Making nets more acoustically visible

Floats as passive mitigation measures to reduce bycatch of harbour porpoise (*Phocoena phocoena)* in gillnets

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Swedish University of Agricultural Sciences, SLU
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NJ Faculty
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Abstract

Incidental capture in fishing gear is today affecting at least 112 marine mammal species worldwide and for many smaller toothed whale species (*Odontocete*), gillnets are considered to be the largest problem. Although some effective mitigation measures exists, these are often context specific and many might be hard to implement due to reasons such as high costs and maintenance. There is a pressing need to develop low-cost solutions to reduce small toothed whale bycatch and one such possible solution is the use of passive acoustic reflectors, making the net more visible to toothed whale echolocation. A systematic literature review was performed to identify previously tested passive acoustic reflectors and their effectiveness. 20 different modification types were identified and two groups were found to have the highest potential: hard plastic floats and acrylic glass spheres. A field trial was performed to further evaluate hard plastic floats as a potential, low-cost, mitigation measure. The aim of the field trial was to investigate harbour porpoise (*Phocoena phocoena*) presence and click behaviour around rope panels equipped with and without floats. Harbour porpoise echolocation clicks was recorded using click detectors (C-PODs). Detection positive minutes per hour (DPM/h) was used as a measure of presence and buzz-clicks, a type of clicks produced with a very short interval between them (inter click interval ≤15ms) used for example when exploring or hunting, was used as a proxy for click behaviour. Results indicate that harbour porpoise presence and click behaviour is affected by floats with a spacing of 2m and 6m compared to control without floats. Placement of panels could however not be excluded to have an impact on the results and further studies are required to confirm the effect of floats on harbour porpoise presence and click behaviour.

Keywords: toothed whales, harbour porpoise, Phocoena phocoena, incidental capture, bycatch, fishing gear, gillnet, mitigation, reduction, low-cost, passive acoustic reflector, float

Table of contents

List of tables

List of figures

Abbreviations

DPM	Detection Positive Minutes
GAM	Generalized Additive Models
ICI	Inter Click Interval
ITI	Inter Train Interval
NBHF	Narrow Band High Frequency
RL	Received Level
SL	Source Level
TS	Target Strength

1. Introduction

Whales (*Cetacea*) worldwide faces many anthropogenic threats, both at the individual and the population level, ranging from direct harvest, incidental entanglement in fishing gear and vessel collisions to acoustic or chemical pollutants, industrial development and climate change (Avila *et al.* 2018). Of these, incidental entanglement of non-target species in fishing gear (here after referred as bycatch), is thought to be the largest and most widespread threat to cetaceans and other marine mammals – affecting at least 112 species worldwide (Read *et al.* 2006; Reeves *et al.* 2013; Avila *et al.* 2018). Whales are bycaught in many different types of fishing gears, but majority of the species caught are dolphins and porpoises (Read *et al.* 2006). For these smaller whales, gillnets are responsible for the most bycatch (Read *et al.* 2006; Reeves *et al.* 2013). Whale bycatch increased dramatically when the use of synthetic gillnets became popular in the 1960s – the nets were more durable, inexpensive and highly attractive for small scale fisheries since they could be set from smaller boats and set to function passively (Leaper 2017; Brownell *et al.* 2019). Gillnets are still widely used today in both artisanal and industrial fisheries and are responsible for the deaths of hundreds of thousands whales every year (Read *et al.* 2006; Brownell *et al.* 2019). Gillnets most likely contributed to the extinction of the baiji (*Lipotes vexillifer*) and today the vaquita (*Phocoena sinus*) is on the brink of extinction due to the very same reason (Turvey *et al.* 2007; Brownell *et al.* 2019).

The concern regarding bycatch of whales and its effect on populations worldwide has been present during several decades but it is still unclear why many of them get entangled in fishing gear in the first place, even though several hypotheses exists in the literature, ranging from that the whales do not perceive the netting as a barrier to them simply making a mistake (e.g. Au & Jones 1991; Dawson 1991; Au 1994; Kratzer *et al.* 2022). Efforts have been made to find solutions to the bycatch-problem and although some mitigation measures like pingers (an active device that emit high frequency sound to alert or deter whales) have proven effective in many cases, the progress has otherwise been limited (Dawson *et al.* 2013; Leaper 2017). A number of reviews of bycatch mitigation measure exists (e.g. Jefferson & Curry 1996; Dawson *et al.* 2013; Leaper 2017; Hamilton & Baker 2019; Sacchi 2021; Lucas & Berggren 2022), but few measures that both reduce risk of bycatch and are realistic to implement in the long term have been identified. Many of the effective mitigation measures also tends to be population and situation specific with no single method that can readily be applied to all cases (Dawson *et al.* 2013). However, the work is still ongoing and many international organizations, as well as national and regional initiatives are addressing bycatch and working towards finding sustainable solutions (Leaper 2017).

1.1 Implementing mitigation methods

Whale bycatch reduction/mitigation methods currently in use can be divided into two main areas (Sacchi 2021):

1) **Fishery management measures: A**ims primarily to prevent whales coming into contact with fishing gear and include implementing marine protected areas, temporary closure of protected zones, fishing effort restrictions or change to alternative fishing gear (Sacchi 2021)..

2) **Technical solutions:** Gear modifications are technical solutions (that can be used as a stand-alone measure or in conjunction with fishery management measures above). The purpose of gear modification is to prevent interactions with fishing gear, using different forms of visual or acoustic deterrents, or alternatively to minimize the risk of a fatal outcome if an interaction occurs, for example excluder devices or weak links (Sacchi 2021).

However, crucial for success when implementing any bycatch reduction measures is the acceptance and compliance by fishers and the wider fishing industry (Leaper 2017; Sacchi 2021). Lack of these have been the cause of many mitigation programs failure to meet their objectives (Leaper 2017). The reasons for lack of acceptance and compliance is often due to social, economic or practicality reasons. Management actions such as closed areas can be unpopular with fishers and require a lot of resources to enforce and many technical solutions are often expensive or logistically challenging to use (Leaper 2017; Kiszka *et al.* 2022). This is especially true for artisanal fisheries were in many regions fishing might be the only source of income or food, as well as an important cultural activity (Berggren *et al.* 2019; Temple *et al.* 2021). These barriers to acceptance are particularly problematic because it is in low- and middle-income nations were the risk of bycatch is highest and in most need of bycatch mitigation measures (Temple *et al.* 2021). From the above, it is evident that there is a pressing need to develop efficient, low-cost solutions to reduce cetacean bycatch that are accepted by fishers in order to reduce cetacean bycatch. In this thesis, I will focus specifically on gear modifications as a means to reduce toothed whale bycatch in gillnets.

1.2 Finding an efficient, low-cost, solution

All whale species use sound to communicate, but active use of echolocation has only been confirmed for the species belonging to the suborder toothed whales (*Odontocete*) (Kratzer *et al.* 2020). Echolocation is the production of acoustic signals that will disperse into the surroundings and then a fraction of those acoustic signals will return in the form of echoes from enzonified structures (Ladegaard 2017). These echoes, and the time delay it takes for them to return, gives the animal information about its surroundings and what lies ahead.

Fishing gear such as gillnets produces very weak echoes making it harder for the whales to detect its presence or perceive the nets as an obstacle (Goodson 1994). Therefore there has been a lot of interest in the possibility to modifying fishing gear to make them more acoustically visible for these species to eliminate bycatch. Both active and passive devices have been investigated. Passive referring to devices that do not emit sound or require a power source but instead utilizes the echoing-capability of the material itself, and active referring to devices that emits a high frequency sound with the purpose to alert or deter whales from the fishing gear. Active acoustic deterrents such as pingers are effective in many cases and are becoming more widely used (Dawson *et al.* 2013; Leaper 2017). However, pingers, can be expensive to buy, deploy and maintain, which limits the implementation of this measure in many artisanal fisheries.

In contrast to active acoustic deterrents which have been relatively well reviewed (e.g. Jefferson & Curry 1996; Dawson *et al.* 2013; Leaper 2017; Hamilton & Baker 2019; Lucas & Berggren 2022), passive deterrents have only been briefly reviewed (e.g. Dawson 1994; Lucas & Berggren 2022).

1.3 Aims of study

1.3.1 Systematic literature review

A systematic literature review was undertaken to identify and review passive acoustic deterrents and their effectiveness in regards to modifying the behaviour and/or reducing the bycatch of toothed whales to be able to conclude if the investigated passive acoustic mitigation methods could be an alternative in the future. Potential gaps in the research effort that has been made to date to identify possible future studies was also investigated.

1.3.2 Field study

The purpose of the field study in this thesis was to further investigate floats as a passive acoustic gear modification, based on the positive findings from the systematic literature review (see section

2.2.1 and 4.1) coupled with their cheap cost, low maintenance and ready availability. Using harbour porpoise as a study species, their presence and click behaviour around panels equipped with floats was investigated by examining their echolocation signals with the help of hydrophones since this has not been done before.

Harbour porpoise presence was examined by studying clicks in terms of detection positive minutes per hour (DPM/h) and click behaviour was examined by extracting the specific buzz-click pattern in relation to total number of clicks (buzz ratio) as a proxy for click behaviour. The aim was to investigate if there was any variation in presence and click behaviour depending on if panels were equipped with floats or not and if distance between floats had any effect on the response.

Presence:
H_0: There is no difference in DPM/h between the different treatments.

H_1: There is a difference in DPM/h between the different treatments.

Click behaviour
H_0: There is no difference in buzz ratio between the different treatments.

H_1: There is a difference in buzz ratio between the different treatments.

2. Systematic literature review

2.1 Method

A literature search was preformed, using ROSES (RepOrting standards for Systematic Evidence Syntheses) as a guide. Six different search platforms/databases were searched (Appendix 1: Table A1.9). Web of Science, Scopus, ProQuest SciTech and EBSCOhost were searched from earliest access up until 2022-12-12 using the search string (cetacean OR whale OR dolphin OR porpoise) AND (bycatch OR by-catch OR entangle* OR incident*) AND (mitigat* OR reduc* OR detect*) AND ("passive acoust*" OR reflect* OR visib* OR “target strength”). “Consortium for Wildlife Bycatch Reduction” and “Bycatch Management Information Systems” (BMIS) are open access search platforms and did not provide an option to search with a search string, available search choices were therefore made to match the search string as closely as possible. The reference list of four key-articles (relevant articles that were known before the systematic literature search and used to validate the search string) were screened at title level to include anything of potential interest.

A search for additional literature was made on organizational websites. To limit the search only the websites of organizations present in the already acquired literature from the database search was used. At these webpages, the search engine on the main page was used and the search was performed using the terms (mitigation+ bycatch). If the webpage were not dedicated to cetaceans, this term was added to the string. To limit the search on each webpage, the first 20 results were screened against previous search results for new relevant sources. If no relevant sources were found, it was decided to not use that webpage for further investigation.

A search on google scholar were performed (2023-01-12), once with the full search string and once with a shortened search string (cetacean+ bycatch+ mitigation+ reflective). The first 50 results were screened against previous search results for relevance and it was decided to not use google scholar for any further investigations since no new relevant sources were found. An outreach for any additional literature was made by email to the ICES working groups WGMME and WGBYC and through the public e-mail list MARMAM, but no new relevant sources was found.

All search results were combined in a database and duplicates were then removed. The screening process started with title and abstract, followed by a full text screening. The screening process were documented using ROSES flow diagram (Appendix 1: Figure A1.13). Title and abstract screening were done simultaneously and included papers had to focus on (1) cetacean species (2) a change and/or modification to fishing gear or fishing gear-prototype (3) the intent of the change/modification had to be to increase the acoustic reflectability or target strength (TS) of the fishing gear (4) the change/modification had to be passive (not using electronics or emitting sound etc.) If it was unclear in the title or abstract if the change/modification were passive or not, the paper was included for the next step. At full text screening, the same criteria applied with the addition to only include papers with primary data. The review articles, workshops etc. were labelled and saved in a separate database. Papers that could not be found were requested from the Swedish University of Agricultural science Library or directly from authors through ResearchGate. The result of the screening process can be found in Appendix 1: Figure A1.13.

2.1.1 Data extraction

Due to the large variety of studies, it was decided to only extract qualitative data for further analysis. The extracted data is explained in Appendix 1: Table A1.10 and the full database can be found in Appendix 1: paragraph 1.2. Author, year of publication, title of study and a link to the article in the google scholar search engine were included as well, and all articles have a unique identification number. 4 papers were excluded from data extraction and analysis due to publications on same trials. The data was extracted on trial basis, every row in the database describes one trial. This means that one study can appear on several rows if more than one trial was performed.

2.1.2 Data synthesis and presentation

All publications from the final stage of the screening process were included to construct a graph of publication year, were numbers of individual publications per year was used. For further data synthesis and presentation, the information from the data extraction was used, the count in all graphs except study count per year is made up of every single row entry in the database relating to a single trial (see data extraction in 2.1.1).

2.2 Results

After the literature search and screening process 27 different publications was found on the subject of passive acoustic mitigation measures, all but one with focus on enhancing the acoustic profile of gillnets. Two different categories of modifications were identified – changing the netting material or adding different types of objects to the net. A clear pattern of published studies could be seen over the years regarding category of modification, with a new recent interest in adding objects to the net, were the latest publication before 2019 occurred in 1998 (Figure 1). Four of these publications were excluded from the data extraction since they reported data from the same trials (Appendix 1: paragraph 1.2).

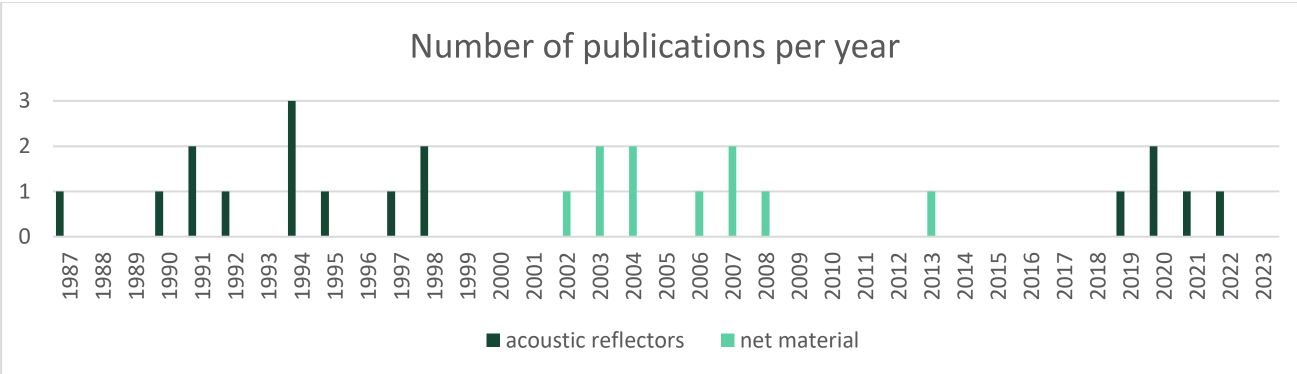

Figure 1 Number of individual publications per year.

2.2.1 Trial outcome

From the remaining 23 publications, 59 different trials were extracted from the studies, these were then sorted into nine different modification groups. Table 1 summarizes the outcome of research done in the field of passive acoustic modifications with the aim to make the fishing gear more acoustically visible to odontocete echolocation. Target strength (TS) of the different object and nets was extracted from the trials as a mean for comparison. TS is a measurement of the intensity of the reflected sound from a target (Gudra *et al.* 2010). It is however important to note that TS is dependent on several factors such as incident angle, source level (SL) and the size of the area enzonified by the transductor beam (Gudra *et al.* 2010; Kratzer *et al.* 2020). This means that the same object might have a different TS depending on how the measurements have been made. As an example, ordinary gillnets have a TS of approximately -55 dB, but when measured in some of the trials it ranges from -46 to -66 dB depending on previously mentioned parameters as well as other net characteristics. For the purpose of this literature review, TS of the different objects is meant to be used as an indication whether the object has high or low TS compared to each other and to ordinary gillnets. A lower TS means that more sound is reflected back to the source, making the object more acoustically visible.

Table 1 Summary of outcome from 59 different trials on passive acoustic modifications, grouped by modification type, number of trials for each group within brackets. Target strength value (TS) is a range representing all values of TS documented for all modifications within that group.

Modification group	Modification type	Species	approximate TS in dB	Summary outcome	Source
1. Different types of metal wires (7)	Vinyl string; plastic coated metal surveyor's tape; galvanised wire; plastic covered copper wire; braided stainless steel wire	Tursiops truncatus; Phocoenoides dalli; dolphin	not recorded for 6 trials*	No recorded outcome for 4 trials. Small sample size and catch per unit effort (CPUE) resulted in no significant outcome for 2 trials, but nets proved unmanageable. In another trial a dolphin passed several times without recognition response.	Hembree and Harwood (1987); Peddemors *et al.* (1991); Hatakeyama *et al.* (1994)
2. Beaded chains (5)	Chains with small beads	Tursiops truncatus; Phocoena phocoena	-50.2 to -62.6; not recorded for 4 trials	TS results indicates that detection range of nets can be increased, strong behavioural response in pool and significant difference in groups altering traveling course compared to corkline alone. Commercial trials did not show significant difference in bycatch rate, more dolphins caught in modified net.	Hembree and Harwood (1987); Au and Jones (1991); Silber *et al.* (1994)
3. Threads and ropes (7)	Air-tube nylon thread; multifilament threads; rope	Tursiops truncatus; Phocoenoides dalli; Phocoena phocoena	-33 to -51*	TS results indicates that detection range of nets can be increased, field trials showed no significant difference in groups that altered course compared to corkline or bycatch rate, more dolphins caught in modified nets. Threads showed significant result in decreasing bycatch rate for some treatments but not for all.	Au and Jones (1991); (Hatakeyama *et al.* 1994); Silber *et al.* (1994); De Haan *et al.* (1997)
4. Aluminium discs (2)	Plasticised aluminium foil squares; flat aluminium disc	Delphinidae (species not defined)	not recorded	Exceptionally low overall CPUE, no dolphin catches or movement was observed. Both aluminium disc-types destroyed in saltwater.	Peddemors *et al.* (1991)
5. Float-like devices (13)	Float; plastic bottle	Tursiops aduncus; Tursiops truncatus; Phocoena phocoena	-27 to -38	TS results indicates that detection range can be significantly increased. Avoidance behaviour showed in several trials, sometimes up to 170m, significant difference in behaviour depending on distance between floats. 2 trials showed no significance in avoidance behaviour compared to floatline only. No bycatch in control or modified nets in 2 commercial trials with plastic bottles.	Goodson *et al.* (1994); Goodson and Mayo (1995); De Haan *et al.* (1997); Koschinski and Culik (1997); Nakamura *et al.* (1998); Berggren *et al.* (2019)

6. Air-filled soft plastics (4)	Plastic tubs; blister sheet	Tursiops truncatus; Phocoena phocoena; dolphin; Phocoenoides dalli	-29.1 to -32.1*; not recorded for 3 trials	TS indicates that detection range can be increased. Strong behavioural response of dolphin in pool and significant difference in groups that altered course compared to corkline alone. No significant difference in bycatch rate. Material problem with tubes collapsing, losing the ability to hold air.	Hembree and Harwood (1987); Au and Jones (1991); Hatakeyama *et al.* (1994); Silber *et al.* (1994)
7. Acrylic glass spheres (4)	Pearls made with acrylic glass	Phocoena phocoena; kHz	-43	Substantially higher acoustic backscattering strength (area TS) compared to standard gillnets when attached at intervals <60cm. TS positively correlated with increase in inclination angle. Significantly decreased presence around modified nets. Less bycatch in modified nets, but no significant difference.	Gustafsson (2020); Kratzer *et al.* (2020); Kratzer *et al.* (2021); Kratzer *et al.* (2022)
8. Infused nylon-nets (15)	$BaSO_4$; IO	Pontoporia blainvillei; Phocoena phocoena; Tursiops truncatus; kHz	-48 to -67; not recorded for 3 trials	TS indicates that detection range can be increased, however TS is not significantly different between modified and unmodified nets at all angles of incidence, negative relationship with increased angle of incidence. Both significantly lower and higher bycatch rate for modified nets have been recorded. Recorded some behavioural reactions as well as no difference in echolocation rate nor occurrence.	Northridge *et al.* (2003); Trippel *et al.* (2003); Cox and Read (2004); Koschinski *et al.* (2006); Larsen *et al.* (2007); Mooney *et al.* (2007); Trippel *et al.* (2008); Bordino *et al.* (2013)
9. Other net materials (2)	Hollow core monofilament; macha tribal setnet	Tursiops truncatus	-36.7 to -55.8	Small difference in TS compared to commercial at different angles.	Au and Jones (1991)

**general number of 20-40dB larger than ordinary net but this value refers to a group of different modification types (Hatakeyama et al. 1994)*

2.2.2 Study design

All trials have focused on small toothed whales divided between mainly two different families, Delphinidae and Phocoenidae, but 30% of the trials have only used simulated sounds of animals or signals of specific amplitude instead of live animals (Figure 2A). 29 of 59 trials (49%) have been theoretical or conducted in a controlled environment (lab) such as indoor pools and calm harbours (Figure 2B). In total, only seven trials have been made in a setting mimicking a bottom-set gillnet (Figure 2C). Of these, five have been performed in commercial trials and two in "theory" with no live animals. Less than half of the trials investigated the reactions of cetaceans to the mitigation measure tried based on behaviour or echolocation of live animals (Figure 2D) and out of 25 trials, only 14 have been done in the field or a commercial setting. Of 59 different trials, only 9 have investigated echolocation behaviour and response with the help of hydrophones (Appendix 1: paragraph 1.2 Systematic literature review database).

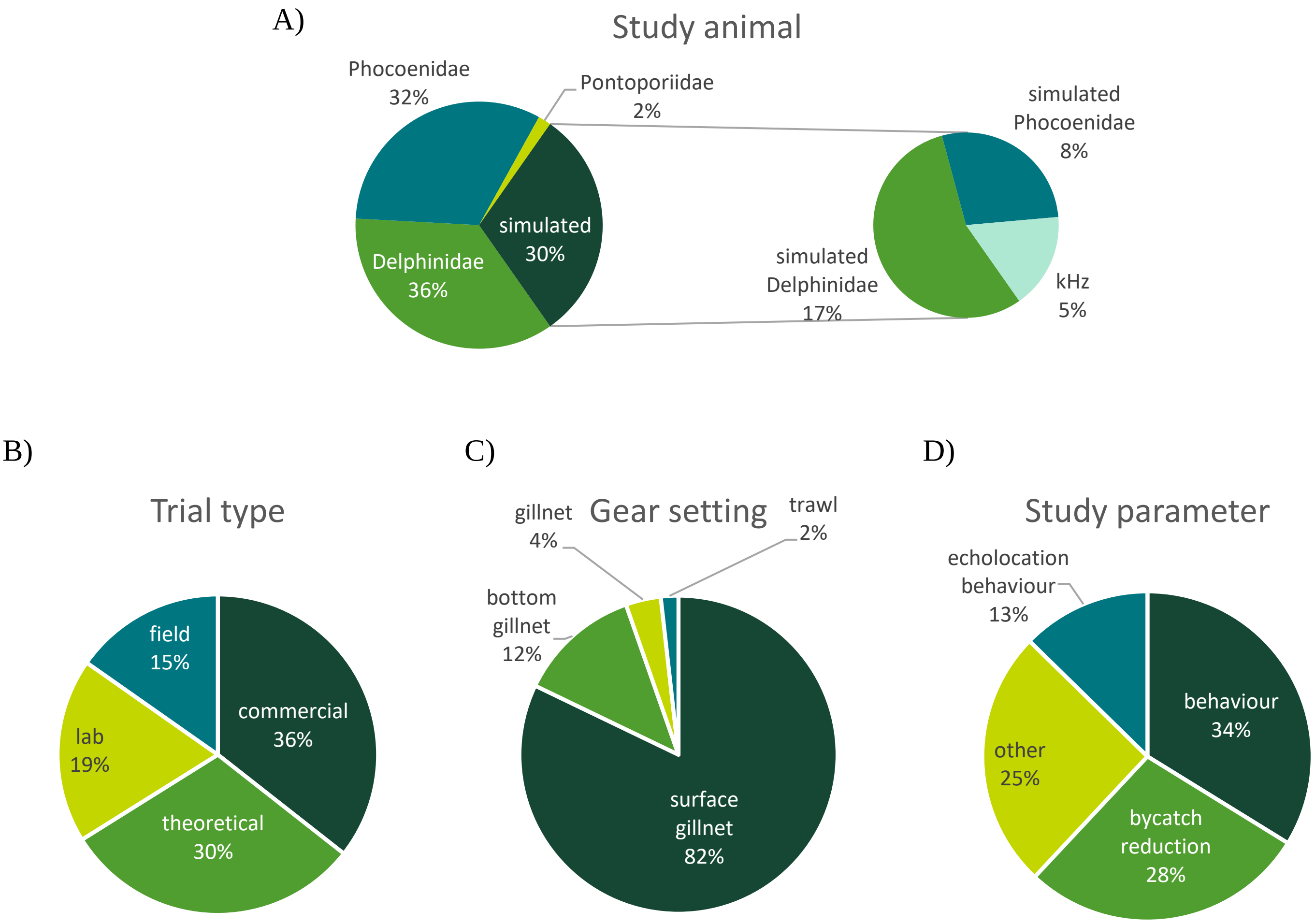

Figure 2 Pie charts displaying different study parameters from the 59 trials extracted from the literature analysis. A) study animal, B) trail type, C) gear setting, D) study parameter. NOTE: Some trials looked at more than one study parameter, to create discrete categories they were split resulting in 12 additional entry rows for that specific pie chart.

3. Field study

3.1 Method

3.1.1 Study location

The study took place in 2022 (Table 2) in the coastal waters of Lysekil, located in the southern part of the Skagerrak Sea on the west coast of Sweden (Figure 3). It is situated in the warm temperate climate zone (SMHI 2022) with surface temperatures ranging between 6-20°C during the year (SMHI 2023a) .The area is part of the Natura 2000 directive and it is one of the most species rich and diverse marine areas in Sweden, it is characterized by the Gullmar fjord with a maximum depth of approximately 120m, coming up to around 40m at the mouth outside Lysekil (Länsstyrelsen Västra Götalands län, 2018). The depths of the ocean in the surrounding archipelago range from a couple of meters down to 50m. The ocean floor is ranging from sandy and muddy soft bottom to hard rock bottom (Länsstyrelsen Västra Götalands län, 2018). Fishing activity in the area include both recreational and commercial small scale fishery. During summertime it is heavily trafficked by recreational boat traffic. Harbour porpoise are present in the Kattegat and Skagerrak seas year-round (Teilmann *et al.* 2008). However Sveegaard *et al.* (2011) observed a slight seasonal variation, based on 24 satellite tagged individuals, with a gradual movement west into the North sea in autumn/winter, returning in spring/summer (Sveegaard *et al.* 2011).

3.1.2 Study species: Harbour porpoise

Harbour Porpoise (*Phocoena phocoena*) is one of many small toothed whales that are frequently bycaught throughout their distribution range and several populations are today of conservation concern – one of these is the critically endangered Baltic Sea subpopulation (Hammond *et al.* 2008). Majority of the recorded bycatch in the area occurs in gillnets or similar gear and there is a pressing need to find an efficient, functioning solution to decrease the bycatch in the small scale fishery (ICES, 2020).

The harbour porpoise have a circumpolar distribution in the cold temperate and subpolar coastal waters of the northern hemisphere (Bjørge & Tolley 2009; Jefferson *et al.* 2015) and are capable of making dives deeper than 200m but more commonly dive in the range of 14 – 41m (Westgate *et al.* 1995; Otani *et al.* 1998; Teilmann *et al.* 2007). It is one of the smallest cetacean species with an average body length of 145-160cm and a weight of 50 – 60kg with females being slightly bigger (Bjørge & Tolley 2009; Jefferson *et al.* 2015). This leads to a low surface-to-volume ratio and therefore a relatively high heat loss in cold water, needing to feed up to 10% of their bodyweight per day (Kastelein *et al.* 1997). A study by Danuta *et al.* (2016) showed that porpoise forage almost continuously day and night to meet their metabolic demands. Their distribution in the coastal waters is therefore strongly connected with prey availability (Sveegaard *et al.* 2012). This leads to high encounters with fisheries whom also occupy the productive coastal waters and bycatch in gillnets is regarded as the most significant threat to harbour porpoises in most of their distribution range today (Danuta *et al.* 2016; Braulik *et al.* 2020).

As other species of toothed whales, harbour porpoise uses echolocation for navigation and foraging, but unlike many other species that have a large vocal repertoire of clicks for echolocation and whistles for communication - harbour porpoises (together with species from four other groups of small toothed whales) can only produce narrow-band high-frequency (NBHF) clicks that are used for both echolocation and communication (Kyhn *et al.* 2013; Sorensen *et al.* 2018). Harbour porpoise vocalize almost continuously and depending on activity, the pattern and inter-click-interval of the clicks produced by the porpoise changes (Koschinski *et al.* 2008; Clausen *et al.* 2010; Linnenschmidt *et al.* 2013). Inter-click-interval, ICI, is the time elapsed between the peaks of two consecutive clicks. This makes it possible to determine porpoise click behaviour by analysing relations between clicks and click trains (Koschinski *et al.* 2008). One such clearly defined behaviour is foraging, porpoises use a click pattern that can be divided into three different phases characterized by changes in click-pattern and ICI – search, approach and terminal (Koschinski *et al.* 2008; DeRuiter *et al.* 2009; Verfuss *et al.* 2009). The last phase is marked by a sudden and rapid shortening of ICI to below 10ms, called a buzz, ending with a constant ICI around 1.5ms just before the prey is caught (DeRuiter *et al.* 2009; Verfuss *et al.* 2009). It has also been shown that porpoises use buzzing when investigating objects at close range (Verboom & Kastelein 1995; Koschinski *et al.* 2008).

3.1.3 Study setup

Four customised rope panels, 7m high and 200m long constructed to simulate bottom-set gillnets used in the cod fishery, were used in the study (see details of construction in section 3.1.4 and Figure 5). Instead of having a wall of netting suspended between a horizontal float- and sink line, single vertical ropes was used to connect the float- and sink line. These vertical ropes could then be used to attach acoustic reflectors. Removing the netting eliminates the risk of catching anything, which is particularly important when working with endangered species. It also made it possible to keep the panels in the water for a longer period of time – increasing the chance of porpoise interaction.

The four customized rope panels were deployed from a smaller boat on three separate occasions at two different sites, “Bonden” and “the Gullmar fjord”, outside of Lysekil (Figure 3; Table 2). Each site was chosen based on previous studies that documented porpoise activity outside of the island Bonden, and on conversations with active fishers in the area that suggested relatively high porpoise presence inside of the Gullmars fjord (Pers. comment Sara Königson, 2022). The panels were placed at depths of 20-30m to maximize chances of porpoise interaction, since most of the dives (64%) done by the species in Scandinavian waters are in the range of 14-32m (Teilmann *et al.* 2007). A passive acoustic monitoring system, called C-PODs (see section 3.1.4.3 for detailed description) was used to record harbour porpoise echolocation activity. To make sure the C- PODs from different panels did not record a porpoise in the proximity of another panel, the panels were placed a minimum of 400m apart. The panels were placed on relatively flat and sandy substrates to make sure they would sit correctly.

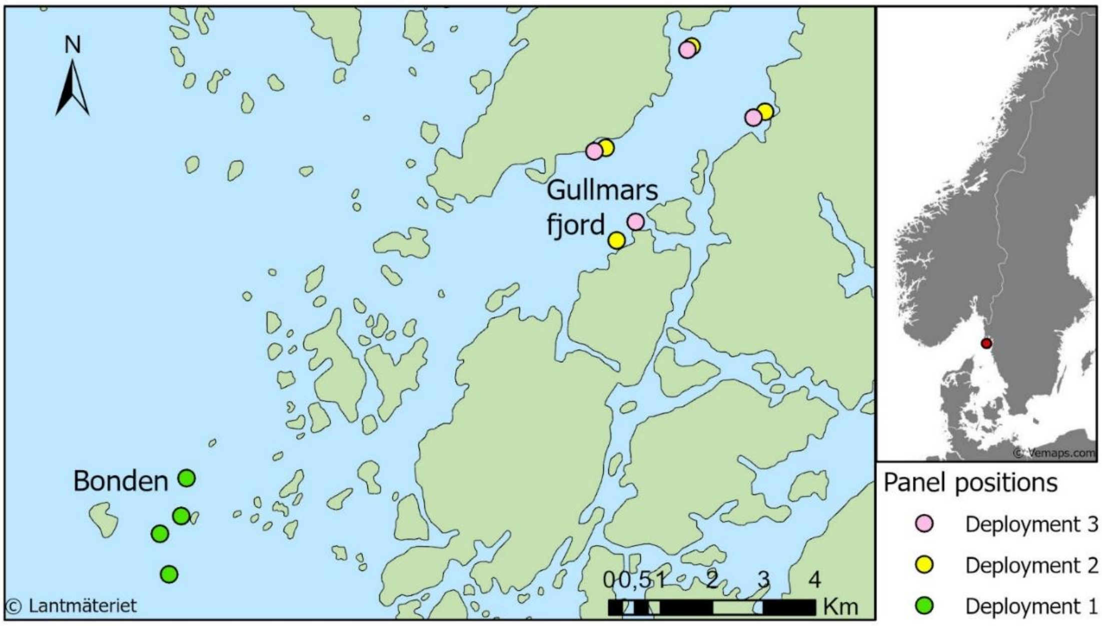

Figure 3 Deployment sites with panel positions. Background image: GSD-Översiktskartan © Lantmäteriet.

Due to the depth of the Gullmars fjord, the panels had to be placed in shallower bays along the edges of the fjord and to keep the required distance between panels (a minimum of 400m), they were divided in two pairs and placed on either side of the fjord (Figure 3). For the second deployment in the fjord, the positions of the panels were rotated. For each new deployment the C-PODs were rotated between the panels so that they never had the same position within a panel twice. During the first deployment at site Bonden, it was only possible to deploy two panels before the weather conditions became too extreme and the remaining two were not able to be deployed until 12 days later (Table 2).

Table 2 Deployment dates at the two different sites, Bonden and the Gullmars fjord.

Deployment #	Start date	Finish date	Location
1	2022-03-31*	2022-04-28	Bonden
2	2022-05-03	2022-06-15	Gullmars fjord
3	2022-08-04	2022-09-19	Gullmars fjord

* Panel 2m and 10m was not deployed until 2022-04-12 due to bad weather.

3.1.4 Floats and rope-panel design

3.1.4.1 Acoustic reflectors

The floats used as passive acoustic reflectors were elliptical air filled hard plastic floats, with 6cm circumference and 60g buoyancy (Figure 4). In addition to being cheap and easily available in fishing supply shops, they were chosen to have similar properties as those tested by Goodson and Mayo (1995) which according to the authors had a target strength (TS) of approximately -35 dB. One of these floats should be detectable by a dolphin sonar at around 70-80m according to calculations by Goodson and Mayo (1995). The received level of sound (the echo returned to the animal) could potentially increase if multiple floats are enzonified by the echolocation beam at the same time, a result of a summing effect of the TS of all the floats within the range of the sonar beam (Goodson & Mayo 1995). Therefore we had different densities of floats in the panels.

Figure 4 Hard plastic float used as acoustic reflector.

3.1.4.2 Panel construction

Four customized rope panels were constructed. The panels were constructed with a float line 8mm in diameter made from polypropylene and a sink line 7mm in diameter made from polyester and polypropylene (Figure 5A). Vertical ropes, of the same material as the sink line, were attached to the float and sink line at either 2m, 6m or 10m intervals where the acoustic reflectors was attached (Figure 5B). The horizontal distance between the acoustic reflectors was based on a previous study by Goodson *et al.* (1994) were they examined the behaviour of wild bottlenose dolphins in the presence of passive acoustic reflectors in a surface set gillnet. For the control panel, vertical ropes were attached to the float and sink line at 10m intervals. Four acoustic reflectors were attached with two meters apart at each vertical rope, the last reflector was positioned one meter from the sink line (Figure 5B). To account for the buoyancy of the floats used as acoustic reflectors, each vertical line was equipped with small weights closest to the sink line.

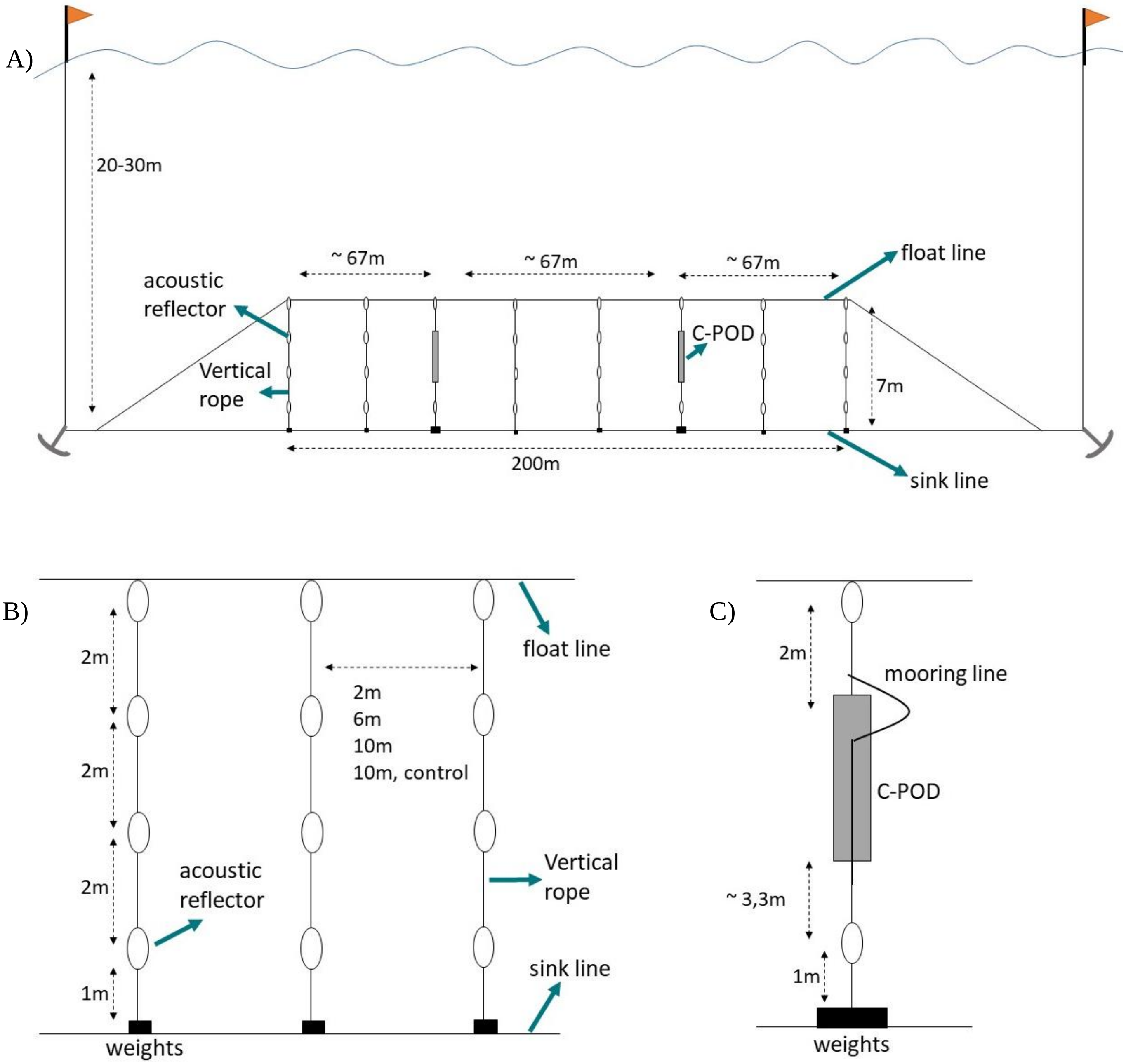

Figure 5: Graphic illustration of the customized rope panels used in the trial. A) General overview of panel construction. B) Detailed overview of panel construction with acoustic reflector positioning. C) C-POD mooring on vertical line within the panel.

3.1.4.3 Passive acoustic monitoring

Porpoise echolocation activity was recorded using a passive acoustic monitoring systems called C-PODs, or Cetacean – POrpoise Detectors, developed by Chelonia Limited. These are self-contained ultrasound monitors with an omnidirectional hydrophone that are used to record clicks within the frequency range of 20-160 kHz. For every click, the time of occurrence, center frequency, intensity, duration, bandwidth and frequency trend is recorded. This click information is then used to recognize click trains of odontocete origin (see https://www.chelonia.co.uk for more information).

Two C-PODS were attached to each panel, each one on a vertical rope approximately 67m from the end, dividing the panel in three parts (Figure 5A). The C-POD have a positive buoyancy of 0.7kg, meaning it will float with the hydrophone hosing upwards when moored to the sea floor. It also contains an angle sensor that records the angle-from-vertical position every minute. To save power and memory it was set to prevent logging until deployed in vertical position (angle sensor default setting, 82 degrees, see Tregenza (2014)). The C-POD were moored 4.3m from the sink line on the vertical rope, the positive buoyancy was compensated by adding extra weight closest to the sink line. A slack rope attached the C-POD to the vertical rope 2m below the float line (Figure 5C) to allow for movement of the panels with the water currents, but keeping the C-POD in vertical position at all times.

3.1.5 Data collection

During deployment of the panels, C-POD ID, setup time and position within the panel as well as GPS position of the panel, depth and deployment end time for each panel was recorded. When the panels were retrieved, end time of retrieval of each panel was documented as well as C-POD turnoff time. The click-data collected in the field by the C-PODs was processed through a click train classification algorithm called KERNO, included in the C-POD.exe analysis software (version 2.048). Different categories and filters can be used to obtain preferred data and for this study the KERNO classifier was set to filter out only narrow band high frequency clicks (NBHF) of high or moderate quality.

The processed data from the KERNO classifier was exported as number of detection positive minutes per hour (DPM/h), were a positive minute has at least one recording of a porpoise-like click train. For every panel, one hour was excluded from the start and end of deployment period respectively, to remove potential effect from the boat being in the area. The latest start-hour and earliest end-hour for each deployment was then used for all C-PODS in that specific deployment resulting in the same start and end time for the four panels within each deployment. Due to different deployment dates for the four panels during deployment one (see method, section 3.1.1), the first 11.7 days of recordings from panel 6m and control were removed so that each panel within the deployment had equally amount of collected data.

Environmental variables thought to affect harbour porpoise presence was obtained from SMHI weather stations. For site Bonden the closest weather station (Måseskär A, ID: 81050) was located approximately 12.5km S away and the oceanographic station (Brofjorden WR boj, ID:

33033) was located approximately 7.5km NW away. No active station could be found closer to the Gullmars fjord and it was decided to use the same stations used for Bonden, as an approximate weather estimation (weather station 22km SW and oceanographic station 15.5km W). Data from the stations was downloaded from the online weather database of SMHI (SMHI 2023b; SMHI 2023c). Water temperature was recorded by the C-PODs.

Differences in daylight is expected to affect harbour porpoise echolocation behaviour based on previous studies (Carlstrom 2005; Todd *et al.* 2009; Konigson *et al.* 2022). Therefor four diel phases per day – dawn, day, dusk and night – was calculated for each deployment period using the matlab function "Sunset.m" (courtesy M. Mahooty, Mathworks file exchange; Table 3). The coordinates for Lysekil used in this calculation was 58°16´52"N 11°27´5"E. Note that the diel phases are not equally long and for some days, diel phases dawn and dusk was less than an hour. These were therefor modified to the closest full hour to match the resolution of the C-POD data set.

Table 3 Definition of diel phases.

Diel phase	Definition
Dawn	Duration of civil dawn to sunrise
Day	Sunrise to start of civil dusk
Dusk	Duration of civil dusk to sunset
Night	Sunset to start of civil dawn

3.1.6 Effect of floats on porpoise click rates

To evaluate if the floats had an effect on porpoise click rate, assuming click detection is proportional to porpoise abundance (Carstensen *et al.* 2006; Verfuss *et al.* 2007; Kyhn *et al.* 2012), two models were created with the response variable detection positive minutes per hour (DPM/h), extracted from the cpod.exe analysis software (see Method 3.1.4.3 for detailed information). DPM/h is a standard measure of how much time the animals are present (Tregenza 2014).

All statistical analyses was made in R Studio version 2022.12.0 (R Studio, Inc). To avoid model violations and identify a suitable model, data exploration needs to be done. One method is to follow the data exploration protocol outlined by Zuur *et al.* (2010) containing eight different steps: checking for (1) outliers, (2) homogeneity, (3) normality, (4) zero-trouble, (5) collinearity, (6) relationships, (7) interactions and (8) independence. To find the most suitable model, the data exploration protocol by Zuur *et al.* (2010) was used as a guideline allowing the identification of possible violations, minimizing the risk for type I and type II errors.

The click-data retrieved from the C-PODs had a non-normal distribution and it was therefor decided to use generalized additive models (GAM) to model the effect of the different treatments on the response variable DPM/h. To account for the excessive number of zero-observations observed in the response variable DPM/h, it was transformed to average DPM/h per diel phase. This reduces the numbers of zeroes, but still allows to test for an effect of diel phase (Konigson *et al.* 2022). A large variation was observed between the different deployments (Figure 8) and it was therefor decided to create two different models, one for site Bonden and one for site Gullmaren, due to differences in predictor variables. AIC, adjusted R-square and diagnostic plots were used to determine if the response variable average DPM/h were best modelled with a Gaussian or negative binomial distribution and it was decided that negative binomial distribution gave the best model fit (see Appendix 2: Table A2.11 and Table A2.12 for AIC and diagnostic plots). To find the set of predictor variables that best explained the variation in average DPM/h, a backwards selection was made. Starting with the full model, predictor variables (Table 4) were removed one at a time, comparing AIC and adjusted R-square values throughout the process until removing any predictor no longer led to an improvement in AIC or adjusted R-square value.

Full model Bonden:

gam(averageDPM ~ treatment+ s(days.from.start)+ diel.phase+ s(averageTemp)+ s(averageWind)+ s(averageWave), family = nb)

Full model Gullmars fjord:

gam(averageDPM ~ treatment+ s(days.from.start)+ diel.phase+ season+ deployment+s(averageTemp)+s(averageWind)+s(averageWave)+side.of.fjord, family = nb)

Table 4 Description of predictor variables used in the models.

Name of variable	Value range	Description
Deployment	Factor with 2 levels: 2-3	Unique number for each deployment, only applicable for model Gullmars fjord.
Diel phase	Factor with 4 levels: 1 (dawn), 2 (day), 3 (dusk), night (4)	Based on civil twilight, see definition in text.
Season	Factor with 3 levels: spring, summer autumn	Calendar season.
Days from start	1: 0-15* 2: 0-43 3: 0-46	Number of days from start of deployment, 1-3 refer to deployment number. Day of deployment = 0.
Treatment	Factor with 4 levels: control, 10m, 6m, 2m	The different distances between floats, see experimental design.
AverageTemp	2-19.6°C	Average water temperature in degree Celsius per diel phase, recorded by c-pod.
AverageWind	0-17.1 m/s	Average wind velocity in meters per second, per diel phase.
AverageWave	0.09-4.04 m	Average wave height in meter per diel phase.
Side of fjord	Factor with 2 levels: South, North	Side of fjord were the panel was placed. Only applicable for deployment 2 and 3 at site Gullmars fjord.

** 11.7 first days removed from panel control and 6m*

3.1.7 Effect of floats on porpoise click behaviour

To analyse if floats have a potential effect on harbour porpoise click behaviour, the collected click data from the C-POD was filtered for the specific click pattern called a buzz – a click pattern with very short inter-click-interval (ICI, see method, section 3.1.2 for more information). The definition of what value of ICI equals a buzz differ slightly between different sources (Koschinski *et al.* 2008; DeRuiter *et al.* 2009; Verfuss *et al.* 2009; Wisniewska *et al.* 2012), but for this analysis it was decided to use ICI=15ms as the upper limit for a buzz, set by Kyhn *et al.* (2018) and also used by Gustafsson (2020) and Amundin (2019). A max interval of 250ms was set to separate intra-train click intervals from inter-train click intervals (ITI) - clicks not belonging to a train but more likely between trains and these where removed (Amundin 2019;

Figure 6). The ratio between ICI≤15ms (buzz) and ICI≤250ms per hour – buzz-ratio per hour – was then used as a response variable to see if floats have an effect on harbour porpoise behaviour.

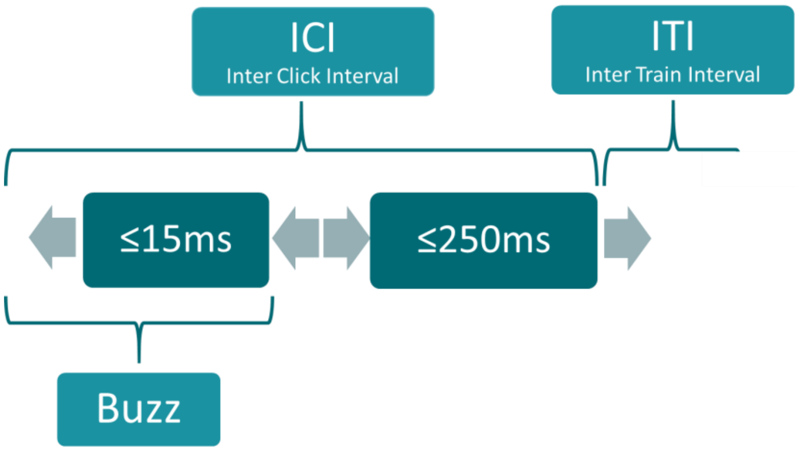

Figure 6 Graphic illustration of the categorization of buzz-clicks, inter click interval (ICI) and inter train interval (ITI)

The cp3-files acquired from the KERNO classifier (see method, section 3.1.5) were run through a custom-written MatLab script (Mathworks Inc., R2018b; Courtesy Jakob Tougaard, Aarhus University, DK) in order to extract ICI's together with their time stamps. To calculate the ratio between the number of buzz-ICI (ICI≤15ms) and ICI<250ms per hour, the resulting text files were run through another custom-made MatLab script (Mathworks Inc., R2018b; Courtesy Eskil Amundin, Amundin Tech AB, SE). The same procedure of removing the first and last hours of the data set of the DPM/h data and removing the first 11.7 days in deployment one for panel control and 6m was applied to the buzz-ratio per hour data.

All statistical analyses were made in R Studio version 2022.12.0 (R Studio, Inc). A Wilcoxon Rank Sum test comparing the C-PODs within the same panel was made and no significant difference within any of the C-POD pairs could be found. Only one C-POD per panel was used for further analysis (see section 3.3). The data did not have a normal distribution, so to investigate if there was any difference in buzz-ratio per hour between the different treatments a Kruskal-Wallis test was used. A post hoc analysis was made with Dunn's test for multiple comparison if the Kruskal-Wallis test gave a significant p-value, to see between which treatments there was a significant difference.

3.2 Result

3.2.1 Overall click observation

Each of the 24 C-PODs had been on and recorded data during the full period for each deployment, number of logged hours are listed in Table 5. There was a large variation in DPM/h between deployments, with most recordings made during deployment one and the least recordings during deployment three (Table 5, Figure 7). Wilcoxon Rank Sum tests for each C-POD pair within the same panel showed significant difference in recorded DPM/h between C-PODs for three out of the twelve different panels (Table 5). All C-PODs that recorded most DPM/h within each panel had the same relative placement within the panel ("S" in deployment one and "SW" in deployment 2 and 3), except in deployment three (Table 5, Figure 7).

*Table 5 Summary of recorded data of all C-PODs and their relative position within the pane. Significant difference (p<0.05) in recorded DPM between C-PODs within the same panel are marked with a *.*

Deployment	Treatment	Number of logged hours	Mean DPM/h (±SD)	
			N/NE	S/SW
1	control	357	2.63 (±5.35)	3.25 (±6.12)
	10m	357	2.92 (±5.25)	3.74 (±6.13)
	6m*	357	4.77 (±6.98)	6.76 (±9.02)
	2m	357	4.00 (±7.27)	4.75 (±8.02)
2	control	1026	0.97 (±3.05)	1.23 (±3.92)
	10m	1026	0.38 (±1.67)	0.39 (±1.53)
	6m	1026	0.42 (±1.61)	0.59 (±2.14)
	2m*	1026	0.39 (±1.47)	0.63 (±2.08)
3	control	1100	0.05 (±0.50)	0.08 (±0.62)
	10m	1100	0.13 (±0.65)	0.09 (±0.54)
	6m*	1100	0.11 (±0.76)	0.07 (±0.50)
	2m	1100	0.33 (±1.45)	0.32 (±1.43)

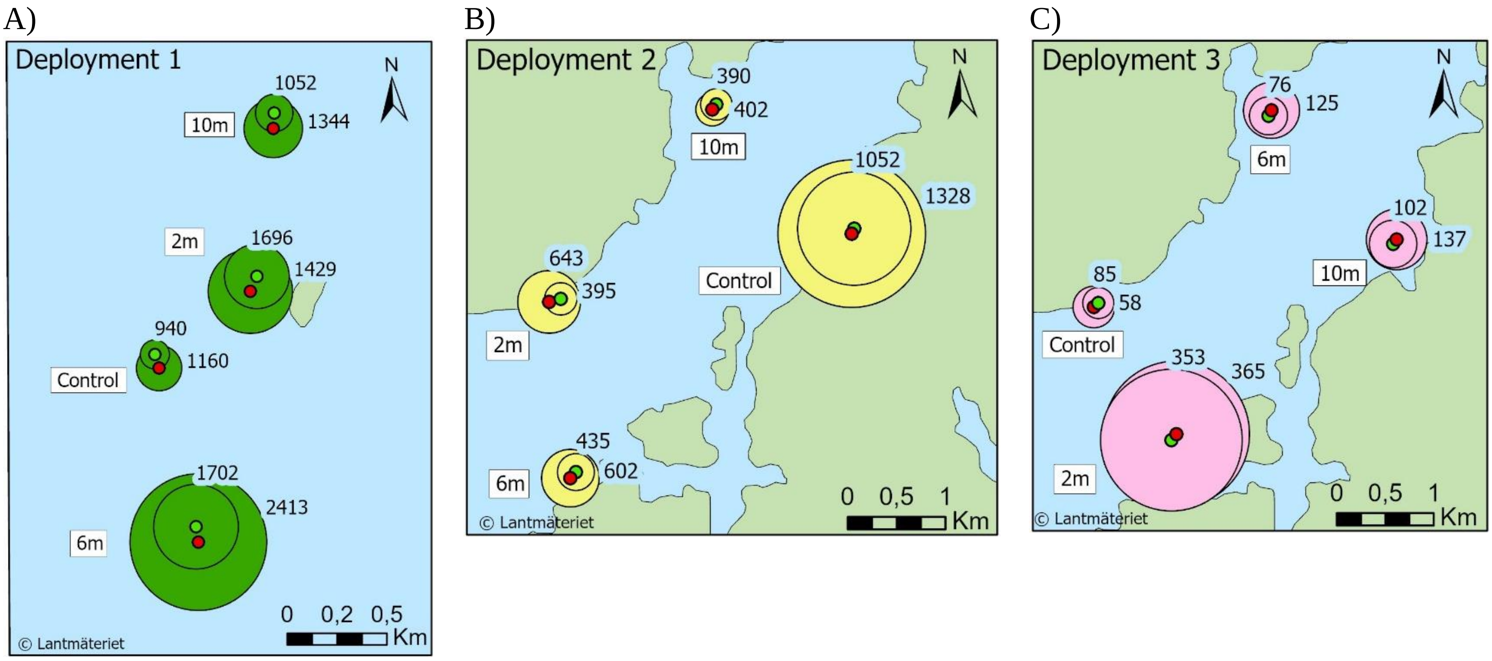

Figure 7 Maps displaying the three different deployments: treatment position and sum of recorded DPM/h for each C-POD. Red dots indicates position of the C-POD that recorded most DPM/h within that panel, green dots the C-POD that recorded the least DPM/h within that panel. NOTE: Size of circles are not comparable between deployments. A) Deployment one at site Bonden.B) Deployment two at site Gullmars fjord. C) Deployment three at site Gullmaren. Background image: GSD-Översiktskartan © Lantmäteriet.

3.2.2 Effect of floats on porpoise click rates

3.2.2.1 General patterns

One C-POD per panel from each deployment, belonging to the group "S+SW", were used in the analysis to eliminate the risk of pseudoduplication of recorded data since there was no significant difference in recorded DPM/h found for majority of the C-PODs within a pair placed in the same panel. The majority of the C-PODs that had the highest recordings of DPM/h belonged to the "S+SW" group (Table 5). The first look at the raw DPM/h data revealed an excessive number of recorded zeroes. To account for this, average DPM/h per diel phase was instead used as response variable for all further analysis on porpoise click rate (see method, section 3.1.6).

A clear pattern between month and average DPM/h per diel phase could be observed, with a decrease in recorded clicks from the spring period to the autumn period (Figure 8). There was no clear pattern of effect of treatment when the raw data was plotted (Figure 8), but an indication of small differences in the effect of treatment, depending on deployment, could be identified from the plots such as a higher average DPM/h per diel phase for treatment 6m during deployment one. As previously stated, a large difference between deployments was observed and two different models were made based on deployment site (Figure 8).

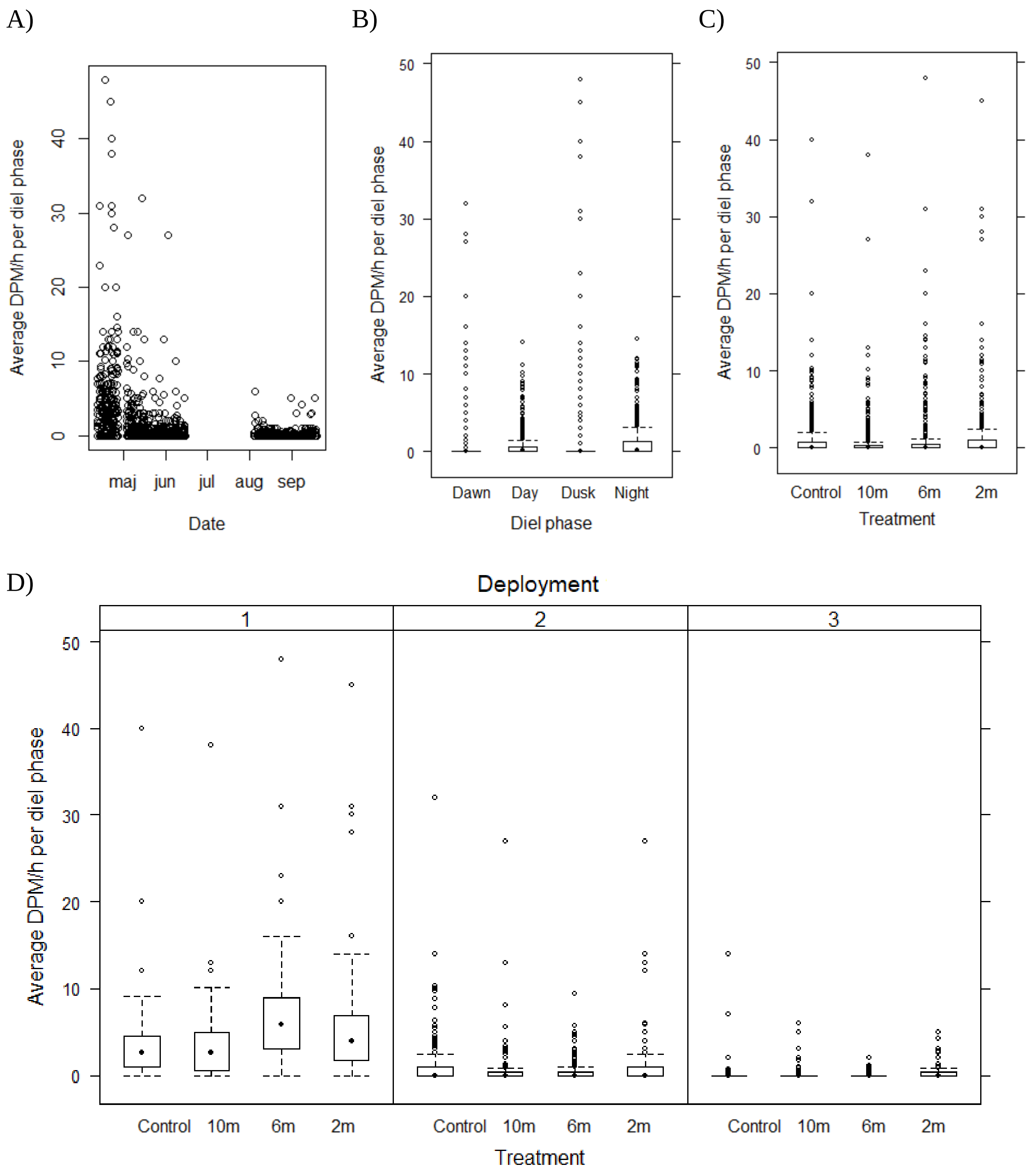

Figure 8 Overview of average DPM/h per diel phase recorded during all three deployments. One scatterplot, displaying average DPM/h per diel phase recorded per day (A), and box plots displaying average DPM/h per diel phase recorded per diel phase (B), per treatment (C) and. per deployment, divided by treatment (D). The boxes contain the second and third quartile, the centre-dot within the boxes displays the median.

3.2.2.2 Model result

The final model that best explained the variance in average DPM/h per diel phase at site Bonden included all predictor variables from the full model except averageTemp (Table 6). This model explained 33.5% of the deviance, had an adjusted R^2 of 0.32 and included the predictor variables treatment, diel phase, days from start, wind and wave height (Table 7). The final model that best explained the variance in average DPM/h per diel phase at site Gullmars fjord included all predictor variables except Deployment and averageWind (Table 6). This model explained 32.4% of the deviance, had an adjusted R^2 of 0.09 and included the predictor variables treatment, diel phase, season, side of fjord, days from start, temperature and wave height (Table 7).

An effect of treatment was found at Bonden, where average DPM/h per diel phase was significantly higher for both 6m and 2m compared to control (Table 7 and Figure 9). A significant effect compared to control was also found for treatment 6m at Gullmars fjord, but here the effect of the 6m treatment had lower average DPM/h per diel phase (Table 7 and Figure 10). In both sites, treatment 10m is quite similar to control in regards to the response variable average DPM/h per diel phase (Table 7, Figure 9 and Figure 10).

Table 6 Summary of backwards selection of predictor variables to best explain the variation in average DPM/h per diel phase.

Model	Variable removed	AIC
Bonden, full	-	1320.115
Bonden, final	averageTemp	1317.759
Gullmars fjord, full	-	2183.163
Gullmars fjord, final	Deployment, averageWind	2180.799

*Table 7 Results of the two different GAM models, Bonden (deployment 1) and Gullmars fjord (deployment 2+3). Deviance explained is a measurement of how well the model explains the variation in the response variable average DPM/h per diel phase. N shows the number of data points in each model. The predictor variables are the variables that was included in the final models and their respective significance level (p-value). Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.*

GAM	Deviance explained	N	Adjusted R^2	Predictor variables	P-value
Model Bonden Family: Negative Binomial (1.452)	33.5%	248	0.319	(Intercept)	<0.001***
				Treatment:	
				10m	0.821
				6m	<0.001***
				2m	0.008**
				Diel phase:	
				Day (2)	0.327
				Dusk (3)	0.425
				Night (4)	0.745
				Days from start	<0.001***
				Wave	0.006**
				Wind	<0.001***
Model Gullmars fjord Family: Negative Binomial (0.517)	32.4%	1440	0.109	(Intercept)	0.732
				Treatment:	
				10m	0.376
				6m	<0.001***
				2m	0.116
				Diel phase:	
				Day (2)	<0.001***
				Dusk (3)	<0.001***
				Night (4)	0.193
				Days from start	<0.001***
				Wave	0.005**
				Season:	
				Summer	<0.001***
				Autumn	<0.001***
				Side of fjord South	<0.001***
				Temp	0.014*

The partial response curves for the predictor variable wave height in both models shows a similar pattern of a slight increase in average DPM/h per diel phase to around 0.4m wave height and thereafter a decrease when waves become higher (Figure 9 and Figure 10). The predictor variable wind in model Bonden shows a similar pattern (Figure 9). In both models, days from start is highly significant but no clear pattern except a slight increase after half of the deployment time in model Gullmars fjord, can be seen when looking at the partial response curves (Figure 9 and Figure 10).

For the two deployments at site Gullmars fjord that together spans over more than one season, average DPM/h per diel phase decreases with the seasons as previously observed and there is a significant difference for summer and autumn compared with spring (Figure 10). There is also a significant difference in recorded DPM depending on side of the fjord, with more recording at the south side (Figure 10). In the fjord there is a negative effect of diel phase 2 (day) and 3 (dusk) compared to diel phase 1 (dawn) on average DPM/h per diel phase (Figure 10). At site Bonden, although not significant, a tendency for less DPM during diel phase 2 and more DPM during phase 3 can be observed (Figure 9).

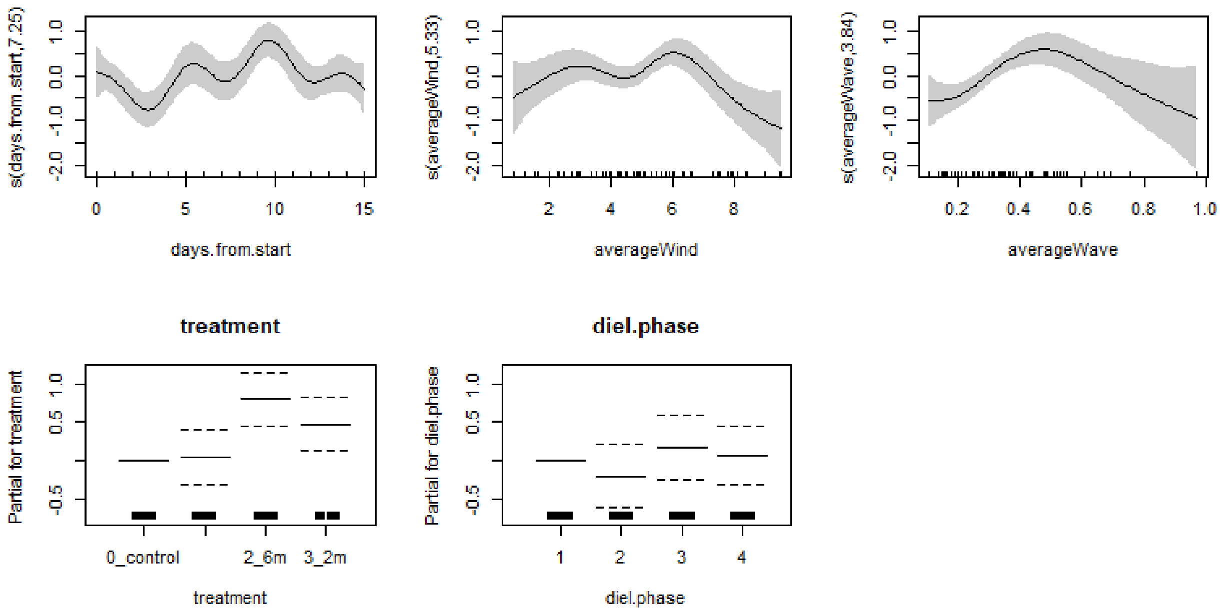

Figure 9 Model Bonden (deployment 1). Partial response curves for average DPM/h per diel phase in relation to the predictor variables days from start, wind velocity, wave height, treatment and diel phase. Value above 0 indicates a positive effect on the response variable average DPM/h per diel phase.

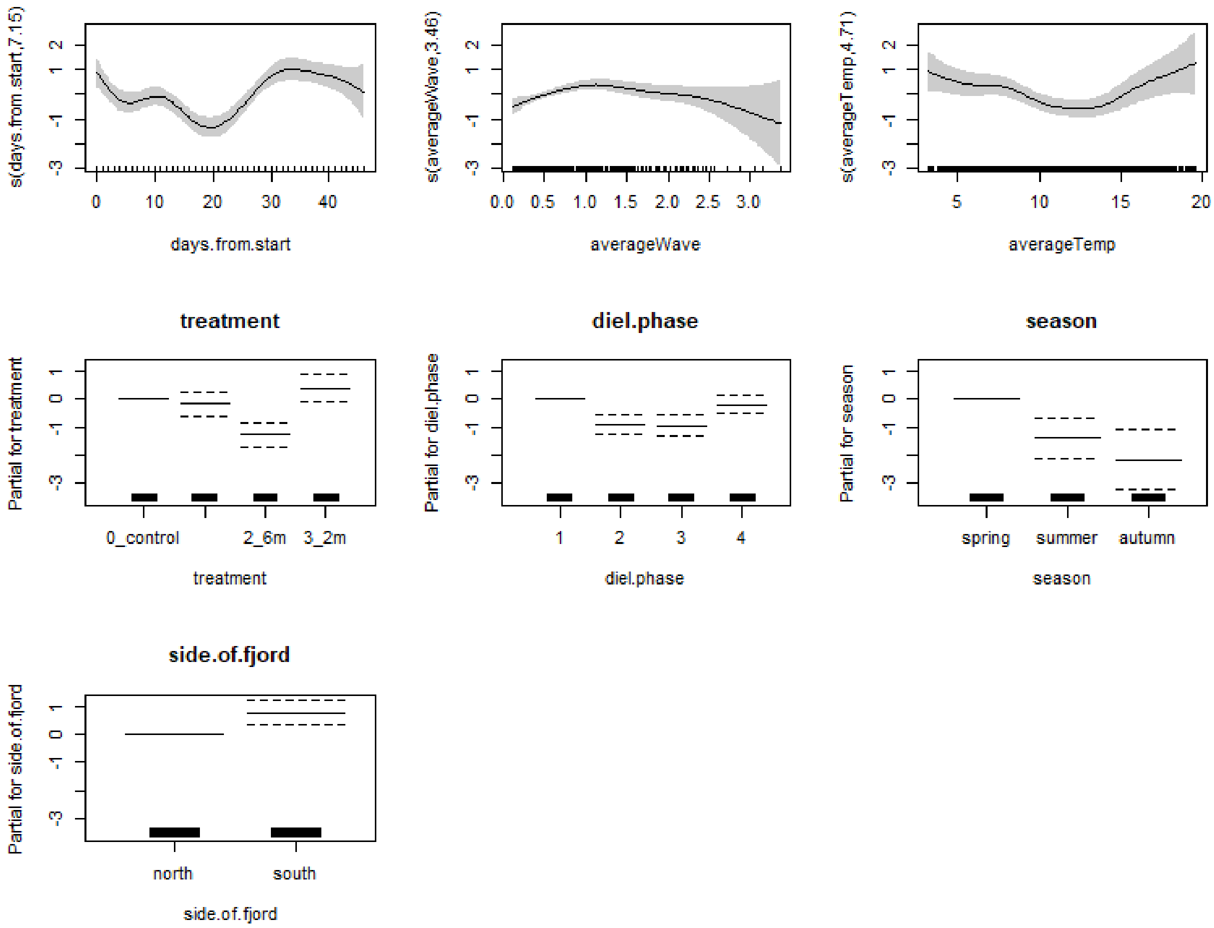

Figure 10 Model Gullmars fjord (deployment 2+3). Partial response curves for average DPM/h per diel phase in relation to predictor variables days from start, water temperature, wave height, diel phase, season, treatment and side of fjord. Value above 0 indicates a positive effect on the response variable average DPM/h per diel phase.

3.2.3 Effect of floats on porpoise click behaviour

Wilcoxon Rank Sum tests showed that there was no significant difference in buzz-ratio/h between C-PODs within the same panel and it was therefore decided to use the same group, “S+SW”, which was used for the analysis of average DPM/h per diel phase for porpoise presence. Using buzz-ratio per hour as a response variable, only hours were the C-POD have registered a minimum of one detection positive minute was used and a large difference in proportion of DPM-positive hours could be observed between treatments (Table 8).

Table 8 Number of hours per deployment were C-PODs in group “S+SW” have recorded at least one detection positive minute (DPM), displaying the amount of hours per deployment that was included in the buzz-ratio analysis.

Deployment	Sum of logged hours	Logged hours with DPM>0	% of hours with DPM>0
1	1428	760	53%
2	4104	740	18%
3	4400	278	6%

The effect of treatment on buzz-ratio per hour was significant in deployment 1 at site Bonden (Kruskal-Wallis test, p=0.005), but no significant difference between treatments could be found during deployment 2 and 3 at site Gullmaren. Difference in buzz-ratio per hour was found between control and treatment 2m as well as treatment 6m and 2m in deployment 1, with the 2m treatment having a higher buzz-ratio per hour compared to the other two treatments (Figure 11). Dial phase had a significant effect on buzz-ratio per hour in deployment 2 (Kruskal-Wallis test, p=0.002) and deployment 3 (Kruskal-Wallis test, p=0.011). Difference in buzz-ratio per hour was found in deployment 2 between day and dawn, and dawn dusk with a higher buzz-ratio during dawn than the other two diel phases (Figure 12). In deployment 3, there was only a significant difference between day and night, with a higher buzz-ratio at night (Figure 12).

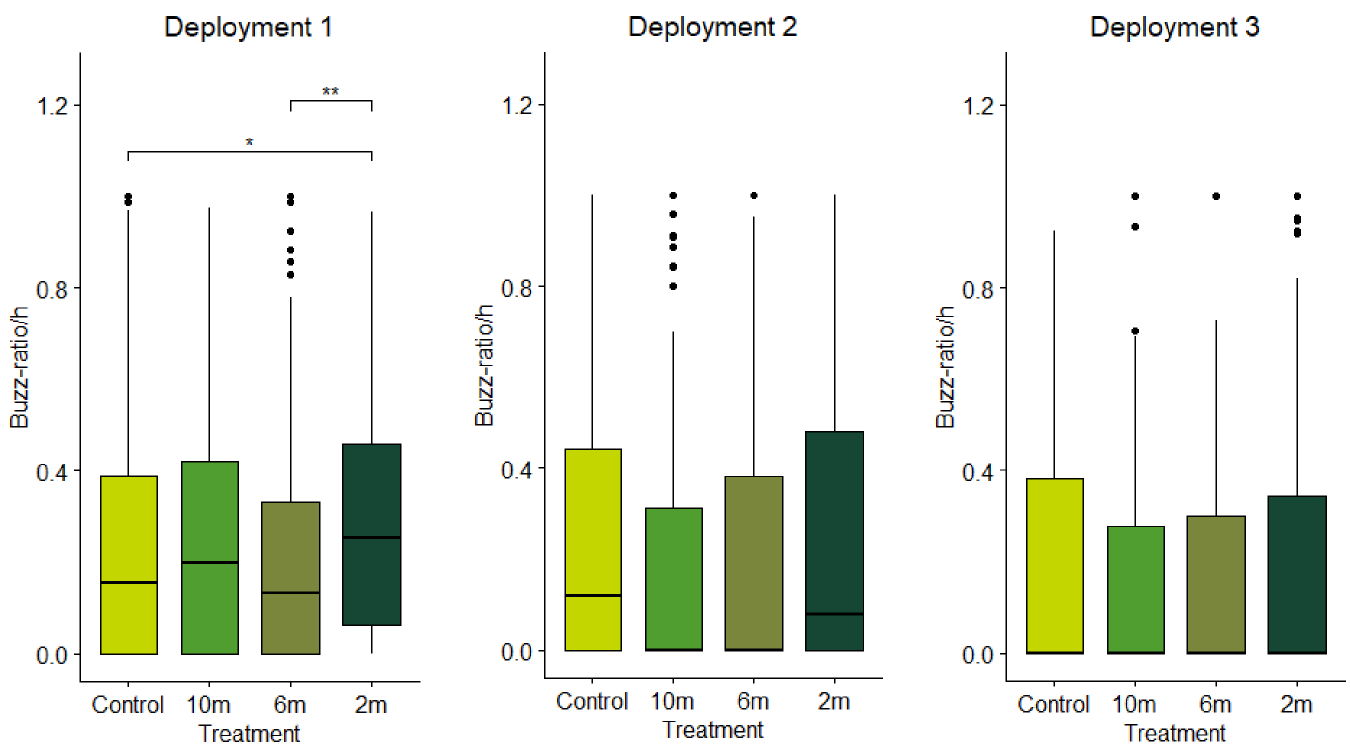

*Figure 11 Buzz-ratio/h for each deployment divided by treatment. Median value for each treatment group represented by the solid line within each box. The boxes contain second and third quartile. Significant difference in buss-ratio/h between treatments is displayed above the boxes. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '. Dunn's test for multiple comparison, adjusted p-values for deployment 1: control-2m=0.019 and 6m-2m=0.0045.*

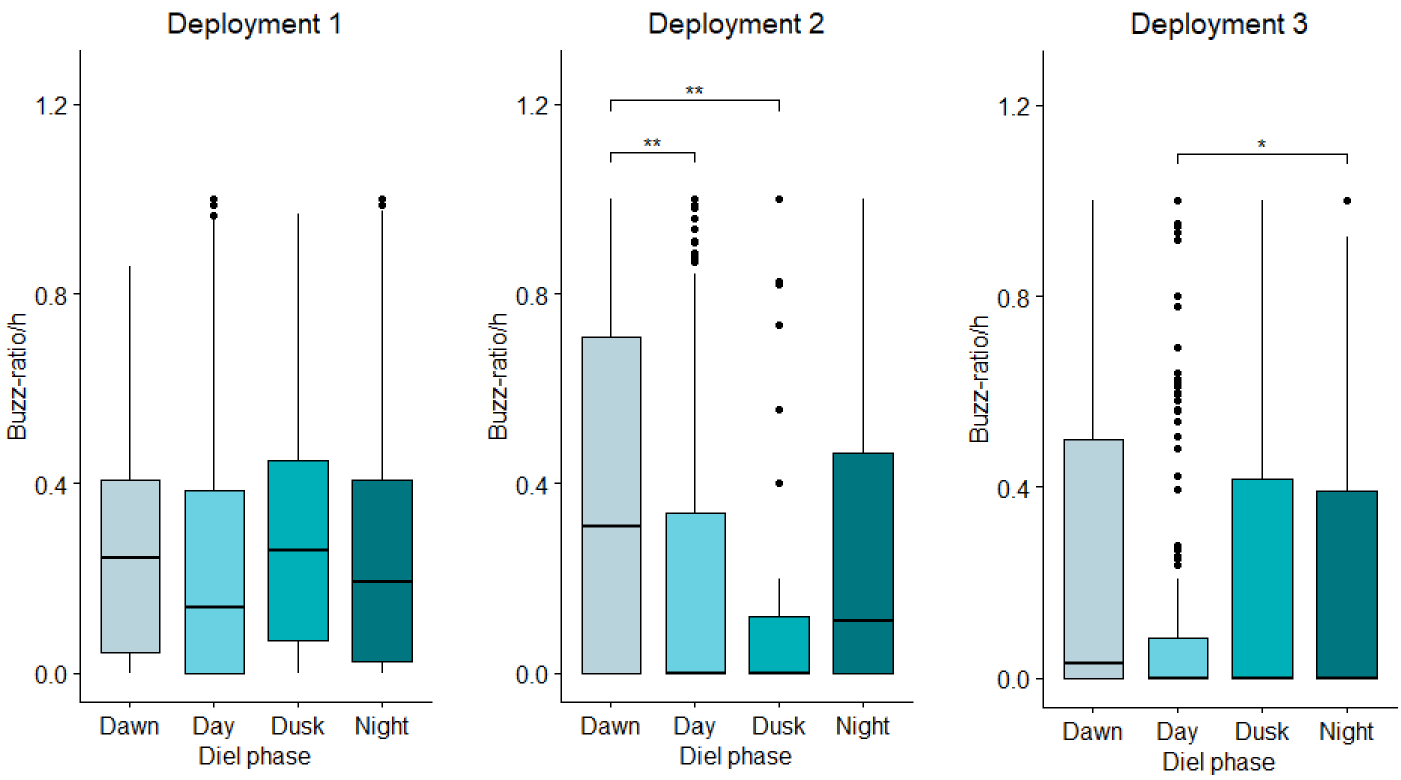

*Figure 12 Buzz-ratio/h for each deployment divided by diel phase. Median value for each diel phase is represented by the solid line within each box. The boxes contain second and third quartile. Significant difference in buss-ratio/h between diel phases are displayed above the boxes. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '. Dunn's test for multiple comparison, adjusted p-value for deployment 2: dawn-day= 0.0052 and dawn-dusk= 0.0052. Adjusted p-value for deployment 3: day-night= 0.0289.*

4. Discussion

4.1 Literature study

Due to the large variation in trial design as well as the amount and quality of the data collected, it was not possible to directly compare the performance of the different mitigation measures. Studies have shown that small toothed whales are able to detect gillnets at relatively long distances in calm conditions and thereby it is possible for them to avoid them (Nielsen *et al.* 2012; Maeda *et al.* 2021; Macaulay *et al.* 2022).

Using TS as an indication value on how much a modification will add to the acoustic image of the gillnet, it is likely that beaded chains, infused nylon-nets and other net materials do not have a large enough acoustical enhancing effect to make the net more visible. Three trials with infused nets have however reported a decrease in bycatch, but it is suggested that increased stiffness of the nets could be the reason (Northridge *et al.* 2003; Larsen *et al.* 2007; Trippel *et al.* 2008), two other studies did not see a decrease of bycatch (one reported an increase in bycatch in the modified net compared to control). TS of cylindrical shapes is sensitive to the incident angle of the incoming sound and any angle except perpendicular rapidly reduces TS (Kratzer *et al.* 2020). As gillnet filaments can be approximated by infinite cylinders, this holds true for the different net materials and is most likely the case for ropes and thread as well as the different types of metal wires. The rubber tubing is another cylindrical shape, but has entrapped air that have a high acoustic reflective capability under water that gives a high TS value (Hembree & Harwood 1987; Silber *et al.* 1994). Although air-filled rubber tubing have shown promise in both regards to high TS and behavioural reactions, this modification have proven unsuitable due to deflation by power blocks when the netting is retrieved and due to exposure to sun and saltwater, resulting in losing the acoustic reflectability based on the entrapped air. The aluminium discs and some of the metal wires was also proven unsuitable due to corrosion.

Hard plastic floats with a similar TS as air-filled rubber tubing, but with a sturdier shell, have shown promise in behavioural studies were avoidance behaviour have been observed at over 100m. In a few isolated occasions however, a straggler from a passing group was observed "crashing" into the float-panel when not echolocating. Another study did not find any significant difference in avoidance behaviour in regards to a panel with floats compared to a floatline alone, but there seems to be a significant difference in response depending on distance between the floats according to another study. The most recent modification type, acrylic glass spheres attached at 60cm or less intervals, have a high TS when multiple spheres are enzonified. These have also shown promise in two commercial trials with less porpoises present around modified nets based on echolocation signals and less porpoises caught compare to control nets.

4.2 Field study

As seen in results section of the field study, the effect of hard-plastic floats as passive acoustic reflectors on harbour porpoise presence (average DPM/h per diel phase) and click behaviour (buzz-ratio) produced mixed results.

4.2.1 Effect of treatment

Rope panels equipped with hard plastic floats did affect variation of average DPM/h per diel phase. However, the results from the two models are not conclusive. In model one, with data from the first deployment at site Bonden, the panel with 6m float spacing had a higher recording of the response variable average DPM/h per diel phase compared to control. In model two, with data from deployment two and three at site Gullmarn, the panel with 6m spacing had less recordings of the response variable compared to control. It is however a large difference in recorded detection positive minutes (DPM) between deployments, with 6 346 DPM recorded in deployment one, 2 975 DPM in deployment 2 and 616 DPM in deployment 3. This results in more zeroes and a less sturdy model for deployment two and three, which is also evident when looking at the diagnostic plots that shows a worse fit for model two compared to model one (Appendix 2). Therefore, perhaps more weight should be given to model one that is based on the data collected during the first deployment at site Bonden with the highest recorded DPM and porpoise presence.

In both models however, distance between the floats seems to have an effect on the response variable average DPM/h per diel phase. A spacing of 10m gave very similar results compared to control, but a spacing of 6m or 2m gave different results compared to control. These results are in agreement with the study done by Nakamura *et al.* (1998) who recorded less avoidance behaviour if floats were spaced further apart. Similar to the present study, Goodson and Mayo (1995) investigated both 2m and 6m spacing between floats and observed avoidance behaviour in the proximity of both panels. These combined results indicates that the harbour porpoise might not perceive the panel with 10m spacing between floats as a barrier.

Treatment only had a significant effect on buzz-ratio in deployment one. Similar to the findings of Gustafsson (2020), the shorter spacing of 2m had a higher buzz-ratio than both control and 6m. This could indicate that the floats give rise to a higher degree of investigative behaviour if they are spaced close enough together – with a closer spacing, a higher number of floats will be enzonified by the porpoise sonar beam, giving rise to a larger echo making the panel more visible (Goodson & Mayo 1995). What is interesting to note however is that treatment 6m in deployment 1, which had the highest recordings of DPM, had the lowest buzz-ratio per hour. The reason for this could be that the panel is in an area where the porpoises are only passing through and not foraging. They see the panel, but it is not interesting enough to investigate any closer and they just pass by.

It is however important to note that there was some difficulties when setting out panel 2m during the first deployment. This resulted in that the 2m panel might not have been standing stretched out on the seafloor as it should, potentially affecting how the panel is perceived by the porpoises. When retrieving the panels after each deployment, we noticed that some of the floats contained water, approximately 10-20 %. This most likely affects the acoustic properties of the floats, making them less visible for harbour porpoise echolocation signals.

4.2.2 Impact from time and environment

The large difference in recorded DPM between deployments could be an effect of seasonal change in harbour porpoise presence in the area - more in spring, less in autumn. If there is less porpoises in the area, there are less individuals that could interact with the deployed panels. This results in more zeroes and less reliable models. Seasonal variation in harbour porpoise distribution have previously been observed by for example Sveegaard *et al.* (2011) and Sveegaard *et al.* (2012) in the area of the North Sea to the western Baltic Sea and intermediate waters. In the study by Sveegaard *et al.* (2011), they recorded a gradual movement of the porpoises tagged in the Skagerrak, from east to west during spring/summer to autumn/winter. This could explain the low positive recordings in autumn that was found in the present study.

In accordance with previous studies (Carlstrom 2005; Todd *et al.* 2009; Konigson *et al.* 2022), the results from this study could show that diel phase affect both average DPM/h per diel phase and buzz-ratio per hour with generally more detections/buzzes during dawn and night compared to daytime. It is however worth noticing that the amount of hours per diel phase differs significantly in the present study, some day-phases are more than 10h while dawn and dusk are merely one hour. This is largely because the variable diel phase is based on civil twilight that vary greatly with the seasons in the northern hemisphere.

The response variable average DPM/h per diel phase followed the same pattern in regards to wind and wave height in both models, slightly increasing with wind and wave height and then a rapid decrease with higher measurements of wind and wav height. Goodson and Mayo (1995) observed a similar pattern, noting that with a higher degree of air bubbles in the water due to higher waves the maximum detection range of the animals' echolocation signals are reduced. The sonar signals produced by the porpoise is reflected of the air bubbles instead of reaching targets further away. In this study, when using C-PODs to detect porpoises, this means that they have to be closer to the C-POD for them to be detected. Because of this, the porpoise might still be in the area around the panels but might not be detected by the C-POD. In regards to wind speed, Goodson and Mayo (1995) speculated that increased wind from a certain direction transferred the foraging activities of the dolphins to calmer areas.

The effect of wave height is not as strong at site Gullmars fjord compared to site Bonden and the effect of wind was not significant to use in the model, this might be due to using weather variables from stations quite far away from site Gullmars fjord, in more open areas, since no closer stations were available. Site Gullmars fjord is not as exposed to waves and winds as site Bonden is, which could also explain why these variables have less effect in model two.

4.2.3 Dependence on location

A spatial pattern of total amount of DPM/h recorded by each C-POD can be observed when plotting these on a map (Figure 7). In deployment one at site Bonden, most recordings have been made by the southernmost panel (6m), decreasing northward with each panel except for the control treatment. Within each panel it is also the southernmost C-POD that have recorded most DPM/h. This suggests that there might be a pattern in how the harbour porpoises move in this area – from south to north, encountering the 6m panel first and then adjusts its swimming direction potentially missing the next panels. This hypothesis is strengthen by the fact that there was a significant difference in the amount of DPM/h recorded by the C-PODs within the 6m panel, with the highest recordings by the southernmost C-POD (pod.position=S, Table 5). In multiple field trials by Goodson and Mayo (1995), they placed similar panels at the surface across a path frequently travelled by dolphins. In these trials, they observed dolphins that seem to detect the panels at up to 170m and thereafter changing their travel course. This could be the case at site Bonden as well.

Another factor that might affect how harbour porpoises moves in the area is the depth of the sea and surrounding islands. Since all four panels needed to be placed at a similar depth around 30m, we were limited by the topography in the area around Bonden. Looking at a nautical chart, the area north of were the panels were placed is significantly shallower. This might influence which way the porpoises prefer to swim, possible avoiding the shallower water and therefor "missing" the southernmost panels. There is however no information on movement patterns of harbour porpoise in the study area.

This type of "travel-pattern" is not as apparent at site Gullmaren, although in deployment two it is always the C-POD positioned closest to the outlet of the fjord (pod.position=SW) that recorded most DPM within one panel. At site Gullmars fjord, the predictor variable "side of fjord" was highly significant with more recordings on the south side of the fjord. Placement of the panels have most likely had an effect on the result, both in regards to relative placement at the site but also in that the panels might have affected each other even though they were placed 400m apart.

4.2.4 Reflections

To decrease the effect of placement of the panels in future studies and also investigate the hypothesis of a potential travel-path in the Bonden-area, I would suggest to place the panels approximately on the same latitude (east-west line) since they were all placed on a longitude-axis (north-south line) in the present study. I would also suggest rotating the panels more often to decrease the effect of placement, as was done during deployment 2 and 3. Due to the difference in length of the diel phases another improvement could be to change the criteria for dividing the hours of the day into diel phases by increasing the dawn and dusk diel phases.

Although the results from the statistical analysis in this study are reasonable, data containing an excessive amount of zeroes (like in this field study) can pose significant challenges when conducting statistical tests and the zeroes might affect the results. To further improve the robustness of the results for this and future studies I would suggest to continue to investigate other possible methods for handling datasets containing an abundance of zeroes.

If possible, it would be interesting to combine C-PODs recording the echolocation activity with visual observation in a similar way to what they did in the trials by Silber *et al.* (1994); Goodson and Mayo (1995); Koschinski *et al.* (2006) – using theodolites to take surface positions of the dolphins, to see how and if the movement pattern was affected by floats. More recently published studies by Maeda *et al.* (2021) and Macaulay *et al.* (2022) used different types of hydrophone arrays to get more detailed information about harbour porpoise movement around gillnets. Multiple different types of behaviour could be extracted from the data, such as animals actively foraging in close proximity of the net without becoming entangled. These could be used to better understand how different mitigation measures, such as the floats tested in this study, affect the behaviour of the harbour porpoise and other toothed whales that use echolocation.

Although harbour porpoises echolocate almost constantly, periods when they are quiet and not as aware of their surroundings do occur (Wright *et al.* 2017). This could be when sleeping or during bottom-grubbing, a special feeding behaviour when they are searching for hidden prey in the bottom sediments by standing vertically pointing their nose and echolocation beam towards the seafloor (Desportes *et al.* 2000). In these situations, passive acoustic reflectors attached to fishing nets will not be anything more than a visual stimuli at best. A way to solve this problem could be to combine passive reflectors with active "noise-makers" such as pinges to alert the porpoise of the presence of the net.

5. Conclusion

5.1 Systematic literature review

In the systematic literature review, I identified and assessed passive acoustic reflectors and their effectiveness in regards to modifying the behaviour and/or reducing bycatch of toothed whales. Although mixed results, there seems to be potential in using passive acoustic reflectors as a bycatch mitigation measure depending on material. It is however important to remember to try and understand why a modification works, using infused nets as an example were stiffness might be more important in describing the decrease in bycatch recorded in some studies rather than the acoustic reflectabillity of the net. Another example is that many studies investigating the behaviour reactions of dolphins and porpoises are dependent on light and/or clear water to be able to see the animals – this makes it hard to deduct if it is the visual stimuli of the modification or the enhanced reflectivity or both that the animals react to. More studies are needed to address the functionality and effectivity of passive acoustic reflectors as a mitigation measure. For future studies, some areas that lack research effort have been identified through this systematic literature review such as different types of gear settings and behavioural studies with focus on echolocation. I have also identified what types of modifications that, up to this date, have shown most promise for further investigation as an effective, low-cost bycatch mitigation measure.

5.2 Field study

The aim for the field study was to examine harbour porpoise echolocation in relation to floats acting as a passive acoustic reflector to enhance the acoustic target strength (TS) of fishing nets, to see if these would have an effect on harbour porpoise presence and click behaviour.

The results show a significant difference in average DPM/h per diel phase when floats were spaced 6m or 2m apart compared to control. The effect of the 6m treatment was nevertheless different between the two sites, with a positive effect on average DPM/h at site Bonden and a negative effect at site Gullmars fjord. An effect on buzz-ratio was only observed at site Bonden. However, due to significantly fewer positive recordings at site Gullmaren, it is argued that more consideration should be given to the results at site Bonden since a higher porpoise density will result in more reliable models.

Focusing at site Bonden, the results indicate that floats have an effect on porpoise presence and click behaviour. It is however very likely that placement of the panels also had an effect on the results. To decrease the effect of placement in future studies in the area, it is suggested to place the panels on approximately the same latitude (compared to present study when they were placed on the same longitude) and rotate the panels. To better understand the movement pattern of the harbour porpoise in relation to floats it is further suggested to combine acoustic recordings with visual observations. The use of a hydrophone array could also provide more detailed understanding of harbour porpoise presence and behaviour around panels equipped with floats. These would allow the echolocation signals of the animals to be related to a spatial positon, helping us to better understand the effects of floats and its potential as a bycatch mitigation measure.

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Popular science summary

Bycatch, the incidental entanglement of non-target species in fishing gear, is thought to be one of the major threats to many whale species around the world today with an estimated bycatch of over hundred thousand individuals each year. Majority of the whales caught are dolphins and porpoises, and gillnets are the fishing gear type responsible for the most bycatch of these species. Porpoises and dolphins that get caught are unable to reach the surface to breath and therefore drown. These nylon-nets most likely contributed to the extinction of the baiji river dolphin and now, the vaquita (a species of porpoise) is also likely to become extinct due to the very same reason.

Efforts have been made to find solutions to the bycatch problem and although some mitigation methods to reduce bycatch have proven effective, they are often expensive or logistically challenging to use, deterring fishermen to use them. It is therefore a need to develop effective, low-cost solutions that will be accepted by fishermen. One such possible solution is the use of passive acoustic reflectors to make gillnets more visible to the so called echolocation signals produced by toothed whales such as porpoises and dolphins. Echolocation is when the animal emits a click-sound into the surroundings which is then reflected of an object, the returning echo gives information to the animal of what lies ahead. Passive acoustic reflectors are different types of materials or devices designed to reflect more of the sound back to the animal compared to the thin nylon threads of the gillnet and in that way make the net more visible, giving the porpoises and dolphins a better chance to avoid getting entangled.

To identify what type of passive acoustic reflectors that previously have been investigated and their potential to reduce bycatch, I performed an extensive literature search (a systematic literature review). Of 20 different types of passive acoustic reflectors found in the literature, two showed the most potential – hard plastic floats and acrylic glass spheres. Based on these results and due to their low cost, maintenance and readily availability in any fishing shop, it was decided to further investigate hard plastic floats and their potential to reduce harbour porpoise bycatch – a species with several threatened populations including the critically endangered Baltic Sea subpopulation.

A field study was performed to investigate harbour porpoise presence and click-behaviour around panels equipped with and without floats. The aim was to examine their echolocation signals using passive acoustic monitoring systems that records porpoise clicks (C-PODs). Custom-made rope panels was used instead of gillnets to avoid catching anything during the trials. Four panels were created, three panels had floats attached at 2m, 6m or 10m interval to investigate if spacing would have an effect on presence and/or behaviour, and one control without floats.

Results show that both harbour porpoise presence and click-behaviour is affected by floats and that spacing have an effect, with no difference between the panel with 10m spacing and control. This indicates that panels equipped with hard plastic floats, attached close enough to each other, are more visible to harbour porpoise's echolocation signals and therefor have potential to make gillnets more visible as well. It is however likely that placement of the panels affected the results to some degree. To reduce this effect in future studies it is suggested investigate the travel pattern of the harbour porpoise in the area beforehand and to rotate the panels during the trial.

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Finally I want to thank all my friends and family for the feedback, continuous support and understanding during this research process, I could not have done it without you!

1. Appendix 1: Systematic literature review

1.1 Details regarding method

Table A1.9 Summary of where and when the literature search was performed,

Search platform or database	Indexes	Searched in	Data ranges available	Date when search was performed
Clarivate Web of Science	- Core collection - Zoological record - BIOSIS citation index	Topic	1945-present 1990-present 2009-present	2022-12-12
Scopus	n/a	article title, abstract, keywords	1970-present	2022-12-12
ProQuest SciTech	Aquatic Sciences & Fisheries Abstracts (ASFA)	anywhere except full text - NOFT	1971-present	2022-12-12
EBSCOhost	Wildlife & Ecology Studies Worldwide	"default"		2022-12-13
Consortium for Wildlife Bycatch Reduction	n/a	n/a	n/a	2022-11-24
Bycatch Management Information System (BMIS)	n/a	n/a	n/a	2022-11-24

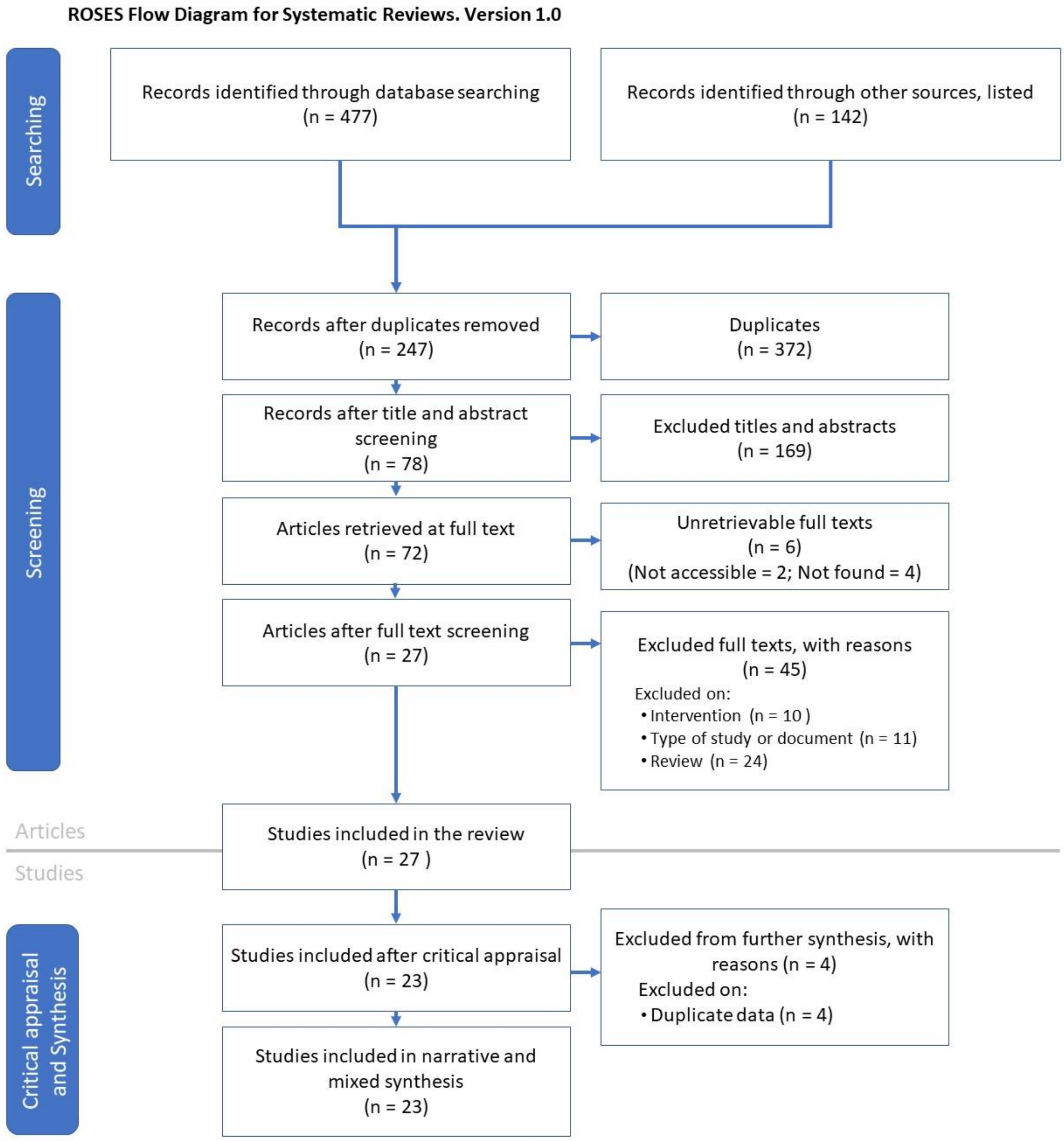


Figure A1.13 ROSES flow diagram (Haddaway et al. 2017) showing the screening process of the articles and studies of the review.

Table A1.10 Description of data extracted from articles sourced from literature search.

Extracted data	**Explanation**
Trial number	The number of trials performed in the same study. If multiple mitigation measures was tested or it is tested on multiple species.
Family	Scientific family name of species in trial.
Species	Scientific species name of species in trial. If trial was not performed with live animals, “simulated” was added.
Continent	Where study was performed, n/a indicates a study done in a setting when environment is not a factor. A * is added if study was performed by a dock in the field or similar.
Ocean	See “continent”.
Country	See “continent”.
Context	Type of study: theoretical: any study done without live animals lab: studies done with captive animals field: studies done in the field commercial: studies done in a commercial setting
Application	What type of gear the modification applies to. When noted, gillnet type is used (surface- or bottom set)
Modification	Detailed description of modification as noted in the study.
Modification group	Modifications with similar characteristics divided in 9 different groups. See Table 1 for group names.
Modification category	Two general categories. Net material: modification of the net material itself, acoustic reflector: objects that might be added to the fishing gear to enhance the acoustic properties of the gear
Method of data collection	How data of studied parameter was collected.
Studied parameter	The parameter that is measured to determine if the modification have an effect or not (Bycatch reduction, Behaviour, Echolocation behaviour, Other).
Potential for bycatch reduction	Based on study result of studied parameter Yes: indicated support for the technology reducing bycatch (not taking into account effect on e.g. target catch), No: indicated no support, Partial: indicated some support or conflicting results, Data Deficient: indicated a sample size too small to get a significant result
Significant	Yes: indicated a significant result (p-value <=0.05) No: indicated a non-significant result Data Deficient: indicated a sample size too small Not reported: indicated results where a significance level was not reported in the study. If multiple trials for the same mitigation was made then ≥50 % significant = significant, and <50% = not significant
Multiple trials	Yes: if multiple trials was performed for same modification in the same study (for example different angles of incidence) No: if only one trial was performed for same modification in the same study
Target catch	If the modification has any effect or not on target catch (the fish that is targeted by the fishing boat) (yes, No, n/a)

Target strength	Measured in dB, see definition in Systematic literature review result, section 2.2.1
notes	Any notes on the results of the study

1.2 Systematic literature review database

Attached excel-document

https://docs.google.com/spreadsheets/d/1Oo0x52bBeV6MLYZYffWi5dkfwhLUNR9Q/edit?usp=sharing&ouid=104525474223447650099&rtpof=true&sd=true

2. Appendix 2: Selection of distribution family for GAM-model

Table A2.11 Result of tools (AIC, diagnostic plots) used to determine if the response variable average DPM/h per diel phase were best modelled with a Gaussian or Negative binomial distribution for the GAM-model Bonden.

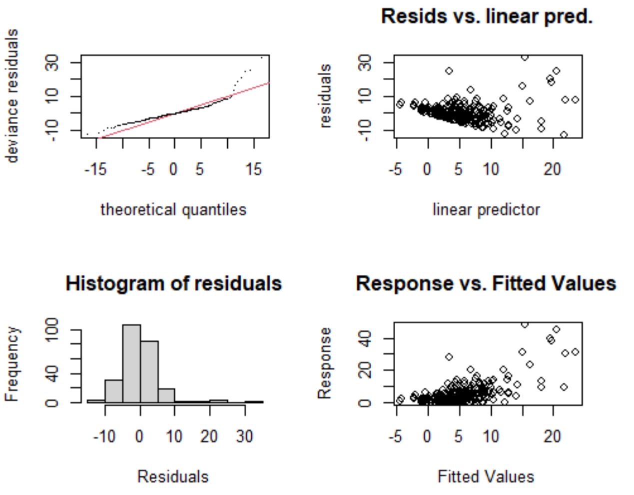
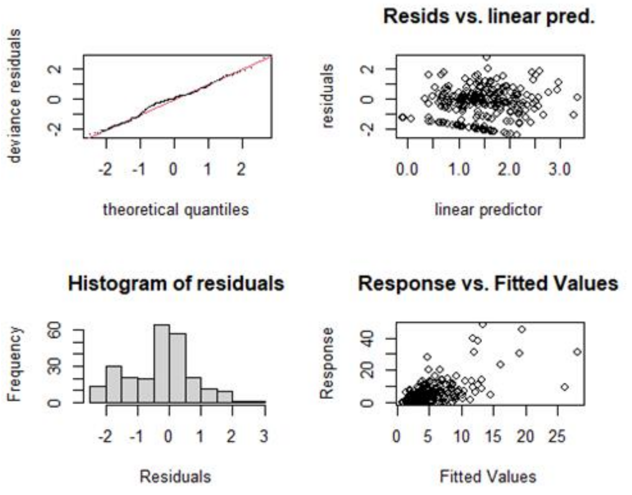
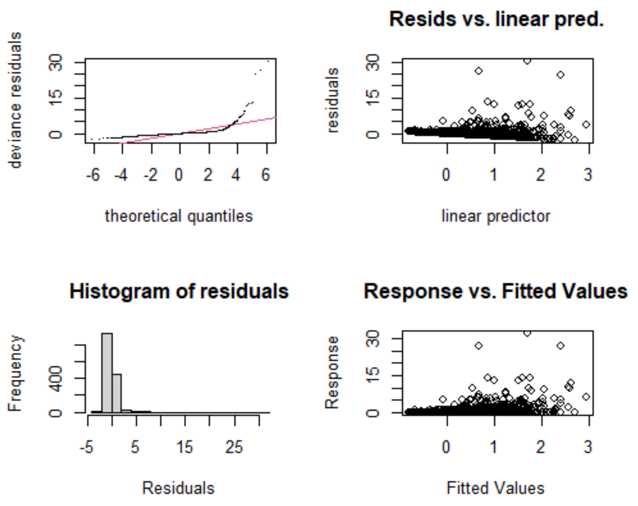
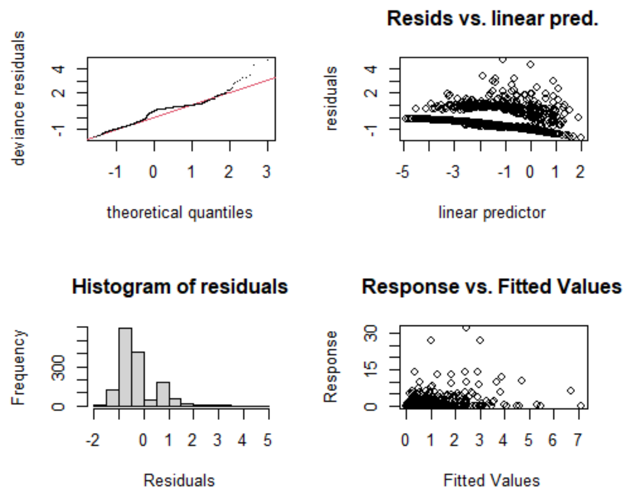
<table>
<tr><th>Model</th><th colspan="2">Bonden (all predictor variables)</th></tr>
<tr><td>Family</td><td>Gaussian</td><td>Negative binomial</td></tr>
<tr><td>AIC</td><td>1602.128</td><td>1320.115</td></tr>
<tr><td>Diagnostic plots</td><td>
</td><td>
</td></tr>
</table>

Table A2.12 Result of tools (AIC, diagnostic plots) used to determine if the response variable average DPM/h per diel phase were best modelled with a Gaussian or Negative binomial distribution for the GAM-model Gullmars fjord

Model	Gullmars fjord (all predictor variables)	
Family	Gaussian	Negative binomial
AIC	5820.717	2183.163
Diagnostic plots		

3. Appendix 3: Diagnostic plots – GAM, final model

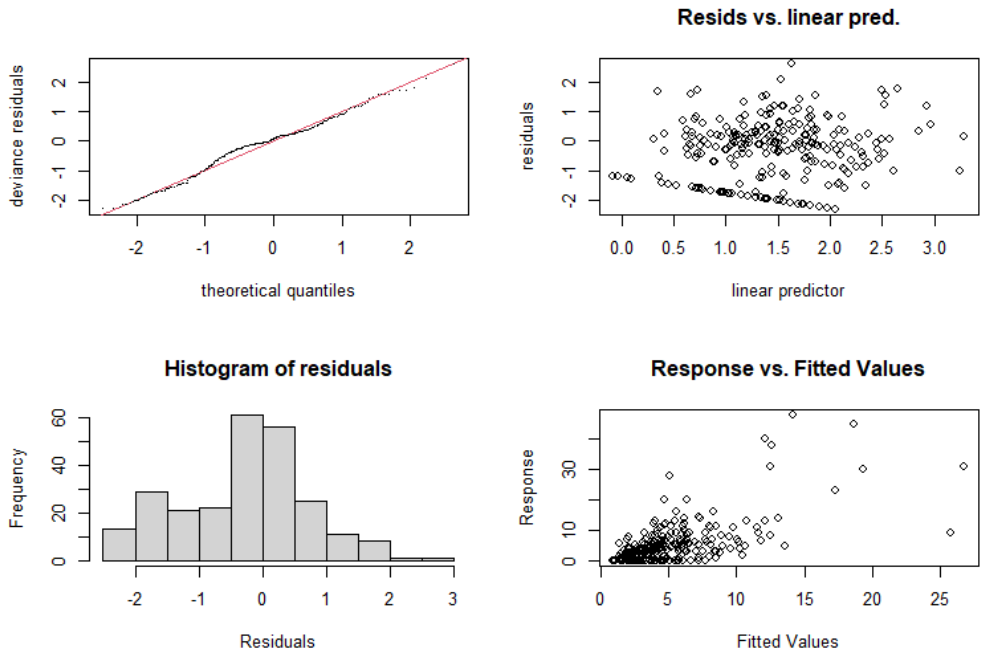


Figure A3.14 Diagnostic plots for GAM-model 1, Bonden.

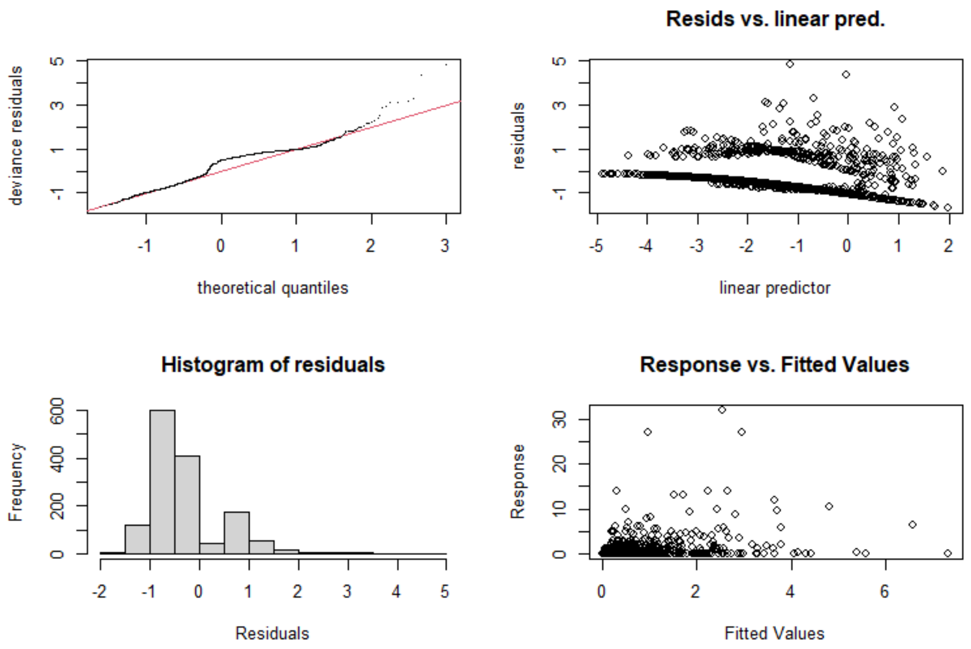


Figure A3.15 Diagnostic plots for GAM-model 2, Gullmars fjord.

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