DTU Aqua
National Institute of Aquatic Resources

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Lotte Kindt-Larsen, Gildas Glemarec, Anne-Mette Kroner, Amalie Walsøe Bruun, and Finn Larsen

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Colophon

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Cover photo: Cormorant at pound net. Photo: Anne-Mette Kroner

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Preface

The work presented here was funded by the European Maritime and Fisheries Fund (EMFF) and the Danish Fisheries Agency via the project ‘Interactions between protected species and fisheries (IMBAF)’ (Grant agreement number 33113-B-20-166). The project leaders were Lotte Kindt-Larsen and Finn Larsen, and the project period was from June 2020 to June 2023.

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Lotte Kindt-Larsen

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Executive summary

The overall objective of the IMBAF project was to propose and test solutions to mitigate the effects of existing conflicts between protected species and coastal commercial fisheries in Danish waters. Specifically, the project aimed to reduce bycatch of marine mammals and seabirds in Danish net fisheries and to minimize the impact of seals on fisheries through the development and optimization of seal-safe gear.

The IMBAF project was divided in seven work packages (WP):

1. Test LED lights as a preventive seabird bycatch method in the lumpsucker gillnet fishery;
2. Measure the scaring effect of looming-eye buoys on seabirds around set pound nets;
3. Assess the potential of thinner twine gillnets to prevent bycatches of porpoises;
4. Compare the attractiveness of different bait types in cod pots;
5. Develop and test novel fisher's ideas for seal-proof gear;
6. Evaluate the effectiveness of acoustically reflective nets at reducing harbour porpoise bycatch in gillnet fisheries;
7. Disseminate the findings and conclusions of the IMBAF project.

WP.1 investigated the seabird bycatch reduction effect of flashing LED lights fixed on lumpsucker. The experimental fishing trials were conducted in 2021 and 2022 during the late winter and early spring. The trials were monitored using electronic monitoring (EM) systems and DTU Aqua onboard observers. During the experiment, a total of 167 bird bycatches belonging to 6 different species was recorded. The results showed a bycatch rate of 0.29 seabird per km.day and 0.4 seabird per km.day for light-nets and for control-nets, respectively. However, these bycatch rates were not significantly different, and therefore, these flashing LED lights cannot be recommended as a mitigation solution for reducing seabird bycatch in lumpsucker gillnets, based on the collected data.

The aim of the trials in WP.2 was to assess the long-term effectiveness of a device designed to scare away seabirds from an area of interest. Here, looming-eye buoys were experimented around pound nets in a fishery in the Western Baltic in 2021. One of two pound nets in the trials was equipped with two looming-eye buoys and the number of seabirds before and after implementation was statistically compared (paired-BACI design). Both pound nets were monitored by DTU Aqua for several weeks before and after the implementation of the mitigation devices. In total, 722 birds belonging to 8 different species were observed. Before the installation of the looming-eye buoys, there were similar numbers of seabirds in the two pound nets. However, after the installation of the buoys, it appeared that there were more seabirds in the control area. The difference between the two areas, however, decreased during the observation period. Based on the data collected in this experiment, no conclusive effect of the scaring effect of looming-eye buoys on seabirds could be detected.

In WP.3, experiments were conducted using thin-twined nets to prevent porpoise bycatch. Three fishers were provided with two types of nets, one set of thin twine and the other with standard gillnet twine. The fishing activities were monitored using video systems and the catch rates and bycatch rates of the standard and of the modified nets were compared to evaluate the effectiveness of thin twine nets at reducing bycatch with affecting catches. In total, 8 months of usable data were collected for the year 2022. During the course of the experiment, 5 porpoise bycatches were recorded in standard nets and 4 porpoises were captured in thin-twined nets. The result of the statistical analyses indicated that the reduction in twine thickness was not enough to significantly reduce porpoise bycatch. Moreover, the fishers involved in the trials believed that further reduction in twine thickness would lead to substantial reductions in fish catches due to the fragility of the gear, while reducing its durability.

WP.4 tested different types of baits in Atlantic cod (*Gadus morhua*) pot fishery in the Baltic Sea. The trials were conducted differently than outlined in the initially submitted application because, over the timeframe of the project, substantial changes in the cod quota were implemented (TAC was reduced to zero), which made it impossible to operate a targeted cod fishery. Therefore, we decided to conduct the baiting experiments without pots to avoid catching cod and, instead, attach the bait bags to sunk anchors that were monitored with underwater video cameras. Five different types of bait (herring, sprat, sandeel, squid, and an artificial bait) were tested, both near Bornholm and in the Belt Sea, Denmark. The results showed that herring, sandeel, and sprat attracted cod, but there was no significant difference between these three types of bait. The artificial bait and squid had a very low attractiveness and therefore, these two types of bait are not recommended for use in cod pots.

WP.5 aimed to develop and test fisher's ideas for seal-proof fishing gear. In total, the project received 4 ideas from the fishing industry: jigging-machines, lumpsucker-fykes, Dyneema-fykes, and a pound net trap with a large chamber. The idea of testing jigging machines was approved, but the fisher who was supposed to carry out the experiment chose to withdraw from fishing shortly after for reasons independent of the IMBAF project. The second accepted fisher’s idea was a large lumpsucker trap. Unfortunately, the landings of lumpsucker in Denmark have hit a record low in 2022 and 2023, following several years of decline. In turn, the partnering fisher could not use the trap, although he plans to test it in 2024. Thirdly, it was proposed to use a new fyke design where parts of the fyke are made in Dyneema twine, a particularly strong material that seals cannot tear apart. These traps were built, but due to a significant reduction in eel fishing in the recent past, the fisher could only conduct very little fishing in the time allocated to the trials. He will however continue to test this design in 2024. The last idea we received was to build a large chamber in a pound net to make it possible for seals to swim out of it and thus not destroy the entire catch and the gear. The idea was approved, but for unknown reasons, the fisher decided not to participate in the project in the last minute, so the idea was not tested.

In WP.6, we conducted experiments using reflective nets aiming to reduce porpoise bycatch in gillnets. Specifically, we tested acrylic pearls, known to be acoustically reflective in the frequencies used by porpoises, and measured if bycatch rates of protected species and catch rates of fish were affected. In this experiment, pearls were attached to the netting material to increase the acoustic reflectivity of the net. The so-called pearl nets were tested multiple times because the initial results suggested that the pearls increased fish catches. However, after repeated experiments, the results showed that the pearls did not seem to change fish catch rates significantly. No porpoises were bycaught in control or treatment nets, so the potential of pearl nets to reduce porpoise bycatch remains unknown. Nevertheless, it is an important step in the development of a pearl net fishery to demonstrate that fish catches are not negatively affected by pearls.

The last work package (WP.7) dealt with disseminating the project’s results. As promised, the IMBAF project was presented to the seal group from the Danish Ministry of Environment and the Ministry of Food, as well as dedicated workshops and working groups within ICES, HELCOM, ASCOBANS, and Birdlife Denmark. Furthermore, a Bachelor student wrote a thesis using data collected in the project, and three scientific articles are currently in the process of being published. The IMBAF project has not yet been presented to the Ministry of Food's porpoise group as initially planned, because the Ministry did not hold such meetings during the project period.

The IMBAF project contributed to scientifically assess the potential of mitigation methods and alternatives to reduce the impact of fishing on sensitive species of marine mammals and seabirds in Denmark and maintain acceptable levels of catches for fishers. Even though the results in several of the work packages proved that some of the tested mitigation devices did not work as well as intended, this work is an important part of the process of developing and testing new tools. It is equally important for the fishing industry to know what does and what does not work, so that unnecessary efforts are not spent on implementing new gear and devices when these have not proven unambiguously effective at achieving their target – i.e., reducing bycatch of protected species and maintain catch rates of target species. That said, the pearl nets tested in WP.6 to replace traditional monofilament gillnets showed promises, as they do not affect fish catches, while potential limiting interactions with cetaceans, thus helping to solve the problem of porpoise bycatch in Danish gillnets, and possibly elsewhere.

WP.1 Gillnet illumination as a means to reduce seabird bycatch rates in lumpsucker gillnets

Introduction

Gillnet fishing is responsible for the capture of numerous non-target species worldwide, including mammals, chelonians, and seabirds (Lewison *et al.*, 2014). Seabirds are globally declining (Dias *et al.*, 2019), and gillnet mortality contributes to the decrease of some populations (Žydelis, Small and French, 2013). Seabirds constitute a very diversified group that shows a great variety of foraging behaviour. Consequently, the effectiveness of bycatch reduction devices (BRDs) likely varies widely from one species to another (Northridge *et al.*, 2017; Mangel *et al.*, 2018). The challenge of mitigating bycatch in gillnet fisheries consists of making the nets conspicuous to seabirds (to reduce bycatch rates), while remaining undetectable to the target fish species (to maintain catch rates).

As for all other amphibious animals, seabirds have evolved specific sensory adaptations to perceive their environment both in-air and underwater. For pelagic-foraging species (e.g., cormorants, auks, loons, or penguins), vision seems to play a major role in the capture of prey (White *et al.*, 2007; Martin, White and Butler, 2008; Martin and Crawford, 2015; Martin, 2017). Yet, the underwater visual acuity of the great cormorant (*Phalacrocorax carbo*), the marine predator with the highest yield level measured to date (Gremillet *et al.*, 2004), is comparable to that of a human being (Fay, 1992; Martin, White and Butler, 2008).

In the past two decades, BRDs using visual or acoustic alerts have been developed to prevent seabird incidental catches in net fisheries. However, few of these mitigation technologies have been reported to reduce bycatch of seabirds while maintaining catch rates of commercial fish (Løkkeborg, 2011). In a lumpsucker gillnet fishery in western Greenland, net modifications that made the lower 45 cm of the nets more visible to seabird were shown to reduce common eider (*Somateria mollissima*) bycatches significantly, while also reducing catch rates of female lumpsucker (Post *et al.*, 2023). In the Puget Sound salmon driftnet fishery (USA), the modification of the upper part of the nets to make them highly visible for seabirds floating at the surface, or the use of acoustic alarms (1.5 kHz pinger at 120 dB attached on the cork line every 50 m), both proved effective at reducing seabird bycatch rates (Melvin, Parrish and Conquest, 1999). Each method ensured that target species catch rates (sockeye salmon *Oncorhynchus keta*) were maintained and resulted in a large reduction in bycatch rates of common guillemots (*Uria aalge*), but not of the rhinoceros auklet (*Cerorhinca monocerata*). Furthermore, experiments conducted in the small-scale Peruvian gillnet fishery showed that using constant green lights on gillnets reduced the bycatch of a pelagic-foraging seabird, the Guanay cormorant (*Leucocarbo bougainvilliorum*), without affecting the catch of target species (Mangel *et al.*, 2018). In parallel, Martin and Crawford proposed to utilise high-contrast panels spaced at regular intervals on the nets to warn the birds diving in the vicinity (Martin and Crawford, 2015). This method was trialled in the Eastern Baltic Sea, in Lithuania and Poland, but failed at reducing overall seabird bycatch, and even increased the bycatch rates of a benthivorous seabird, the long-tailed ducks (*Clangula hyemalis*) (Field *et al.*, 2019). The same authors also experimented with illuminating nets with LED lights. However, neither the steady green nor the flashing white LED lights that they tested were able to decrease the bycatch rates of the most commonly affected bird species. White lights significantly increased the bycatch of long-tailed duck, indicating that this species may have been attracted to the lights. These examples illustrate a major problem for seabird bycatch mitigation, which is that there is no universal solution to tackle this worldwide problem. Generally, trials using similar mitigation devices may be effective in one particular fishery but not in another, depending on fishery-specific operational factors (soak time, net length, mesh size), ecological factors (water transparency, depth), and on species-specific reactions to particular stimuli (visual, acoustic, or other).

The north Atlantic lumpsucker (*Cyclopterus lumpus*) is a valuable fish species targeted across its entire range. The fish is mostly captured in gillnets set in shallow waters, whereto the fish migrate in large numbers during the spawning season. Females are kept for their roe that can reach very high market values (up to >3000DKK per kg in 2023 in Denmark), while most males are discarded alive. Lumpsucker gillnetting is generally associated with high seabird bycatch rates (Christensen-Dalsgaard *et al.*, 2019; Merkel *et al.*, 2022), due to a combination of operational factors (large mesh sizes, long soak times, long net fleet lengths) and ecological factors (e.g., nets often set in areas where coastal seabirds aggregate in large numbers). Although strong evidence is lacking in Danish waters, such high bycatch levels are susceptible to pose a threat to the long-term sustainability of some vulnerable seabird populations. Concomitantly, catch rates have considerably decreased in the past half century in Denmark, and even more so in the last few years (Vinther, Kindt-Larsen and Dalskov, 2022). This reduction may be due to a decrease in the local populations size, a reduction in fishing effort, or both. Nevertheless, the level of fishing effort in the areas of high seabird densities is still susceptible to pose a risk to the bycatch-prone species, and, as a result, finding efficient mitigation solutions is a priority to maintain a viable lumpsucker fishery in Denmark, while guaranteeing sustainable populations of seabirds.

Here, we report the results of testing flashing white LED lights to reduce the bycatch of seabirds in a Danish demersal gillnet fishery targeting lumpsucker.

Materials and Methods

Mitigation trials were conducted during the lumpsucker fishing season (from February to April) in the western Baltic Sea in 2021 and 2022, completing earlier trials on the same vessel and in the same area from 2019 and 2020 (Table 1). Specifically, we tested whether flashing white LED lights (hereafter, net lights) attached to gillnets could reduce seabird bycatches in the southern part of the Kattegat and in an adjacent small fjord (Isefjord) during the lumpsucker fishing season while wintering bird densities are high in this area (NOVANA 2023). One commercial vessel (16m in overall length) participated in the study, targeting lumpsucker seasonally with gillnets. The entire fishing activity of the vessel was monitored using electronic monitoring (EM), including the recording of length and soak duration of each haul with and without net light. Each catch of lumpsucker was recorded, as well as all seabird bycatches, which were identified down to species level, similarly to what is described in Glemarec et al. (2020). We equipped 76 standard lumpsucker 125mm half-twine monofilament net panels (0,45 x 125mm x 12,5ma x 2000kn; float line length = 60m; lead line length = 66,0m) with flashing white LED lights (*Netlight* – Fishtek Marine, Devon, UK). The net lights used in this trial emitted a sequence of intense white flashes (luminous flux = 10 lumen; wavelength: 430 – 630 nm; maximal intensity at 480 nm). One complete flash sequence lasted approximately 10 s and consisted of repeating 52 ms flashes in decreasing intervals of 2 s down to 250 ms, followed by a pause of 5.5 s. We used alkaline batteries to power the devices, which ensured a lifetime of 800 h according to the manufacturer's specifications. The power level of each light was controlled after each haul, and all the batteries were replaced after 30 days at sea. The net lights were spaced alternatively on the leadline and on the floatline every 10 m, i.e. the horizontal distance between two consecutive lights on the floatline (leadline) was 20 m. Enchased in their rubber carrier, each net light (with battery) weighed 25 g in the water, so no additional float was added on the floatline to compensate for the extra weight. Identical net panels with no net light attached were used as control. The total length of the control net fleets varied between days as the vessel's master frequently attached and re-assembled the control net panels for fitting the requirement of the day's fishing operations. As a result, the total net length of both controls and treatments varied between fishing days (FD). The lumpsucker gillnet fishery is characterised, among others, by its very long soaking durations. Few net fleets are usually set each day (or each few days) and hauled after a period of several days. Net fleets equipped with net lights were always set the same day, together with control net fleets, and all were hauled the same day to guarantee the comparability of the results using a matched pairs experimental design.

An observer was present onboard the vessel at least once every 2 fishing trips where gillnets with net lights were used (i.e., set in the water or hauled back onboard) to check that the equipment was working, change the net lights batteries, and ensure that the trial protocol was respected.

Bycatch per unit effort (BPUE) was estimated for treatment and control nets for each FD as the number of birds captured per kilometre of net times 24 h of soak [seabird bycatches / (net length x soak time)]. Likewise, we estimated catch per unit effort (CPUE) as the number of non-discarded lumpsucker captured per kilometre of net times 24 h of soak [lumpsucker catches / (net length x soak time)]. We then compared statistically the mean catch and bycatch rates per FD between treatment and control during the entire study period. Seabird bycatch rates (BPUE) and lumpsucker catch rates (CPUE) were compared between net light and control net fleets using Wilcoxon signed-rank tests. The Wilcoxon signed-rank test is a rank-based non-parametric test used to analyse matched samples (Quinn and Keough, 2002). The null hypothesis was that the median between the two datasets was null (no difference), against the alternative hypothesis that there was a significant difference in the median between the two datasets (Fowler, Cohen and Jarvis, 2013). For seabirds, we chose a one-tailed test to test if the net light treatment *reduced* bycatch rates, while for lumpsucker catches, we preferred a two-tailed test to test whether the net light treatment *affected* catch rates (increase or decrease). Data preparation and statistical analyses were conducted in R (R Core Team, 2023) and in the graphical statistical software GraphPad Prism.

Table 1. Summary of the data collected during the net light mitigation trials between 2019 and 2022 in Kattegat and Isefjord. BPUE (bycatch per unit effort) expressed as number of seabird per km.day; CPUE (catch per unit effort) expressed as number of lumpsucker per km.day.

Fishing trip number	Date	Treatment	Net fleet length (m)	Soak time (h)	# seabirds	# lumpsucker	BPUE	CPUE
1	08/03/2022	net light	982.8	185.11	2	9	0.26	1.19
	08/03/2022	control	6400.3	185.11	17	29	0.34	0.59
2	30/03/2021	net light	1901.7	145.76	0	12	0.00	1.04
	30/03/2021	control	3408.8	145.76	1	18	0.05	0.87
3	29/03/2021	net light	133.9	185.31	1	1	0.97	0.97
	29/03/2021	control	6505.5	185.31	13	95	0.26	1.89
4	14/03/2021	net light	1575.8	144.97	0	13	0.00	1.37
	14/03/2021	control	5928.3	144.97	14	53	0.39	1.48
5	13/03/2021	net light	517.6	74.86	0	6	0.00	3.72
	13/03/2021	control	4464.7	74.86	3	20	0.22	1.44
6	04/03/2021	net light	1571	93.19	0	4	0.00	0.66
	04/03/2021	control	2907.7	93.19	0	16	0.00	1.42
7	25/02/2021	net light	1373.2	92.33	0	13	0.00	2.46
	25/02/2021	control	8123.6	92.33	6	51	0.19	1.63
8	24/02/2021	net light	1431.6	144	5	6	0.58	0.70
	24/02/2021	control	8346	144	33	19	0.66	0.38
9	21/02/2021	net light	1312.8	120	7	16	1.07	2.44
	21/02/2021	control	4864.6	120	63	53	2.59	2.18
10	03/03/2020	net light	806.7	23.65	0	1	0.00	1.26
	03/03/2020	control	5812	23.65	0	17	0.00	2.97
11	28/04/2019	net light	963.7	76.21	0	2	0.00	0.65
	28/04/2019	control	4105.1	76.21	0	16	0.00	1.23
12	04/04/2019	net light	562.7	73.34	1	2	0.58	1.16
	04/04/2019	control	9132.6	73.34	1	4	0.04	0.14

Results and Discussion

During the course of the experiment, we recorded 12 FD where at least one net fleet was equipped with net lights. The total net length ranged between 4.5 and 9.8 km (mean 6.9 ± 0.5 km; hereafter mean ± standard error, SE). The mean length of treatment and control nets were 1.1 ± 0.1 km and 5.8 ± 0.6 km, respectively. The difference in mean soak duration between fishing days was quite substantial and ranged from 23.7 h to 185.3 h (mean 113.2 ± 14.2 h). In total, during the 12 FD monitored in the study, we recorded 167 seabirds from 6 species and 3 families and 476 female lumpsuckers (Table 1 and Table 2).

Table 2. Seabird bycatches recorded during the trial period (12 fishing days between 2019 and 2022) on one gillnet vessel targeting lumpsucker in southern Kattegat and Isefjord.

Family	Species	Number of bycatches
Anatidae	Common eider (*Somateria mollissima*)	28
	Velvet scoter (*Melanitta fusca*)	34
	Common scoter (*Melanitta nigra*)	30
	Unidentified duck	9
Gavidae	Black-throated loon (*Gavia arctica*)	5
Alcidae	Razorbill (*Alca torda*)	3
	Common guillemot (*Uria aalge*)	29
	Unidentified auk	22
	Unidentified bird	9

The mean BPUE of treatment net fleets was 0.29 seabird per km.day (± 0.11 SE) and the mean BPUE of control net fleets was 0.40 seabird per km.day (± 0.20 SE) (Figure 1). Although we monitored 12 fishing days during the study period, we registered no seabird bycatch in 3 out of these 12 FD. In a Wilcoxon signed-rank test, the ties between control and treatment (i.e., when the difference is equal to zero) have to be ignored. As a result, the effective sample size for the one-tailed test was reduced to 9 FD (Table 1). The test statistic was higher than the critical value for that sample size and we thus failed to reject the null hypothesis that net fleets equipped with net lights reduced the bycatch rates of seabirds in lumpsucker gillnets.

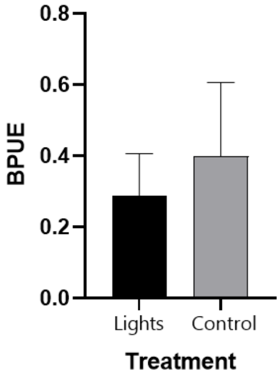

Figure 1. Comparison of mean seabird bycatch rates (BPUE) between treatment (light) and control net fleets (n = 9). Error bars show the standard error of the mean.

The mean CPUE of treatment net fleets was 1.47 lumpsucker per km.day (± 0.26 SE) and the mean CPUE of control net fleets was 1.35 lumpsucker per km.day (± 0.22 SE) (Figure 2. No ties were observed, and the sample size of the two-tailed Wilcoxon signed-rank test was 12 FD (Table 1). The test statistic was much higher than the critical value and we failed to reject the null hypothesis that net fleets equipped with net lights reduced the catch rates of target species in lumpsucker gillnets.

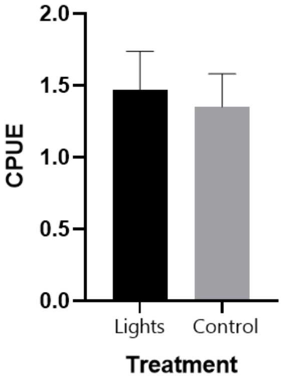

Figure 2. Comparison of mean lumpsucker catch rates (BPUE) between treatment (light) and control net fleets (n =12). Error bars show the standard error of the mean.

The flashing white LED lights used in Denmark (Western Baltic) had been previously tested in the Lithuanian coastal set net fishery (Eastern Baltic). The authors of this study concluded that using flashing white lights did not reduce seabird bycatch (Field *et al.*, 2019). They even observed a significant increase of BPUE of long-tailed duck in the experimental nets, suggesting that this benthic-foraging seabird was attracted to the net lights. In Denmark, only common eiders, common scoters, and velvet scoters were recovered from the nets during the course of the net light trial, and long-tailed ducks were totally absent from the records (Table 2). Contrasting with what was recorded in Lithuania, the bycatch rates of these benthic-foraging seaducks were not significantly different between the experimental nets equipped with lights and the controls in Denmark (Figure 1). The dissimilar response to the same treatment between both sides of the Baltic Sea suggests that different species of seaducks may be responding differently to flashing white lights, going from probable indifference (common eider and scoters) to potential attraction (long-tailed ducks). However, the number of replicates in the paired-design experiment (n = 9) may be too small to conclude with certainty that net lights do not affect bycatch rates of seabirds in lumpsucker fisheries in Denmark. Moreover, results from the Peruvian set gillnet fishery of Constante showed that using constant green LED lights to illuminate gillnets reduced the bycatch of a pelagic-foraging bird, the Guanay cormorant, by more than 85% (Mangel *et al.*, 2018). Additionally, driftnets in the sockeye salmon fishery in the Puget Sound (USA), modified to make the upper section highly visible from the surface, reduced the bycatch of common guillemot considerably (Melvin, Parrish and Conquest, 1999). In the light of the above, increasing the visibility of gillnets may still be in some cases an effective solution to reduce the bycatch of visual predators as pelagic-foraging seabirds, but not of other diving birds like benthic-foraging seaducks. However, reviewing the sensory adaptations of amphibious seabirds, Martin and Crawford (2015) advised against using lights on nets as BRD. They argued that seabird eyes need time to adapt to the low light conditions found at foraging depths. Exposed to intense light levels at depth, the pupils would be forced to shut rapidly, which in turn would result in temporary visual impairment for the birds.

High concentrations of particles in the water column directly affect water transparency, thereby reducing the potential of using light as BRD. The Baltic Sea is a semi-enclosed body of water, in which eutrophication has been a recurring problem for decades (HELCOM, 2018b). Generally, water turbidity is higher in the Baltic Proper than in the Western Baltic. For instance, in the Lithuanian coastal waters, where the net lights showed no reduction in seabird bycatch (Field *et al.*, 2019), water clarity remains ordinarily below 3.8 m in the summer, while it averages 8.26 m in the Sound in the same period (HELCOM, 2018a). The relatively high clarity of Danish waters may have contributed to the lower bycatch rates of cormorants and auks observed in the nets equipped with lights in the Sound. These pelagic-foraging seabirds can perceive the flashes of light at a higher distance in more transparent waters, thus giving them more time to react before encountering the nets. In contrast, benthic-foraging sea-ducks like common eiders and scoters typically search the sediment for food. Particle resuspension in the water column resulting from this behaviour can locally increase turbidity, making the nets and the net lights less visible for the birds. Benthic foragers may therefore be unable to detect the lights at a distance sufficient to elicit an evasive response.

Reducing the impact of commercial fisheries on ecosystems while maintaining economic value for the fishing sector is a priority in fisheries research. Mitigation device development needs to integrate fishers' needs for a practical and economical solution that does not reduce the catches of target species (Aranda *et al.*, 2019). The methods that we tested in this study did not reduce lumpsucker CPUE but did not significantly reduce seabird BPUE either. Consequently, and unless more data can be collected that would demonstrate a significant effect of net lights on seabird bycatch, we cannot recommend this BRD as a solution to reduce seabird captures in lumpsucker gillnets in Denmark.

WP.2 Looming-eye buoy experimental trials on pound nets

Introduction

Research on bird cognitive abilities shows that some groups of wild birds are highly sensitive to specific visual cues that mimic the presence and approach of a predator; such "super-stimuli" generally induce an aversive reaction on the tested birds (Inglis, 1980). For instance, projecting a moving eye-shaped pattern on a large television screen (suggesting that the "eyes" are moving toward the watcher;) can effectively repel birds of prey and corvidae from an area (Hausberger *et al.*, 2018).

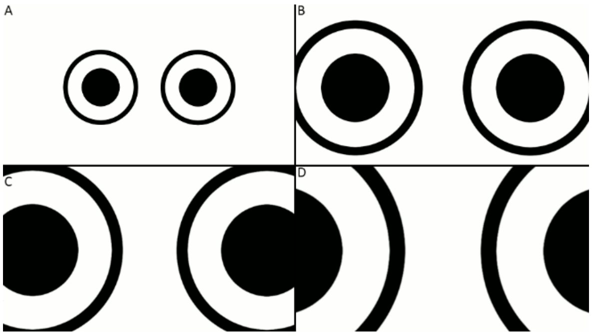

Figure 3. Snapshots of a sequence figuring an eye-shaped pattern "looming" toward the observer. The full sequence (A, B, C, then D) is composed of more intermediate images, and its repetition induces a super-stimulus, which is supposed to repel birds from the screened area [modified from Hausberger et al. (2018)].

Following this principle, the so-called "looming-eye buoy" was developed in the United Kingdom by the company Fishtek Ltd in collaboration with BirdLife International (Figure 4). The apparatus was tested in a coastal area in Lithuania where it showed promising results to deter seabirds (Rouxel *et al.*, 2021). Contrary to other visual or acoustic bird scarers commonly used on land, which lose efficacy as birds become habituated to the stimuli (Inglis, 1980; Stevens *et al.*, 2007), Rouxell *et al.* (2021) reports that the looming-eye shape did not induce habituation in the targeted groups of birds.

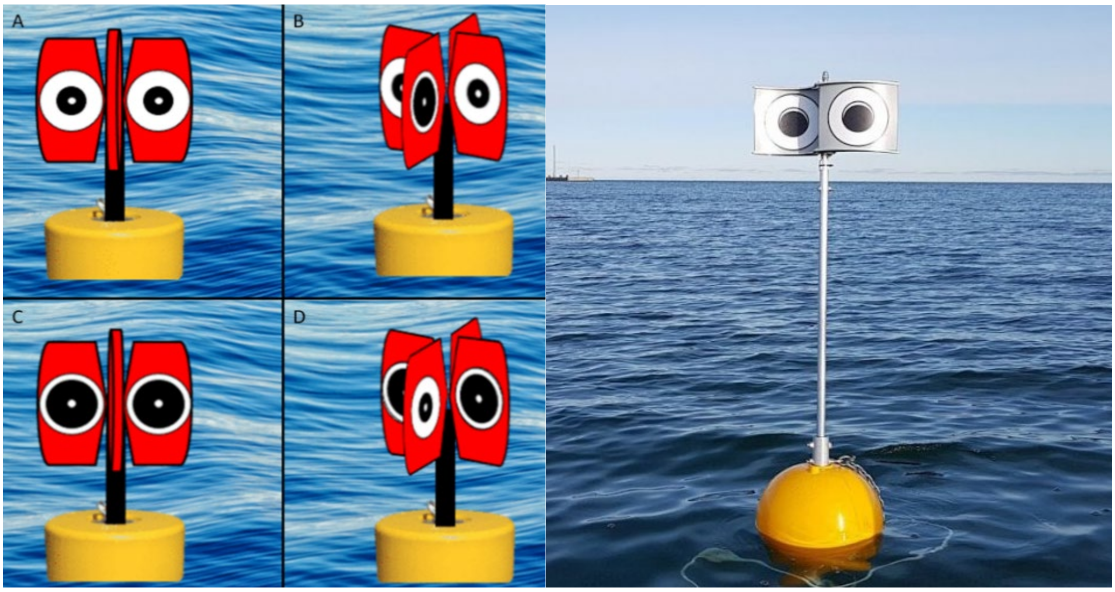

Figure 4. Left: Principle of a floating windmill seabird scarer for static fishing gears. The windmill turns with the wind, alternatively showing small and big eye shapes (A, B, C, then D), inducing an avoidance reaction in seabirds [courtesy of Yann Rouxel, Royal Society for the Protection of Birds (RSPB)]. Right: Detail of a looming-eye buoy with two aluminium wings (twin blade model).

The purpose of this work package was to test the effectiveness of the looming eye buoy (twin blade model) at eliciting an escape or an avoidance response in common pelagic-feeding seabirds like the great cormorant (*Phalacrocorax carbo*). Great cormorants are opportunistic piscivorous seabirds that commonly target man-induced fish aggregations, e.g., opened aquaculture facilities, pound nets, discards from fishing vessels or catches taken in gillnets. For this study, the proposed mitigation devices were installed on stationary pound nets in the Western Baltic Sea that are commonly used by seabirds to rest and feed during the fishing season. Pound nets are a type of large stationary fishing traps, relatively common along the Danish Baltic shore to target migratory fish species as Atlantic mackerel (*Scomber scombrus*) or garfish (*Belone belone*). A pound net (Figure 5) consists of a net fence running perpendicular from the coast that prevents the passage of target fish species to direct them directly or via a system of additional standing nets (called the heart) into the trap itself (the pound). Fish entrapped in a pound net can stay alive for long period once captured and the traps are usually emptied every few days.

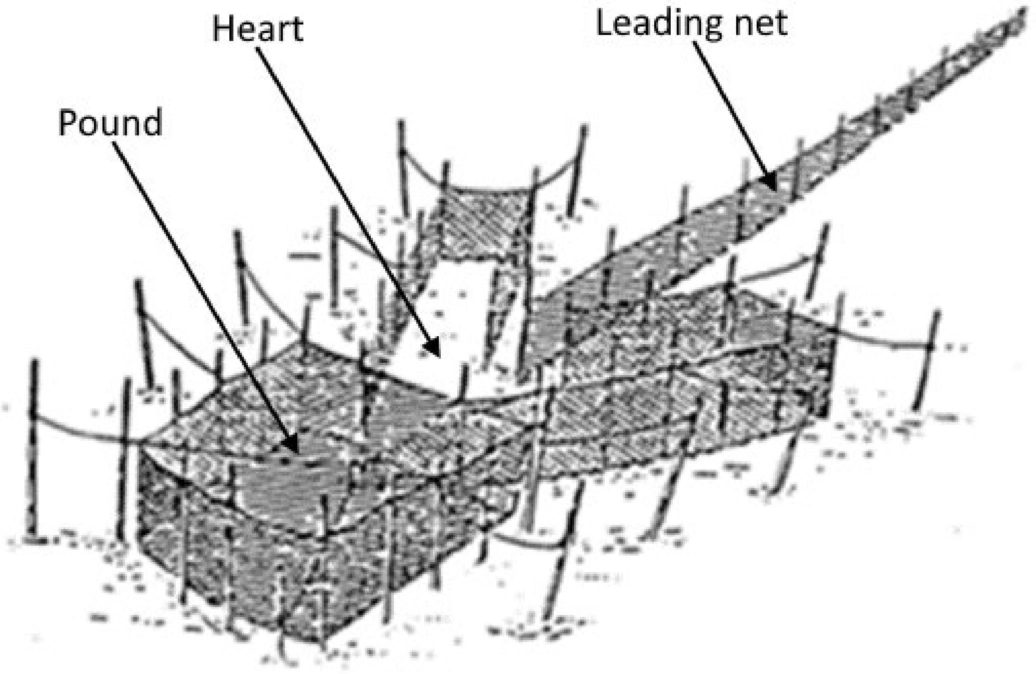

Figure 5. Schematics of a pound net (source: FAO/FIIT Fishing Gear Type Fact-Sheet).

In this part of the project, we wanted to test the hypothesis that the presence of looming-eye buoys placed on the surrounding poles of a pound net reduces the number of seabirds (species-specific) swimming in and around the pound net.

Materials and Methods

The looming-eye buoy field trials were conducted in Korsør (Denmark) between March 2021 and June 2021. Two pound nets of similar diameters and located 1200m apart as the crow flies were selected for this experiment (Figure 6).

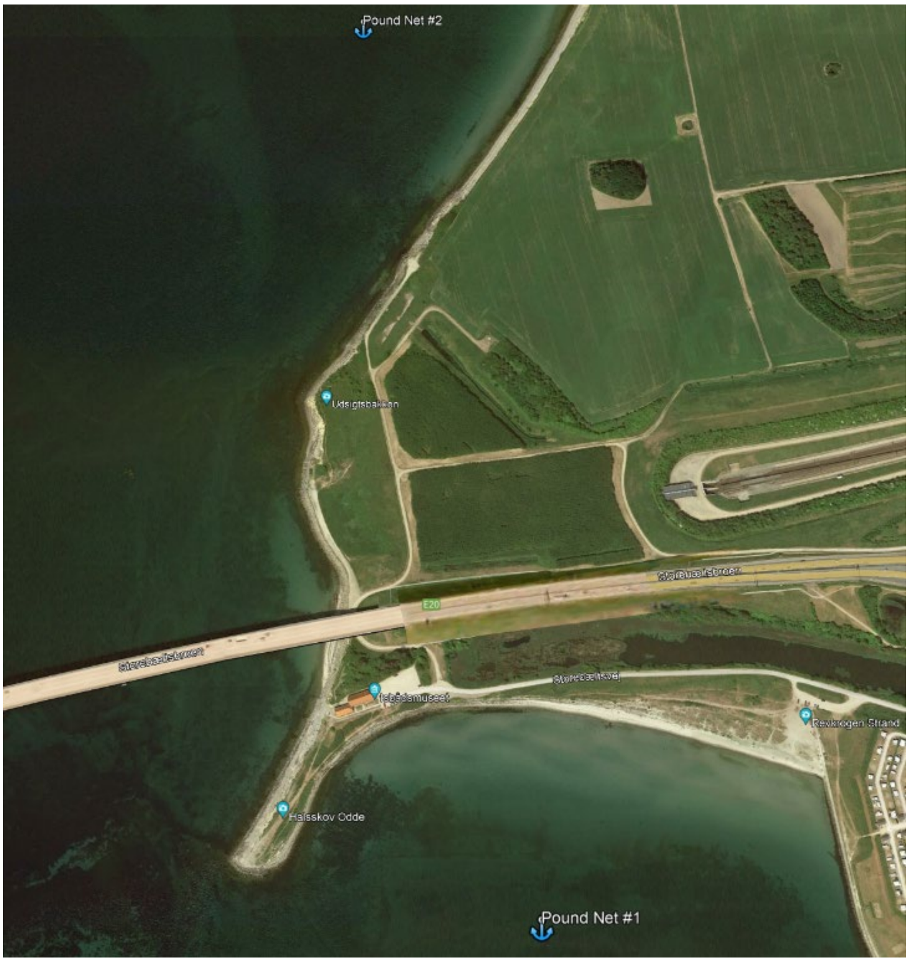

Figure 6. Locations of the pound nets used in the looming-eye buoys experiment near Korsør, Denmark (55°21'4"N 11° 5'51"E).

After the first two days of observations, where the pound nets had been left untouched, a pair of looming eye buoys was installed on one pound net (identified as pound net 1 hereafter) (Table 3). The study followed the principles of a paired BACI (Before-After Control-Impact) design, consisting on replicating observations from an experimental and a control site, before and after the implementation of the looming-eye buoy on the experimental site (Smith, 2014).

Table 3. Observation dates and treatment usage (no mitigation in place; LEB = looming-eye buoys installed around the pound net).

Date	Pound Net 1 (Treatment)	Pound Net 2 (Control)
2021-04-26	no mitigation	no mitigation
2021-04-28	no mitigation	no mitigation
2021-05-05	LEB	no mitigation
2021-05-13	LEB	no mitigation
2021-05-19	LEB	no mitigation
2021-05-28	LEB	no mitigation
2021-06-02	LEB	no mitigation
2021-06-11	LEB	no mitigation

Field observations consisted of 10-minutes sessions every half hour from 8:00 to 12:00 on each pound net – simultaneously when two observers were present, or alternatively when only one observer was present. Observers were trained to identify coastal and marine seabird species commonly present in the region and were equipped with binoculars, telescope, and bird identification field guides. All birds and marine mammals were identified down to species level, or when not possible due to bad visibility to family level. The animals were counted and assigned to different categories depending on their position relative to the pound net: 1. *inside* when they swam/dove within the pound at least once during the 10-minutes observation slot; 2. s*urrounding poles* when they rested on one or several of the wooden poles maintaining the pound; 3. *outside* when they swam/dove directly outside (<30 metres from the centre of) the pound net or inside the heart during the 10-minutes observation slot; 4. *leading poles* when they rested one or several of the wooden poles maintaining the leading net (Figure 7).

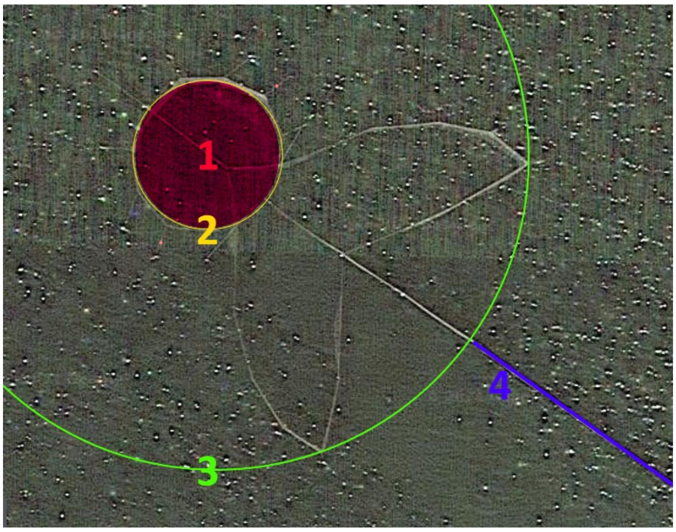

Figure 7. Aerial view of one of the pound nets surveyed during the looming-eye buoy field trial and relative positions of the categories used to define the position of the birds observed in and around the trap enclosure. 1. *inside* area of the pound; 2. s*urrounding poles* maintaining the pound in place; 3. *outside* area (<30 metres from the centre of the pound net); 4. *leading poles* maintaining the leading net in place.

In this study, there was only one site where we could measure the difference in seabird counts before and after the implementation of the mitigation devices around the pound net (treatment site). The other pound net was also monitored in the same way and during the same period, while not being subject to any modification (control site). Our primary hypothesis was that the presence of looming-eye buoys reduces the total number of birds in the direct vicinity of a pound net, particularly fish-eating birds like the great cormorant and the gull species commonly observed in the area, and who seem to use pound nets as a feeding and resting area. The potential deterring effect of looming-eye buoys was also assessed for the other seabird species observed on the study sites. Specifically, we tested the hypothesis that the presence of looming-eye buoys on a pound net reduces the number of seabirds (species-specific) swimming/diving in the pound, perching on the wooden poles around the pound, or swimming/diving in the direct vicinity of the buoy (identified as the categories 1, 2, and 3 on Figure 7).

We tested this proposition by analysing the temporal variations in seabird numbers (both total and species-specific number) in the two study sites using a generalised linear model (GLM), before and after the implementation of the looming-eye buoys on one of the study sites. We fitted a negative-binomial GLM using the daily average number of birds (both total and species-specific) per observation slot as response variable. Because the looming-eye buoys were only tested in one study site, the effects of treatment (whether the looming buoys are in place or not) and the study sites were co-founded in our experimental design. Therefore, we fitted the models using study site (treatment or control), period (before or after implementation of the looming buoys), and interaction between study site and period were used as the fixed predictors. Specifically, we wanted to test whether the interaction term was significant, which would strongly suggest that looming-eye buoys affect the presence of seabirds in and directly around a pound net. All data analyses were conducted in the R statistical language (R Core Team, 2023). The level of significance for statistical tests was set to 0.05.

Results and Discussion

We observed a total of 722 individuals of 8 seabird species on the two observation sites during 8 observation sessions spanning from end of April to early June 2021 (Table 4).

Table 4. Number of individuals of (Groups of) seabird species observed swimming, resting, or diving inside the pound, or directly outside of it (categories 1, 2, and 3 on Figure 7) during the study period (end of April to early June 2021) in two nearby pound nets near Korsør (Denmark).

Species (or group of species)	Treatment site	Control site
Great cormorant **(*Phalacrocorax carbo*)**	161	326
Unidentified large gull **(Laridae)**	38	105
Greater black-backed gull **(*Larus marinus*)**	32	116
Herring gull **(*Larus argentatus*)**	46	55
Lesser black-backed gull **(*Larus fuscus*)**	0	1
Other small gulls **(Laridae)**	3	20
Tern **(Laridae)**	2	6
Common eider **(*Somateria mollissima*)**	33	65
Merganser **(*Merganser spp.*)**	2	6

Effects of looming-eye buoys on all seabirds

Before the implementation of the looming-eye buoys on the treatment site, the total number of seabirds observed in or in the vicinity of the pound was similar in both sites; after the implementation, the control site seemed to attract more birds, but the difference between the two sites decreased over the observation period (Figure 8).

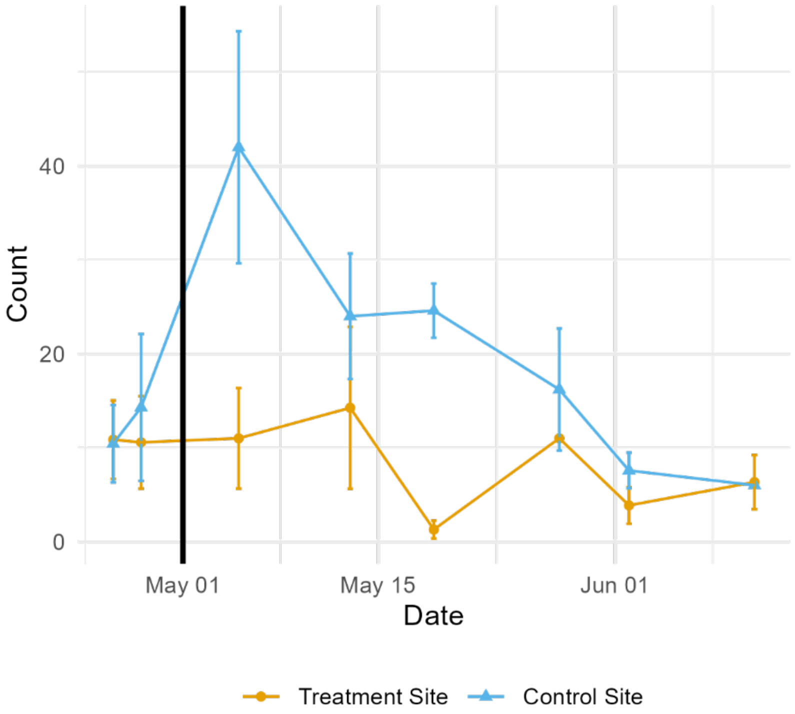

Figure 8. Mean and standard deviation of seabird counts per observation slot during the study period in the treatment and in the control sites. The date of the implementation of the looming-eye buoys on the treatment site is marked with a vertical black line.

The model fit showed that the interaction term (treatment and site) was not significant, which an analysis of variance (ANOVA) confirmed (p-value: 0.22). We can therefore conclude, based on these data, that the number of seabirds present in and around the pound net following the installation of the looming-eye buoys is not significantly different than before the implementation.

Effects of looming-eye buoys on the great cormorant

Before the implementation of the looming-eye buoys on the treatment site, the total number of cormorants observed in or in the vicinity of the pound was similar in both sites; after the implementation, the control site seemed to attract more birds, but the difference between the two sites decreased over the observation period (Figure 9).

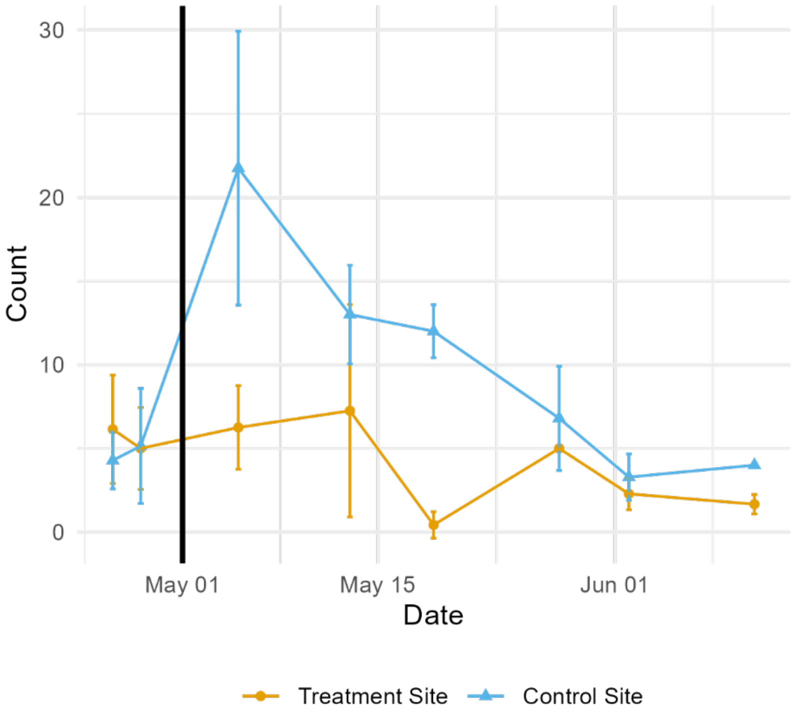

Figure 9. Mean and standard deviation of great cormorant counts per observation slot during the study period in the treatment and in the control sites. The date of the implementation of the looming-eye buoys on the treatment site is marked with a vertical black line.

The model fit showed that the interaction term (treatment and site) was not significant, which an analysis of variance (ANOVA) confirmed (p-value: 0.10). We can therefore conclude, based on these data, that the number of seabirds present in and around the pound net following the installation of the looming-eye buoys is not significantly different than before the implementation.

Effects of looming-eye buoys on the seagulls (Laridae)

Before the implementation of the looming-eye buoys on the treatment site, the total number of seagulls observed in or in the vicinity of the pound was similar in both sites; after the implementation, the control site seemed to attract more birds, but the difference between the two sites decreased over the observation period (Figure 10).

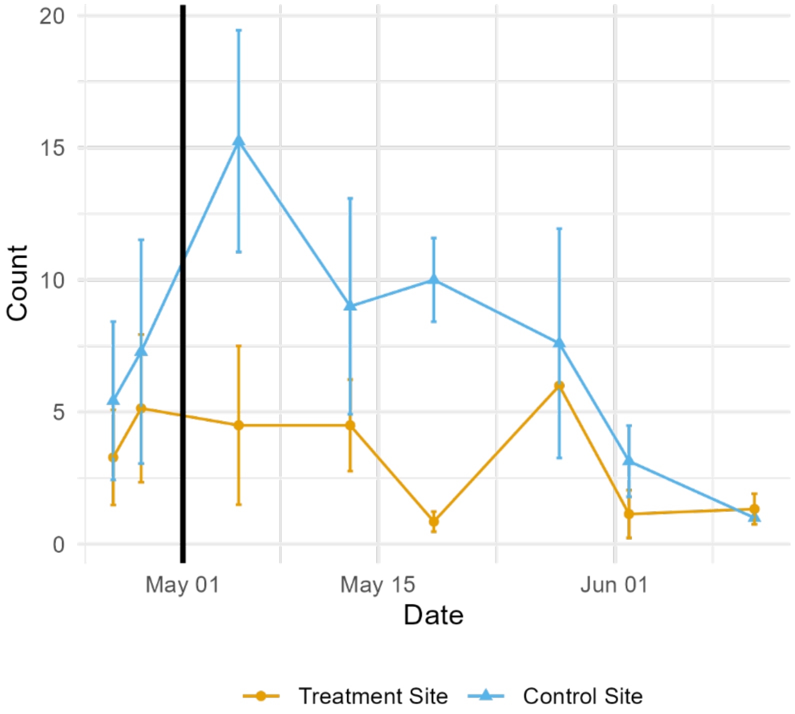

Figure 10. Mean and standard deviation of seagulls counts per observation slot during the study period in the treatment and in the control sites. The date of the implementation of the looming-eye buoys on the treatment site is marked with a vertical black line.

The model fit showed that the interaction term (treatment and site) was not significant, which an analysis of variance (ANOVA) confirmed (p-value: 0.46). We can therefore conclude, based on these data, that the number of great cormorants present in and around the pound net following the installation of the looming-eye buoys is not significantly different than before the implementation.

Effects of looming-eye buoys on ducks (Anatidae)

Before the implementation of the looming-eye buoys on the treatment site, the total number of ducks observed in or in the vicinity of the pound was similar in both sites; after the implementation, the control site seemed to attract more birds, but the difference between the two sites decreased over the observation period (Figure 11).

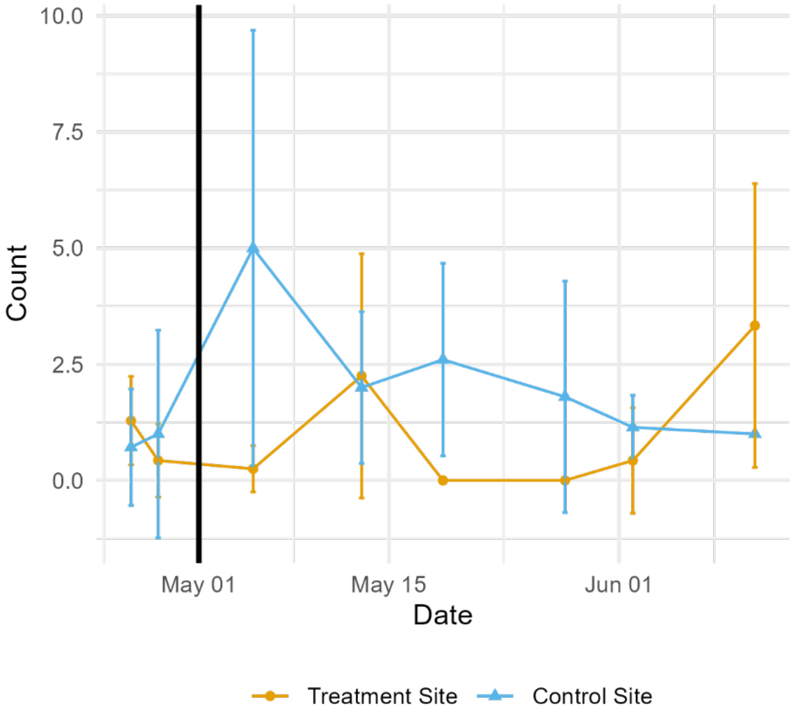

Figure 11. Mean and standard deviation of seagulls counts per observation slot during the study period in the treatment and in the control sites. The date of the implementation of the looming-eye buoys on the treatment site is marked with a vertical black line.

The model fit showed that the interaction term (treatment and site) was not significant, which an analysis of variance (ANOVA) confirmed (p-value: 0.52). We can therefore conclude, based on these data, that the number of seagulls present in and around the pound net following the installation of the looming-eye buoys is not significantly different than before the implementation.

WP.3 Thin-twine nets as a means to reduce bycatches in gillnets

Introduction

In the 1950s the use of thin, flexible, and transparent nylon fibres became dominant in net fisheries notably because of nylon robustness and because it tended to increase catch efficiency compared to previous thread material (Gabriel and Brandt, 2005). However, the use of nylon also increased the risk of unintended bycatch of marine megafauna, such as marine mammals, sea turtles, and seabirds (Northridge *et al.*, 2017). While gillnets or trammel nets are simple in their design, they offer a high degree of versatility. Various aspects of the net construction can be adjusted to enhance catchability, both in relation to target species and size classes. These adjustable features include mesh size, twine type and diameter, net height, actual fishing height, or hanging ratio. Therefore, when designing gillnets for a specific target species (or target group), the size, shape, and behaviour of the target fish species are considered in order to maximize capture probability (Hamley, 1975; Fridman, 1986).

Even though gillnets and trammel nets have many possible design options, most efforts to reduce incidental bycatch have focused on developing mitigation tools that does not modify the geometry and catchability of the fishing gear, such as using acoustic deterrent or pingers to scare away cetaceans (FAO, 2021). Comparatively, less attention has been given to technical adjustments of core gillnet features. Such features have however shown to be important to bycatch and twine diameter is known to be one of the driving factors for bycatch (Northridge *et al.*, 2017; Kindt-Larsen *et al.*, 2023). Adjusting the diameter of the twines can help reduce incidental captures of non-target species that have the strength to break free from it (López-Barrera, Longo and Monteiro-Filho, 2012). This approach is most likely to succeed for larger, more powerful animals like marine mammals and (adult) sea turtles but is less likely to work for seabirds that are often closer in weight and swimming strength to the fish species targeted by the gillnet fishers. Furthermore, thinner twines will result in more mesh breakage, which may affect the target fish catch rates, while the potential reduction in gear longevity would incur higher running costs for fishers.

One important question in the IMBAF project was to test if a thinner twine netting material can reduce bycatch of porpoise in net fisheries taking place in Denmark. At the same time, the twine reduction should not reduce fish catches, as this would likely decrease the acceptance of this mitigation tool at a later stage. In this study, we measured the difference between thin-twine nets and standard nets in terms of catch rates of target and non-target protected species of seabirds and marine mammals, including the harbour porpoise (*Phocoena phocoena*), in a set net fishery for Atlantic cod (*Gadus morhua*) in the Western Baltic Sea.

Materials and Methods

The mitigation trials were conducted onboard a Danish commercial gillnet vessel during 7 months in 2022 the south-western Baltic Sea. All trials were conducted with a standard 3-folds trammel net used in this area to target Atlantic cod and flatfish as the control net. In the control nets the middle net panel had a twine size of 0.4, mesh size of 45 mm (half mesh), and a net height of 2 m. The two outer nets had a twine size of 0.9, and a mesh size of 200 mm (half mesh). The “thin twine” nets middle net panel had a reduced twine size of 0.3, mesh size of 45 mm (half mesh), and a net height of 2 m. The two outer nets had a twine size of 0.9, a mesh size of 200 mm (half mesh).

Each net of both thin twine and control was 60 m in horizontal length. The number of nets in each net fleet differed accordingly to the fishing ground but thin twine nets and control nets were never mixed.

To compare bycatch rates from standard nets with thin twine nets, the nets were deployed on the same fishing grounds, at the time, and soaked in the water for the same duration.

The trials were recorded using electronic monitoring (EM). The EM system installed onboard (Black Box Video, Anchorlab, Denmark; www.anchorlab.dk) consisted of a control unit, associated with a position sensor (GPS), and two waterproof CCTV (closed-circuit television) cameras. The cameras were positioned to allow catch items to be observable from different angles—where the net appears from the water and at the sorting table—maximizing the chance of identifying target species (Kindt *et al.*, 2012; Kindt-Larsen *et al.*, 2023). All EM data were analysed in the software Black Box Analyzer (Anchorlab). The programme presents a map with the GPS tracks of the vessel for each fishing trip alongside the corresponding videos, and annotations can be entered manually to mark events of interest. Trained EM analysts reviewed all the fishing trips having taken place during the trial periods to detect fishing events (setting and hauling of nets) and each individual catch. That is, within each haul, the analysts marked and identified every single catch of cod, flatfish, seabird, and marine mammal in the thin twine nets and the control nets. The fisher was required to fill a logbook to register the date, number of sets with thin twine and standard twine, and the corresponding cod catches in kg and number of bycaught marine mammals.

We tested the potential difference in bycatch rates between standard trammel nets and modified trammel nets with a thinner twine size by building generalized linear mixed models (GLMM) for each of the sensitive species (or group of species) of interest; here, harbour porpoise, harbour seal, and seabirds. The response variables were the number of animals of each species (group of species) taken as bycatch in the nets. We defined the factor treatment (standard net or modified net) as fixed variable with net length and soak duration used as offsets. The fishing date was used as random group intercept. The response variables being counts, we fitted the models using a Poisson and a negative binomial distribution of errors and selected the best models based on their AIC scores. All data manipulation and analyses were conducted in R, using the *glmmTMB* package to create the models (Brooks *et al.*, 2017; R Core Team, 2023). The predictions from the regression models were estimated using the package *ggeffects* (Lüdecke, 2018).

Results and Discussion

In total, 77 individual fishing days were conducted and analysed in the thin twine net bycatch mitigation trial. During the period, 295 net fleets were set in total (162 standard net fleets and 133 thin twine net fleets). We registered 9 bycatches of porpoises (4 in standard net fleets and 5 thin twine net fleets), 3 bycatches of harbour seals (1 in standard net fleets and 2 thin twine net fleets), and 21 bycatches of seabirds of undetermined species (17 in standard net fleets and 4 thin twine net fleets). The analysis of the result of the models showed that thin-twinned trammel nets did not significantly affect the bycatch rates of any of the species (groups of species) considered in the study (Table 5).

Table 5. Mean bycatch rates of protected species (as number of animals per net length*soak time) in thin-twinned nets and control nets and 95 % confidence intervals, estimated from model predictions.

	Treatment	Bycatch rate	95% confidence interval
Harbour porpoise	**thin twines**	0.01	[0.00, 0.08]
	control	0.01	[0.00, 0.07]
Harbour seal	**thin twines**	0.00	[0.00, 0.03]
	control	0.00	[0.00, 0.01]
Seabirds	**thin twines**	0.02	[0.00, 0.09]
	control	0.03	[0.01, 0.16]

This study shows the results of the first pilot trials conducted in a commercial trammel net cod fishery in Denmark using a thinner twine as a method to reduce bycatch of harbour porpoises, harbour seals, and seabirds. The experimental trials yielded however no evidence of bycatches reduction for any of these protected species.

Even though our results showed no significant reduction of bycatch rates in the studied fishery, it might still be that thinner twine are a valid solution to mitigate incidental captures in other cases. Indeed, in the experimental trials presented here, the fisher used a modified trammel net where *only* the "middle-net" twine diameter was reduced. It could well be that if the twine diameter had been reduced for *all* the 3 nets constituting the trammel net, bycatch rates would have been differed between treatment and controls. Nevertheless, it can also be emphasised here that little is known about animals like marine mammals or seabirds entangle in trammel nets, that is whether the external panels, the middle panel, or both present the highest risk of entanglement. From the results presented here alone, it seems that modifying the characteristics of the middle panel only is not sufficient to reduce bycatches significantly, but we recommend continuing thin-twine trials in trammel net fisheries, reducing the twine diameter of all the panel, as well as in monofilament gillnet fisheries.

Nets (trammel- and gill- nets) with thicker have on average longer lifetime than thin-twined nets and tend to reduce gear turnover, are less likely to be lost, abandoned, or discarded, and in turn contrite to reducing marine plastic pollution (Brinkhof *et al.*, 2023). These authors conducted a trial in commercial fishing conditions in a Northeast-Arctic cod gillnet fishery, where they compared catch efficiency between gillnets of varying twine thickness for two different mesh sizes. Their results demonstrate that a 30% increase in breaking strength and twine stiffness does not affect catch performance of the target fish species (here, Atlantic cod). Therefore, thicker gillnet twines can potentially reduce marine litter by plastic debris from damaged and lost gears without compromising target catch performance. In future studies, if twine diameter is found to reduce bycatch of marine mammals or seabirds in some fisheries, it is important to consider the possible consequences that imposing the usage of a more fragile and less durable fishing gear could have on the marine ecosystems, in terms of plastic pollution and increase of ghost fishing from derelict gears.

WP.4 What do you want to bait? Testing bait types for Atlantic cod

Introduction

Two critical issues for gillnet fisheries in Denmark are the bycatch of protected species – including marine mammals – and the damage to target catches and fishing gears caused by predatory species like the grey seal (*Halichoerus grypus*). Studies show that grey seals can depredate very high amounts of fish from gillnets, making it difficult to have a fishery that is economically viable in some areas (Königson *et al.*, 2010). In addition, high numbers of seabirds and marine mammals are taken as bycatches every year in Danish gillnet fisheries, even though gillnets are generally viewed as sustainable, low-impact gears (Larsen *et al.*, 2021). In recent years, alternative gears have been developed to reduce bycatch and decrease damage on target catch in response to an increasing grey seal population in the Baltic Sea (Königson, Lövgren, *et al.*, 2015; Kindt-Larsen *et al.*, 2022). One such gear is the fish pot, which is an easily transportable, passive trap that encloses the fish in a compartment that can be made seal-safe (Königson, Fredriksson, *et al.*, 2015). DTU Aqua developed a type of fish pot that fulfils three important requirements : i) to protect the catch from seal damage, ii) to be usable by one person on a small vessel, and iii) to maintain or increase catch rates to ensure an economically viable fishery (Ljungberg *et al.*, 2016; Kindt-Larsen *et al.*, 2022).

Previous research has worked on optimising catches in pots (in terms of species target, number and size of trapped fish), showing that many factors can influence catch efficiency, e.g., season, depth, soak time, or placement according to the current (Königson, Fredriksson, *et al.*, 2015). It has also been demonstrated that Atlantic cods (*Gadus morhua,* henceforth cod) seldom enter pots at night; at dawn, entry and exit rates increase rapidly, so it seems optimal to set pots before dawn to improve catch rates (Chladek *et al.*, 2021). Pots are classified as a LIFE (Low Impact and Fuel Efficient) gears, which means that they have numerous advantages compared to other passive and – even more so – active gears targeting the same species in the same areas (Suuronen *et al.*, 2012). Among other advantages, fish pots are excellent at keeping captured fish alive and in good condition for many days, while bycatches of unwanted fish species are substantially reduced compared to other gear types, or even eliminated, since most of unwanted catches are released alive. Additionally, pots have only minimal impacts on the seabed and have low energy requirements. Moreover, marine mammal bycatch risks are considerably lowered with pots compared to e.g., gillnets targeting the same fish species. This makes fish pots ideal candidates for fishing in areas where active gears such as trawling are banned or in areas where bycatch risks of protected species is high (Suuronen *et al.*, 2012).

Pots are typically baited to attract cod in Danish waters, and a common bait is herring (*Clupea harengus*) (Ljungberg *et al.*, 2016). Squid (*Loligo spp.*) is also frequently used in the pot fishery for cod, because this bait type stays fresh for several days in the water (Furevik *et al.*, 2008). Some fishers use other types of bait e.g., sprat (*Sprattus sprattus*), sandeel (*Ammodytes marinus*), crab, or Atlantic mackerel (*Scomber scombrus*) (Kindt-Larsen *et al.*, 2022). Studies on the release of feeding attractants from natural bait have shown that a baited fishing gear releases feeding attractants at a high rate shortly after being set and then at a lower, slowly decreasing rate (Løkkeborg, 1990). If the chemical attractants are the essential factor for the fishing gear, it is thus much more effective in the first 1.5 hours after setting. The duration of the attractiveness of the bait will depend on the target species' sensitivity to the bait and the distribution of the attractants in the environment (Løkkeborg, 1990). Königson *et al.* (2015) on the other hand found that pot catches increase with soak time, with catches doubling after 6 days, on average. Other factors than bait can also have an effect on cod attraction, e.g., when a cod chews on the bait, feeding particles will be released in the surroundings, which could attract other cods (Königson, Fredriksson, *et al.*, 2015).

The aim of this work package was to determine which bait is the most effective for cod pots in the Western and Central Baltic Sea from a pre-selection of 5 bait types (herring, sandeel, sprat, squid, and artificial bait) and to investigate the seasonal and regional differences in catch rates for these different baits.

Materials and Methods

Two locations were chosen for the experiment, offshore Hasle (island of Bornholm, Central Baltic Sea – Denmark) and near the old bridge of Lillebælt off Fredericia (Belt Sea, Western Baltic Sea – Denmark). The first part of the experiment took place from March to May 2022 in Hasle (Figure 12), and the second part was carried in January 2023 in Lillebælt (Figure 13).

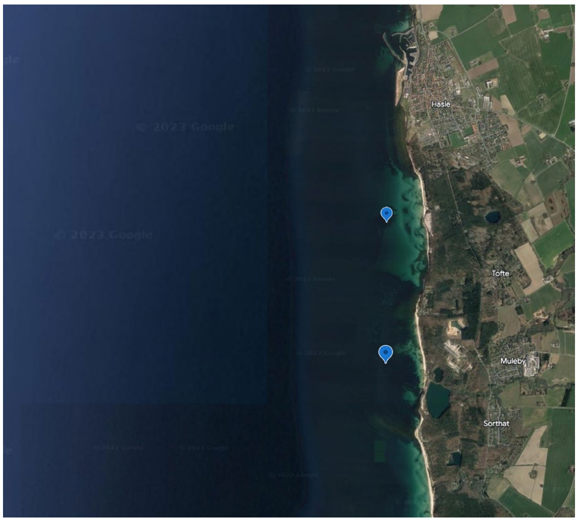

Figure 12. Positions of the anchors outside of Hasle, Bornholm (Central Baltic, Denmark). The 5 anchors were set between the two blue pins.

Figure 13. Approximate position of the 3 anchors set outside of Fredericia in Lillebælt (Western Baltic, Denmark).

An experimental setup was conducted by modifying a P-ring weighing 25 kg. Holes were added to fit 3 ropes and a small shelf for fixing a waterproof camera house (Figure 14). The ropes were connected to a small buoy and underneath it was possible to attach a bait-bag at the correct angle for the cameras field of view. A rope was attached to the buoy and connected to another buoy to mark the place of deployment and to pull it onboard. The rope was also connected to the P-ring for safety if the thinner ropes should break. The bait-bag could float in the current, so a weight was added in the bottom of the bag.

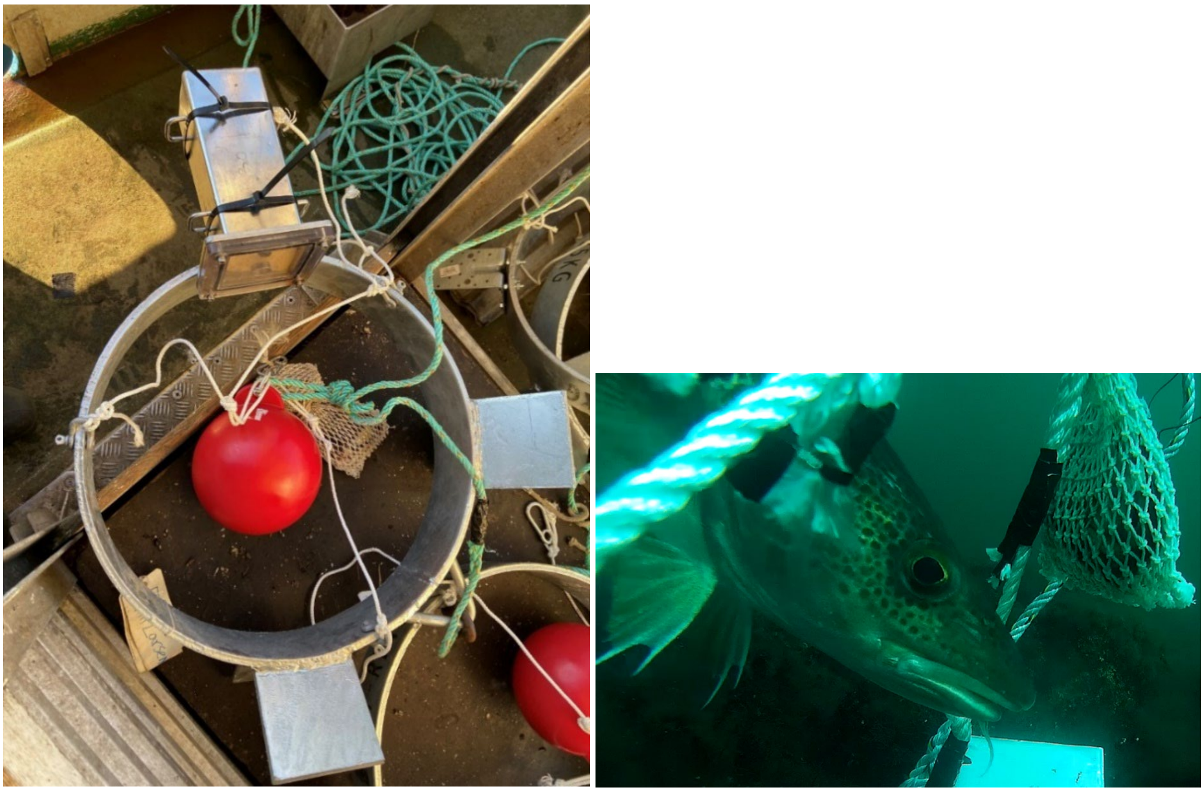

Figure 14. Experimental setup. Right: the anchor with buoy and camera house; left: underwater view of the bait bag and a cod.

A Mobius action camera v2.41 with a SD-card of 200 GB was connected to an external battery mounted in the waterproof camera house with a recording time of up to 24 hours. The anchor was lowered carefully over the site of the boat, and dropped when it was horizontal, so it would land with the buoy on top. The anchor was dropped between 8- and 15-meters of depth and we left at least 200 m between each bait type.

We chose 5 different baits: herring, sprat, sandeel, Artificial bait, and squid. Herring and sprat were provided by the collaborating fisher; sandeel was either provided by the fisher or collected from discard fish collected by DTU Aqua; squid was bought frozen from a fishmonger. The Artificial bait used in our experimental trials is a commercial product manufactured by the Norwegian company Kvalvik and designed for anglers to attract cod. It consists of a tube of paste to apply on the lure. We used the product as bait by placing the whole tube in the bait bag, after having poked numerous large holes in it, so its smell could defuse in the surrounding area. Sprat, herring, and sandeel were chosen because they are typical prey items for cod and available in the areas we were investigating (Pachur and Horbowy, 2013). Squid was chosen because it is a common bait type in the cod pot fishery (Furevik *et al.*, 2008), and artificial bait was chosen to investigate the attractiveness of an artificial bait in the Baltic cod pot fishery. For the trial in Lillebælt we decided to skip the Artificial bait and squid baits, because occurrences of cods were so low in the videos. So only three baits were used in the Lillebælt: sprat, herring, and sandeel.

Every day, the anchors were pulled up onboard, and the SD-cards and batteries were changed. The old bait (if any left) was discarded, and the bait bag was refilled with fresh bait. The video recordings were checked daily to ensure the anchor was placed correctly on the seabed.

The underwater videos were analysed in the open-source software Boris (Behavioural Observation Research Interactive Software; https://www.boris.unito.it/). An ethogram was created with three different behaviours: swimming, touching, and eating. Swimming was characterized as a state event (an event with a duration, i.e., a starting and ending point), starting when a cod would enter the field of view, and ending when it would no longer visible. Touching was defined as a point event (an event with no duration associated), corresponding to the touching of the bait bag with the snout. Eating was defined as a point event corresponding to the biting of the bait bag. For the analysis, eating and touching were combined because they both showed a feeding behaviour. Focal subjects were cod in this trial, but other species (groups of species) were also registered, i.e., flatfish, harbour porpoise (*Phocoena phocoena*), and seals. The data from BORIS was extracted to as a spreadsheet and the number of unique occurrences of cod touching the bait was counted.

To test whether there was a significant difference between bait types in terms of how well they attract cod, we built a generalized linear mixed model (GLMM) with the number of cod occurrences per hour as the response variable. The fixed variable was bait type (3 factors: herring, sprat, and sandeel) and we added a nested random effect structure to account for the experimental design, with the intercept varying among sites (variable location with 2 factors: Hasle or Lillebælt) and among dates within sites (calendar date, i.e., the day the pots were set). The response variable being a rate, we used a Gaussian distribution of the errors with an identity link. We used the R statistical language for data management and statistical analyses (R Core Team, 2023) and fitted the models using the *glmmTMB* package (Brooks *et al.*, 2017).

The soak time for the different bait trials was the same for each date, as well as the anchor setup, the cameras, and the bait quantity. Artificial bait and squid were taken out of the analysis because of the very number of interactions recorded (cod occurrences per hour were 0 for the artificial bait and 6 for the squid bait).

Table 6. Bornholm part 1. The first part of the data from Bornholm were collected from 08-03-2022 to 13-03-2022. Positions and depths for the 5 different bait setups (mean of the 5 days).

Bait	Position N	Position E	Depth
Herring	55°09’95	14°41’80	11
Sprat	55°09’35	14°41’74	10
Sandeel	55°09’71	14°41’78	11
Squid	55°09’53	14°41’70	9
Artificial bait	55°09’19	14°41’60	9

Table 7. Bornholm part 2. Second part of the data from Bornholm was collected from 19-03-2022 to 24-03-2022. Positions and depths for the 5 different bait setups (mean of the 5 days).

Bait	Position N	Position E	Depth
Herring	55°09’30	14°41’70	10
Sprat	55°09’80	14°41’80	9.5
Sandeel	55°09’44	14°41’71	9
Squid	55°09’62	14°41’77	9.5
Artificial bait	55°10’00	14°41’75	9.5

Table 8. Bornholm part 3. Third part of the data from Bornholm was collected from 28-04-2022 to 02-05-2022. Positions and depths for the 5 different bait setups (mean of the 5 days).

Bait	Position N	Position E	Depth
Herring	55°09’57	14°41’40	13
Sprat	55°09’93	14°41’45	14
Sandeel	55°09’40	14°41’55	15.5
Squid	55°10’10	14°41’45	16
Artificial bait	55°09’75	14°41’44	15

Table 9. Positions and depths for the 3 different bait setups in Lillebælt from 05-01-2023 to 09-01-2023.

Bait	Position N	Position E	Depth
Herring	55°31’17	09°42’77	13
Sprat	55°31’10	09°43’25	13.5
Sandeel	55°31’13	09°42’91	13.5

Results and Discussion

A total of 793 hours of video were exploitable and analysed from Bornholm and 77 hours from Lillebælt; videos recorded during nighttime were not exploitable and were discarded.

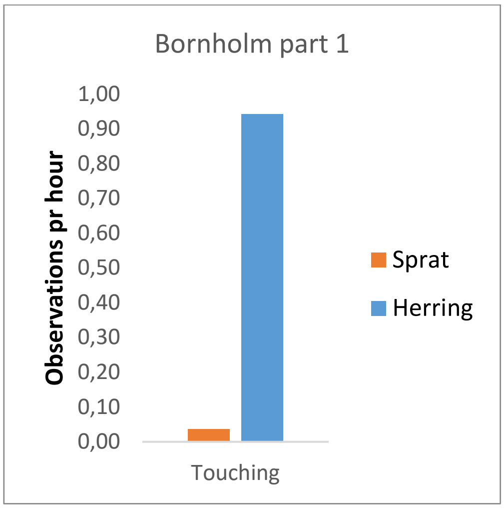

Figure 15. Results from Bornholm part 1 – March 2022. No cod touched the bait bags with sandeel, squid, or Artificial bait, so the results are shown for sprat and herring only. One cod touched the bait bag with sprat: 0.04 observations per hour; 53 cod touched the bait bag with herring: 0.94 observations per hour.

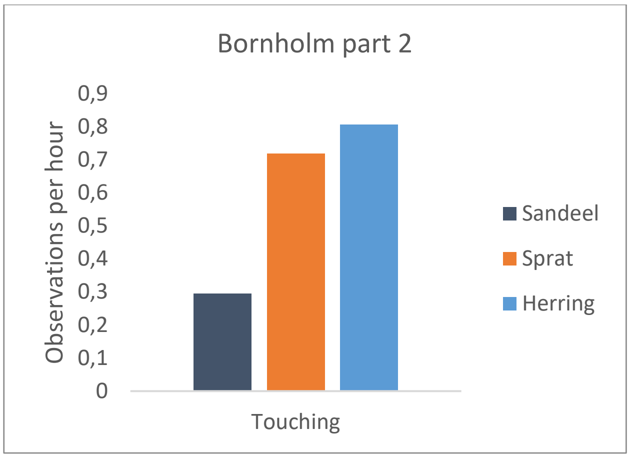

Figure 16. Results from Bornholm part 2 – March 2022. No cod touched the bait bags with squid or Artificial bait, so the results are shown for sandeel, sprat, and herring only. 20 cod touched the bait bag with sandeel: 0.37 observations per hour. 46 cod touched the bait bag with sprat: 0.88 observations per hour. 48 cod touched the bait bag with herring: 1.03 observations per hour.

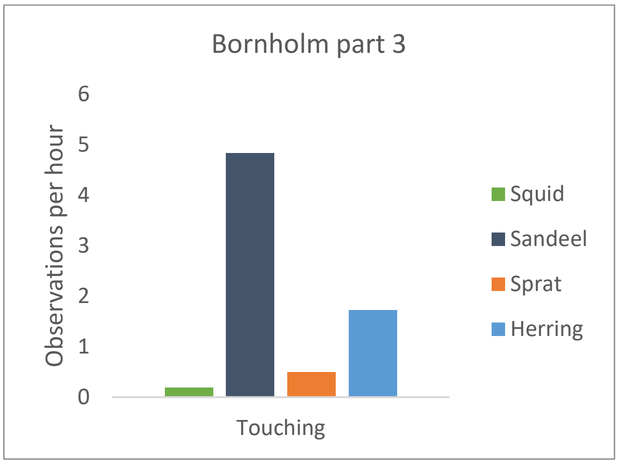

Figure 17. Results from Bornholm part 3 – April and May 2022. No cod touched the bait bags with Artificial bait, so the results are shown for squid, sandeel, sprat and herring. 6 cod touched the bait bag with squid: 0.19 observations per hour. 269 cod touched the bait bag with sandeel: 4.83 observations per hour. 24 cod touched the bait bag with sprat: 0.5 observations per hour. 108 cod touched the bait bag with herring: 1.72 observations per hour.

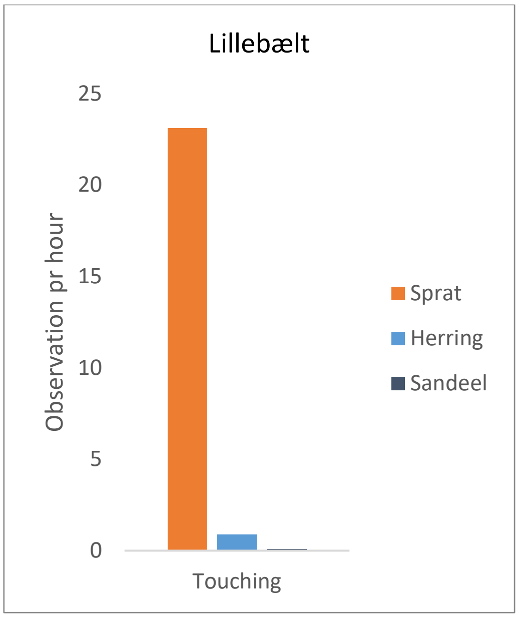

Figure 18. Results from Lillebælt – January 2023. 557 cod touched the bait bag with sprat: 23.11 observations per hour. 26 cod touched the bait bag with herring: 0.88 observations per hour. 2 cod touched the bait bag with sandeel: 0.08 observations per hour.

Artificial bait and squid were taken out of the statistical analysis as the cod occurrences per hour were considered too low for these bait types. The model-predicted number of cod occurrence per bait type was predicted from the model. The results are shown in Table 10, together with the 95% confidence intervals around the point estimator.

Table 10. Mean number of cod per hour and 95% confidence interval for each bait type.

Bait type	Predicted number of cod per hour	95% confidence interval
Herring	1.71	[-2.31, 5.73]
Sandeel	1.86	[-2.16, 5.88]
Sprat	4.91	[0.89, 8.92]

From the model prediction, cod seemed to show a preference for sprat as a bait, with a rate more than 3 times higher than for herring and sandeel (Table 10). However, the occurrence of cod touching the bait was not significantly different between any of the three bait types (at the 5 % significance level). Many factors could be influencing these results, e.g., the season and the area, but also the effect of cod chewing on the bait, thereby releasing particles into the environment, and attracting more cod. In the cases with high occurrence per hour, like in Bornholm part 3, this could be a reinforcement that led to attraction of more cods. However, it was often the same individual that was touching the bait numerous times and trying to eat it through the bait bag meshes. Therefore, the number of occurrences does necessarily reflect how many cods had visited the bait.

We recorded different species in the two areas surveyed in the study; in Bornholm we saw mostly relatively large cod, some flatfish, and some small fish that could not be identified from the video recordings. A grey seal was also seen investigating the anchor setup, but it did not touch any of the baits. In the Lillebælt, crabs were always almost immediately attracted to the baits and were generally recorded eating it for almost the entire duration of the films. Cods seemed smaller in Lillebælt than in Bornholm, which was expected considering the declining condition of the stock in Lillebælt (Timmermann *et al.*, 2022). Diverse snails, flatfishes, and one eelpout were also recorded on the videos, as well as three harbour porpoises swimming by the surface water.

The conditions in the water outside Hasle were excellent, as the current was not too strong, and the anchors only rarely hit the seabed in the wrong direction. In Lillebælt, the current was very strong, and therefore we had trouble with the anchors turning upside down and the buoys being pulled under water, so we could not retrieve the anchor at times. Consequently, we had to adjust the positions of the anchors when the current was too strong.

In this study, we used whole fish as bait, which might have reduced their potential to attract cods. A previous study by Westerberg and Westerberg (2011) found, that the relative flux of the bait decreases rapidly after submersion, and already after one hour it has decreased to less than 20 %. After a soak duration of 24 hours the diffusion length of the bait was only 4 mm in that study. It is thus encouraged to cut up the bait to have as much surface as possible to release molecules that will attract target species. In future studies with bait, it should be noted that the release of attractants will be higher if the bait is cut up in relatively small pieces.

Earlier research investigated the possibility to make an artificial bait with a more evenly distributed release of attractants over time. The efficiency of the bait can be improved by timing the release of attractants to the soak time of the gear (Løkkeborg, 1990). In our study, the artificial bait we tested did not prove effective at attracting cod, but the proper use of it is meant to be on lures on a fishing pole. It is not supposed to release attractants for longer periods of time, and it could still be effective at catching cod on a hook. The direction of the current has been shown to be a significant parameter in baiting studies, as the bait plume spreads over a larger area if the pot is set perpendicular to the current (Königson, Fredriksson, *et al.*, 2015). This was not an issue in our trial, as the cod could access the bait from any side, but in trials with pots that have only one entrance, this could be a very important factor to consider. A study by Chladek *et al*. (2021) found that cods move slower and are less active at night. As we had no lights on our anchors, we did not record data on nocturnal movements, however we could measure a reduction in the amount of bait left in the bag after sunrise, meaning that some of the bait had been consumed during nighttime. It was also shown that cods exit and enter pots at increased rates at dawn compared to the rates in the previous night hours, indicating that they primarily use vision to navigate (Chladek *et al.*, 2021). Likewise, we saw a lot more activity just before sunset, so both dawn and dusk seem to be periods of peak activity for cod.

Several conclusions emerge from the results of these experimental bait trials. First, the Kvalvik artificial bait is not an effective alternative to more traditional bait and did the worst in terms of attracting cods in our study. What is more, very few cods touched the squid bait, which could be explained by the fact that squid are not common in the area, and therefore that cods in the Baltic may recognise this smell as food. The squids were also added to the bait bag whole, so it could be interesting to investigate if they would attract cod were they to be cut in smaller pieces. Sprat was estimated to be three times more attractive to cods than herring and sandeel, but with no significant difference between the three bait types (Table 10). The three sampling periods in Bornholm show very varying results, with herring being most attractive in the first trial, herring, and sprat almost equally attractive in the second trial, and sandeel being considerably more attractive in the final trial. This suggests that clupeids are more attractive during the colder months of the year, while sandeel attracts more cod in spring. For Lillebælt, sprat was attracting 20 times more cod than herring, and sandeel had only 2 touching occurrences. So, in during the winter, sprat seems to be a very efficient bait for catching cod in Lillebælt.

WP.5 Fishers' ideas to reduce negative interactions between protected species and fisheries

Introduction

The development of new fishing gears is often a long and time-consuming process. Besides the time it may take to test and implement new ideas, it is necessary to gather in-depth knowledge on the species targeted by the gear(s), on the fishing areas, and on all the factors that could influence how the gear is used in the fishery it is designed for. All this knowledge is difficult to obtain without including professional fishers in the process of developing new gears. Even though a fisheries science Institute like DTU Aqua has come far in the development of alternative gears, both to avoid depredation and bycatch, it has most often been a "one-way-approach". This means that researchers have often presented new ideas and solutions to fishers that had been developed internally, then asking the end-users (the fishers) to test and validate these new tools or gears. The idea behind WP.5 was to turn this fact around and to let willing fishers come up with new ideas to reduce bycatch and depredation issues (e.g., building new gears, adapt old gears, or testing different materials). The data thus collected could then be analysed by the researchers collaborating to the IMBAF project to demonstrate the efficiency of these so-called "fishers' ideas". In other words, the main focus of this WP was to give fishers an opportunity to test their own ideas to potentially reduce seal depredation and solve bycatch issues.

Materials and Methods

The first step of WP.5 was to exchange information and knowledge with fishers and representatives from the fishing sector. This was done by reaching out to both the Danish Fishers Producer Organization (DFPO, Danmarks Fiskeriforening Producent Organisation) and the Danish producers organisation for sustainable coastal fishing (FSK, Foreningen for Skånsomt Kystfiskeri Producent Organisation), both partners in the project, with which we discussed views and ideas on how to get the professional fishers enrolled in this project. The WP was received very positively, and first through emails followed by several meetings, the two POs promised to contact their members and ask for their input, ideas, and if they would like to join such project. The fishers would receive a compensation of up to 45.000DKK for their involvement and the development of a potential new gear. They would have the opportunity to build the gear themselves or have the gear made at the gear manufacturer of their choice. The ideas however had to be validated by DTU staff beforehand in order for them to receive the funds. After the validation, the participating fishers were asked to develop and produce the new equipment. Then, the gear at to be tested in real fishing conditions (sea trials) to test its reliability, compare it with the previous fishing gear used to replace it when relevant, and possibly propose additional amendments to adapt and enhance the gear. After the fishers had become familiar with the gear they had developed, they were asked to contact DTU Aqua and report on the gear. Hereafter, it was agreed that DTU Aqua staff should join on several of fishing trips to collect independent data on catches/bycatches, seal depredation, but also to study the gear in detail using e.g., onboard cameras or other additional sensors. These data could then be used to validate the fisher-collected data and to confirm the interest of the tested gear both in terms of functionality, catch efficiency, but also potential to reduce protected species bycatch and possible depredation problems.

Results and Discussion

Idea 1: Jigging machines to replace gillnets

The jigging machine idea was supported by a cod gillnet fisher from the island of Bornholm (Central Baltic Sea), who suffered of important seal depredation problems, and also set his nets in an area where a single bycatch event of harbour porpoise is susceptible to jeopardise the entire critically endangered Baltic Proper porpoise population. Jigging is a fishing method that has evolved over many centuries from a manual technique to a more sophisticated one using dedicated jigging machines. It consists of swinging lines in a rhythmic up and down motion the jigging machine to simulate the movement of small fish in the water column. Artificial lures with hooks are attached on the lines and used to attract and capture target predatory fish like cods.

Equipping a vessel with jigging machines is expensive and costs much more than the 45.000DKK which could be allocated by the IMBAF project, so this idea could not be financed to buy new machines. However, we found the idea very good and managed to loan 5 machines from the Thünen Institute in Germany. We planned to use the available funds to cover the installation cost instead. Unfortunately, despite everything being ready to install, the fisher decided to quit the project and sell his boat shortly before the equipment could be installed onboard, following the drop in cod quota in the Baltic Sea that made it impossible for him to continue fishing. In turn, whether jigging machines are a valid alternative to gillnet fishing in the Baltic Proper remains unknown.

Idea 2: A fyke for lumpsuckers

The seasonal lumpsucker gillnet fishery is responsible for numerous bycatches of seabirds and marine mammals each year in Denmark (Christensen-Dalsgaard *et al.*, 2019; Larsen *et al.*, 2021). Lumpsucker nets are usually soaked for extensive durations (several days to weeks) and use large mesh sizes to entangle the target fish, which are known to correlate with high bycatch rates of megafauna bycatch (Northridge *et al.*, 2017). Any solution that could reduce these bycatch rates while maintaining acceptable catch rates would thus be extremely valuable. Furthermore, lumpsucker is a highly prioritized target species for the fishers, mainly because the price of its roe is generally very high, but also because lumpsucker s a non-quota species, which can guarantee very high income if the catches follow. Like many other gillnet fisheries in the region, lumpsucker net suffers from seal depredation since the seals also fancy lumpsucker roe. Answering the call for ideas from DTU Aqua, two fishers wanted to try to catch lumpsucker using specifically designed, very large fykes. The idea of catching lumpsuckers in fykes has actually already been seen in the past, however not using a gear of the dimensions these fishers suggested. Large fykes seem to offer the potential to catch lumpsuckers without putting seabirds and marine mammals at risk of bycatch. The fykes, however, could still suffer from seal depredation, as the suggested dimensions were so big that seals could potentially enter in the trap and devour the catch. After a dialogue with the fishers, it was agreed to try and build the lumpsucker fykes and later adapt the gear if seal damages were found to be problematic. The two interested fishers built the lumpsucker fykes in agreement and in collaboration with DTU Aqua staff. The photos below show the fyke from different angles (Figure 19, Figure 20, and Figure 21). The general idea was to have a very large opening from the seabed that would reach the surface (Figure 19). After entering the fyke the lumpfish would swim through the middle funnels (Figure 20), and then enter the end funnel (Figure 21).

Figure 19. Opening of the lumpsucker fyke designed from fishers' ideas.

Figure 20. End part of the lumpsucker fyke, with the funnels visible inside the fyke.

Figure 21. End part of the lumpsucker fyke.

The initial plan was to test the lumpsucker fyke in the Limfjord from January to March 2023. However, in 2023 the lumpsucker landings hit a record low all over Denmark and very few fish were captured in the Limfjord too. Given the investment necessary to install and check the catches in a fyke such as this one, and because the potential income they would get from their catches was so low, the fishers preferred to postpone the trial of this new lumpsucker fyke design. They agreed with DTU that if the lumpfish fishery will continue in 2024, they will resume using the fyke and report their results to DTU Aqua, even if the IMBAF project would have ended in the meantime.

Idea 3: Dyneema fykes

Figure 22. Details of the seal damages on a fyke net using traditional non-reinforced netting material.

In Denmark, the fyke-net fishery is highly affected by seal damages both in the western part of the Limfjord, some areas in the Kattegat, the waters between Zealand and Falster/Møn, and in the western Baltic Sea. Damages to the fyke nets occur when seals try to get hold of the catch by attacking the net or when they try to pull a fish out through the small meshes of the fyke. This action results in the fyke netting and/or the fish being damaged. Moreover, if the hole is large enough, the rest of the catch trapped in the fyke can escape (Figure 22). The economic losses vary depending on the extent of the damage. If there are only a few mesh breaks, they can be quickly repaired while the fishers are still out at sea. However, if all the fykes are damaged, they must be taken in and can only be set again once the fishers have had time to repair them.

For fishers in the areas affected by frequent seal depredation damages, there is a significant economic incentive to make the nets inaccessible to seals. It is thus common practice to use an overlay net (a sock). Although a sock does not completely prevent damages, it can limit them greatly. The sock makes the net heavier to lift out of the water, and overall, it is not a satisfactory solution to the problem. Others have tried to solve the problem by making the fykes using another material, untearable, and resistant to seals. Dyneema is such a material that is a lightweight high-strength fibre with a strength-to-weight ratio eight times that of high-strength steel and 40% stronger than e.g., aramid, which is normally used is bicycle tires or in body armour fabric. It is possible to reduce seal attacks using dyneema, however, this is a highly expensive material and one idea that came from a fisher who contacted us was to only change the catch-chamber to dyneema meshes and not the entire fyke netting.

One fisher has now built fykes, where only the catch holding chamber was changed to dyneema (Figure 23). Because of the almost complete closure of the eel fishery in Denmark, the trials with the dyneema fykes were very limited in the course of the IMBAF project, not allowing any analyses of the results. The fisher tried the same gear design to target round goby and, according to him, the rugged catch chamber works as intended and he reported far less seal attacks compared to earlier when he was not using dyneema. DTU Aqua agreed to follow up with the fisher after the end of the IMBAF project to see how well the dyneema fykes can perform in the long run.

Figure 23. Detail of the eel fyke catch chamber with dyneema.

Idea 4: Big holding pound net chamber

The last idea we received from fishers was to increase the size of the holding chamber of a pound net (similar to the pound net shown on Figure 5). The thought was that the seal easier could turn, when trapped and swim out, thus making the chances for the seal to destroy both the trap and the catch much less. The idea was, however, not pursued as the fisher supporting this project decided to quit only a few weeks after having initially contacted us.

Conclusions of the fishers' ideas

Despite excellent initial feedback from the fishers that we met and from the PO (FSK and DFPO), DTU Aqua received far less ideas than expected and only 2 were actually built during the course of the project. Still, we think that some fishers have the knowledge to come with innovative ideas to reduce the depredation and the bycatch problem in Danish fisheries and we see this as a very important point to collaborate with industry and listen to the ideas that come up from these discussions.

WP.6 Pearl nets as a means to reduce harbour porpoise bycatch in gillnets

Introduction

Currently, only one method has proven effective at mitigating porpoise bycatch without affecting target species catch rates namely acoustic deterrents or pingers (Kraus *et al.*, 1997). Noise pollution induced by pinger usage may however also repel porpoises from their favoured habitat and reduce their fitness, which can eventually negatively affect entire populations (Carlström, Berggren and Tregenza, 2009; Kindt-Larsen *et al.*, 2019; Lusseau, Kindt-Larsen and Van Beest, 2023) To avoid negative side effects of acoustic deterrent usage, alternative mitigation solutions have been trialled in the past, focussing on enhancing the reflectivity of the netting material using e.g., barium sulphate impregnated thread (Trippel *et al.*, 2003) or hollow core nets (Au and Jones, 1991), or on limiting the risk of entanglement using stiff nets (Bordino *et al.*, 2013). These trials showed that while in some cases such mitigation methods reduced porpoise bycatch, the treatment associated to these gear modifications tended to also reduce target species catches significantly (Larsen, Eigaard and Tougaard, 2007). Recent research on increasing the acoustic reflectivity of fishing gears – to make them more detectable by porpoises in their acoustic landscape – while maintaining catch rates, showed that acrylic pearls are highly reflective to sound underwater, particularly in the frequencies used by porpoises for echolocating (Kratzer *et al.*, 2020). The acoustic image (echogram) of a gillnet with plastic pearls demonstrates a distinct highly visible acoustic pattern, in theory making the fishing gear highly “visible” to echolocating porpoises. Gillnets equipped with such spheres have substantially higher acoustic backscattering strength and exhibit a positive relation between backscattering strength and inclination, i.e., gillnets ensonified from an angle have a larger echo than gillnets ensonified perpendicularly. Gillnets with sphere-to-sphere distances of 20 cm perform best, while the acoustic backscatters of gillnets with 40 cm and 60 cm sphere-to-sphere distances are similar (Kratzer *et al.*, 2020). These so-called “pearl nets” are thus susceptible to reduce bycatch rates drastically by making the cetaceans aware of the presence of gillnets in their surroundings.

One important question is however not only how the pearls affect the porpoise catches but also if the pearls cause any changes in the fish catches as this could affect the acceptance of this mitigation tool at a later stage. In this study, we measured the changes in catch rates of target and non-target species, including harbour porpoises, in a set gillnet fishery for Atlantic cod (*Gadus morhua*) in the Western Baltic Sea when using pearl nets as a mitigation tool.

Materials and Methods

The mitigation trials were conducted onboard a Danish commercial gillnet vessel during three distinct periods, in November 2022, February 2023, and May-June 2023 in the Western Baltic Sea. All trials were conducted with a standard 3-folds trammel net used in this area to target Atlantic cod and flatfish. The middle panel had a twine size of 1.5x3denier, a mesh size of 55 mm (half mesh), and a net height of 1.5 m. The two outer nets had a twine size of 6x3denier, a mesh size of 90 mm (half mesh), and a net height of 90 cm.

We used 18 identical net panels of approx. 60 m in horizontal length, of which five net panels were equipped with acrylic pearls on one of the outer nets, resulting in 13 control and 5 treatment panels. The pearls were small acrylic glass (Polymethylmethacrylate, PMMA) spheres (Ø 8 mm) with a groove (4 mm long and 0.8 mm wide) into which to fit the net thread (Kratzer *et al.*, 2021). After sliding the thread in the groove, the cavity was filled with glue to make the pearl adhere to the netting material. The pearls were attached with a 30 cm-spacing horizontally and vertically. To compare with normal fish catches, the standard cod nets and pearl nets were deployed on the same fishing grounds, at the time, and soaked in the water for the same duration. Each fishing day, the fisher kept the 5 pearl net panels set together in one continuous string and completed the string with one to 3 control panels on either one end or on both. The rest of the control panels were set together in two distinct net fleets of 4 to 8 panels. As a result, there was always 3 net fleets soaked each fishing day, with two full controls and one with a mixture of treatment and control panels.

The trials were recorded using electronic monitoring (EM). The EM system installed onboard (Black Box Video, Anchorlab, Denmark; www.anchorlab.dk) consisted of a control unit, associated with a position sensor (GPS), and two waterproof CCTV (closed-circuit television) cameras. The cameras were positioned to allow catch items to be observable from different angles—where the net appears from the water and at the sorting table—maximizing the chance of identifying target species (Kindt *et al.*, 2012; Kindt-Larsen *et al.*, 2023). All EM data were analysed in the software Black Box Analyzer (Anchorlab). The programme presents a map with the GPS tracks of the vessel for each fishing trip alongside the corresponding videos, and annotations can be entered manually to mark events of interest. Trained EM analysts reviewed all the fishing trips having taken place during the trial periods to detect fishing events (setting and hauling of nets) and each individual catch. That is, within each haul, the analysts marked and identified every single catch of cod, flatfish, seabird, and marine mammal in the pearl and control sections of the nets. The fisher was required to fill a logbook to register the date, number of nets with and without pearls, and the corresponding cod catches in kg (only cod above the minimum conservation reference size; 35 cm). Additionally, the fisher was asked to check if the pearl nets were damaged (pearl loss) and if the handling of the gear with pearls was more prone to problems than the one without, e.g., mesh entanglement around the pearls.

To test the effect of acrylic glass pearls, generalized linear mixed models (GLMM) were developed, using the fisher logbook data. All data treatments and analyses were conducted in R, using the *glmmTMB* package to create the models (Brooks *et al.*, 2017). We modelled fish catches in weight as a response to pearl treatment using the fisher-sampled data. The response variable was defined as the weight of cod per fishing day (kg per day). The fixed variables were treatment (pearls/control) with the number of nets (on a log scale) as offset, and the variable “date” was used as a random group intercept. We assumed that the error was normally distributed on a log scale.

Results and Discussion

In total, 17 individual fishing days were conducted and analysed during this pearl net bycatch mitigation trial. During the period, no bycatch of marine mammal was registered, but we recorded all catches of cod and flatfish (in number of fish and in weight). All flatfish species were grouped as it in some cases were not possible from the video to distinguish between plaice (*Pleuronectes platessa),* common dab (*Limanda limanda*), and flounder (*Platichthys flesus).* Furthermore, six bycatches of common guillemot (*Uria aalge)* were observed. The detailed datasets are available online (https://www.doi.org/10.11583/DTU.23932014). The fitted model showed no significant difference in the catch rates of target fish species (here, cod) between the standard nets and the identical nets with pearls (Table 11). Similar results were observed for catch rates of flatfish (not shown here).

Table 11. Mean cod CPUE (cod per net length * soak time) and 95% confidence interval for standard nets and for modified nets with pearls.

	Predicted cod CPUE	95% confidence interval
Control nets	23.7	[17.8, 31.4]
Pearl nets	22.5	[16.9, 29.8]

These experimental trials constitute the first attempt in a commercial cod fishery to test the effect of pearl nets on catch rates of target species and bycatch rates of protected species. The results demonstrate that that pearl nets do not reduce catch rates of target species. However, the small number of incidental captures of marine mammals and seabirds prevented to conclude on the effectiveness of pearl nets as a bycatch mitigation solution.

Moreover, in this experiment, we did not distinguish between flatfish species, and instead grouped them together. Still, it cannot be excluded that the pearls may influence the catch rates of one of the flatfish species, but not of another. Likewise, the catches of fish of specific length classes might have been affected by pearl nets, while other length classes were not. These details could not be picked up in our analysis. Kratzer *et al.* (2021) is the only other study that measured the variations in fish catches in pearl nets, using data collected along the Turkish coast of the Black Sea. The authors reported very low catches of the main target species in this fishery, the Black Sea turbot (*Scophthalmus maeoticus*), in both the pearl and control nets. Small catch rates of turbot are common in this fishery between September and December (Bilgin, Kose and Yesilcicek, 2018) when the experimental trials occurred, as most of the migration to shallow areas takes place in spring. Generally, the authors reported very few catches of other species, yet registering small numbers of common stingray (*Dasyatis pastinaca*), spiny dogfish (*Squalus acanthias*), thornback ray *(Raja clavata),* whiting (*Merlangius merlangus*), Black Sea harbour porpoise (*Phocoena phocoena relicta*), and one unidentified loon (family Gaviidae). The data collected during these trials did not support a thorough statistical analysis of the effect of pearl nets on the catch rates of target and on the bycatch rates of protected species.

In the experiment conducted in the IMBAF project, we sought to determine if and how pearl nets could affect the process of clearing the catch from the net. The collaborating fisher was asked to report if the pearls were causing additional burden compared to a standard gillnet, e.g., by noting down the additional time spent handling catches due to the pearls tangling in the netting material. He also registered if the pearls tended to fall off the twine during handling. The report from the fisher indicted no such problem and that the handling of catches in pearl nets was no different from the one in standard gillnets. On the contrary, Kratzer *at al.* (2021) reports problems of entanglement in pearl nets, e.g., with thornback rays, where it took on average six seconds longer per fish. That said, a few more seconds of handling time per individual fish might be difficult for a fisher to notice, so further analyses of the handling time are still an interesting research question to pursue in the future. In our trial, we did not notice any entanglement of the netting in itself when using pearl nets. The reason might be that in this case the pearls were attached to a thicker twine material compared to the experiment in Kratzer *et al.* (2021), thus making the pearls less prone to fall into the underlying meshes while stored in the pounders before the next set.

Unlike traditional gillnets, the manufacturing of pearl nets is not standardised and currently requires a lot of manual handling to attach the plastic pearls on the netting material (see description in materials and methods). The process of gluing each individual pearl is obviously extremely time-consuming and, if the potential for bycatch reduction of pearl nets is confirmed in future studies, the attachment issue needs to be solved. Besides automatising the process of gluing the pearls on the net, an idea could be to mould the plastic pearls with a hole in the middle instead of a groove to allow sewing the pearls onto the nets instead of gluing them. Ideally, this process could be further optimised by net manufacturers in order to reduce construction time and ultimately the cost of the gear.

Our results are important, as pearl nets will only be accepted as a bycatch mitigation method by the fishing community if they do not lower target species catches. However, the question of pearl nets decreasing bycatch rates of harbour porpoises still remains unanswered at this stage, since the data we collected could not demonstrate whether the new gear significantly reduces bycatch.

This part has been written into a scientific paper:

Pearls are not just for girls: Plastic spheres do not interfere with target catches in a set net fishery

Fisheries Research 2024 | Journal article | *Author* DOI: 10.1016/j.fishres.2024.107032

SOURCE-WORK-ID: b4011fab-fd4f-48f8-94b7-e01361fa009c

EID: 2-s2.0-85192318528

Contributors: Lotte Kindt-Larsen; T. Noack; Mollie Elizabeth Brooks; A-M Kroner; Gildas Glemarec

WP.7 Outreach

The purpose of this work package was to coordinate all the different work packages of the project and ensure focused and effective dissemination of the project's results.

Activities

To lead and coordinate the project, a steering committee was made consisting of the project-leader (Finn Larsen, Lotte Kindt-Larsen), work package leaders (Gildas Glemarec, Hanne Lyng Vinther (FSK), Lotte Kindt-Larsen and Finn Larsen), and the management secretariat.

Other activities were:

- Kick-off meeting with all project participants
- Project management throughout the project
- Discussions on project setup and statistical analysis
- Financial management throughout the project
- Dissemination of the project and its results
- Group meetings approximately every second month
- Scientific articles:
    - Pearls are not just for girls: Plastic spheres do not interfere with target catches in a set net fishery. Fisheries Research. 2024 | Journal article | Author
      DOI: 10.1016/j.fishres.2024.107032
      B4011fab-fd4f-48f8-94b7-e01361fa009c
      SOURCE-WORK-ID: EID: 2-s2.0-85192318528
      Contributors: Lotte Kindt-Larsen; T. Noack; Mollie Elizabeth Brooks; A-M Kroner; Gildas Glemarec
    - Looming-Eye Buoys Temporarily Reduce Seabird Depredation in Pound Nets. Available at SSRN: https://ssrn.com/abstract=4819192 or http://dx.doi.org/10.2139/ssrn.4819192
      Pre-print on SSRN http://papers.ssrn.com/sol3/papers.cfm?abstract_id=4819192
      Contributors: Gilda Glemarec; Lotte Kindt-Larsen; Anne-Mette Kroner; Casper Berg
    - Associated dataset and data analysis:
      10.11583/DTU.25118207
      10.11583/DTU.25911484
- Preparation of a final report

Furthermore, the project and results have been presented at:

- The Ministry of Environment and the Ministry of Food, Agriculture and Fisheries seal group
- ICES WGBYC (Working Group on Bycatch, 2022 & 2023)
- ICES JWGBIRD (Joint Working Group on seabirds, 2022, 2023)
- ASCOBANS (invited talk, 2022)
- HELCOM (invited talk, 2022)

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