Linköping University | Department of Physics, Chemistry and Biology
Master thesis, 60 hp | Educational Program: Applied Ethology and Animal Biology
Spring term 2020 | LITH-IFM-x-EX—20/3794--SE

Do potentially seal-safe pingers deter harbour porpoises (*Phocoena phocoena)* in the vicinity of gillnets and thereby reduce bycatch?

Simon Björklund Aksoy

Examinator, Urban Friberg, IFM Biologi, Linköpings universitet
Supervisor: Mats Amundin, Kolmården Wildlife Park, Sara Königson and Emilia Benavente Norrman, SLU Aqua

LINKÖPINGS
UNIVERSITET

Avdelning, institution
Division, Department

Department of Physics, Chemistry and Biology
Linköping University

Datum
Date

Språk
Language

☐ Svenska/Swedish
☐ Engelska/English

☐ ______________

Rapporttyp
Report category

☐ Licentiatavhandling
☒ Examensarbete
☐ C-uppsats
☐ D-uppsats
☐ Övrig rapport

☐ ____________

URL för elektronisk version

ISBN

ISRN: LITH-IFM-x-EX--20/3794--SE

Serietitel och serienummer
Title of series, numbering

ISSN
____

Titel
Title
Do potentially seal-safe pingers deter harbour porpoises *(Phocoena phocoena)* in the vicinity of gillnets and thereby reduce bycatch?

Författare
Author
Simon Björklund Aksoy

Sammanfattning
Abstract

Incidental bycatch in gillnets is a substantial threat to small cetaceans. Using Acoustic Deterrent Devices, “pingers”, have successfully reduced bycatch of harbour porpoises in gillnets. However, seals can use pingers as “dinner-bells” to easier find gillnets in order to raid and destroy them, further aggravating the existing conflicts between seals and coastal fisheries. Therefore, in the present study, the efficiency of two alleged “seal-safe” pingers, an experimental Banana pinger “SSB” and a Future Oceans F70 pinger “FO”, in deterring harbour porpoises from the vicinity of gillnets and thereby reducing bycatch in commercial gillnet fisheries, was tested. This was done by deploying click detectors, “C-PODs”, recording Detection Positive Minutes per hour, at each end of gillnets, provided with the two pinger types or no pingers at all. Bycatch instances were recorded into logbooks by participating fishermen and verified using video footage from on-board video cameras. Results showed that video monitoring was a reliable method for verifying the number of bycatches of porpoises and seals, but not seabirds, recorded in the fishermen’s logbooks. The experimental SSB pingers and the FO pingers significantly reduced porpoise presence, measured as Detection Positive Minutes per hour in the vicinity of the nets, compared to gillnets without pingers. However, the sample size was too small to yield a significant result regarding the bycatch reducing efficiency and dinner bell effect of the experimental pingers. Nevertheless, bycatch trends suggest that pingers did in fact reduce porpoise bycatch. Although both successful, FO pingers were slightly more efficient in deterring porpoises than SSB pingers. The SSB pinger sounds had bigger directionality variations than the FO pinger, which may have affected its deterrent effects. Therefore, additional trials are needed to further investigate this aspect.

Nyckelord
Keyword
Acoustic Deterrent Device, Banana pinger, Bycatch, Commercial fishery, C-POD, Dinner-bells, Future Oceans pinger, Harbour porpoise

Table of contents

1 Abstract

Incidental bycatch in gillnets is a substantial threat to small cetaceans. Using Acoustic Deterrent Devices, "pingers", have successfully reduced bycatch of harbour porpoises in gillnets. However, seals can use pingers as "dinner-bells" to easier find gillnets in order to raid and destroy them, further aggravating the existing conflicts between seals and coastal fisheries. Therefore, in the present study, the efficiency of two alleged "seal-safe" pingers, an experimental Banana pinger "SSB" and a Future Oceans F70 pinger "FO", in deterring harbour porpoises from the vicinity of gillnets and thereby reducing bycatch in commercial gillnet fisheries, was tested. This was done by deploying click detectors, "C-PODs", recording Detection Positive Minutes per hour, at each end of gillnets, provided with the two pinger types or no pingers at all. Bycatch instances were recorded into logbooks by participating fishermen and verified using video footage from on-board video cameras. Results showed that video monitoring was a reliable method for verifying the number of bycatches of porpoises and seals, but not seabirds, recorded in the fishermen's logbooks. The experimental SSB pingers and the FO pingers significantly reduced porpoise presence, measured as Detection Positive Minutes per hour in the vicinity of the nets, compared to gillnets without pingers. However, the sample size was too small to yield a significant result regarding the bycatch reducing efficiency and dinner bell effect of the experimental pingers. Nevertheless, bycatch trends suggest that pingers did in fact reduce porpoise bycatch. Although both successful, FO pingers were slightly more efficient in deterring porpoises than SSB pingers. The SSB pinger sounds had bigger directionality variations than the FO pinger, which may have affected its deterrent effects. Therefore, additional trials are needed to further investigate this aspect.

2 Introduction

Incidental bycatch in gillnets is a substantial threat to harbour porpoises (*Phocoena phocoena*) and other small cetaceans (Jefferson and Curry, 1994; Kraus et al., 1997; Read et al., 2006). It is estimated that bycatch related mortality of cetaceans exceeds hundreds of thousands yearly globally (Read et al., 2006). Especially threatened is the critically endangered Baltic Sea harbour porpoise population, consisting of around 500 mature individuals (www.Sambah.org; Amundin et al., In prep.).

The countries around the Baltic Sea have entered the ASCOBANS agreement which includes a special management plan for the Baltic Sea harbour porpoise population, the so called Jastarnia plan (ASCOBANS, 1992). In this plan several protective provisions are listed, among which bycatch mitigation is stated as the most important and urgent. EU has also instituted special requirements to reduce the incidental bycatch of small cetaceans in all European waters, the EU regulation 2019/1241 (Tajani and Ciamba, 2019). This regulation states that Acoustic Deterrent Devices, so called “pingers”, must be used on gillnets with specified mesh size and in specified areas. Pingers transmit sounds that deter harbour porpoises and hence make them avoid the vicinity of gillnets (Kastelein et al., 2000; Kindt-Larsen et al., 2018). Additionally, pingers are required on vessels exceeding 12 m overall length. Moreover, vessels with 15 m overall length are required to have on-board observers to monitor bycatch, whereas bycatch on smaller vessels are assessed through scientific studies and sometimes through technical means. Furthermore, some of the Natura2000 areas (Natura2000 is a network of protected areas in the European Union [EC 1979, 1992]) offer protection to harbour porpoises in European Union waters. However, gillnet fishing per se is not banned inside these areas and management plans for new Natura2000 areas in the Baltic Sea (https://skyddadnatur.naturvardsverket.se/), established in 2017, are still pending.

The use of pingers to reduce bycatch of harbour porpoises have been successful (Kraus et al., 1997; Kastelein et al., 2000; Larsen and Eigaard, 2014; Kindt-Larsen et al., 2018). Based on the success of Kraus et al. (1997), binding requirement to use pingers were introduced in the US section of the Atlantic Ocean (NOAA, 1998). However, due to costs, practical issues and a lack of surveillance, pingers have only been used to a limited degree in gillnet fisheries within the EU (ICES, 2012). Moreover, there is a concern that seals may use pingers as so called “dinner bells”, making it easier for them to find the nets to raid them for fish and often destroying the nets in the process (Stridh, 2008). This increases the already intense conflict between seals and coastal fisheries and makes fishermen reluctant to use pingers, especially so in the Baltic Sea where seal depredation is already a severe issue (Fjälling, 2006; Jefferson and Curry, 2006).

For the last several years, Kolmården Wildlife Park, in collaboration with the Swedish University of Agricultural Sciences (SLU) Aqua, has examined the reaction of wild harbour porpoises to a new “seal-safe” pinger, an experimental version of the Banana pinger. In this pinger the lower frequency cut-off has been raised to 59 kHz, making the pingers sounds virtually inaudible to seals, and thus less likely to be used as a “dinner bell”.

There were four objectives investigated in the present study. The first objective was to explore if there was a difference in recorded porpoise click trains in the vicinity of commercial gillnets equipped with either two types of experimental “seal safe” pingers: the Banana pinger (abbreviated as SSB) or the Future Oceans Netguard 70 kHz Dolphin pinger (abbreviated as

FO), or gillnets without pingers. Here, it was predicted that pingers on gillnets would deter porpoises, i.e. having fewer recorded porpoise click trains than gillnets without pingers, Second, it was investigated if bycatch of porpoises in gillnets with pingers would decrease compared to gillnets without pingers. It was predicted that gillnets with pingers would have a reduced number of bycaught porpoises compared to gillnets without pingers. Third, video footage of bycaught porpoises, seals and seabirds from the on-board video monitoring systems were compared with the catch logbooks to assess the reliability of using catch logbook data. On-board video monitoring systems are more cost efficient than implementing on-board observers (Kindt-Larsen et al., 2012). It was predicted that on-board video systems would be more efficient than the fishermen's catch logbooks, since some bycatches could potentially drop out from the net before reaching deck and thereby be missed by the fishermen (Kindt-Larsen et al., 2012). Finally, it was investigated if the pingers used in the present study were actually seal safe i.e. would not attract seals, as claimed by the manufacturers, by comparing bycatch of seal, damage to fish and fishing gear between gillnets with pingers and gillnets without pingers.

3 Material & method

To retain the anonymity of the participating fishermen, the geographical locations where the data was collected are referred to as "areas" throughout the text, with a corresponding number indicating the area in question.

3.1 Study area

Data collection ran from September 2018 to January 2020. Four fishermen operating along the west coast of Sweden participated in this project. In Area 1 and 2, fishermen tested both the SSB pinger and the FO pinger during spring 2019. In Area 3 only the SSB pinger was tested during the autumn of 2018 and the SSB pinger and the FO pinger during the spring and autumn of 2019. In Area 4 only the SSB pinger was tested during the autumn of 2018 and the SSB pinger and the FO pinger during the autumn of 2019.

3.2 Experimental set-up

The participating fishermen used their own bottom-set gillnets throughout the experiment. Gillnet lengths ranged from 370 m to 800 m and were set for cod (*Gadus morhua*) in the autumn fishing season and for lumpfish (*Cyclopterus lumpus*) in the spring season. Due to cod being less enduring than lumpfish after being entangled, gillnets set for cod were emptied daily, whereas gillnets set for lumpfish were emptied on average every three days. The coordinates of the flag buoys in each end of the gillnets were recorded as well as the distance between the buoy and the net. The fishermen were provided with pingers and C-PODs and were responsible for securely deploying them in conjunction with setting the gillnets. The C-PODs were attached to the flag buoy rope, except in Area 2 where the C-PODs in the northern-most end of each net link, which was always deployed in a north/south orientation, were anchored at a short distance east of the flag buoy, to avoid strong water currents bringing it at risk of entanglement in the net. Since the number of C-PODs was limited, some fishermen included gillnets without C-PODs to obtain more data on actual bycatch.

The C-POD is an autonomous odontocete click train logger that can log continuously for a period of 4-5 months. It has a maximum detection range of approximately 400 m for porpoise click trains (Chelonia Ltd, UK). The C-POD analysis system includes a species classification algorithm (KERNO) which makes it possible to extract porpoise click trains with a source quality measure. Detection Positive Minutes per hour (DPM/h), which is the number of minutes, with at least one porpoise click train per hour, were exported from the processed C-POD data. This measure was used as a proxy for porpoise presence. Kolmården/SLU Aqua were responsible for the C-POD set-up before delivering them to the fishermen. Data from the C-PODs were uploaded at the end of each data collection period, which typically lasted for three months.

3.2.1 Verifying fishermen logbook records

Catch yield and any porpoise bycatch, together with net set and haul dates, were compiled by the fishermen in catch logbooks provided by us. However, bycaught porpoises are sometimes missed by the fishermen, which is usually due to them dropping out of the gillnet before reaching the deck. To verify potentially missed bycaught porpoises, electronic monitoring in the form of a Mobius camera connected to an external battery was installed on each vessel of the participating fishermen. The camera filmed the net between the water surface and the winch roll during hauling, allowing possible bycaught porpoises, seals or birds to be documented. To investigate the plausibility of using electronic monitoring to verify the fishermen’s logbooks, bycatch of seals and seabirds were included in the video analysis, in addition to the porpoises. A fully video documented net haul was called one emptying, which, depending on the target fish, may cover one to three days’ soak time. Each gillnet emptying was scored for their video quality, “good” if the overall footage was good enough to be fully analysed, with minor disturbances such as short duration sun-glares and shades allowed, and “bad” if such disturbances made the video analysis nonreliable. Examples of a “bad” video include footage where the camera did not show the hauled net, footage where sun glares and shades were present throughout the recording and footage with poor light conditions (Figure 1).

Figure 1. Examples of picture disturbances, negatively affecting the analysis of the video footage from the onboard camera system. Left picture shows glares from the sun, middle picture shows poor light conditions. The footage was scored as “bad” if disturbances like these were present throughout the video. Right picture shows footage scored as “good”.

3.2.2 Pinger efficiency

To investigate the efficiency of the two “seal-safe” pinger types in reducing porpoise bycatch, fishermen’s gillnets were equipped with either the experimental SSB pingers, FO pingers or no pingers. As mentioned above, each experimental gillnet had pingers evenly spaced along the gillnet. The distance between pingers were at the most 200 m, in accordance with the specifications of the pinger manufacturer (Fishtek Marine and Future Oceans) and EU regulation 2019/1241, and to ensure that there would be no silent gaps that might entice the porpoises to swim in between two pingers and thus get entangled. The SSB pinger was chosen as candidate for further study since it emits several different 300 ms frequency-modulated, multi-harmonic signals at semi-random intervals of 4-15 s, thus reducing the possibility of the porpoises habituating to the pinger sounds. The manufacturer, Fishtek Marine Ltd, was asked by us to adjust the lower frequency cut-off to 60 kHz (in effect to 59 kHz; Figure 2), to make the sounds less audible to seals compared to the standard SSB pinger, where the lower frequency cut-off is 5-7 kHz lower. As can be seen in figure 2, there were some sound energy between 30 and 50 kHz, but it was > 30 dB lower than the 59 kHz peak. The FO pinger generated 64-66 kHz 300 ms tones with overtones at 125-133 kHz and 191-200 kHz (Figure 3) and with fixed ping intervals of 4 s. According to the audiograms available for grey and harbour seals (the seal species resident in the Baltic Sea) (Wolski et al., 2003; Nedwell et al., 2004; Kastelein et al., 2009; Reichmuth et al., 2013; Cunningham et al., 2014a; Cunningham and

Reichmuth, 2016), 59 kHz and 60-66 kHz might be detectable by the seals, but only at rather short distances. Hence it is unlikely that any of these two pingers can have a "dinner bell" effect.

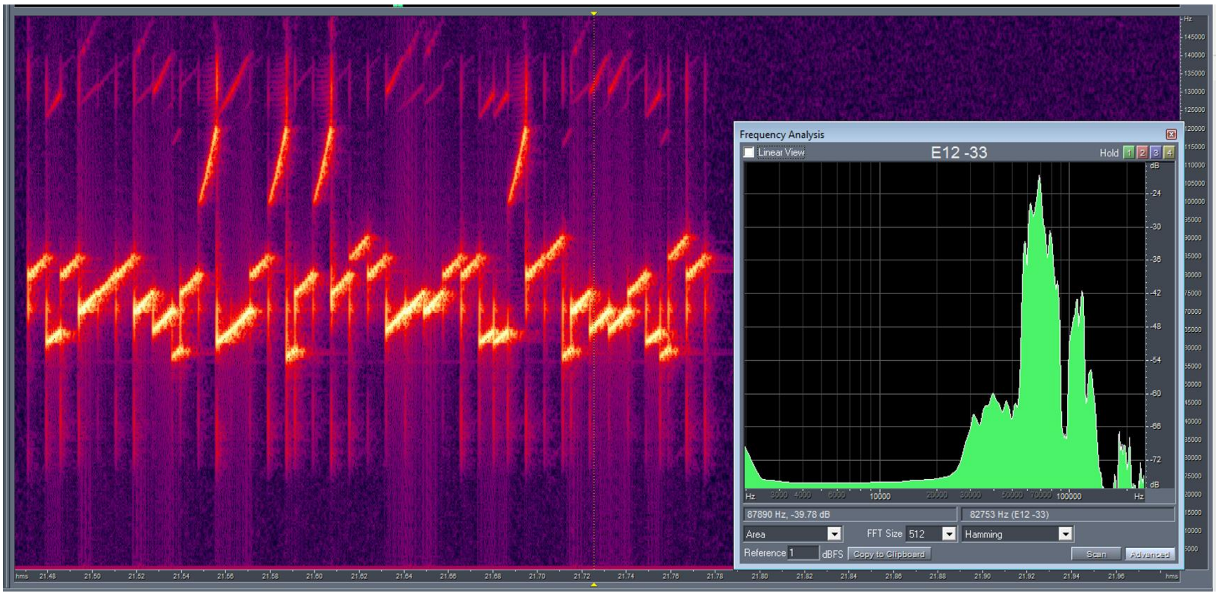

Figure 2. Spectrogram and power spectrum of an SSB pinger sound. The lowest frequency peak is at around 59 kHz. The frequency components between 30 kHz and 50 kHz are 33-37 dB below the 59 kHz peak. The frequency peak at 59 kHz as well as the one at ca 115 kHz is within the best hearing range of the harbour porpoise, whereas frequencies at 59 kHz and below would be audible to seals only at short distances.

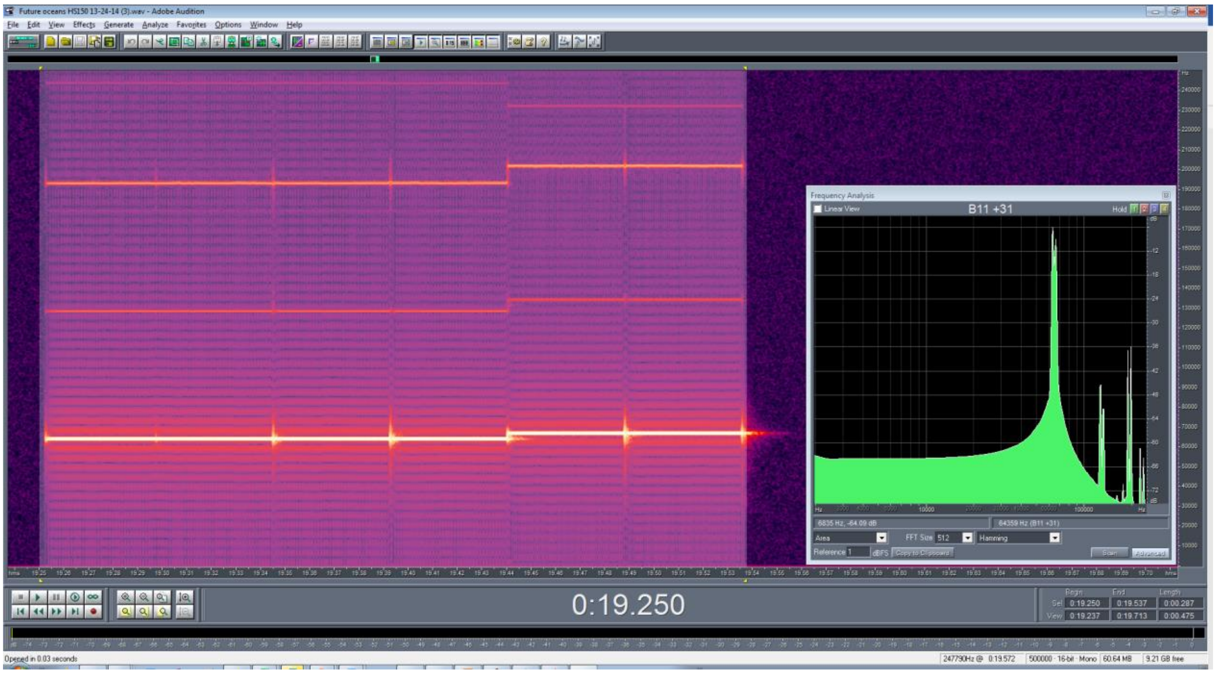

Figure 3. Spectrogram and power spectrum of the FO pinger sound. The main frequency component is at around 64 kHz in the first 2/3rd of the signal, and at ca. 66 kHz in the last third of the signal. Both frequencies are within the best hearing range of the harbour porpoise, whereas frequencies at 64-66 kHz would be audible to seals only at short distances.

Since high frequencies attenuate faster than lower frequencies it is important to test that these pingers actually deter the porpoises far enough to reduce bycatch.

4 Statistical analysis

4.1 Comparison between fishermen protocols and video footage

Video footage from the fishermen were analysed using the observation software BORIS (Friard and Gamba, 2016). To investigate if video monitoring could be an efficient tool in verifying data from catch logbooks kept by the fishermen, the number of bycaught porpoises, seals and birds in each of the emptied gillnets, detected in the video footage, was compared with the corresponding data in the catch logbooks.

4.2 C-POD data

Statistical analyses were carried out using IBM SPSS Statistics. Click data recorded by the C-POD was processed using a porpoise click train classifier, called KERNO, included in the analysis software C-POD.exe, which is part of the C-POD system (Chelonia Ltd, 2019). This analysis tool also has an export function whereby selected parameters, such as DPM/h, from the processed data can be exported for further analysis in SPSS.

4.2.1 Pinger efficiency in reducing harbour porpoise presence

The C-PODs differed in their soak time (defined as the time they were logging in the water) and recording dates. Therefore, only C-POD data with the same soak time and overlapping dates and from the same area were compared. Since the porpoise click detection data (DPM/h) was not normal distributed, a Kruskal Wallis test was performed to investigate if there was a difference in DPM/h among C-PODs from the same area, and a Dunn's post hoc test was performed to investigate between which C-PODs there was a difference in DPM/h. However, there were instances were one or two C-PODs did not record at the same time as the other C-PODs from the same area for most of the data collection. Therefore, a Mann-Whitney U test was also performed to investigate pairwise differences in DPM/h between all C-PODs from the same area and then compared with the groupwise results from the Kruskal Wallis test. Results from the pairwise Mann-Whitney U test comparisons in each study area is compiled in the Appendix.

Data from C-PODs attached to gillnets without pingers in Area 3 (autumn 2019) showed signs of error and were therefore excluded from the analysis.

4.2.2 Pinger efficiency in reducing harbour porpoise bycatch

Gillnet length and soak time differed between participating fishermen. Thus, the probability of bycatch differed between areas. Bycatch frequencies were therefore calculated by "Bycatch/effort unit", where effort is based on the gillnet length and soak time. Since the bycatch frequencies were not normal distributed, a Kruskal Wallis test and a Dunn's post hoc test was performed to investigate bycatch differences between gillnets with SSB pingers, FO pingers and without pingers.

4.3 Seal-safe credibility of the SSB pinger and the FO pinger

Both pinger types used in the present study are potentially "seal-safe", due to their low frequency cut-off leaving only frequencies too high for the seals to be able to hear them at long distance and thus not allowing them to be used as "dinner bells". This assumption may be tested by comparing damages to fish and fishing gear and the occurrence of bycaught seals in gillnets with SSB pingers, FO pingers and without pingers. During data collection, after each emptying, the fishermen noted in their catch logbooks if the gillnet had any bycaught seals, seal related damage to fish or fishing gear. Damage to fish and fishing gear could not be reliably assessed through the video footage. Therefore, only data from the catch logbooks were used for this analysis. Any instance of bycaught seal and damage to fish or fishing gear for each emptying was scored as "seal interaction" (1), and then compared with "no seal interaction" (0) using Fisher's exact test.

5 Results

5.1 Comparison between fishermen logbooks and video footage

Data from a total of 397 emptied gillnets were entered into the fishermen's catch logbooks throughout the project duration from September 2018 to January 2020. Video footage from September 2019 to January 2020 were only analysed for bycaught porpoises due to time constraints. Video footage of 35 emptied nets were scored as "bad" and hence did not provide data for further analysis. Additionally, there were no video footage from 29 emptied gillnets that were entered into the fishermen's catch logbooks. Thus, when comparing logbooks and video footage, this brought down the comparable number of emptied logbook gillnets to 333. Of these 333 gillnets, 264 emptied gillnets were successfully verified through video footage and used during the analysis. Of the 264 video verified gillnets, 69 had FO pingers, 96 had SSB pingers and 99 had no pingers. Pingers could not be video verified on four of the 178 experimental gillnets with pingers.

5.1.1 Harbour porpoise

Overall, electronic monitoring through video recordings was efficient in verifying porpoise bycatches in the logbooks. One bycaught individual in the logbook could not be verified on film due to poor light conditions, and an additional bycaught porpoise not noted in the logbook was discovered through the video footage.

5.1.2 Seal

Like with the porpoises, electronic monitoring through video recordings were efficient in verifying seal bycatches in the logbooks. In total, three bycaught seals that were recorded in the logbooks could not be verified when analysing the video footage.

5.1.3 Birds

In total, 28 bycaught birds were recorded in the catch logbooks by the fishermen. Of these, 15 were confirmed when analysing the video footage. An additional bird bycatch not noted in the logbooks was discovered through the video footage. Overall, birds were very difficult to notice and distinguish.

5.2 Pinger efficiency in reducing porpoise presence

5.2.1 Fisheries with lumpfish as target species

In Area 1, the Kruskal Wallis test revealed a significant difference in the average DPM/h between the three experimental set-ups ($H[2] = 1290.613$, $p < 0.001$) (Figure 4). Post hoc results using Dunn's test showed significant differences between all C-PODs except between C-POD 1199 and C-POD 1266, both deployed with FO pinger gillnets. C-PODs deployed with gillnets without pingers showed a significantly higher average DPM/h than C-PODs deployed with gillnets with pingers. C-PODs deployed with gillnets with SSB pingers showed significantly higher average DPM/h than C-PODs deployed with gillnets with FO pingers. As mentioned in the statistical analysis section, pairwise comparisons using a Mann-Whitney U test were also made between C-PODs from the same area, since the soak time from all C-PODs did not overlap for the Kruskal Wallis test. In Area 1, the result from the Mann-Whitney U tests was consistent with the results from the Kruskal Wallis test (see Appendix for Area 1).

In Area 2, the Kruskal Wallis test revealed a significant difference in the average DPM/h between the three experimental set-ups ($H[2] = 118.404$, $p = 0.001$) (Figure 4). Post hoc analysis using Dunn's test showed significant differences between all C-PODs except between C-POD 1188 and C-POD 2190, both deployed with gillnets without pingers, and C-POD 1381, C-POD 1188 and C-POD 2190. C-PODs deployed with gillnets without pingers and with SSB pingers showed a significantly higher average DPM/h than gillnets with FO pingers. No significant difference in average DPM/h was found between C-PODs deployed with gillnets without pingers and C-PODs deployed with gillnets with SSB pingers. In Area 2, the result from the Mann-Whitney U tests was consistent with the results from the Kruskal Wallis test (see Appendix for Area 2).

In Area 3 (spring 2019), the Kruskal Wallis test revealed a significant difference in DPM/h between the three experimental set-ups ($H[2] = 15.219$, $p = 0.004$) (Figure 4). Post hoc analysis using Dunn's test showed significant differences between all C-PODs deployed with pingers and C-POD 1197 deployed with gillnet without pingers, and between C-POD 1245 and C-POD 1197, both deployed with gillnet without pingers. Overall, C-PODs deployed with gillnets without pingers had a higher average DPM/h than C-PODs deployed with gillnets with pingers, but only significantly higher in comparisons with C-POD 1197 deployed with gillnets without pingers. C-PODs deployed with gillnets with SSB pingers had higher average DPM/h, but not significantly higher. Apart from no significant difference in DPM/h found between C-POD 1245 and C-POD 1197, both deployed with gillnets without pingers. In Area 3, the result from the Mann-Whitney U tests was consistent with the results from the Kruskal Wallis test (see Appendix for Area 3).

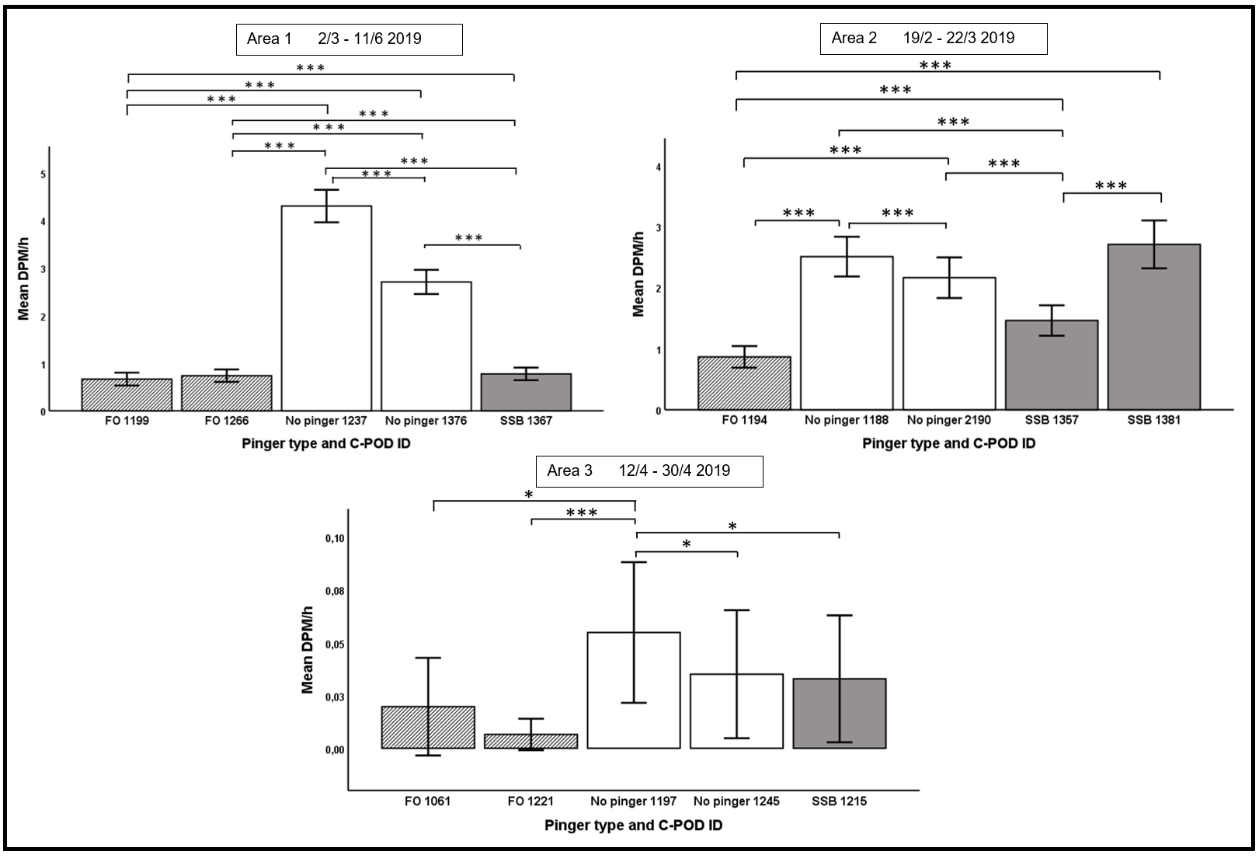

Figure 4. Influence of pingers on DPM/h, used as a proxy for porpoise presence, in areas with lumpfish as target species. * shows significance at 0.05 level, and *** at 0.001 level. Bars show mean DPM/h and whiskers show ± 95% CI.

5.2.2 Fisheries with cod as target species

In Area 4 (2018), the Kruskal Wallis test revealed a significant difference in the average DPM/h between the two experimental set-ups ($H[2] = 13.478$, $p = 0.001$) (Figure 5). Post hoc results using Dunn's test showed a significant result at 0.05 significance level between C-POD 1197 deployed with gillnet without pingers and C-POD 1368 deployed with gillnet with SSB pingers and C-POD 1221 deployed with gillnets with no pingers and C-POD 1368 deployed with gillnets with SSB pingers. C-PODs deployed with gillnets without pingers had a significantly higher average DPM/h than C-PODs deployed with gillnets with SSB pingers.

In Area 4 (2019), the Kruskal Wallis test revealed no significant difference between the three experimental set-ups in the average DPM/h ($H[2] = 6.420$, $p = 0.170$) (Figure 5). Although the Kruskal Wallis test was not significant, post hoc results using Dunn's test showed a that C-POD 1253 deployed with gillnets without pingers had significantly higher average DPM/h than C-POD 1376 deployed with FO pingers. Although not significant, C-POD 1253 deployed with gillnets without pingers had higher average DPM/h than C-PODs deployed with gillnets with pingers.

In Area 3 (autumn 2019), where only SSB pingers were tested against FO pingers, the Kruskal Wallis test revealed no significant difference in average DPM/h between the two experimental set-ups (H[2] = 6.071, p = 0.108) (Figure 5). Although the Kruskal Wallis test was not significant, post hoc results using Dunn's test showed a significant difference between C-PODs 1221 and 1381, both deployed with gillnets with SSB pingers. Although not significant, C-POD 1381 deployed with SSB pingers had higher average DPM/h than C-PODs deployed with gillnets with FO pingers.

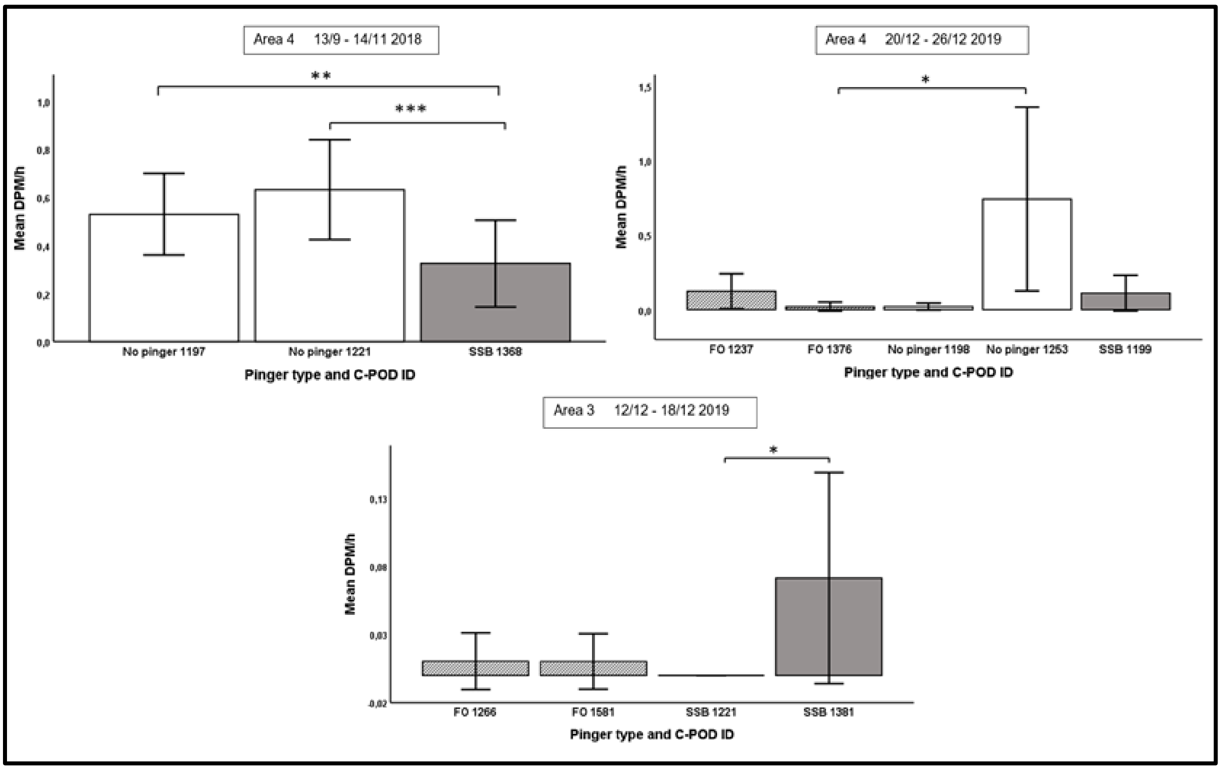

Figure 5. Influence of pingers on DPM/h, used as a proxy for porpoise presence, in areas with cod as target species. * shows significance at 0.05 level, ** at 0.01 level and *** at 0.001 level. Bars show mean DPM/h and whiskers show ± 95% CI.

The C-PODs in Area 3 (2018), where only SSB pingers were tested against no pingers, only overlapped pairwise in their soak time. Thus, only a Mann-Whitney U test was made. C-PODs deployed with gillnets without pingers had significantly higher average DPM/h than C-PODs deployed with gillnets with SSB pingers (Table 1).

Table 1. Results from the Mann-Whitney U test of Area 3 (2018). Summary of SSB pingers effect on porpoise prescence, shown as DPM/h, compared to gillnets without pingers.

C-POD ID	Type of pinger	DPM/h (mean ± SE)	U	p value	Time period
1198	SSB	0.01 ± 0.008	7021	0.317	September
1367	SSB	0			
1198	SSB	0	527	0.009*	September
1376	No pinger	0.37 ± 0.15			
1367	SSB	0.89 ± 0.13	96628	0.001*	September - December
1376	No pinger	2.63 ± 0.35			
1261	No pinger	1.43 ± 0.18	200499	0.185	November - December
1376	No pinger	2.36 ± 0.28			

* Statistically significant at at $\alpha = 0.05$

5.3 Pinger efficiency in reducing porpoise bycatch

5.3.1 Fisheries with lumpfish as target species

The Kruskal Wallis test revealed no significant difference in bycatch frequency, measured as bycatch per unit effort, between the three experimental set-ups ($H[2] = 2.977$, $p = 0.226$) (Figure 6). A post hoc power analysis revealed an observed power of 0.18. “Power” refers to the probability of identifying a statistical difference between the two compared groups. Thus, if a sample has insufficient power, the statistical test may not yield a statistical significance even if there actually is a statistical difference between the two groups. The lowest acceptable level of power is 0.8, i.e. the sample size was not large enough to determine a statistical significance, making the results from the Kruskal Wallis test dubious. However, the data presented here show a possible trend, where gillnets without pingers had a higher bycatch frequency than gillnets with SSB pingers and FO pingers, respectively. Likewise, gillnets with SSB pingers indicated a higher bycatch frequency than gillnets with FO pingers (figure 6).

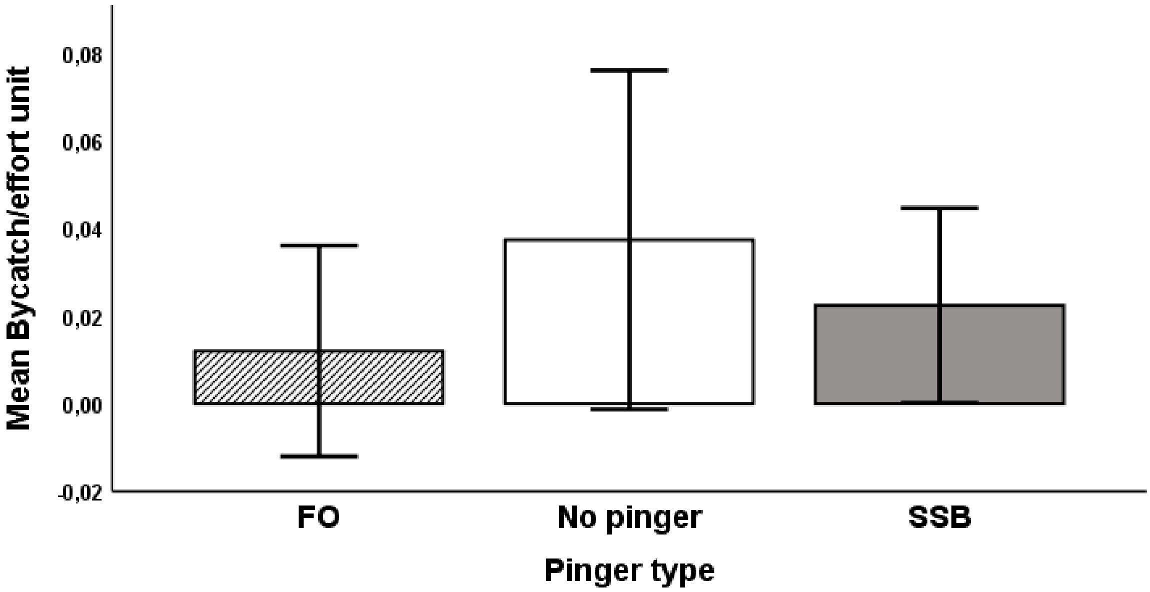

Figure 6. Mean porpoise bycatch frequencies, measured as number of bycatches/effort unit, for each experimental treatment in areas with lumpfish as target species. Bars show mean and whiskers show ± 95% CI.

5.3.2 Fisheries with cod as target species

The Kruskal Wallis test revealed no significant difference in bycatch frequency between the three experimental set-ups ($H[2] = 1.289$, $p = 0.525$). Like in the areas with lumpfish as target species, a post hoc power analysis revealed an observed power of 0.161, which means that the sample size was not large enough to determine a statistical significance. There was only one bycaught porpoise in the areas with cod as target species, i.e. Area 4 (2018). Thus, no conclusions can be made regarding possible bycatch trends in areas with cod as target species.

5.4 Seal-safe credibility of the SSB pinger and the FO pinger

In lumpfish fisheries, the frequency of seal related damage to fish and fishing gear was 0.08 for gillnets with FO pingers, 0.15 for gillnets with SSB pingers and 0.1 for gillnets without pingers. In cod fisheries, the frequency of seal related damage to fish and fishing gear was 0.083 for gillnets with FO pingers, 0.024 for gillnets with SSB pingers and 0.012 for gillnets without pingers. The Fisher's exact test revealed no significant result between the three experimental set-ups in neither cod or lumpfish fisheries. However, a post hoc power analysis revealed an observed power of 0.152 for lumpfish fisheries, and 0.11 for cod fisheries. As previously mentioned, "Power" refers to the probability of identifying a statistical difference between the two compared groups. Since the lowest acceptable level of power is 0.8, the sample size was not large enough to determine a statistical significance, making the results from the Fisher's exact test dubious.

6 Discussion

6.1 Using video footage to verify fishermen logbooks

Electronic monitoring was a successful method for verifying porpoise bycatch data in the fishermen's catch logbooks. Only one of all bycaught porpoises recorded in the logbooks was not confirmed when analysing the video footage. This individual could not be seen due to poor light conditions in the video. An additional porpoise bycatch not noted in the logbook was discovered through the video footage. This individual was probably missed by the fisherman because it dropped out of the gillnet before it reached the deck. Due to this kind of error, Kindt-Larsen et al. (2012) claimed that electronic monitoring was overall more reliable than logbooks when assessing porpoise bycatch in gillnets. Even though this was not the case in the present study, it might be wise not to rely on logbooks alone; in bigger fishing vessels observers are required to ensure correct bycatch data. Since observers are not an option on small fishing vessels, onboard video footage, even though it may not be analysed to 100%, introduces the possibility for auditing of the logbooks, which may make fishermen more likely to enter all bycatches in the logbook.

Like with the porpoise bycatches, electronic monitoring was efficient for verifying the number of bycaught seals in the logbooks. In total, three bycaught seals recorded in the logbook could not be verified by the video footage. Interestingly, the gillnets with these three missing seals were video recorded without any major picture limitations, which makes it unclear why these individuals could not be found in the video footage. Since these nets belonged to the same fisherman, one possible explanation is that non-experimental gillnets were mixed up with experimental gillnets when the bycatches were entered into the logbook.

The majority of the 28 bycaught sea birds in the logbooks could either not be found or identified when analysing video footage. This was mainly due to the smaller size and the darker colours of the bycaught birds which made them blend in with algae and fish in the gillnets. Additionally, as noted by Glemarec et al. (2020), bird identification in video footage is also limited by poor light and foul weather conditions. Furthermore, some fishermen could not identify the bycaught birds, which made it especially difficult to analyse the video footage. A solution would be to ask participating fishermen to present the bycaught birds in close view of the video camera. This would greatly increase the probability of verifying and identifying bycaught birds.

Pingers were successfully identified on most of the video recorded gillnets marked in the logbooks to be provided with pingers. Still, there were four instances where the pingers could not be seen in the video footage. Since the catch logbooks contain the ID of each C-POD emptied on a specific date, unidentified gillnets were identified through the process of elimination, and then verified in C-POD.exe using CP1 files. CP1 files contain the raw sounds logged by C-PODs, including the pinger sound, the frequency content of which makes it possible to verify the pinger type noted in the logbook. However, some fishermen used gillnets with pingers but without C-PODs, in these cases, like with the bycaught birds, an efficient approach would be for the fisherman to hold the pinger in the view of the video camera.

It is also important to acknowledge that not all emptied gillnets in the logbooks were successfully video recorded in the present study, as mentioned in the results. The onboard cameras needed to be powered on and off manually, which in some instances led to cameras being turned off too early and in other instances turned on too late. Kindt-Larsen et al. (2012) and Glemarec et al. (2020) also reported such loss of data when comparing video footage with corresponding logbook data. Therefore, a combination of both methods is recommended.

6.2 Pinger efficiency

Both pinger brands used in this study have been reported successful in either deterring or reducing porpoise and dolphin bycatch. Vingada et al. (2011) found that the Future Oceans Netguard 70 kHz dolphin pinger (identical to the FO pinger used in the present study) significantly lowered dolphin bycatch in gillnets (Vingada et al., 2011). Likewise, Omeyer et al. (2020) found that Banana pingers (although not the seal-safe type used in the present study) reduced harbour porpoise acoustic activity in the vicinity of the pinger. Moreover, Königson et al. (in prep) also found a reduced harbour porpoise acoustic activity, like in the present study used as a proxy for porpoise presence, in the vicinity of the pinger, and that this pinger effect was restricted to close range. Furthermore, in none of these studies there were any signs of habituation or habitat exclusion. Similarly, in the present study, both pinger types significantly reduced porpoise acoustic activity in the vicinity of gillnets compared to gillnets without pingers. In the lumpfish fishery the FO pingers were overall more efficient in reducing porpoise presence than the SSB pingers. The only areas where the FO pingers were less efficient than the SSB pingers were in Area 3 (autumn 2019) and Area 4 (autumn 2019), with cod as target species. However, these areas had very few detections of porpoises overall, so these differences should be treated with caution.

As mentioned in the results, no significant conclusions on the pinger efficiency in reducing bycatch could be drawn. However, in areas with lumpfish as target species, where bycatch of porpoises was found in all three experimental gillnet set-ups (Figure 6), the bycatch ratio indicated a similar tendency as the C-POD DPM/h findings. That being that FO pingers were overall more efficient in reducing porpoise bycatch than SSB pingers, but both pingers had less bycatch than gillnets without pingers. Thus, the results from the pinger trials suggest that there actually was a bycatch reduction with the pingers, but the sample size with the low observed bycatch ratio was too small to yield a significant result.

The result that gillnets with SSB pingers set for lumpfish showed very high average DPM/h in Area 2 was unexpected. In fact, the C-POD 1381 deployed with SSB pingers showed the highest average DPM/h throughout the entire data collection period in this area (see Figure 4 and Appendix for Area 2). It is a possibility that the SSB pinger closest to C-POD 1381 was malfunctioning. If this was the case, it may have allowed porpoises to approach closer to this end of the net, resulting in the high DPM/h, and thereby also risk of entanglement. Palka et al. (2008) noted that bycatch was not reduced in gillnets with incomplete sets of pingers, resulting in silent gaps along the net. In fact, bycatch rates were the highest in gillnets with incomplete sets of pingers, which Palka and his co-workers argued might be a result of porpoises interpreting the silent gaps as physical gaps in the gillnet that could be used for passing the net. However, it is not reasonable to assume that the difference in efficiency between the FO and SSB pingers in the present study was due to pinger malfunctions alone, since the FO pinger was consistently more efficient in deterring porpoises than SSB pingers across the study areas.

One further factor that may have influenced the DPM/h is the directionality of the pinger transmissions. Both the FO and SSB pingers have the electronics and the disk-shaped transducer at one end of the device and the battery filling the rest of the casing. It is thus possible that the battery was shadowing the transmission of the sounds from the transducer. Therefore, additional trials were made after the data collection to investigate if the orientation of the pinger was important for the C-PODs' detection of the pinger sounds and potentially for the deterrent effect on the porpoises. Directionality measurements with the SSB pinger showed that it transmitted 7 dBrms lower from the transducer end and 11 dBrms lower from the battery end of the container, re. to perpendicular to the horizontal directions (Courtesy Magnus Wahlberg, University of Southern Denmark). The directionality variations in the FO pinger sounds were much less, with a maximum 3 dBrms difference between the battery end and one of the horizontal directions and 1 dBrms difference between the transducer end and one of the horizontal directions. A large proportion of the SSB pinger sounds have higher frequencies than the FO pinger sounds. Higher frequencies tend to be more directional and attenuate faster than lower frequencies, which may reduce the range of the SSB pinger's deterrent effect. Since the pingers are tied with their long axis aligned with the float line, the logging of the SSB pinger sounds by the C-POD deployed at a distance from each end of the net, will be very much affected by the orientation of the casing of the pingers attached at the end of the net. According to the manufacturers' recommendations, the pingers were separated by up to 200 m on the gillnet float lines; due to the directionality pattern of the SSB pinger, this means that there will be a minimum SPL half-way between the pingers and close to the net, aggravated if the battery ends are facing each other. It cannot be excluded that this may have influenced the bycatch rate in gillnets with SSB pingers.

It is also important to discuss the experimental set-up in the present study. During data collection, some of the fishermen did not randomize the positions of their experimental gillnets throughout the experiment, resulting in each of the three experimental set-ups being assigned to the same specific part of each area. The lumpfish fisheries in Area 2 was one such case, and it cannot be ruled out that there were more porpoises in the part with the SSB gillnets, resulting in the high DPM/h that was recorded by the C-PODs in these gillnets. Furthermore, depending on the area, the fishermen deployed the C-PODs at different distances, ranging from 30-100 m, from the beginning of each gillnet and thus from the closest pinger, which may also have affected the DPM/h. Due to strong water currents in Area 2, the northernmost C-PODs of each gillnet were deployed separated from and east of the gillnet on its own buoy, with a distance of 50-100 m from the beginning of the net and the closest pinger. Königson et al. (in prep) reported significant effects of an experimental SSB pinger on porpoise presence at distances from zero to 100 m, some, but insignificant effects at 400 m and no effects on larger distances. Similarly, Omeyer et al. (2020) found a considerable reduction in the pinger effect on DPM/h at distances > 100 m. Hence, the high DPM/h recorded by C-POD 1381 deployed with SSB pingers in this area may simply be due to the distance between the C-POD and the nearest pinger being at the upper limit of the pingers' deterring effect. Furthermore, the fact that the northernmost C-POD (1581) deployed with FO pingers in Area 2 still showed low DPM/h despite the long distance between the C-POD and the nearest pinger, may be explained by the previously discussed finding that FO pinger frequencies were less attenuated than those of the SSB pingers.

Since the porpoise is a small aquatic species, being active around the clock, with a very inconspicuous surfacing behaviour, its presence in the vicinity of fishing nets cannot be reliably determined by visual observations. Therefore, in the present study, DPM/h, which is based on the assumption that porpoises are clicking all the time both in connection with almost continuous foraging (Wisniewska et al., 2016), and communication (Sørensen et al., 2018), was used as a proxy for porpoise presence. There are observations indicating that porpoises may be silent in periods that have been associated with resting (Wright et al., 2017). This was associated with shallow so-called parabolic dives, recorded by depth and click recording tags attached to the dorsal fin of seven porpoises. The parabolic dives constituted on average 7.5% of all dive time and 4% of the total time logged by the tag. The longest silent period logged was ca 24 min. Even though these silent porpoises would go undetected by the C-PODs, it is questionable if such a low proportion of short-time silence would be detectable with a coarse measure as the DPM/h. Also, it may be assumed that porpoises close to nets with pingers would be less inclined to rest and thus to be silent than those around nets without pingers. Even if this was true, there was still significantly lower DPM/h at gillnets with pingers than at those without pingers.

As mentioned in the results, the sample size was not large enough to determine a statistical significance regarding a possible “dinner bell” effect from the experimental pingers. Thus, no conclusions can be drawn regarding the seal safe efficiency of the SSB and FO pinger.

6.5 Conclusion

In the present study, the efficiency of two potentially “seal-safe” pingers, an experimental Banana pinger (abbreviated as SSB) and the Future Oceans Netguard Dolphin pinger 70 kHz (abbreviated as FO), in deterring porpoises and reducing porpoise bycatch in commercial cod and lumpfish gillnet fisheries, was tested. In conclusion, electronic monitoring was effective to verify fishermen’s logbooks of bycaught porpoises and seals, but not birds. Based on C-POD data, it was found that gillnets with pingers had significantly reduced porpoise presence compared to gillnets without pingers, but bycatch in gillnets with or without pingers could not be statistically compared due to a low sample power due to the total number of bycaught porpoises being too low, and not due to pinger inefficiency. Nevertheless, the results did suggest that porpoise bycatch was reduced by the pingers, with the FO pingers being overall more efficient than the SSB pingers. Furthermore, the sample size was not large enough to determine a statistical significance regarding a possible “dinner bell” effect from the experimental pingers. The reason why the SSB pinger appeared slightly less effective in reducing porpoise bycatch and deterring porpoises may be found in the frequency content of the pinger sounds: they contained more high frequencies than the FO pinger sounds, which suffer from bigger transmission losses due to frequency-dependent absorption. Also, the SSB pinger sounds had bigger directionality variations, which may have affected its deterrent effects. Additional trials need to be done with the SSB pinger to further investigate these aspects.

7 Society & Ethical aspects

As previously mentioned in the introduction, incidental bycatch in gillnets is a major issue for the conservation of smaller cetaceans, especially so for the critically endangered Baltic Sea porpoise population. Since pingers are cost efficient and easy to use, the results of this study could help promoting pingers as a cost-efficient method to mitigate bycatch, until alternative fishing methods, not subject to porpoise bycatch, have fully replaced gillnets. Furthermore, since the tested pingers are claimed to be seal safe, it may be possible to shift the negative attitude of fishermen towards pingers.

8 Acknowledgments

I would like to thank my supervisors Mats Amundin, Sara Königson and Emilia Benavente Norrman for all guidance and helpful comments. I would also like to thank all participating fishermen for helping with the data collection.

9 References

Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas, "ASCOBANS". (1992). www.ascobans.org (accessed 24 May 2020).

Amundin, M., Carlström, J., Thomas L., Carlén, I., Koblitz, J.C., Teilmann J., Tougaard J., Tregenza N., Wennerberg, D., Loisa, O., Brundiers, K., Kosecka, M., Kyhn, L.A., Tiberi Ljungqvist, C., Sveegaard, S., Burt, L., Pawliczka, I., Jussi, I., Koza, R., Arciszewski, B., Galatius, A., Jabbusch, M., Laaksonlaita, J., Lyytinen, S., Niemi, J., Šaškov, A., Yermakovs, V., MacAuley, J., Wright, A.J., Gallus, A., Benke, H., Blankett, P., Skóra, K., Dähne, M., Acevedo-Gutiérrez, A.. In prep. Estimating the abundance of the critically endangered Baltic Proper harbour porpoise (*Phocoena phocoena*) population using passive acoustic monitoring.

Aquatec Subsea Ltd. http://www.aquatecgroup.com/ (accessed 24 May 2020).

CPOD.exe: a guide for users (2014). Chelonia Ltd, Mousehole, U.K. URL https://www.chelonia.co.uk/cpod_downloads.htm (accessed 6 June 2019).

Cunningham, K.A., Hayes, S.A., Wargo Rub, A.M., Reichmuth, C. (2014a). Auditory detection of ultrasonic coded transmitters by seals and sea lions. *The Journal of the Acoustical Society of America*, 135, 1978–1985.

Cunningham, K.A, Southall, B.L., Reichmuth, C. (2014b). Auditory sensitivity of seal and sea lions in complex listening scenarios. *Journal of the Acoustical Society of America*, 136, 3410–3421.

Cunningham, K.A., Reichmuth, C. (2016). High-frequency hearing in seals and sea lions. *Hearing Research*, 331, 83-91.

Fishtek Marine. https://www.fishtekmarine.com/deterrent-pingers/ (accessed 6 June 2019).

Fjälling, A., Wahlberg, M., Westerberg, H. (2006). Acoustic harassment devices reduce seal interaction in the Baltic salmon-trap, net fishery. *ICES Journal of Marine Science*, 63, 1751-1758.

Friard, o., Gamba, M. (2016). BORIS: a free, versatile open-source evet-logging software for video/audio coding and live observations. *Methods in Ecology and Evolution*, 7, 1325-1330.

FutureOceans.https://www.futureoceans.com/netshield-dolphin-anti-depredation-pinger 70khz/ (accessed 6 June 2019).

Glemarec, G., Kindt-Larsen, L., Lundgaard, L. S., & Larsen, F. (2020). Assessing seabird bycatch in gillnet fisheries using electronic monitoring. *Biological Conservation*, 243, 108461.

Hammond, P.S., Bearzi, G., Bjorge, A., Forney, K.A., Karczmarski, L., Kasuya, T., Perrin, W., Scott, M.D., Wang, J.Y., Wells, R.S. & Wilson, B. (2008). *Phocoena phocoena* (Baltic Sea subpopulation). *The IUCN Red List of Threatened Species*. ISSN 2307–8235 (online).

Hardy, T., Williams, R., Caslake, R., Tregenza, N. (2012). An investigation of acoustic deterrent devices to reduce cetacean bycatch in an inshore set net fishery. *Journal of Cetacean Research and Management*, 12, 85-90.

International Council for the Exploration of the Sea (ICES). (2012). Report of the working group on bycatch of protected species (WGBYC). ICES, Copenhagen, Denmark.

Jefferson, T.A., Curry, E.B. (1994). A global review of porpoise (Cetacea: Phocoendae) mortality in gillnets. *Biological Conservation*, 67, 167–183.

Kastelein, A.R., Rippe, T.H., Vaughan, N., Schooneman, M.N., Verboom, C.V., de Haan, D. (2000). The effects of acoustic alarms on the behavior of harbour porpoises (*Phocoena phocoena*) in a floating pen. *Marine Mammal Science*, 16, 46–64.

Kastelein, R.A., Wensveen, P.J., Hoek, L., Verboom, W.C., Terhune, J.M. (2009). Underwater detection of tonal signals between 0.125 and 100 kHz by harbour seals (*Phoca vitulina*). *The Journal of the Acoustical Society of America*, 125, 1222–1229.

Kindt-Larsen, L., Dalskov, J., Stage, B., & Larsen, F. (2012). Observing incidental harbour porpoise *Phocoena phocoena* bycatch by remote electronic monitoring. *Endangered Species Research*, 19, 75–83.

Kindt-Larsen, L., Berg, W. C., Northridge, S., Larsen, F. (2018). Harbour porpoise (*Phocoena phocoena*) reactions to pingers. Marine Mammal Science, 35, 552-573.

Kraus, D.S., Read, J. A., Solow, A., Baldwin, K., Spradlin, T., Anderson, E., Wiliamson, J. (1997). Acoustic alarms reduce porpoise mortality. *Nature*, 388, 525–525.

Königson, S., Naddafi, R., Hedgärde, M., Pettersson, A., Östman, Ö., Amundin, M. (in prep.)

Does a pinger inaudible to seals deter harbour porpoises (*Phocoena phocoena*)?

Larsen, F., Eigaard, R.O. (2014). Acoustic alarms reduce bycatch of harbour porpoises in Danish North Sea gillnet fisheries. *Fisheries Research*, 153, 108-112.

National Oceanic and Atmospheric Administration. (1998). Taking of marine mammals incidental to commercial fishing operations; Harbor porpoise take reduction plan regulations. *Federal Register Notice*, 63(231), 464-90. [Department of Commerce, National Oceanic and

Atmospheric Administration 50CFR Part 229]. National Oceanic and Atmospheric Administration. https://www.noaa.gov/ (accessed 24 May 2020).

Nedwell, J.R., Edwards, B., Turnpenny, A.W.H., Gordon, J. (2004). Fish and Marine Mammal Audiograms: A summary of available information. Subacoustech Report ref: 534R0214.

Omeyer, L., Doherty, P. D., Dolman, S., Enever, R., Reese, A., Tregenza, N., ... & Godley, B. J. (2020). Assessing the Effects of Banana Pingers as a Bycatch Mitigation Device for Harbour Porpoises (Phocoena phocoena). *Frontiers in Marine Science*, 7, 285.

Palka, D. L., Rossman, M. C., Vanetten, A., Orphanides, C. D. (2008). Effect of pingers on harbour porpoise (*Phocoena phocoena*) bycatch in the US Northeast gillnet fishery. *J. Cetacean Res. Manage*, 10(3), 217-226.

Read, J. A., Drinker, P., Northridge, S. (2006). Bycatch of marine mammals in U.S. and Global fisheries. *Conservation Biology*, 20, 163–169.

Reichmuth, C., Holt, M.M., Mulsow, J., Sills, J.M., Southall, B.L. (2013). Comparative assessment of amphibious hearing in pinnipeds. *Journal of Comparative Physiology A*, 199, 491-507.

Stridh, H. (2008). Can grey seal (Halichoerus grypus) learn to use acoustic deterrents to locate fishing gears? MSc thesis In: Institute of Systems Ecology Vol MSc Stockholm University.Sørensen, P. M., Wisniewska, D. M., Jensen, F. H., Johnson, M., Teilmann, J., & Madsen, P. T. (2018). Click communication in wild harbour porpoises (Phocoena phocoena). *Scientific reports*, 8(1), 1-11.

Tajani, A., Ciamba, G. (2019). Regulation (EU) 2019/1241: On the conservation of fisheries resources and the protection of marine ecosystems through technical measures. In. *Brussels: Official Journal of the European Union.*

Vingada, J., Ferreira, M., Santos, J., Araújo, H., Oliveira, I., Monteiro, S., ... & Eira, C. (2011). SafeSea-Manual de Apoio para a Promoção de uma Pesca Mais Sustentável e de um mar seguro para cetáceos.

Villadsgaard, A., Wahlberg, M., Tougaard, J. (2007). Echolocation signals of wild harbour porpoises, *Phocoena phocoena*. *The Journal of Experimental Biology*, 210, 56-64.

Wisniewska, D.M., Johnson, M., Teilmann, J., Rojano-Doñate, L., Shearer, J., Sveegaard, S., Miller, L.A., Siebert, U., Teglberg Madsen, P. (2016). Ultra-high foraging rates of Harbor porpoises make them vulnerable to anthropogenic disturbance. *Current Biology*, 26, 1441-1446.

Wolski, L.F., Anderson, R.C., Bowles, A.E., Yochem, P.K. (2003). Measuring hearing in the harbour seal (*Phoca vitulina*): Comparison of behavioral and auditory brainstem response techniques. *Journal of the Acoustical Society of America*, 113, 629-637.

Wright, A.J., Akamatsu, T., Mouritsen, K.N., Sveegaard, S., Dietz, R., Teilmann, J. (2017). Silent porpoise: potential sleeping behaviour identified in wild harbour porpoises. *Animal Behaviour*, 133, 211-222.

Zaharieva, Z., Yordanov, N., Venislava, R., Ventseslav, D. (2019). The effect of pingers on cetaceans bycatch and target catch in the turbot gillnets in Bulgarian Black Sea. *ZooNotes*.

10 Appendix

Pairwise comparisons of C-PODs using Mann-Whitney U test

Area 1– lumpfish fisheries

Results from the Mann- Whitney U test. Summary of FO and SSB pinger influence on average DPM/h, used as a proxy for harbour porpoise presence.

C-POD ID	Type of pinger	DPM/h (mean ± SE)	U	p value	Time period
1199	FO	0.64 ± 0.07	2179870.5	< 0.001*	March - June
1237	Ingen	3.38 ± 0.18			
1199	FO	0	7200	1	April
1253	SSB	0			
1199	FO	0.62 ± 0.06	2245848	0.221	March - June
1266	FO	0.72 ± 0.06			
1199	FO	0.65 ± 0.07	2126058	< 0.001*	March - June
1367	SSB	0.77 ± 0.07			
1199	FO	0.64 ± 0.06	2622923.5	< 0.001*	March - June
1376	Ingen	2.79 ± 0.13			
1266	FO	0.719 ± 0.06	2955503	< 0.001*	March - June
1237	Ingen	4.28 ± 0.17			
1266	FO	0.72 ± 0.06	2229741	< 0.001*	March - June
1367	SSB	0.77 ± 0.07			
1253	SSB	0	6600	0.001*	April
1237	Ingen	0.217 ± 0.09			
1253	SSB	0	7800	0.001*	April
1367	SSB	0.23 ± 0.09			
1253	SSB	0	5640	< 0.001*	April
1376	Ingen	0.81 ± 0.24			
1253	SSB	0	7200	1	April
1266	FO	0			
1237	Ingen	4.26 ± 0.17	1263375	< 0.001*	March - June
1367	SSB	0.77 ± 0.07			
1237	Ingen	3.93 ± 0.15	2443864	< 0.001*	March - June
1376	Ingen	2.76 ± 0.12			
1376	Ingen	2.69 ± 0.13	1523994	< 0.001*	March - June
1367	SSB	0.77 ± 0.07			
1376	Ingen	2.79 ± 0.13	2354165	< 0.001*	March - June
1266	FO	0.48 ± 0.06			

*: Statistically significant at $\alpha = 0.05$ level of significance

Area 2 – lumpfish fisheries

Results from the Mann- Whitney U test. Summary of FO and SSB pinger influence on average DPM/h, used as a proxy for harbour porpoise presence.

C-POD ID	Type of pinger	DPM/h (mean ± SE)	U	p value	Time period
1357	SSB	2.50 ± 0.16	196438	< 0.001*	February - March
1188	No pinger	1.45 ± 0.12			
1357	SSB	1.54 ± 0.10	688149	< 0.001*	February - April
1194	FO	1.11 ± 0.08			
1357	SSB	1.54 ± 0.10	711956	< 0.001*	February - April
1381	SSB	2.53 ± 0.15			
1357	SSB	1 ± 0.15	30927	0.255	February - April
2190	No pinger	1.61 ± 0.30			
1381	SSB	2.71 ± 0.20	212140	0.728	February - March
1188	No pinger	2.51 ± 0.17			
1381	SSB	2.58 ± 0.13	1269347	0.096	February - April
2190	No pinger	2.20 ± 0.12			
1194	FO	1.15 ± 0.08	1354831	< 0.001*	February - April
1381	SSB	2.59 ± 0.13			
1581	FO	1.41 ± 0.25	39995	0.001*	April
1381	SSB	3.03 ± 0.39			
1581	FO	1.58 ± 0.27	38149	0.384	April
1194	FO	1.52 ± 0.27			
1581	FO	1.41 ± 0.25	38383	0.018*	April
2190	No pinger	2.73 ± 0.38			
1188	No pinger	2.51 ± 0.16	160031	0.001*	February - March
1194	FO	0.85 ± 0.09			
1188	No pinger	2.51 ± 0.17	273952	0.47	February - March
2190	No pinger	2.12 ± 0.14			

*: Statistically significant at $\alpha = 0.05$ level of significance

Area 3 (2019) – lumpfish fisheries

Results from the Mann- Whitney U test. Summary of FO and SSB pinger influence on average DPM/h, used as a proxy for harbour porpoise presence.

C-POD ID	Type of pinger	DPM/h (mean ± SE)	U	p value	Time period
1061	FO	0.02 ± 0.007	357475.000	0.109	April - May
1215	SSB	0.04 ± 0.011			
1061	FO	0.02 ± 0.008	214175.000	0.013*	April
1197	No pinger	0.04 ± 0.012			
1061	FO	0.02 ± 0.008	221112.500	0.222	April
1245	No pinger	0.03 ± 0.011			
1221	FO	0.64 ± 0.072	895800.500	0.001*	March - May
1197	No pinger	0.07 ± 0.011			
1221	FO	0.01 ± 0.004	105116.000	0.2	April - May
1215	SSB	0.03 ± 0.015			
1221	FO	0.01 ± 0.004	541845.000	0.2	April - May
1061	FO	0.02 ± 0.006			
1197	No pinger	0.04 ± 0.012	207709.000	0.194	April
1245	No pinger	0.03 ± 0.012			
1197	No pinger	0.05 ± 0.017	106235.000	0.04*	April
1215	SSB	0.03 ± 0.015			
1245	No pinger	0.04 ± 0.015	103965.500	0.998	April
1215	SSB	0.03 ± 0.015			
1245	No pinger	0.03 ± 0.012	211906.500	0.22	April
1221	FO	0.01 ± 0.006			

*: Statistically significant at α = 0.05 level of significance

Area 3 (2019) - cod fisheries

Results from the Mann- Whitney U test. Summary of FO and SSB pinger influence on average DPM/h, used as a proxy for harbour porpoise presence.

C-POD ID	Type of pinger	DPM/h (mean ± SE)	U	p value	Time period
1221	SSB	0	6158.5	0.044*	December
1381	SSB	0.06 ± 0.035			
1266	FO	0.09 ± 0.037	34433	0.04*	December - January
1221	SSB	0.01 ± 0.007			
1266	FO	0.01 ± 0.01	4848	0.18	December
1381	SSB	0.07 ± 0.039			
1581	FO	0.01 ± 0.006	27145.5	0.65	December
1221	SSB	0.01 ± 0.007			
1581	FO	0.01 ± 0.01	4950	0.172	December
1381	SSB	0.07 ± 0.039			
1266	FO	0.15 ± 0.038	59225	< 0.001*	December - January
1581	FO	0.01 ± 0.004			

*: Statistically significant at α = 0.05 level of significance

Area 4 (2018) – cod fisheries

Results from the Mann- Whitney U test. Summary of SSB pingers influence on average DPM/h, used as a proxy for harbour porpoise presence.

C-POD ID	Type of pinger	DPM/h (mean ± SE)	U	p value	Time period
1197	No pinger	0.67 ± 0.10	203758	0.83	September - November
1221	No pinger	0.71 ± 0.11			
1197	No pinger	0.53 ± 0.09	172157.5	0.002*	September - November
1368	SSB	0.33 ± 0.09			
1221	No pinger	0.63 ± 0.11	171590	0.001*	September - November
1368	SSB	0.33 ± 0.09			

*: Statistically significant at $\alpha = 0.05$ level of significance

Area 4 (2019) – cod fisheries

Results from the Mann- Whitney U test. Summary of FO and SSB pinger influence on average DPM/h, used as a proxy for harbour porpoise presence.

C-POD ID	Type of pinger	DPM/h (mean ± SE)	U	p value	Time period
1376	FO	0.02 ± 0.015	14028.000	0.027*	December
1253	No pinger	0.67 ± 0.27			
1198	No pinger	0.11 ± 0.051	7626.000	0.76	December
1061	SSB	0.08 ± 0.051			
1061	SSB	0.25 ± 0.13	9105.5	0.23	December
1199	SSB	0.05 ± 0.032			
1237	FO	0.15 ± 0.073	6551.5	0.984	December
1061	SSB	0.09 ± 0.055			
1253	No pinger	0.86 ± 0.30	11439	0.124	December
1061	SSB	0.23 ± 0.11			
1376	FO	0.02 ± 0.01	6729.5	0.243	December
1061	SSB	0.09 ± 0.06			
1237	FO	0.12 ± 0.05	18704	0.772	December
1198	No pinger	0.08 ± 0.03			
1198	No pinger	0.02 ± 0.012	15412	0.057	December
1253	No pinger	0.64 ± 0.26			
1376	FO	0.03 ± 0.016	19404.5	0.239	December
1198	No pinger	0.08 ± 0.03			
1198	No pinger	0.02 ± 0.011	11937	0.305	December
1199	SSB	0.10 ± 0.06			
1237	FO	0.13 ± 0.06	10365	0.99	December
1199	SSB	0.11 ± 0.06			
1253	No pinger	0.64 ± 0.26	14831	0.279	December
1199	SSB	0.10 ± 0.05			
1376	FO	0.02 ± 0.015	10656	0.152	December
1199	SSB	0.11 ± 0.06			
1237	FO	0.12 ± 0.047	19093	0.148	December
1376	FO	0.03 ± 0.016			
1237	FO	0.11 ± 0.05	13783.5	0.204	December
1253	No pinger	0.67 ± 0.27			

*: Statistically significant at $\alpha = 0.05$ level of significance