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**PearlNet - Passive acoustic reflectors to reduce odontocete bycatch in gillnets – update 2023**

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# PearlNet - Passive acoustic reflectors to reduce odontocete bycatch in gillnets – update 2023

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## Introduction

The need to minimize bycatch of toothed whales (odontocetes) in gillnets has long been recognized, because they are often top predators and thus essential to ecosystem resilience (IWC, 2018; Lewison et al., 2014; Reeves et al., 2013). It is likely that a key to achieving this goal is the improvement of gillnet acoustic visibility, because these species use underwater sonar for orientation. Previous work on increasing gillnet detectability for echolocating animals by making the nets more recognizable has been based on trial and error, without understanding the fundamental acoustic properties of the tested modifications. Consequently, these studies have produced mixed and sometimes contradictory result (Bordino et al., 2013; Larsen et al., 2007; Perrin et al., 1994; Trippel et al., 2009). To move forward, a systematic approach was taken to increase the acoustic reflectivity of gillnets

We systematically identified small, passive reflective objects that can improve the visibility of gillnets at a broad range of frequencies, i.e., for many odontocete species. We used a combination of simulations and experimental verification to identify ideal, single objects that have a strong echo (or technically target strength), but are very small (Kratzer et al., 2020). During the simulation approach, a large number of parameter combinations was tested for their echo strength (target strength). This included material and shape properties of passive reflective object (e.g. density, Young's Modulus, shape, size, wall thickness) and environmental properties (temperature and salinity of sea water). As these calculation were conducted for frequencies between 1 and 200kHz, optimal acoustic reflectors were identified for the echolocating frequencies of a large number of odontocete species (Kratzer et al., 2020), allowing a worldwide application of this approach. Additionally, we compared sonar images (and echo data) of gillnets equipped with and without optimal passive acoustic reflectors.

In this report, we re-iterate and summarize the past work (Kratzer et al., 2022, 2021, 2020) and update it with results from fishing trials to evaluate the fishing performance for target species (which is essential for an acceptance in fisheries) and focus on next steps.

## Material and methods

*a) Identification of optimal passive acoustic reflector (Kratzer et al., 2020)*

We simulated the acoustic reflectivity as target strength (MacLennan et al., 2002; Mooney et al., 2004) of a wide range of materials in different shapes, sizes, and environmental conditions using the software COMSOL Multiphysics (*COMSOL Multiphysics*®, 2018). We verified the simulation results experimentally in an acoustic tank and took sonar images using a standard SIMRAD EK60 echosounder for a qualitative comparison.

*Table 1: Overview of parameters and their ranges used for parameter study using COMSOL*

| **parameter** | **range** | **unit** |
|---|---|---|
| Frequency | 1–200 | kHz |
| Diameter (d) | 0.25–60 | mm |
| Wall thickness | 1–2.8 | mm |
| Young's modulus (E) | 0.1–10 | GPa |
| Object density (ρ) | 1000–8000 | kg/m³ |
| Salinity (Sal) | 0–31 | psu |
| Temperature (T) | 0–18 | °C |

*b) Angle-dependent acoustic reflectivity of modified gillnets* (Kratzer et al., 2022)

The angle-dependent acoustic reflectivity of different gillnets was measured with an EK80 echosounder in a harbour berth. Acrylic spheres with a size of 8mm were used to improve the acoustic visibility of gillnets. The size of the spheres was based on the simulated resonance peaks for the echolocation frequency of harbor propoises (*Phocoena phocoena*) (Kratzer et al., 2020). Echograms of gillnets with several different numbers of spheres per m² (Table 2) were ensonified across a broad range of frequencies (38 kHz – 170 kHz) from three different angles (0°, 20°, 45°). Acoustic reflectivity of these gillnets was measured in area backscattering strength $S_a$ (MacLennan et al., 2002) as well as target strength TS.

*Table 2: Properties of ensonified gillnets, spheres were made of Acrylic (PMMA) with a size of 8mm.*

| Name | Material | Sphere-sphere interval [cm] | Stretched mesh size [mm] | Height of net [m] | Approx. number *n* of spheres/m² [$m^{-2}$] | Hanging ratio |
|---|---|---|---|---|---|---|
| Cod Ref | Nylon | N/A | 110 | 3.6 | 0 | 0.5 |
| Cod 60cm | Nylon | 60 | 110 | 3.6 | 4 | 0.5 |
| Cod 40cm | Nylon | 40 | 110 | 3.6 | 9 | 0.5 |
| Cod 20cm | Nylon | 20 | 110 | 3.6 | 25 | 0.5 |
| Turbot Ref | Natural fiber | N/A | 400 | 2 | 0 | 0.33 |
| Turbot 35cm | Natural fiber | vertical: 37 horizontal: 35 | 400 | 2 | 9 | 0.33 |

*c) First pilot trials of an acoustically visible gillnet in a commercial fishery* (Kratzer et al., 2021)

A first pilot trial using acoustically reflective nets took place in the turbot fishery in the Black Sea that is characterized by seasonally high bycatches of harbour porpoises (Bilgin et al., 2018; Bilgin and Köse, 2018). A total of 10 paired hauls, each with 2000 m of standard and 2000 m of modified gillnet took place off the coast of Sinop (Figure 1) between Sept – Dec 2019. The modified gillnets were equipped with 8 mm acrylic glass spheres at a vertical distance of 37 cm and horizontal distance of 35 cm from each other, as this is considered to be the "personal space" of a harbor porpoise (Nakamura et al., 1998). The size of the acrylic glass sphere was based on the simulation results (Kratzer et al., 2020) and matches the echolocation frequency of harbor porpoises. Aside from the addition of acrylic glass spheres, the nets were identical (mesh size: 400 mm, hanging ratio 0.33, height 5.5 meshes, orange/yellow natural filament).

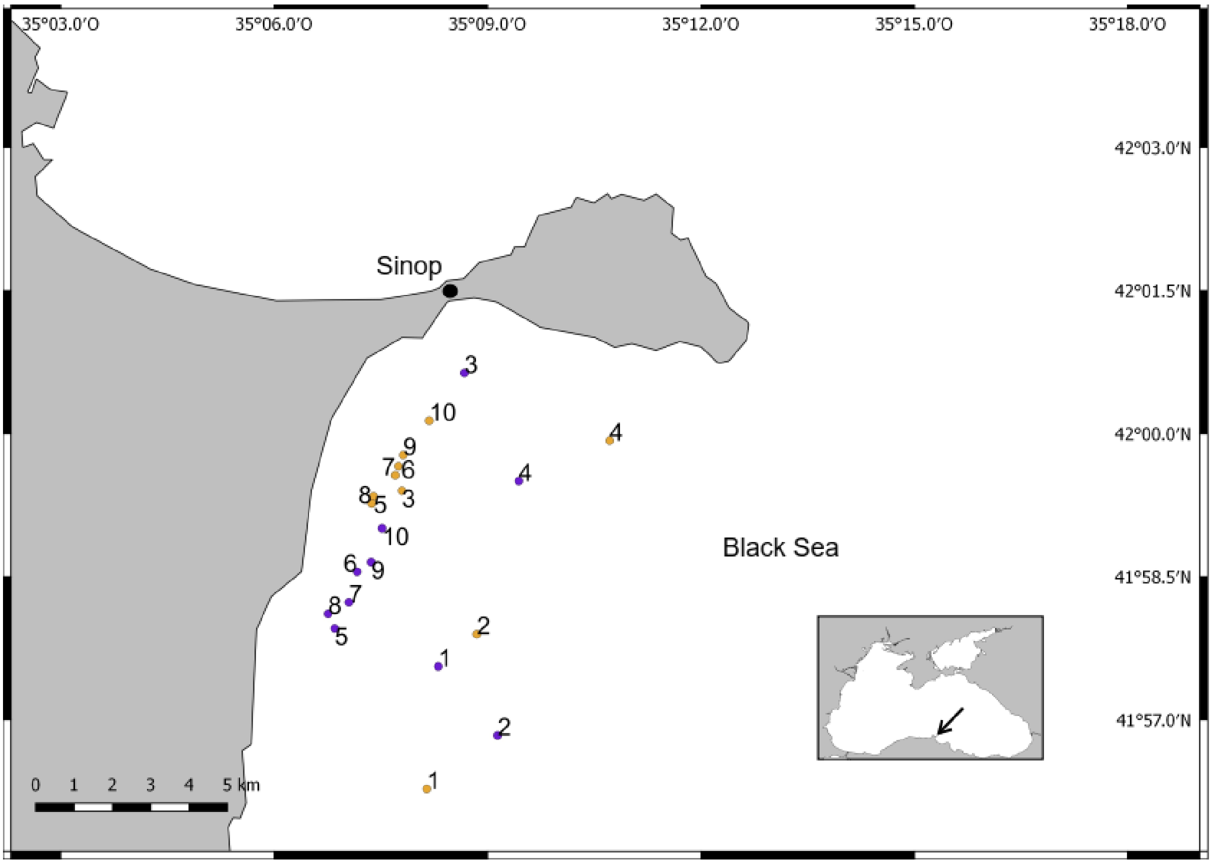


*Figure 1: Study area of the 10 hauls off the coast of Sinop, Turkey. The dots mark the middle of the gillnets (purple=standard, yellow = modified).*

*d) Target species catch efficiency of an acoustically visible gillnet in a commercial fishery (Schartmann et al. in prep.)*

Modification of the net must meet two objectives: a) reduce bycatch of toothed whales and b) provide good catch efficiency of target species to allow for easy uptake in commercial fishery. Therefore, Schartmann et al. (in prep) conducted a catch comparison experiment in the German Baltic gillnet fishery in autumn 2022. This experiment compares the target species catch efficiency of standard trammelnets (2000m) with PearlNets (as standard trammelnets, but with optimized acrylic "pearls" and a pearl-distance of 30cm).

## Results

*a) Identification of optimal passive acoustic reflector (Kratzer et al., 2020)*

In a first step, it was investigated whether a change in gillnet yarn/filament could improve the acoustic visibility of the gillnets. The simulation of thin filaments as a proxy for gillnets showed that increasing the density of filaments is not going to substantially change the acoustic target strength (TS). The only potential increase in TS is given for very elastic filaments, however, these often do not have a high tensile strength, making them unsuitable as gillnet material.

Consequently, the option of additional passive acoustic reflectors was investigated. In a first step, we simulated TS of spheres in a large range of parameters (diameter, wall thickness, density, elasticity) in order to narrow the parameters down to the relevant properties and combinations of size and material characteristics for different odontocetes frequencies. From these simulations, it became evident that the ideal material that could be used for reflectors smaller than 20 mm in diameter, is acrylic glass. It has a similar density as seawater, thus will likely not influence the net behavior, is transparent and thus inconspicuous to fish and, most importantly, spheres made from acrylic glass resonate when the so-called eigenfrequency of a sphere matches the ensonification frequency. The eigenfrequency is an object-specific characteristic which results from geometric properties (diameter) and mechanical properties (density, elasticity). This means, that the echolocation frequency of different odontocetes species matches a certain diameter of acrylic glass sphere, resulting in a design guide for many odontocetes (Figure 2). The results were confirmed by measuring the target strength of two acrylic glass spheres (6.4 mm, 9.6 mm diameter) as well as reference objects (table tennis ball, steel ball). At 130 kHz, the acrylic glass spheres had similar TS values as the reference objects, despite being substantially smaller (Figure 3).

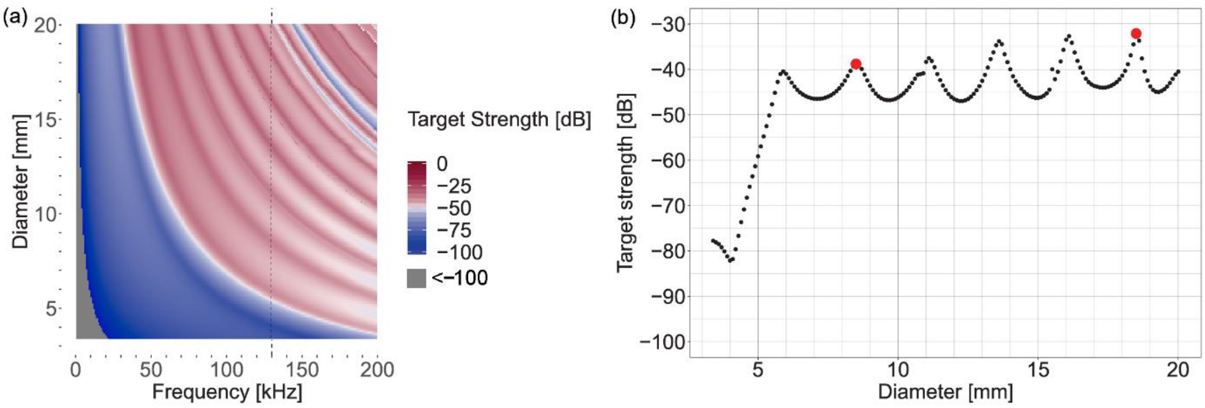


*Figure 2: Target strength of acrylic glass spheres across frequency range (x-axis) and different sizes (y-axis); the white areas are values of -50 dB, the target strength of a gillnet (Kastelein et al., 2000) (a). Target strength of acrylic glass spheres exemplarily at 130 kHz, the echolocation frequency of harbor porpoises (b). The dashed line in (a) shows the cross-section displayed in (b). Red dots mark the maximum target strength values of spheres below 10 mm and 20 mm, respectively.*

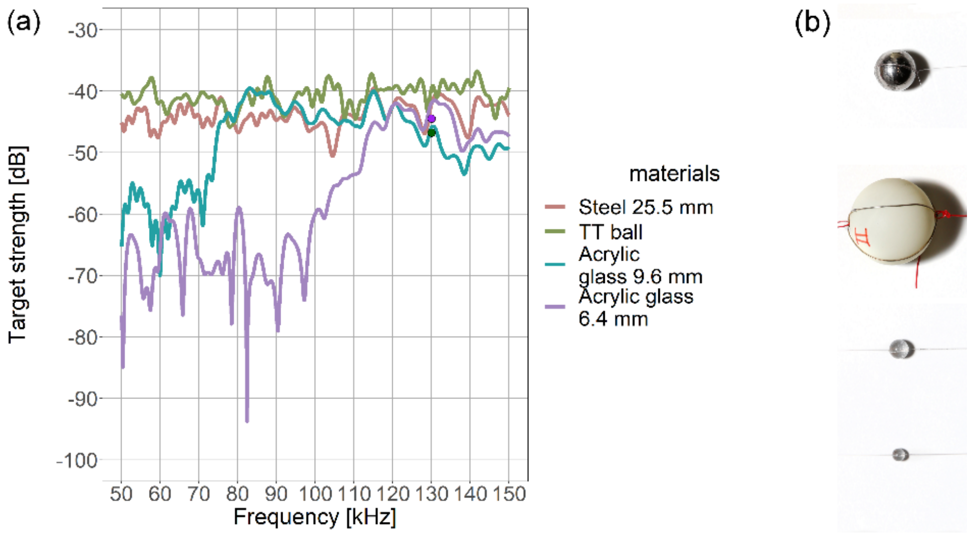


*Figure 3: Target strength values (a) of various measured objects (b) of different materials. Dots in (a) indicate the corresponding simulated values at 130 kHz.*

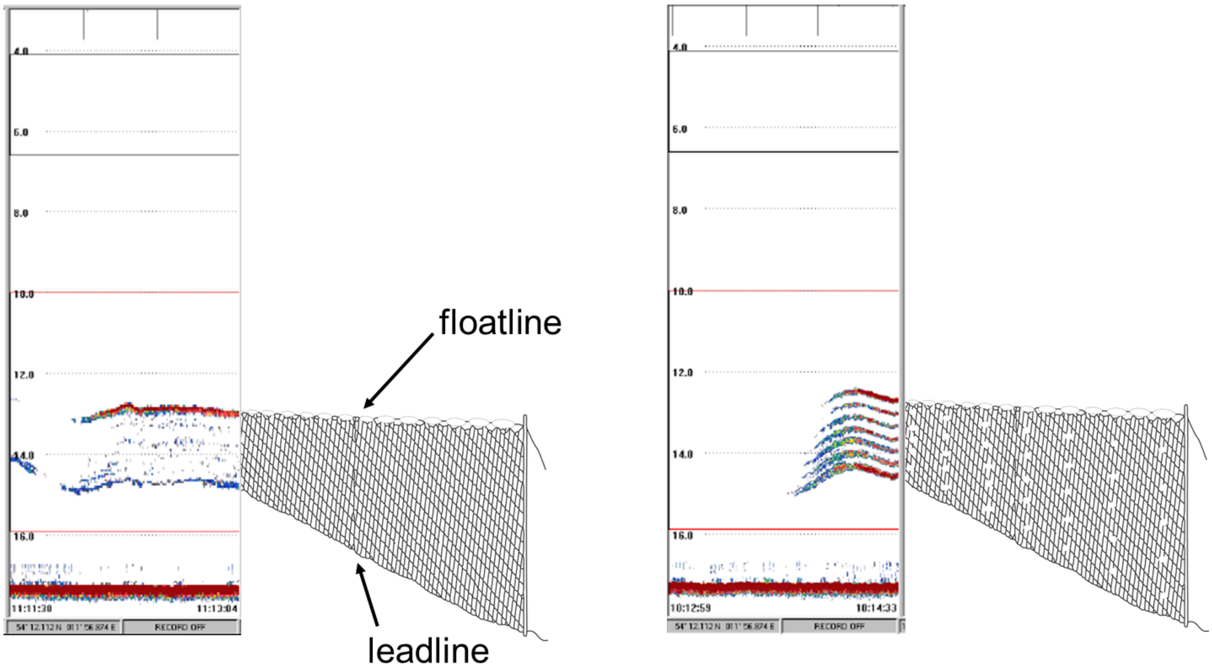


*Figure 4: Left: echogram of standard gillnet; right: modified gillnet at 120 kHz. The added spheres are clearly visible at 120 kHz, whereas net panel of the the standard gillnet is hardly visible.*

*b) Angle-dependent acoustic reflectivity of modified gillnets (Kratzer et al., 2022)*

Following the determination of the optimal acoustic reflector (acrylic glass sphere), the acoustic reflectivity of gillnets with different numbers of spheres per m² from different angles (angle of attack) was determined. The acoustic reflectivity was determined qualitatively in terms of the spatial distribution of echoes in the acoustic beam (echograms, Figure 5 exemplarily for the 120 kHz transducer) as well as quantitatively by determining area backscattering strength (Figure 6 a, b) and target strength (Figure 6 c, d) from the echograms. The area backscattering strength and TS were determined for each single frequency as well as the frequency range 120 – 140 kHz, which corresponds to the echolocation frequency range of harbor porpoises (Møhl and Andersen, 1973; Villadsgaard et al., 2007), the odotontocete that this gillnet modification is designed for. Gillnets equipped with acrylic glass spheres have a substantial increase in acoustic reflectivity, both in terms of area backscattering strength and target strength. Additionally, the acoustic pattern in the echolocation beam is changed and appears as a barrier in the acoustic beam.

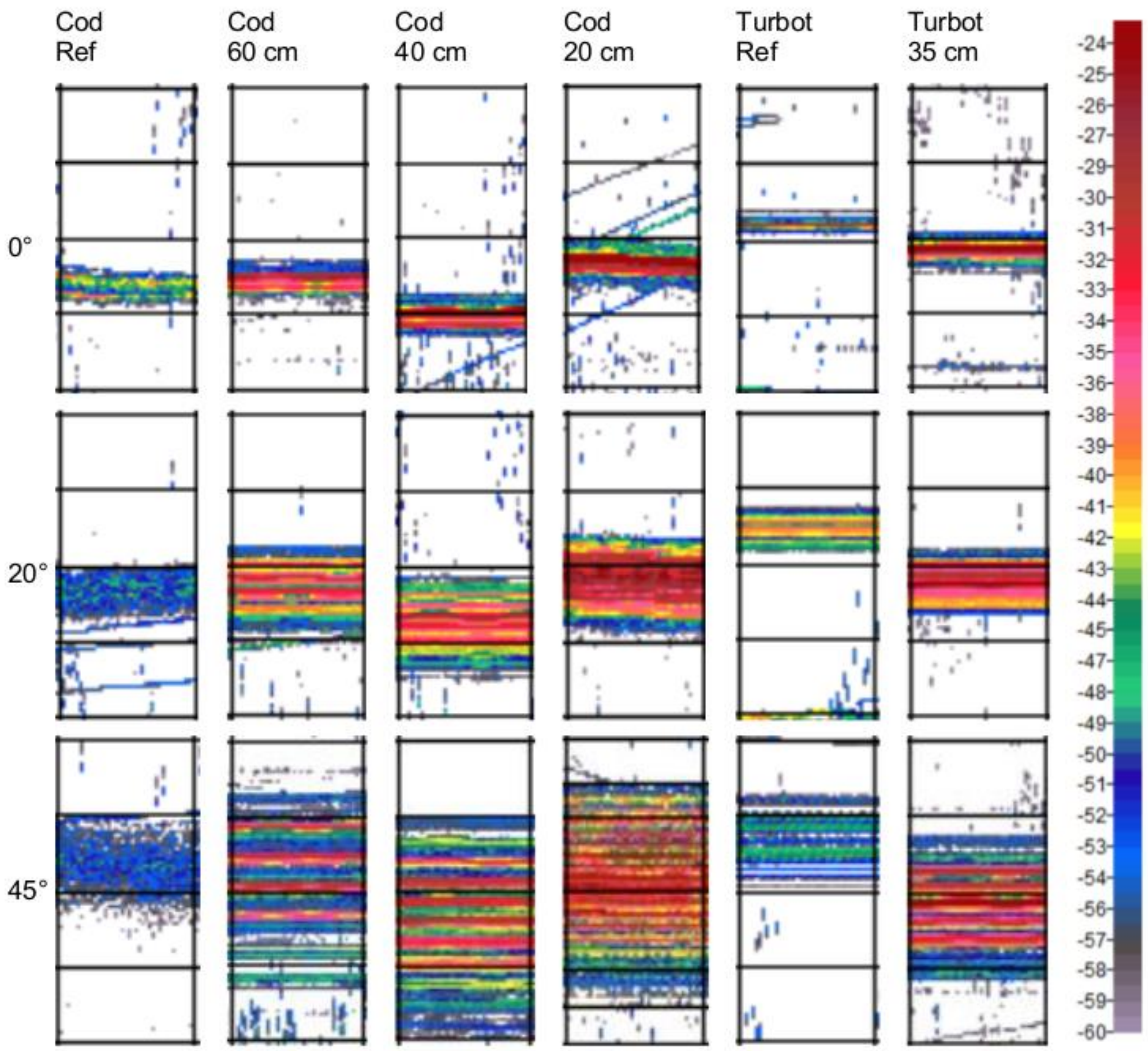


*Figure 5: Echograms of standard („Ref“) gillnets and gillnets modified with different sphere-sphere intervals from three different ensonification angles (0°, 20°, 45°) using the 120 kHz transducer. Echo strength is depicted in $S_v$ [dB] (grey: low echo, red: strong echo, see color scale). The spheres become clearly visible as red rows, especially at 45° inclination. Small echoes around the gillnet are noise or small fish – these data points were excluded from the analysis.*

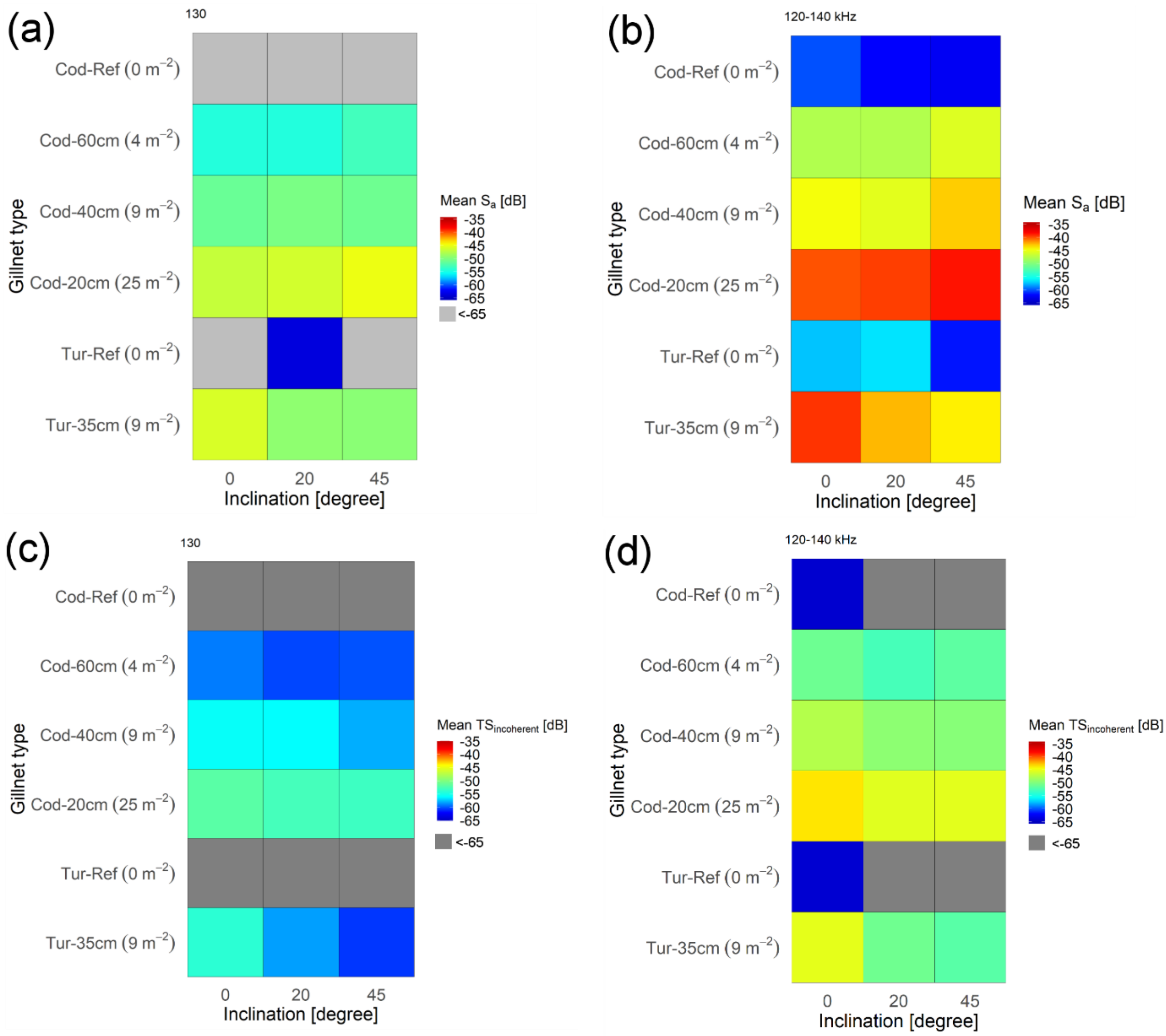


*Figure 6: $S_a$ values (a, b) and incoherent TS values (c, d) of all measured gillnets (number of spheres per m² in brackets) at 130 kHz (a, c) and in the frequency range 120 – 140 kHz (b, d).*

*c) First pilot trials of an acoustically visible gillnet in a commercial fishery*

To test the effect of an acoustically visible gillnet on the bycatch of harbor porpoises as a model species as well as to investigate the practical handling of a new fishing gear, 10 paired hauls were carried out in the commercial turbot fishery in Sinop, Turkey.

The most commonly caught fish was thornback ray (*Raja clavata*, 193 individuals) with no significant difference between standard and modified gear. Only 4 specimens of the target species Black Sea turbot (*Scophthalmus maeoticus*) were caught. The catch efficiency for bottom-dwelling species did not seem to be compromised by the attachment of acrylic glass spheres.

In total, seven harbour porpoises were caught, five in the standard net and two in the modified gillnet (Figure 7). Possibly due to the low number of hauls, no statistical difference could be determined, as a power analysis showed that with the given bycatch rate, 130 hauls would be needed to determine a difference with 80% power.

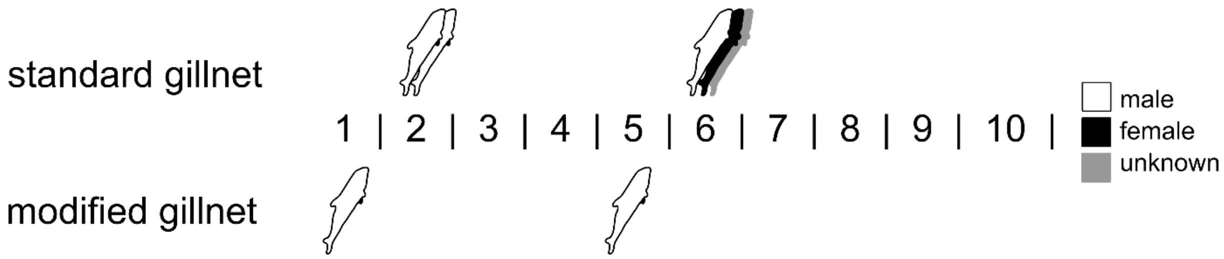


*Figure 7: Overview of the bycaught harbor porpoises during the ten hauls (numbers) in the Black Sea. Animals are shown by gear and sex.*

The handling in the Turkish Black Sea Fisheries was somehow challenging due to the special configuration of the netting used in this fishery and the way of handling the nets. The fishers faced some issues with both the standard net and the modified net, e.g. the nets become entangled and wrapped around the headline as they pass the pulleys of the hauler. Changing the headrope from a twisted rope to a braided rope could mitigate this issue. Furthermore, the clearing of the nets is done by hand after each haul, which can take up to five days, depending on the amount of litter and seaweed. An automated net stacker, as often used on, e.g., Danish and German vessels, could greatly facilitate this process in this Black Sea fisheries.

*d) Target species catch efficiency of an acoustically visible gillnet in a commercial fishery (Schartmann et al. in prep.)*

In total, 20 hauls were conducted in autumn 2022, comparing the catches (species composition and length) of standard trammel nets and modified trammel nets with acrylic “pearls”. No differences was found in the catchability for all commercial target species, including several flatfish species (flounder, plaice, dab, turbot) and roundfish species (cod and whiting). No handling issues were detected during these trials with the used netting and handling equipment (gillnet hauler, gillnet cleaner).

## Discussion

Creating sustainable ways to reduce species loss while maintaining provisional ecosystem services can be a challenge. Previous work to reduce the bycatch of toothed whales (odontocetes) includes time and area closures (Gormley et al., 2012; Murray et al., 2000), the use of acoustic deterrent devices (pingers), and experiments with supposedly acoustically enhanced nets (Bordino et al., 2013; Dawson et al., 2013; Kraus et al., 1997; Larsen et al., 2007; Larsen and Eigaard, 2014; Mangel et al., 2013).

Here, in order to expand the portfolio of technical measures to reduce bycatch of toothed whales, we systematically explored the acoustic properties of a wide range of gillnet filaments, as well as a range of objects that could be added to gillnets to enhance their acoustic detectability. We identified species-specific resonators that might increase the TS of gillnets and thus potentially increase the detection distance for odontocetes. The modifications might not only let odontocetes detect gillnets earlier, but also make the gillnets appear as objects they cannot swim through, if mounted properly.

Based on the requirements omnidirectionality, small size, neutral buoyancy and strong echo we identified acrylic glass spheres as the optimal reflector, which also has further advantages like transparency, availability and a low water absorption coefficient.

We also showed that changing the filament itself is not going to increase the acoustic reflectivity of the gillnet, as there is a size threshold that limits the interception of acoustic energy. If objects are too small in diameter, the acoustic wave bends around the object rather than being reflected (Medwin and Clay, 1998).

Following the simulations, the acoustic reflectivity of gillnets with different sphere patterns was tested in a harbor berth. The echograms revealed distinct patterns when gillnets are equipped with acrylic glass spheres, even at relatively large (60 cm) distances. As the gillnets were inclined relative to the transducer, the acoustic reflectivity of some gillnets with spheres increased, while the acoustic reflectivity of the standard nets decreased, similar as in other experiments (Au and Jones, 1991; Kastelein et al., 2000; Mooney et al., 2004). The increase in reflectivity of gillnets with spheres is likely a result from more simultaneously ensonified targets, resulting in the addition of the reflectivity of the single spheres. The increase in absolute reflectivity as well as the improvement in acoustic pattern shows that the barrier effect of gillnets with acrylic glass sphere could be achieved from any angle of approach.

The first pilot trial of the gillnets with acrylic glass spheres in the commercial fishery revealed promising, but not ultimately conclusive results. While a bycatch reduction was achieved when using the gillnets with acrylic glass spheres, the low number of hauls hampers drawing a statistically robust conclusion. Further trials on a larger scale are needed to confirm the bycatch reduction potential.

The trials also show that also using acoustically visible nets cannot eliminate bycatch entirely. One reason why harbor porpoises still entangle in acoustically visible nets could be that their narrow echolocation beam (Koblitz et al., 2012) is not directed towards the net due to distraction

(Kastelein et al., 1995) or bottom-grubbing (Lockyer et al., 2001), or they are swimming in silence (Linnenschmidt et al., 2013; Wright et al., 2017). Early research has suggested to combine a "wake-up call" with acoustically visible nets to most effectively reduce bycatch in gillnets (Goodson, 1997). For harbor porpoises such a device could be a PAL (PorpoiseALert), a device that has shown to reduce bycatch of harbor porpoises in the Western Baltic Sea (Chladek et al., 2020) and increases the echolocation rate of harbor porpoises (Culik et al., 2015). Combining PAL and gillnets with acrylic glass spheres has a promising potential to be a technical mitigation effort to effectively reduce bycatch of harbor porpoises.

The next steps would be:

a) *behavioral experiment:* a behavioral experiment observing odontocetes around gillnets with and without acrylic spheres with and without a wake-up call. The experiments were already conducted in 2019 and 2021, but the detailed analysis is still ongoing. The behavior of harbor porpoises around gillnets (with and without passive acoustic reflectors) was observed using CPod, 4 channel-acoustic recorders (soundtraps) and visual tracking (theodolite and drone). **If you are an expert in the analysis of such data (especially 4-channel acoustic recorder) and willing to contribute in the analysis, please contact the authors!**

*b) alternative material for passive acoustic reflector:* The above-mentioned experiments were conducted using passive acoustic reflector made of acrylic glass (PMMA) due to its material properties which were assumed to be beneficial (same density as sea water, transparent). Nevertheless, other polymer materials (such as polycarbonate or Nylon) could also be used as acoustic targets. During several discussions about the "PearlNet", the issue of recyclability of the fishing gear was raised. When acrylic spheres are permanently attached to the Nylon netting the combination of two materials might hamper its recyclability. Additionally, PMMA is rather brittle and might limit the possibilities of an industrial production process of PearlNets. Therefore, the acoustic properties of targets made of other materials (especially Nylon, PA) needs further investigation. Therefore, we will investigate the optimal sphere size for different echolocation frequencies for Nylon-spheres.

c) *improved production of PearlNets*: So far, the PerlNets are still produced by gluing spheres individually onto the net by hand. For larger trials to confirm the promising results regarding the bycatch reduction potential and more importantly for a wide introduction into commercial fishery, there is the need to develop an automated process to equip gillnets with spheres. Several approaches are under investigation at the moment. **If you are (e.g.) a net producer and you have ideas on improving the production process of PearlNets, please contact the authors!**

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