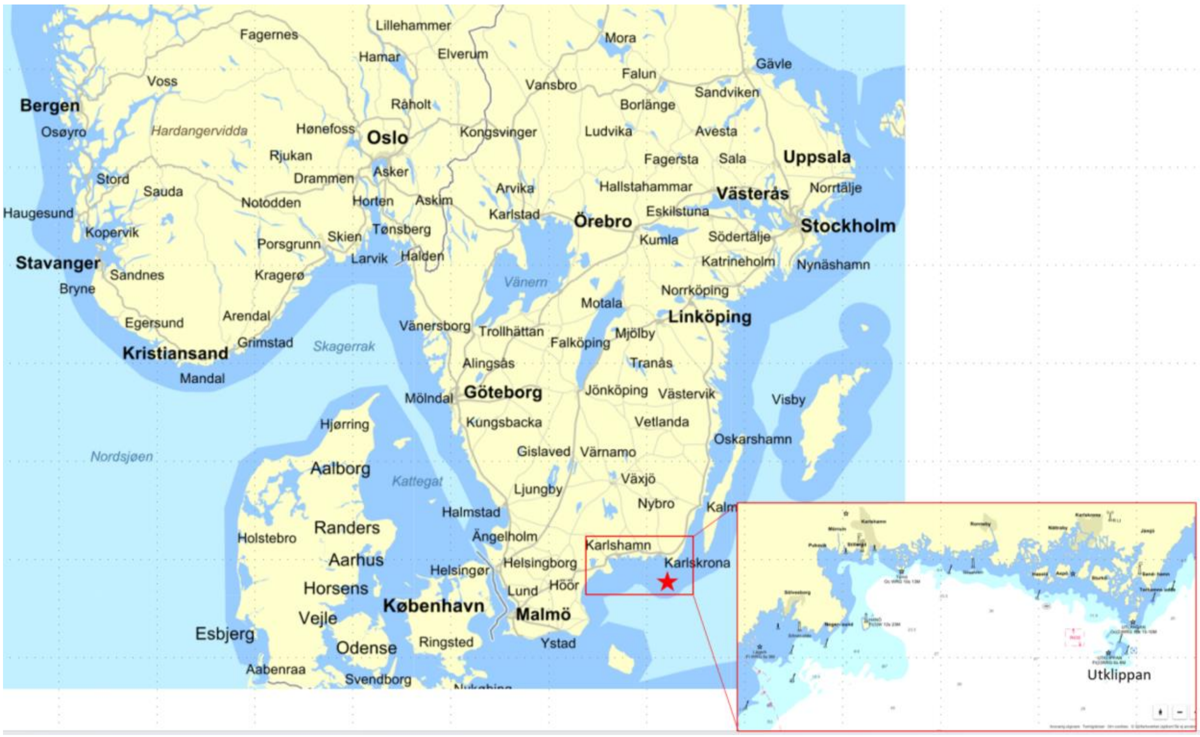

Figure 5. Map showing the location of the islands of Utklippan in Southern Sweden (Blekinge County), where the data collection for the "dinner bell" effect part of the project took place.

To understand whether the different types of pingers are audible to seals, buoy stations baited with fish, with and without pingers, were deployed. If the pingers were audible to the seals over long enough distances, and if this led to a "dinner bell" effect, the baited stations with pingers would be expected to be visited more frequently.

There were sixteen baited buoy stations, five without pingers (control), five with banana pingers, five with future ocean (FO) pingers and one with the PAL pinger. They were placed at depths varying between 6.6m-14.9m. The stations were deployed in random locations, at least 200m apart from each other. In total, the control and FO pinger stations were deployed 59 times each, the banana pinger stations were deployed 55 times and the PAL pinger station was deployed 11 times.

The buoys were attached to an anchor by a rope. Suspended about 4m above the sea floor, the bait (two dead herring) was attached using a wire and a float was tied to the rope just above the bait to keep the rope tense and vertical. In stations with pingers, these were attached to the rope between the float and the wire with the bait (Figure 6A). In some cases, a camera was placed one meter below the bait, facing upwards, to document whether a missing bait had been taken by a seal or fallen off. Between the bait and the buoy at the surface the line had varying lengths, depending on the depth at which the buoy station was placed.

The type of bait used for these stations, and throughout most of the experiment, was dead herring. On one occasion, four dead cods were deployed, one on each baited buoy station (control, banana pinger, FO pinger and PAL pinger) together with a herring to test if that would increase seal interest. All fish were provided by a local fisherman. The herring arrived packed and frozen and was stored in a freezer until use, then thawed in the morning or directly on the boat.

Each station was checked daily, except for two days due to adverse weather. When the bait was found still attached it was replaced with fresh fish and if both fish were missing or had only their head left (a typical sign of a seal having taken the fish), the station was moved to a new random location, somewhere around the islands, with a new fresh bait. The time of deployment and recovery was noted for each station regardless, as well as water depth, and latitude and longitude of the station. For the stations with cameras, batteries were replaced with recharged ones, and memory cards were exchanged with empty ones. Due to barely any fish disappearing or showing signs of being taken by a seal, the cameras were removed after the first week, with the intention to set them out again if seal activity increased.

In addition to the baited buoy stations, there were also two cod pots baited with live cod, deployed at depths of 5m to 7m. On the buoy line attached to the pot, two dead herring were suspended just above the pot as a visual bait, so that, if there was any seal encounter, it would be clear which type of bait the seals preferred, live inside the pot or dead outside. Above the dead bait there was a camera pointed downwards, so that it would record the pot and the herring attached above it (Figure 6B). One of the pots had an FO pinger placed above the camera while the other one had no pinger (control).

The pots were checked every second day, when the weather allowed it, and were deployed a total of six times each. During checks, untouched dead bait was replaced with new fish and the live cods in the pot were checked with the help of an aquascope. If the cods could not be seen or showed signs of poor health, the pot was brought to the surface and the fish replaced, if necessary. The live bait for these stations was kept in a fyke net suspended from a pier at the entrance to the Utklippan harbour. Time spent in the water, location, water depth and weather data were all also recorded during checks and the cameras were supplied with empty memory cards and recharged batteries. Like in the buoy stations, this footage was also thoroughly inspected.

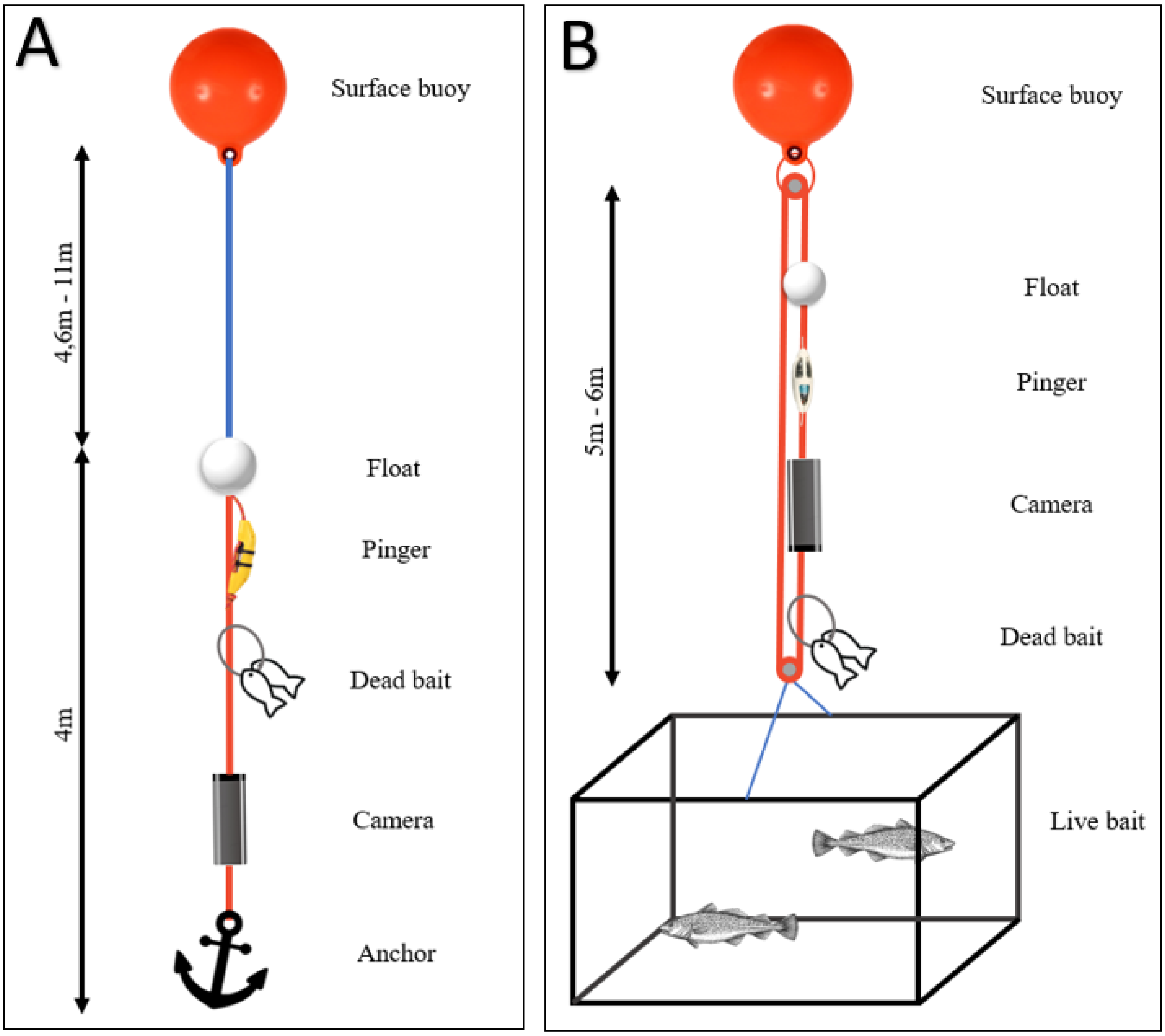

Figure 6. The setup of the buoy stations (A) and the cod pots (B) with pingers, bait and cameras. Note that in the buoy stations the camera was facing up towards the bait, while in the cod pots the camera was facing down towards the dead bait and the pot with the live bait. In the pot setup there was a pulley system, allowing the pinger, camera and bait to be hauled to the surface without lifting the pot.

The characteristic sign of a seal having taken a fish is when only the head remains attached to the wire and the body is missing. However, this was only recorded three times (once each in a control, banana and FO pinger stations) and the second fish of the bait was always found still attached and intact. For this reason, the different possible instances of seal activity were put together into one category, which includes instances when one or two fish were missing, or when only the head remained attached.

Concurrent to these experiments, bidaily seal counts were conducted, once in the morning (around 08:00) and once in the evening (around 17:00). The counting process, as the name suggests, involved tallying the number of seals visible on two different skerries from the

Southern Utklippan island, using binoculars. Each skerry's seals were counted twice, and the average of these two values was recorded, along with the deviation between the two observations. If the values differed significantly, a third count was conducted and included in the average. The daily average number of seals was calculated as the sum of the averages from the two skerries. These seal counts served as an indicator of the size of the daily seal population in the area and as a potential explanatory variable for variations in seal activity from day to day.

3.3 Fishery bycatch

3.1.1 Study area

This part of the project relied on the voluntary participation of commercial fishermen operating off the West Coast of Sweden, more specifically in ICES subareas 20 (Skagerrak), 21 (Kattegat) and 23 (Öresund/The Sound) (Figure 7). This was part of an ongoing project by SLU Aqua, which allowed for the inclusion of data since 2018.

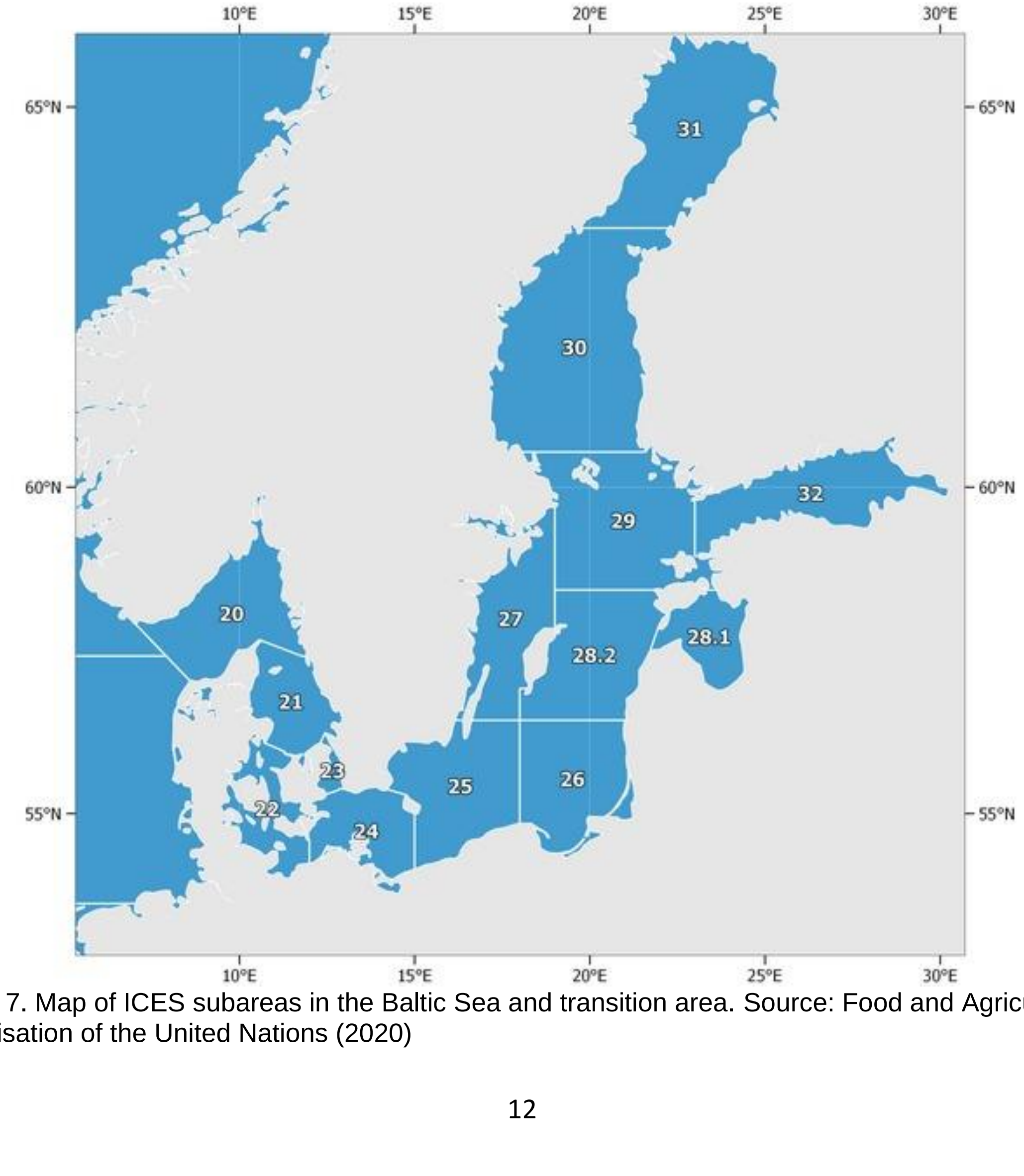

Figure 7. Map of ICES subareas in the Baltic Sea and transition area. Source: Food and Agriculture Organisation of the United Nations (2020)

3.2.2 Data collection and experimental setup

Logbooks were kept by the fishermen detailing porpoise bycatch per emptied gillnet link. Other information in the logbooks included link dimensions (length, height, mesh size), haul date, soak time, presence and type of pingers, seal and seabird bycatch, amount of and fish species caught, and any seal damage noticed. Additionally, a monitoring system with two onboard cameras and GPS loggers was installed onboard the fishing vessels so that the haul of the gillnets and the sorting table could be filmed. The cameras were turned on by the fishermen operating that boat before leaving port and off when coming back to port and thus recorded continuously throughout the fishing trips. The camera footage and the logbook protocols were collected every few weeks, depending on how many days the fishermen had been fishing and recording. The resulting camera footage was analyzed using BlackBox Analyser, a program developed by Anchor Labs (http://www.anchorlab.dk/ Analyzer.aspx). Logbooks with bycatch data have successfully been used in previous studies with similar goals (Lunneryd *et al.*, 2005), where logbook data was found to be sufficiently reliable. The current study also aimed to investigate the reliability of logbooks compared to the corresponding camera footage. If the logbooks were found to be reliable, a much more extensive dataset would be available for analysis, because logbooks have been maintained for longer than the onboard camera monitoring system. Another significant advantage is the potential to avoid time-consuming video analysis.

Ideally, each fisherman would deploy strings of nets always of the same size (length, height and mesh size), with or without pingers each time, so that varying parameters would have a minimal impact on the results, but this was not always achieved. Each fisherman used their own equipment, which meant that the nets often had varying dimensions, especially between fishing boats and depending on the target species. Any trips in which the pinger had not been used according to the instructions given (incorrect spacing or using different types of pingers for the same string of nets) were excluded from the analysis.

3.2.3 Electronic monitoring of catch

As already mentioned, there were two cameras on each boat: one covering the outside of the boat, where the net came out of the water, and one covering the fish sorting table (Figure 8). The outside camera allowed for the detection of any catch or bycatch, as well as “drop-outs”, which occur when a catch or bycatch falls out of the net without making it onto the boat and thereby not being seen by the fisherman. The fish sorting table camera is vital for species identification and confirmation of bycatch captured by the outboard camera. Only one of the boats did not have an inboard camera.

This camera system was set up as part of an ongoing bycatch study by SLU Aqua which explores the fact that video monitoring has been shown to be more cost-effective and reliable than onboard observers (Kindt-Larsen *et al.*, 2012).

The footage of each camera was classified into different quality categories, depending on factors such as weather, dirt on the camera lens, focus and sun glare. Camera angle was not taken into consideration for film quality but registered separately so that the camera position and orientation on the boat could be adjusted accordingly in the future. The different quality categories were “very good” (1), “good” (2), “bad” (3), “very bad” (4) and “camera not working” (5). The quality category of the film was determined in the following way: qualities 1 and 2 allowed for the identification of almost all bycatch and catch species; quality 3 allowed for the recognition of certain species (e.g. smaller species of birds may be hard to distinguish from fish species, but an educated guess is still possible) and in quality 4 identification was very difficult (e.g. a porpoise might still be identifiable due to its shape and size, but bird species would be extremely hard to distinguish from fish or algae), if not impossible (Figure 8). Start and end time of each haul (period of time during which the net is being removed from the water) were noted, as well as the coordinates of these start and end times. Bycatch was, of course, also registered in the film analysis, with information such as species, coordinates of the bycatch and whether the catch was a “drop-out”. Periods where most of the net could not be seen on the outboard camera film were also registered, as this did not allow “drop-out” catch to be seen and logged.

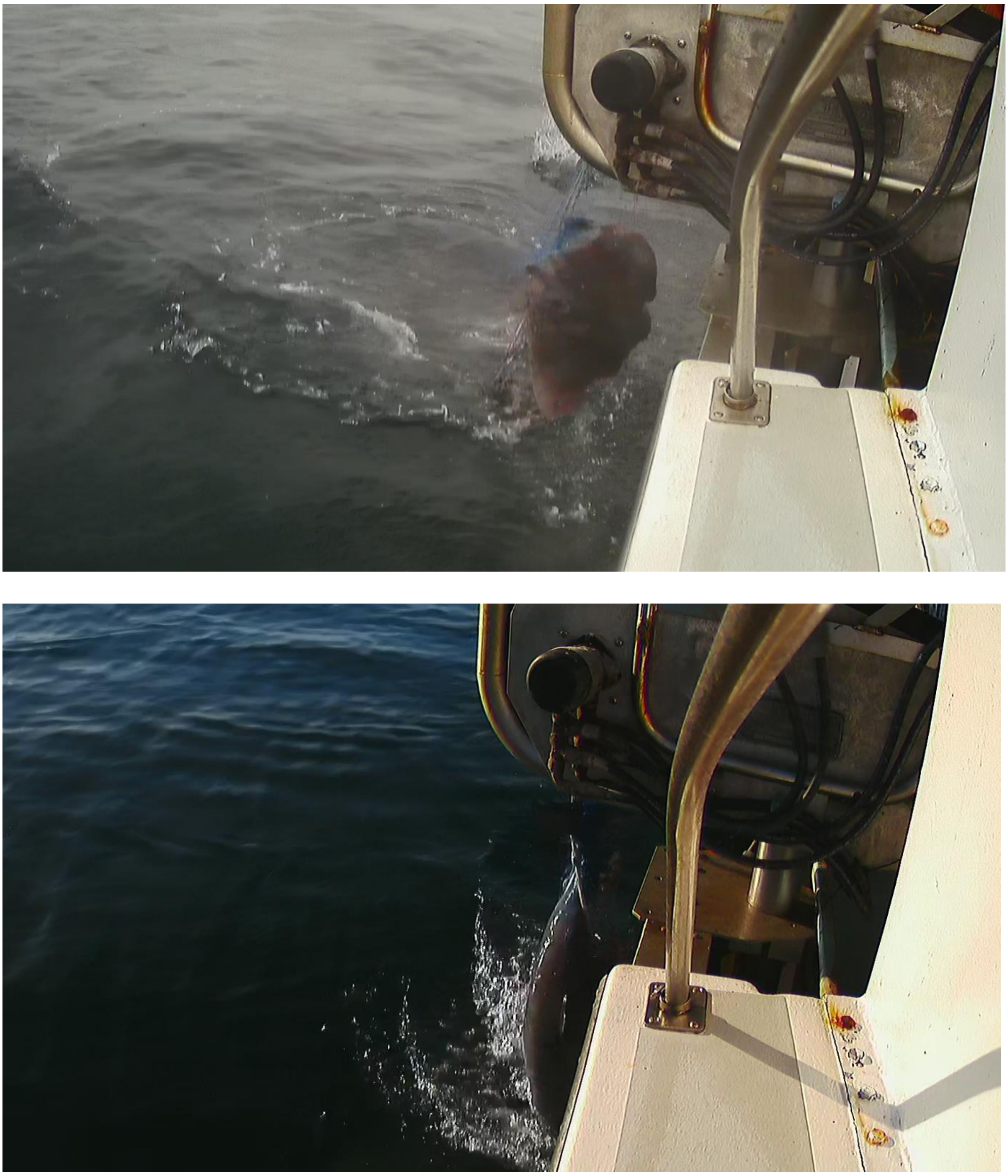

Figure 8. Top: a ray caught in the fishing net, captured by the outboard camera. The quality of this image was considered a 3. Bottom: a porpoise caught in the fishing net, also captured by the outboard camera. The quality of this image was considered a 2.

3.2.4 Statistical analysis

A Cohen's Kappa test was performed to compare the data reported in the fishermen's logbooks and the data obtained from the camera footage that was analysed by various members of SLU Aqua. If the information in the logbooks was found to match the one extracted from the camera footage, then it could be used in the statistical analysis, which would allow for a much larger number of data points. A high coefficient in this test indicates a high agreement between logbooks and camera footage, however, a case-by-case comparison was also carried out, so that the nature of the agreement or disagreement could be determined. In the assessment of bycaught birds, for example, it is not only important that the presence or absence of bycatch is reported, but also the number of individuals bycaught can affect results greatly.

Cohen's suggested interpretation of Kappa results (Cohen 1960) categorizes them as follows: values less than or equal to 0 indicate no agreement, values between 0.01 and 0.20 suggest none to slight agreement, values between 0.21 and 0.40 represent fair agreement, values between 0.41 and 0.60 indicate moderate agreement, values between 0.61 and 0.80 suggest substantial agreement, and values between 0.81 and 1.00 imply almost perfect agreement. However, it is worth noting that this would mean that even relatively low levels of agreement could be deemed substantial. Therefore, many references recommend setting a threshold of at least 0.8 (80%) as an acceptable level of agreement (e.g., McHugh, 2012) which was the reference value used in the present study.

Given the large number of different factors that could potentially influence the dependent variable and the nature of the data, a negative binomial regression analysis was performed. The dependent variable was the number of porpoises caught per haul. The fixed factors included in the model were “type of pinger” (categorical), “year” (categorical) and “fishing area” (categorical). “Soak time” (continuous), “net mesh size” (continuous), “link height” (continuous) and “link length” (continuous) were included as covariates. The categories for type of pinger were control, FO and banana; the categories for year were 2018, 2019, 2020 and 2021 and the categories for fishing area were 20 (Skagerrak), 21 (Kattegat) and 23 (Öresund/The Sound). All the models were run in IBM SPSS Statistics version 28.

4 Results

4.1 “Dinner bell” effect in grey seals

The possible instances of seal activity per type of baited station can be found in Table 1. In Table 2, these are compared with the numbers obtained from the seal counts carried out twice per day, as well as the average wind speed recorded on that day (Swedish Meteorological and Hydrological Institute). The stations were not checked on the 12th and 13th of June due to adverse weather conditions which resulted in very long soak times for the stations deployed on the 11th.

There were some difficulties with the cameras attached to the baited buoy stations, either with the positioning of the camera, the camera turning off for no apparent reason or water leaking into the case. For this reason, all cameras were removed until potential signs of seal interactions increased, which did not happen. A total of 152 hours of film were collected, but no seal was spotted in any of them.

Table 1. Possible instances of seal interactions with the baited buoys per number of times stations of each type was deployed, with average depth (m) and average soak time (h). The single PAL station was temporarily lost for three days, hence the high average soak time.

Type of station	***Number deployments***	***Average soak time (h)***	***Average depth (m)***	***Possible instances of interaction***
Control	59	28.40	9	9
Future Ocean	59	28.37	10	10
Banana	55	28.66	12	7
PAL	11	34.60	8	0

Table 2. Number of stations where seal interactions may have occurred, with average of bidaily seal counts on the haul out skerries, average wind speed of the day and average soak time of the deployed baited buoy stations. No stations were checked on the 12th and the 13th of June due to adverse weather conditions, hence the high average soak time for the 11th. The * indicates the days where scat collection was carried out on the haul out skerries, which forced the seals away from the haul-out site.

Date	***Average seal count***	***Average wind speed (m/s)***	***Average soak time (h)***	***Number of stations deployed***	***Possible instances of activity***
02/06/2021	63	7.4	25.98	12	3
03/06/2021	106.5	6.2	24.82	16	2
04/06/2021	117.5	5.8	28.69	16	0
05/06/2021	39*	3.4	15.96	16	1
06/06/2021	11.5	3.4	27.31	16	3
07/06/2021	22.7	4.0	19.99	16	0

08/06/2021	17.5	5.8	23.54	16	2
09/06/2021	54	7.1	26.14	16	1
10/06/2021	51*	6.6	25.23	16	0
11/06/2021	22.5	5.0	69.90	16	8
12/06/2021	19.5	10.4	-	-	-
13/06/2021	6	10.0	-	-	-
14/06/2021	5.5	7.7	30.42	16	6
15/06/2021	44	7.9	26.82	12	0

Regarding the cod pots, all the dead and live bait were found intact each time they were checked and replaced. A single live cod escaped from the pot due to it not being closed properly. Each pot was checked a total of six times, with the soak times varying between one and three days. In total, about 231 hours of film were recorded, out of which about 158 hours contained usable footage (enough daylight to see the pot and some of the surrounding seabed). No seal was seen in any of this footage which meant that no visiting rate could be calculated.

4.2 Fishery bycatch

A total of 216 hauls from 71 different fishing trips were analysed in BlackBox Analyser. From these 216 hauls, 7 porpoises, 1 seal, 26 birds, 188 Elasmobranchii and 4 pieces of litter were seen on film.

The Cohen's Kappa test showed that the porpoise bycatch data from the protocols had a high coefficient (k=0.852) with the haul data. From the 216 hauls analysed, there was only a single instance in which a bycaught porpoise had not been noted in the correct haul protocol. After discussing with the fisherman in question, it was determined that this mistake was due to written miscommunication and so the protocol information was considered fully reliable and usable. Bycatch data regarding bird bycatch had a much lower coefficient (k=0.696), while bycatch data regarding sharks and rays was completely absent from the protocols and therefore could not be compared. A case-by-case inspection showed that bird bycatch data had several inconsistencies between protocols and analysed footage, not only in the presence/absence of bycaught birds but also in the number of individuals recorded (e.g., ten bird were seen on film but fishermen reporting only one bird or none). For this reason, only porpoise bycatch data from the protocols was used as a dependent variable in the model.

The protocol dataset consisted of 1422 hauls in total, of which 709 had no pingers, 377 had banana pingers, and 336 had FO pingers (detailed descriptive statistics can be found in Table 3). For the model, regular banana pingers and “seal-safe” banana pingers (SSB) were put together in the same category, as there were very few hauls with the SSB and these two pinger types are very similar. In all the 1422 hauls, 35 porpoises were caught, of which three in the same haul and three in hauls with two porpoises each. The proportion of hauls in which bycatch occurred was 2.65% for the control, 2% for the banana pinger and 0.59% for the FO pinger (Figure 9).

All continuous variables had quite a large range of values, with link length ranging from 70 to 2000 meters, soak time ranging from 2 to 768 hours, link height ranging from 1.5 to 6 meters and mesh size ranging from 55 to 250 mm.

Table 3. Descriptive statistics of the protocol data. Effort is a measure created by multiplying the length of net (in kilometres) of a haul by its soak time (in days).

		Type of Pinger			
		Control	**Banana**	**Future oceans**	***Total***
Skagerrak (ICES 20)	**Number of hauls**	61	71	45	
	Average effort (km*day)	3.56	3.81	3.33	
	Number of porpoises	10	6	2	
Kattegat (ICES 21)	**Number of hauls**	95	96	82	
	Average effort (km*day)	1.18	1.4	1.41	
	Number of porpoises	3	4	0	
Öresund (ICES 23)	**Number of hauls**	553	210	209	
	Average effort (km*day)	0.66	0.76	1.01	
	Number of porpoises	9	0	1	
Total	**Number of hauls**	709	377	336	1422
	Average effort (km*day)	0.98	1.5	1.42	1.22
	Number of porpoises	22	10	3	35
	Average link height (m)	2.91	2.59	2.71	2.78
	Average mesh size (mm)	144.03	178.51	173.99	160.25

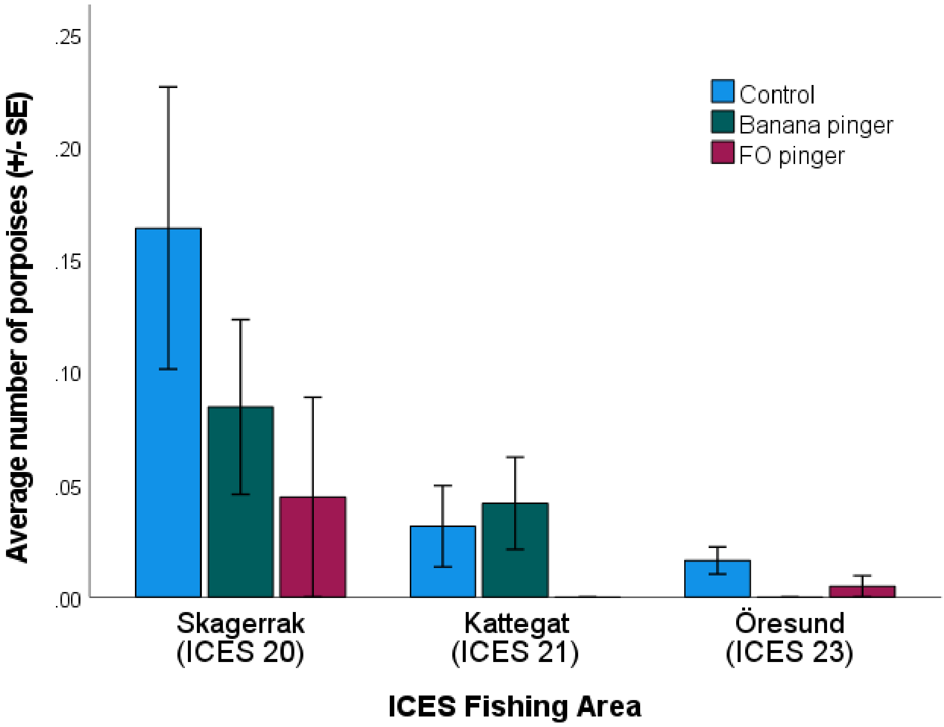

Figure 9. Graph detailing the average number of bycaught porpoises (+/- SE) per haul in the three ICES fishing areas (Skagerrak, Kattegat and Öresund/The Sound), for the three treatments (control, banana and FO).

The type of pinger was a significant factor ($F_{(2,1422)}$=9.475, p=0.009), with the banana pinger marginally reducing bycatch ($B_{(1,1422)}$= -0.747, p=0.071) and the FO pinger significantly reducing bycatch ($B_{(1,1422)}$= -1.609, p=0.012). Link length was also a significant factor in the amount of bycatch ($F_{(1,1422)}$=11.412, p<0.001) while soak time ($F_{(1,1422)}$=3.449, p=0.063), ICES fishing area ($F_{(2,1422)}$=5.297, p=0.071), link height ($F_{(1,1422)}$=0.322, p=0.571), mesh size ($F_{(1,1422)}$=0.793, p=0.373) and year ($F_{(3,1422)}$=3.711, p=0.294) did not significantly affect bycatch.

The pinger battery life test showed that there was an issue with some of the FO pingers. All ten FO pingers tested ran out of their factory battery before the expected time, which should have been five to six months of continuous operation. After having their factory batteries replaced, several pingers showed signs of the new battery also running out sooner than expected, some failing after just 2 months. For comparison, over the three and a half months that this battery test was running, none of the banana pingers ran out of their factory batteries, and their status light indicated that they still had over 70% of charge at the end.

5 Discussion

5.1 "Dinner bell" effect in grey seals

The aim of this part of the project was to evaluate whether any of the tested pingers produced a "dinner bell" effect. Considering that grey seals can hear up to ca 60kHz (Nedwell *et al.*, 2004) and have been known to use certain pingers as a locator for fishing nets (Gearin *et al.*, 1994; Stridh, 2008; Carretta & Barlow, 2011), it was expected that the baited stations provided with the banana pinger, that emits sounds as low as 50kHz, would be visited more often than other stations. The PAL pinger emits frequencies as low as 30kHz which should also have been audible to seals, although these frequencies are emitted at much lower source levels than the peak amplitude frequencies between 80 and 130kHz. No indication of a "dinner bell" effect was found for any of the pingers, which was a positive finding, as such a "dinner bell" effect would aggravate depredation and discourage fishermen from using these porpoise bycatch-reducing devices. However, the overall low rate of seal engagement with the baited buoys makes it impossible to safely conclude that all the tested pingers would not produce a "dinner bell" effect. Follow-up studies will be required, especially with the banana pinger.

A low engagement rate (18%) with baited buoys was also observed by Fjälling *et al*. (2007), even though their stations were deployed over 600 times over the course of 2 months. Their study also concluded that wind speed, number of seals in the area, buoy size and even the presence of cameras affected the number of visits. Undeniably, the scat collections on the haul-out skerries that were carried out twice during the three-week period of this study disturbed the seals and forced them into the water. Three weeks may also not be enough time for the seals to learn that the pinger sounds are associated with fish, especially given the low engagement rate.

Dead herring was the primary bait used on the baited buoys as herring has been shown to be one of the preferred prey species of seals (Lunneryd, 2001). However, Lunneryd (2001) used larger fish (up to 50cm) so in future studies it would be recommended to use larger baits. The cod pots were set out halfway through the three-week period, to compare the dead herring with two live cod in a pot that was not seal safe. Possibly, these pots were not deployed long enough for the seals to discover and explore them.

There is also a possibility that the seals were, in a way, overwhelmed by the multiple projects being carried out in the vicinity of this haul-out site. A few days before the data collection officially started, some baited stations were set out without any pingers, and the seals seemed to have been taking the fish. There is a possibility that, as the data collection was in full swing, the disturbances and the many nets and stations in the area made the seals more wary. For future studies, it would be recommended to extend the data collection to allow the seals to “learn” to use pinger sounds to locate the baited buoy stations, in case they can hear them. Additionally, incorporating a pinger that has been demonstrated to be audible to seals could enhance future discussions and comparisons.

5.2 Fishery bycatch

The aim of this part of the project was to evaluate whether pingers that are claimed to be “seal-safe” are still effective at reducing porpoise bycatch. The expected result was, of course, that gillnets with pingers would have lower porpoise bycatch numbers or a lower bycatch rate than the control nets. While the FO pinger was shown to be effective, the results on the banana pinger require further investigation. While pingers are generally considered effective at reducing bycatch (Gearin *et al.*, 1994; Kraus *et al.*, 1997; Carlström *et al.*, 2009; Gönener & Bilgin, 2009; Crosby *et al.*, 2013; Larsen & Eigaard, 2014; Zaharieva *et al.*, 2019; Omeyer *et al.*, 2020), the different sounds the pingers emit can lead to varying effectiveness. In this study, the 'banana pinger' category included a small number of SSB pingers, which were grouped together due to the limited number of hauls with SSB pingers. However, the lower frequency limit of 59 kHz from the SSB pingers may have generated results different from the regular banana pingers, the lower frequencies of which may have travelled longer and thereby have a longer deterrent range. Additionally, recent source level measurements show that the banana pinger sounds exhibit significantly lower energy levels than the FO pinger sounds. This is attributed to considerable amplitude variations within the different sections of the 300ms duration (Courtesy M. Amundin, Kolmården Wildlife Park, Sweden). As the mammalian ear functions as an energy detector, this phenomenon may reduce both its transmission range and potential deterrent effect. The FO pinger, on the other hand, transmits an almost pure tone with even amplitude, thus with a higher energy content, which makes it audible over longer ranges. These sound energy differences may account for the variations observed in the effectiveness of the different pingers.

There is also a possibility that the banana pinger is reducing bycatch, but that some unknown technical or user error caused the higher bycatch rate seen in Kattegat. Considering that this was restricted to only one fishing area, it could be that it was a more bycatch-prone area, or that a specific fishing boat was causing this inflation. Further investigation is necessary to determine the most likely cause.

Most studies that focus on the effectiveness of pingers do not rely on the voluntary participation of fishermen and are often set up with standardised nets with equal size and equal soak times. This allows for a much simpler statistical analysis, as there is much less variation in the data. In this case, each fisherman used their own nets of varying sizes, generally depending on their target species, but also sometimes used varying sizes for the same species. Soak times also varied immensely depending on target species, but also other factor that could not be controlled for, such as scheduling or bad weather. While this makes the analysis more complex and extensive, it is very important that pinger effectiveness is measured in real-life settings. The experimental setup of the current study also provides further information regarding which of the factors included in the model affect bycatch.

The overall low number of bycaught porpoises, resulting in a high number of zeros in the data, also increased the difficulty of the analysis. However, a low porpoise bycatch rate is common when carrying out studies of this dimension (Björklund Aksoy, 2020), especially in the Baltic Sea where the porpoise density is extremely low (Amundin et al., 2022). This would make it very difficult to monitor bycatch as well as the possible effect of pingers in the Baltic. It is therefore important to verify that the efficiency of pingers to be used in the Baltic Sea is optimized.

There are also other factors that were not included in the present analysis, but which may have had an impact on porpoise bycatch numbers. Northridge *et al.* (2017) identified several factors that affected marine mammal bycatch in gillnets, such as time of the year and water depth. Larsen *et al.* (2021) confirmed that time of the year was an important factor that affected porpoise bycatch in gillnets in the ICES areas also included in this study. Bjørge *et al.* (2013) recommended that nets with large mesh size should not be used at depths less than 50m, as both large mesh size and shallower depths greatly affected porpoise bycatch. These factors could be further explored in future studies; however, it is important to keep in mind that the more factors are included in a statistical model, the harder it is for the model to pick up on statistical differences caused by the different factors.

The negative binomial regression was chosen as the final model because it resulted in the best fit for the factors and the type of data collected. Other models, such as GAM or zero inflated versions of these two models were also considered but ultimately dismissed, as they resulted in a worse fit or could not be explored fully due to the limitations of the software used. Besides pingers, link length was the only other parameter to significantly impact porpoise bycatch, which agrees with the intuitive assumption that the longer a fishing net is, the higher the chance that a porpoise may swim into it and get entangled. According to a review performed by Northridge *et al.* (2017), link length, link height, mesh size and soak time have all been shown to have an impact on marine mammal bycatch. This does not completely agree with the results obtained in the present study, but there could also be differences between target fish species that were not explored in the study. Fishing area is certainly an interesting factor to explore further, as it came close to being a significant factor. Exploring whether specific locations are more prone to bycatch, particularly in relation to seasonal variations, could facilitate more efficient and effective policymaking.

User error can also be an issue when working with logbooks kept by voluntary fishermen (Lunneryd et al., 2005). There were some instances in which incorrect use of the pingers was detected (such as incorrect placement on the net) either through the video analysis or through the data collection visits and check-ins with the fishermen. Any hauls in which incorrect usage of pingers was detected were removed from the analysis. The discovery that the FO pingers were running out of battery much faster than expected, lead to the small battery life test also carried out in this project. The exact reason why this was happening remains unclear, though it is being investigated by the manufacturers. This reinforced the importance of regular checks, to account for the possibility of equipment failure, leading to incorrect datapoints. However, even with the battery issues, the difference in bycatch rate between the FO pingers and the control hauls was still detectable.

Elasmobranchii bycatch was not registered in any of the logbook protocols and could therefore not be looked into in the same way as porpoise bycatch. Only one fishing boat had any shark/ray bycatch and they interrupted their fishing activity when this bycatch remained high. The film showed that at least 188 specimens were bycaught, and while that was not the focus of this study, it would be of interest to study whether pingers can have an impact on the bycatch rates of species other than porpoises and seals.

Film analysis is considered one of the more cost-effective ways of collecting bycatch data (Kindt-Larsen et al., 2012), but studies have indicated that logbooks can be an alternative, and effective way of saving time and effort as well (Lunneryd et al., 2005; Bjørge *et al.*, 2013). The film analysis in this project was very time consuming and, given the low number of bycaught porpoises and seals, compared to the overall number of hauls, it was a positive finding that the logbook protocols were shown to be reliable regarding porpoise bycatch. There was only one instance in which the protocol data and the film data did not agree, and it was a situation in which the porpoise was recorded on the correct fishing day by the fisherman, but not in the correct haul. The Cohen's Kappa test initially flagged this as a discrepancy, but after discussing it with the fisherman, it became evident that it was a miscommunication issue. This prompted the development of a revised logbook protocol version to enhance clarity and prevent similar errors. The consistency between these two datasets also indicates that the chance of a porpoise dropping out of the net before being seen by the fisherman is low, as all porpoises seen on film were also registered in the protocols.

5.3 Conclusions

No "dinner bell" effect was found in any of the three tested pingers (Banana pinger, Future Oceans Netguard Dolphin pinger and a custom-designed PAL pinger). However, low seal engagement rates make the results of this part of the experiment dubious. An experimental design with a larger number of repetitions and longer time for the seals to potentially learn to associate pinger sounds with the baited buoys would be necessary to confidently determine the presence or absence of a "dinner bell" effect.

Fishermen's logbooks were shown to be a reliable source of porpoise bycatch. Logbook data regarding bird bycatch and seal bycatch was not considered reliable, and bycatch data on sharks and rays was completely absent in the protocols. This indicated that logbooks can be a valuable tool to keep track of porpoise bycatch on a large scale and an important and time-saving alternative to electronic monitoring systems that require trained staff to analyse the resulting extensive film footage.

The Future Oceans pinger was shown to be effective at reducing porpoise bycatch and link length was found to be a significant factor. An in-depth analysis of possible reasons for the banana pinger to sometimes not reducing bycatch is necessary. Surprisingly, mesh size was not found to be a significant factor affecting bycatch. Future studies should explore other factors such as water depth and time of the year, but also current state of porpoise populations in the study areas.

6 Societal and ethical considerations

Bycatch poses a large threat to multiple species of marine mammals, including the Baltic Sea subpopulation of harbour porpoises. Pingers effectively reduce harbour porpoise bycatch and are very cost-effective compared to other alternatives. Studies such as this one are very important to not only encourage fishermen to use pingers, but also to find truly "seal-safe" pingers, that would not aggravate depredation by seals. It was decided to measure bycatch in running commercial fishing operations and not in experimental nets, since this would have resulted in extra and unnecessary bycatch.

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Appendix

The logbooks kept by the fishermen, containing various data including date, soak time, link dimensions (length, height, mesh size), target species, presence of pinger, catch and bycatch.

Länk nr	Datum vittjningsdag	Ståtid (Timmar)	Redskaps-kod	Länk längd (m)	Garn höjd (m)	Maskstorlek (mm)	Målart	Pinger Ja/Nej	Pinger Modell	Pinger Antal	Total bifångst (antal och art)				
											Tumlare	Säl		Fågel	
1											Antal	Antal	Art	Antal	Art
2											Antal	Antal	Art	Antal	Art
3											Antal	Antal	Art	Antal	Art
4											Antal	Antal	Art	Antal	Art
5											Antal	Antal	Art	Antal	Art
6											Antal	Antal	Art	Antal	Art
7											Antal	Antal	Art	Antal	Art
8											Antal	Antal	Art	Antal	Art
9											Antal	Antal	Art	Antal	Art
10											Antal	Antal	Art	Antal	Art
11											Antal	Antal	Art	Antal	Art
12											Antal	Antal	Art	Antal	Art

Kommentarer:

Total fångst per dag (kg)		
Torsk ☐ Orens Rens ☐	Skrubbskädda ☐ Orens Rens ☐	Rödspätta ☐ Orens Rens ☐
Sandskädda ☐ Orens Rens ☐	Äkta tunga ☐ Orens Rens ☐	Piggvar ☐ Orens Rens ☐
Slätvar ☐ Orens Rens ☐	Sjurygg ☐ Orens Rens ☐	Makrill ☐ Orens Rens ☐
Sill ☐ Orens Rens ☐	Art: ☐ Orens Rens ☐	Art: ☐ Orens Rens ☐
Art: ☐ Orens Rens ☐	Art: ☐ Orens Rens ☐	Art: ☐ Orens Rens ☐

Totalt utkast per dag	
KG	Antal

Vägt/räknat ☐ Uppskattat ☐

Totalt sälskadade fiskar per dag	
KG	Antal

Vägt/räknat ☐ Uppskattat ☐

Totalt ospec skadade fiskar per dag	
KG	Antal

Vägt/räknat ☐ Uppskattat ☐