# Pearls as bycatch mitigation strategy for Harbour porpoise *(Phocoena phocoena)*

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## Pärlor som åtgärdsstrategi mot bifångst av vanlig tumlare (*Phoecena phoecena)*

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# Can pearls save harbour porpoises from dying in fishing nets

One of the major threats to harbour porpoises all around the world is believed to be the high numbers of harbour porpoises getting bycaught and dying in fishing nets. Harbour porpoises accidentally swim into the nets where they get entangled and drown as they cannot go to the surface and breathe. A lot of research have been done on how to decrease bycatch of harbour porpoises in fishing nets. One way to decrease bycatch of harbour porpoises in nets is by modifying fishing nets in ways which makes the nets more visible to harbour porpoises.

In a previous study by Kratzer et al. (2019) custom-made acrylic glass pearls were attached in rows on a fishing net with the theory that the addition of pearls on the net would make the net appear as a wall and be more visible to harbour porpoises leading to decreased bycatch. The Kratzer et al. (2019) study showed that adding pearls did reduce bycatch of harbour porpoises but more research was needed to confirm the results. The aims of this study was to examine if attaching the same custom-made acrylic glass pearls on a fishing net effected harbour porpoise presence around the net and if harbour porpoises showed any changes in their behaviour because of the pearls.

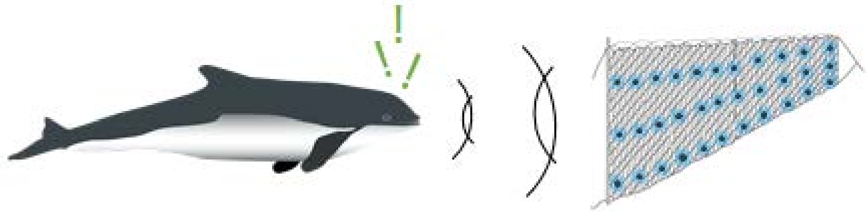

Figure by Kratzer et al., (2019)

Harbour porpoises like other whales use reflected sound, so called echolocation, to locate objects under water by making clicking sounds. These clicking sounds or clicks can be analysed to estimate how many porpoises there are in one area. The clicks can also be analysed to see what the harbour porpoises were doing in the area because they click in specific patterns depending on what they are doing, like for example catching prey or investigating objects.

In this study harbour porpoise click recordings from a fishing net with pearls and a fishing net without pearls were used in a mathematical model. This model included variables believed to affect porpoise presence (e.g. use of pearls, spacing between pearls, part of day, wave height, water temperature, depth). The version of the mathematical model that best explained changes in porpoise presence also showed which variables that are most important for porpoise presence. The same click recordings were also analysed for a specific click pattern called "buzzes" that harbour porpoises have been seen to use when investigating objects. The number of buzzes was then compared between the net with pearls and the net without pearls.

The mathematical model on porpoise presence showed that adding pearls to a fishing net decreased porpoise presence significantly compared to the net without pearls. The model also showed that attaching pearls closer together decreased porpoise presence significantly more compared to when pearls were attached further apart. This means that adding pearls to a fishing net leads to a decrease in porpoise presence around a net. This leads to a decreased risk for entanglement and drowning in the net. The analysis of the click pattern called buzzes showed indications of changes in click behaviour with more buzzes when pearls are used. An increase in the number of buzzes around the net with pearls suggests that the net is investigated to a higher degree by the harbour porpoises. This most likely means that they are more aware of the net with pearls and are therefore less likely to accidentally swim into the net with pearls and get entangled.

Modifying fishing nets by attaching acrylic glass pearls shows promise as a strategy to protect the harbour porpoise from accidental entanglement and drowning in fishing nets.

# Abstract

One of the major threats to harbour porpoise population sustainability is thought to be the high incidence of bycatch specifically in gillnets. This study aims to examine the use of acrylic class pearls developed in an earlier study as acoustic reflectors on gillnets in an effort to increase their visibility to echolocating harbour porpoises in the lumpsucker fishery in Kattegatt. This was done by using passive acoustic monitoring (F-PODs) on a net with pearls and a control net to detect porpoise clicks in the vicinity of the two nets as a proxy for porpoise presence. The study was divided into two periods during which different spacing between pearls (30 cm and 60 cm) was used. The click data was also analysed for called buzz feeds, clicks with inter click intervals of 15 ms, as an indicator of differences in click behaviour. Porpoise presence was analysed and presented by click rate-based distribution models (GAM), and the potential role of different kinds of variables (e.g. use of pearls, pearl spacing, diel phase, wave height, water temperature, depth) as potential drivers of porpoise presence was examined. Click behaviour was analysed and presented as number of buzzes per diel phase and buzz ratio per hour and per diel phase using a custom written Matlab algorithm. The study found that the use of pearls and using different spacing between pearls had a significant effect on porpoise presence. The study also found indications for changes in click behaviour caused by the use of pearls. Using acrylic glass pearls as acoustic reflectors on gillnets show promise as a bycatch mitigation strategy for harbour porpoise.

*Keywords:* Harbour porpoise, bycatch mitigation, acoustic reflector, pearl, gillnet, F-POD, click rate, click behaviour, inter-click-interval, terminal buzz, diel phase, GAM.

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# Abbreviations

| | |
|---|---|
| DPM | Detective positive minutes |
| GAM | Generalized Additive Model |
| ICI | Inter-Click-Interval |
| NBHF | Narrow Band High Frequency |

# Introduction

Every year very large numbers of small cetacean whales die around the world in fishing gear and little is known about why they end up as bycatch (Read et al., 2003). One of these species is the harbour porpoise (*Phocoena phocoena*). The harbour porpoise is a small toothed (odontocete) whale species that lives in cold-temperate sub-arctic neritic coastal waters of the northern hemisphere and can also spend time in inland waters such as fjords, rivers, estuaries and tidal channels (Gaskin, 1984). The harbour porpoise is the only cetacean found all year round in the waters of Kattegat and Skagerrak (Teilmann et al., 2008). The harbour porpoise is greatly affected by human disturbances as their habitat is used for many anthropogenic activities and their diet often overlaps with species that are commercially important (Jefferson and Curry, 1996). The status of the harbour porpoise subpopulation inhabiting Kattegatt and Skagerrak is classified as least concern by Artdatabanken SLU (Tjernberg and Thurfjell, 2019). One of the major threats to harbour porpoise population sustainability is thought to be the high incidence of bycatch specifically in gillnets (Jefferson and Curry, 1994; Trippel et al., 1996; Bisack, 1997).

The harbour porpoise like other odontocetes uses echolocation clicks to communicate, forage and navigate under water (Tyack, 1999). The majority of research on echolocation of odontocetes comes from studies in captivity and thus very little is known about echolocation of dolphins and porpoises in the wild and its ecological and behavioural significance (Au, 1993; Cox and Read, 2004). Harbour porpoises display specific click patterns for orientation, prey capture and intraspecific communication (Verfuss et al. 2005, Koschinski et al. 2008, DeRuiter et al. 2009, Verfuss et al. 2009, Clausen et al. 2011). This enables discrimination of different behavioral categories such as communication (Clausen et al. 2011), foraging (Koschinski et al. 2008, DeRuiter et al. 2009, Verfuss et al. 2009, Linnenschmidt et al. 2013) and navigation (Verfuss et al. 2005) by analyzing click patterns.

When a porpoise find and encounter an object which they want to investigate, such as potential prey, they display a specific pattern of clicks. This click pattern or click sequence can be divided into phases characterised by changes in echolocation behaviour causing altered inter-click intervals (ICI), the time elapsed between the peaks of two consecutive clicks (Madsen et al., 2005). The phases consist of a search, approach and terminal phase (Verfuss et al. 2009). The pattern in ICI during the search phase seems to be driven by a range locking to objects until a potential target can be detected (Koschinski et al., 2008). The approach phase is characterised by inter-pulse intervals that decreases linearly with target distance (Morozov et al., 1972; Au and Benoit-Bird, 2003; Verfuss et al., 2009; Linnenschmidt et al., 2012). The terminal phase is marked by a sudden and rapid shortening of ICI to levels of below 10 ms (DeRuiter et al. 2009, Verfuss et al. 2009) which is called terminal buzz (buzz feed) which is when porpoise click repetition rates in an echolocation series reach a peak in speed as the animal arrives close to the target. Porpoises have been shown to specifically use buzzes when inspecting objects at close range (Schevill et al., 1969; Au, 1993; Verboom and Kastelein, 1995; Lockyer et al., 2001)

Studying porpoise echolocation behaviour can be done by using different forms of passive acoustic monitoring either by acoustic tagging of animals or static recording devices like click detectors and sound recorders (e.g. Akamatsu et al., 2010; Nielsen et al., 2012; Boström et al., 2013; Dede et al., 2014). Earlier studies have shown that click detectors like the F-POD

(Chelonia Ltd) is a promising tool for behavioural studies (e.g. Sveegaard et al., 2017; Kyhn et al., 2018; Kindt-Larsen, 2019; Amundin, 2020). It is possible to recognize certain acoustic behavioural categories by looking for specific click patterns but it is important to also look at the click patterns in relation to the other clicks in the click data as click patterns can otherwise be misinterpreted (Akamatsu et al., 2007; Koschinski et al., 2008; Todd et al., 2009; Sørensen et al., 2018; Berges et al., 2019).

One of the major research areas in bycatch mitigation of small cetaceans is development of passive acoustic deterrents and gear modifications. To date the use of pingers appear to be the most effective available alternative for decreasing bycatch while still continuing to fish with gillnets but their use have also resulted in additional problems and questions regarding their overall effects on wildlife (Dawson et al., 2013; FAO, 2018). As the use of pingers can cause some problems in its own and the fact that even when used properly pingers do not prevent bycatches entirely for reasons yet unknown there is a need for additional tools for bycatch mitigation. In particular for the species of small cetaceans that only exist in very small numbers where bycatches need to be eliminated (Dawson et al., 1998 and 2013; FAO, 2018). A possible alternative could be the development of new gillnet modifications that increases the detectability of nets (Trippel et al., 2003; Cox and Read, 2004; Koschinski et al., 2006; Mooney et al., 2007). One such possible mitigation strategy for bycatch of small cetaceans is acoustic modification of gillnets through the use of air filled spheres. Acoustic reflectors targeting odontocete cetaceans in fisheries with demersal longlines such as bubble screens or attaching components like acrylic beads have previously been used as acoustic-camouflage. In attempts to simulate the acoustic signal of target catch to confuse marine mammals from detecting the actual catch (O’Connel et al., 2015). Acoustic reflectors have however not shown any promise experimentally for decreasing depredation (O’Connell et al., 2015; FAO, 2018). The use of acoustic reflectors (air filled nylon-strands, bead chains, metal enriched nets) to make gillnets more acoustically visible to echolocating cetaceans have been tested in several studies with mixed results (Koschiski and Culik, 1997; Goodson 1997; Gordon and Northridge, 2002; Tripperl et al., 2003; Cox and Read, 2004; McPherson and Nishida, 2010; McPherson, 2011; ACCOBAMS, 2019). The advantage of acoustic reflectors is that it represents a relatively low cost gear modification and use of the technique requires no skill to attach acoustic-producing units (FAO, 2018).

Kratzer et al. (2020) wanted to test the use acoustic reflectors in the form of small air filled spheres used on gillnets as a possible mitigation strategy for bycatch of harbour porpoise. The theory was that attaching small air filled spheres on nets would make nets appear as a wall to harbour porpoises. Different materials and sizes of spheres were tested to find a material that resonated at the same frequency as harbour porpoise clicks (130 kHz). They found that acrylic glass pearls of 8 mm in diameter gave the best results and tested them in a study on fishing nets in the turbot fishery in the Black Sea outside Turkey. This showed that the net with pearls had a lower bycatch of harbour porpoises but the difference in bycatch was not significant.

The aim of the present study was to evaluate the use of acrylic glass pearls as acoustic reflectors on a gillnet as a possible bycatch mitigation strategy for harbour porpoise as the earlier study by Kratzer et al. (2020) showed promising results. This was examined by looking at porpoise clicks (detective positive minutes per hour, DPM/hour) assuming that DPM/hour is proportional to porpoise abundance which in turn is proportional to bycatch rate (Kyhn et al. 2012, Kindt-Larsen et al. 2016 and 2018). We wanted to focus on evaluating if there was any variation in DPM/hour depending on if the gillnets had pearls or not, diel phase, depth, weather, wind velocity, wave height and consecutive days from start of the experiment. The click data was also filtered for the specific click pattern called buzz feeds in relation to total number of clicks (buzz ratio) as a proxy for click behaviour to see if there were any differences in click behaviour (buzz ratio) between the net with pearls and control net.

# Method

## 2.1. Study site and set up

The study was carried out in Skagerrak in the lumpsucker fishery, in the spring of 2020. The set up consisted of two gillnets, one experimental gillnet with acrylic pearls and one commercial gillnet as control. The study was divided into two parts. In the first part of the study (period 1) three rows of pearls were attached to the experimental with a larger spacing of 60 cm and during the second part of the study (period 2) an additional three rows of pearls were attached to the experimental net making the total number of rows six, with a smaller spacing of 30 cm (Figure 3). The distance between pearls was chosen based on the previous study by Kratzer et al. (2020) which choose the 30 cm distance as it was determined to be the maximum distance between two objects needed so that a porpoise does not attempt to swim through by Nakamura et al. (1998). The larger spacing of 60 cm was chosen to see the effects of a larger spacing between pearls (half the total amount of attached pearls).

Each gillnet was 240 m long and consisted of a string of four net panels each 60 m long with a height of 2 m and a mesh size of 250 mm targeting *Cyclopterus lumpus.* The net filament was a multi-mono blue coloured fibre with a thickness of 0,5 mm. The experimental and control net were set at a minimum of 400 m distance from each other. One porpoise click detector (F-POD) was placed at each end of the two nets moored in the anchor line in line with the lead line, approximately 5 meters above the sea bed (Figure 1). To record harbour porpoise clicks around the gillnets as a proxy for porpoise presence which in turn functions as a proxy for bycatch rate (Kyhn et al. 2012; Kindt-Larsen et al. 2016 and 2019). To simplify deployment for the fisherman and analysis of the click data the same pair of F-PODs were always used for the same net. F-PODs C6178 and C6179 were always attached to the control net and F-PODs P6180 and P6181 were always attached to the net with pearls.

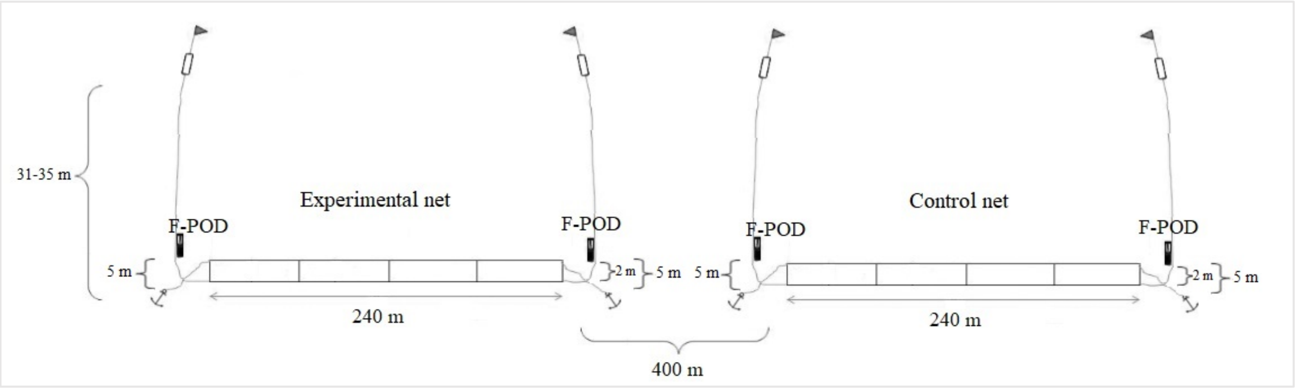


*Figure 1. Set up of experimental and control net. Deployment depths varied between 31 to 35 m. The F-PODs were suspended 5 m from the ocean floor. The nets were 2 m high and 240 m long and set a minimum of 400 m apart.*

The catch including any bycatch of harbour porpoise was filmed by the fisherman with a portable automatic video system developed by SLU Aqua and also recorded in a protocol. In the protocol the fisherman noted for the experimental net and control net separately date of deployment of and end of deployment, deployment depth, F-POD id of the two F-PODs used on the net, coordinates for each end of the net, target catch as number of fish, number of bycaught porpoises, number of bycaught birds and species, number of bycaught seals and species, any seal damage on the net and any practical problem arising from the pearls on the experimental net. The video data was later visually inspected for each deployment noting times for beginning of deployment and end of deployment of each net and also the total time that the fisherman was in the area as the nets of a pinger study was deployed during the same trips and also filmed with the same video system. Any catch and bycatch of porpoise, seal, bird and other bycatch was noted in number of individuals and then compared to the fisherman’s notes in the protocol.

The study was carried out from the 3rd of March to the 5th of June 2020 at water depths between 31 and 35 m at open sea (Figure 2). Period 1 took place between the 3rd of March to the 30th of March lasting 27 days, and period 2 took place between the 18th of May to the 1st of June lasting 15 days. Nets were deployed in the mornings and the nets were moved and set in a new spot each deployment. Each deployment usually lasted 3 days but at times when the weather conditions didn’t allow deployment a deployment could last longer. The bottom consisted of clay (Naturvårdsverket 2009).

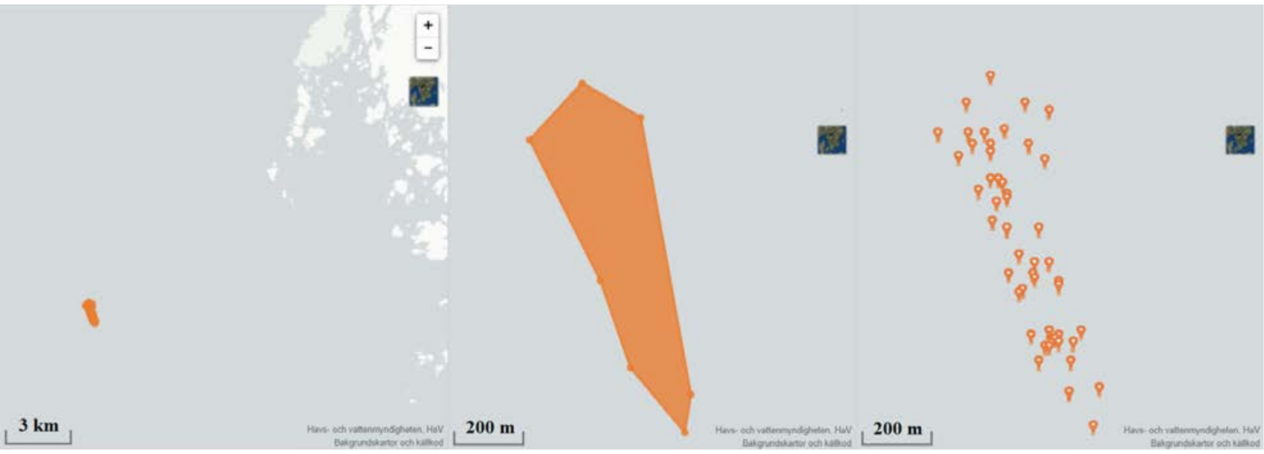


*Figure 2. Left: study area on in relation to the coast (scale 1 cm:3 km), middle: size of study area (scale 1cm: 200 m) and right: deployment coordinates for end of nets during the study (scale: 1 cm: 200 m) (Havochvatten.se).*

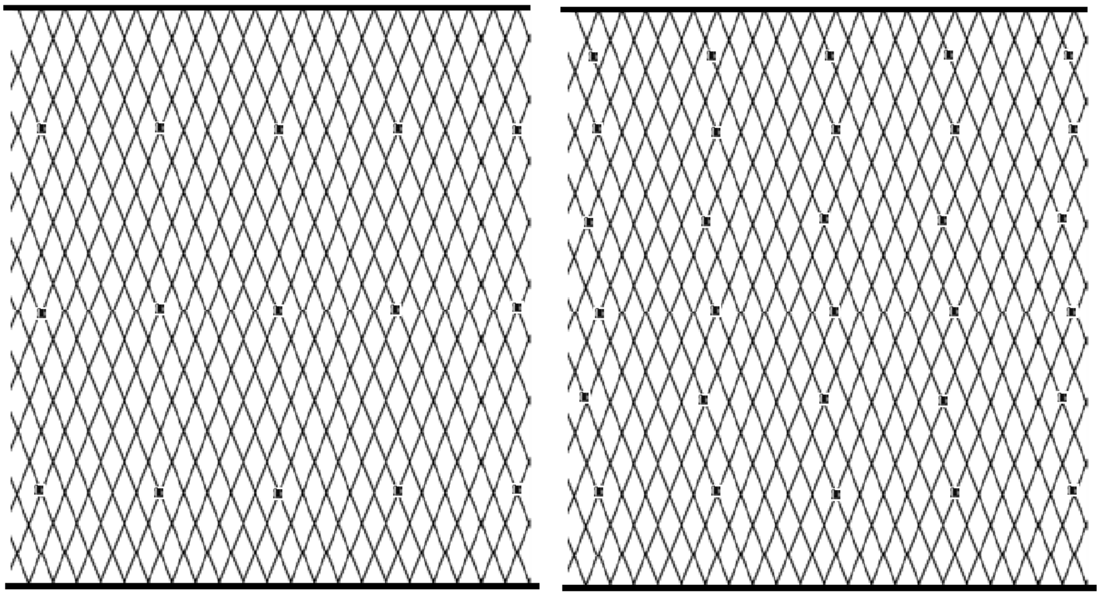
After four weeks which corresponded to the middle of the project and the end of period 1both the pearled net and control net were taken ashore to attach the final number of pearls to the experimental and then redeployed for period 2 after two weeks. The total number of hauls for the study was eleven for the control net, six hauls in period 1 for the experimental net and five hauls in period 2 for the experimental net. The project was planned to end in the middle of May but as the fishing was very poor with almost no catch of the target species *Cyclopterus lumpus* during the entire project and large bycatches of *Squalus acanthias* in the end of April it was decided to end the project early. This meant that the period 2 of the project with a set up with 30 cm distance between pearls was only deployed for two weeks instead of the planned 4 weeks as for period 1 and 60 cm distance between pearls. However it was discovered during data retrieval from the FPODs that both the FPODs attached to the net with pearls had malfunctioned after less than an hour after being switched on. It was therefore decided to extend the project three more weeks to the beginning of June in a new attempt to collect data for period 2 with the 30 cm distance between pearls.

## 2.2 Pearls

The experimental net was equipped with 8 mm acrylic pearls developed in a collaboration between Thünen-Institute for Baltic Sea Fisheries, DTU Aqua and Sinop University, in an attempt to make fishing nets more visible to harbour porpoises (Kratzer et al. 2020).

Each of the four 60 m net panels of the pearl net were suspended above the floor by the lead line so that the sink line was in level with the floor for the attachment of pearls. The pearls were attached to the net by inserting the twine in a slit of each pearl after which acrylic glass adhesive (ACRIFIX 1R 0192) was added to fill and seal the slit and lock the twine in place. To ensure that pearls stayed attached to the net until the final glue was added and was dry enough for the pearls not to fall off, a small amount of glue was added to the slit of each pearl and allowed to dry until the glue was sticky enough for the pearls to stick to the twine prior to them being put on the net. The spacing of 60 cm between pearls required approximately 2500 pearls for 240 m net, where the first row of pearls was 1,5 meshes from the sink line. The second row was 3 meshes from the first row. The third row was 3 meshes from the second row with 2 meshes to the lead line (Figure 3). Between each pearl in the same row the spacing was 5 meshes. After attaching all pearls and adding the final glue the net panels were allowed hang over night and were taken down the following morning.

After the first part of the study both control and experimental net were taken ashore and the procedure of attaching pearls was repeated for the pearled net this time with a spacing of 30 cm between pearls. The spacing of 30 cm between pearls required approximately a total of 5000 pearls, where the first row of pearls was 1,5 meshes from the sink line. The second row was 1,5 meshes from the first row. The third row was 1,5 meshes from the second row. The fourth row was 1,5 meshes from the third row. The fifth row was 1,5 meshes from the fourth row. The sixth row was 1,5 meshes from the fifth row with 1 mesh to the lead line. Between each pearl in the same row the spacing was 5 meshes (Figure 3).



Experimental net 60 cm spacing between pearls (period 1)

Experimental net 30 cm spacing between pearls (period 2)

*Figure 3. Placement of pearls in period 1 and period 2 with 60 cm spacing in period 1 between pearls and 30 cm spacing in period 2 between pearls.*

## 2.3 Passive acoustic monitoring and porpoise echolocation activity

Porpoise echolocation activity was recorded using porpoise click detectors (F-PODs, Chelonia Ltd., Mousehole, U.K.). F-PODs are automatic ultrasound monitors that detect tonal clicks such as echolocation signals and consist of an omnidirectional hydrophone that records short duration sound clicks within a frequency range of 20-160 kHz. For each click the F-POD log start time, duration, dominant frequency, and sound pressure level which is used to recognize porpoise click trains. F-PODs were calibrated for the main frequency of a harbour porpoise click (130 kHz) and standardized to the same acoustic threshold (±3 dB) (see http://www.chelonia.co.uk for further information).

The raw data was exported to the custom-made analysis software FPOD.exe version 1.0.0.03 (Chelonia Ltd, UK) for click classification where the created FP1 files were run through the KERNO classifier which is a train detection and classification algorithm that classifies the origin of clicks in FPOD.exe. The KERNO classifier was set to only extract Narrow Band High Frequency NBHF clicks of porpoise origin of high to moderate quality. After identification of high and medium quality porpoise clicks in the KERNO classifier in FPOD exe the output FP3 files were exported as clicks per minute and detection positive minutes (DPM) per hour for each F-POD and imported into Excel in a database. Data recorded between 06.00 in the morning to 14.00 during days of deployment which corresponded to the total time the boat was in the area were omitted to exclude the effect of noise from the fishing boat used for deploying gillnets and F-PODS as the fishing boat also retrieved and deployed nets for another study in the same area at the same time and thus was present in the area for a considerable amount of time and the order in which the different nets were handled differed between deployments.

## 2.4 Effect of pearls on porpoise click rates

To analyse any effects of the use of pearls on porpoise click rates a model was created. The data in the database in Excel was imported into R studio version 1.2.5033 (R Studio, Inc) to create the models. The click data had a non-normal distribution and was therefore analysed using generalized additive models (GAM) to relate detective positive minutes per hour to predictor variables including fishery with or without pearls, water temperature, depth, wind velocity, maximum wave height, diel phase and day of period.

It was discovered that the distance between the control net of the pearl study and nets with pingers of another study in the same area during period 1 had only between 450-500 m from a pinger. The distance was checked between the nets of the pearl study and the nets of the pinger study by calculating the distance using the coordinates for ends of the nets provided by the fisherman. This meant that the pingers may have affected the results of the control net of the pearl study during period 1. As the instructions of a minimum distance of 500 m between the nets of the pearl study during period 1 and the nets of another study with pingers which took place at the same time in the same area had not been followed to a full a variable of "minimum distance to pingers" was added for period 1 in order to assess the potential role of the pingers on porpoise presence around the nets of the pearls study in period 1. The minimum distance between each end of the nets of the pearl study and each end of the nets with pingers of the other study was calculated using the GPS-coordinates for the position for each end of the nets provided by the fisherman. The smallest distance was then put in the database and used for the variable for the pinger distance.

The environmental variables weather, wind velocity and maximum wave height were obtained and downloaded from the online weather database of SMHI. Water temperature was obtained from the F-POD data. Depth was obtained from the fisherman's log. A variable for currents was supposed to be included but as no reliable open database was found so this variable was excluded. All the SMHI variable data was available on an hourly basis. As the study area was less than half a square kilometre the data used for all F-PODS came from the same measuring station (Figure 2). All environmental predictor variables were expected to influence porpoise presence. Diel phase times were obtained from vackervader.se. The diel phases were defined as followed:

Phase 1: Duration of civil Dawn to Sunrise.

Phase 2: Sunrise to start of civil Dusk.

Phase 3: Duration of civil Dusk to Sunset.

Phase 4: Sunset to start of civil Dawn the following day.

AIC, R-squared and diagnostic plots (residuals versus fitted-, normal qq-, scale location- and residuals versus leverage-plot) was used to determine whether the dependent variable number of porpoise detections per hour (DPM/hour) were most adequately modelled using a GAM model with either Gaussian distribution or Negative Binomial distribution. All models were based on the filtered F-POD data. As the models on DPM/Hour resulted deviating diagnostic plots (residuals versus fitted-, normal qq-, scale location- and residuals versus leverage-plot) it was decided to perform the models on averages of DPM/Hour per date per diel phase which gave more parsimonious models with lower AIC scores, better R-squared values and normal diagnostic plots (Appendix 1). The GAM model with a Negative Binomial distribution on DPM per hour per day and diel phase was most parsimonious so this model was chosen for further analyses of the data. In order to find the set of predictor variables that best explained variations in DPM/Hour, the full model was compared with models using different combinations of the predictor variables removing the variables without significance and looking at AIC score and R-squared values (Table 1).

Full model:

gam(DPM/Hour) ~ as.factor(pearls) + as.factor(diel phase) + s(depth) + s(water temperature) + s(wind velocity) + s(wave height) + s(day of period) + s(distance pinger)*, family= Negative bionomial (1)

*Only used for period 1 model data.

*Table 1. Predictor variables used in the models with respective names, abbreviations, the value range for each predictor variable and a description of each predictor variable.*

| **Predictor variables** | **Abbreviations** | **Value range** | **Description** |
|---|---|---|---|
| Pearls on net | Pearls | Factor with 2 levels "yes" or "no" | Net with pearls (experimental net) or without pearls (control net). |
| Diel phase | Diel phase | Factor with 4 levels diel phase 1 (dawn), diel phase 2 (day), diel phase 3 (dusk), diel phase 4 (night) | Diel phases are defined as described above in the text. |
| Depth | Depth | 30-36 m | Deployment depth of net in meters. |
| Water temperature | Water temperature | 1-2 °C | Temperatures in degree Celsius registered by the F-PODs. |
| Wave height | Wave height | 0,22-6,06 m | Maximum wave height each hour in meters. |
| Wind velocity | Wind velocity | 0-18,1 m/s | Wind velocity each hour in meters per second. |
| Day of period | Day of period | Period 1: 1-27<br>Period 2: 1-15 | Day of study where the date of first deployment of nets corresponds to "day 1". |
| Shortest distance to pinger | Distance pinger | Control net: 0,46-0,52 km<br>Experimental net: 0,857-0,981 km | Shortest distance in kilometres of between the end of a net to a pinger from another study in the same area in period 1. Only used for period 1. |
| Period | Period | Factor with 2 levels "period 1" or "period 2" | Used to analyse the effect of different spacing between pearls 60 cm (period 1) and 30 cm (period 2) |

## 2.5 Classification of buzz feeds

To analyse possible differences in click behaviour between the experimental and control net the click data was filtered for the specific click pattern called buzz feeds. For classification of buzz feeds the methodology of Pirotta et al. (2014) was used. The F-POD output FP3 files was used to get the Inter-Click Intervals (ICI) of the click data using the ICI-export in FPOD.exe. This gave ICI's with time stamps of all individual clicks classified as porpoises by FPOD.exe. Click intervals within click trains identified by the F-POD software were then classified as either high-repetition rate (indicative of a buzz) or low-repetition rate (indicative of search). But instead of using an adaptive modelling procedure to determine the best cut-off value between high and low repetition rates as Pirotta et al. (2014) a fixed criterion of 15 ms for buzzes based on Wisniewska et al. (2012) was used, low-repetition rate ICI's were defined as <250ms based on previous studies (Villadsgaard et al. 2007, Koschinski et al. 2008, Amundin 2020).

To acquire the "buzz ratio", which is the ratio between the number of "buzz ICI's" and the total number of ICI's per diel phase, the resulting text files were run through the custom-made Matlab script (Mathworks Inc., R2018b) "Data_reader_2019_01_08_MA.m" (Courtesy Eskil Amundin, Amundin Tech AB, SE). This script calculates the buzz ratio for each diel phase (Night, Dawn, Day, and Dusk); file format "ratio_diel_phase_SMnn YYY MM DD POD# file01.txt". The buzz ICI ratio for the night was calculated using the number of BuzzICI's and ICISum between midnight and start of Dawn and d:o from end of Dusk until midnight of the same date. The script also extracts the total number of buzz ICIs (BuzzSum) per dial phase for each day; file format "Buzz_sum_SMnn YYYY MM DD POD# file01.txt". The diel phases for the buzz ratios were calculated using the Matlab function "Sunset.m" (M. Mahooty, Mathworks file exchange). This function uses the coordinates for the study area for the calculations, LAT (=phi in Sunset.m) and LON (=lambda in Sunset.m). To get the buzz ratio per hour each day another Matlab script called "Data_reader_2019-06-26.m" (Courtesy Eskil Amundin, Amundin Tech AB, SE) was used to calculate the buzz ratio per hour for each day; the file name was "ratio_hour_SMnn YYYY MM DD POD# file01.txt". The hours where there were no detections at all were marked "-1", to separate them from hours where there were no buzzes, but still ICI's; these hours were marked 0. The extraction of buzzes gave number of buzzes per diel phase per date

The hours during which the fishing boat was in the area during hauling of nets was not removed from the click data before export of buzzes. It is therefore possible that the buzz data contains "false" click detections that are not of porpoise origin. However the F-POD files had been run through the same process as the DPM per hour data using the F-POD exe. KERNO classifier set to only extract moderate to high quality clicks which decrease the chances of "false" click detections. And all buzz data from the start date and the date for retrieval of the nets for both periods were excluded from the analysis of buzzes and buzz ratios to decrease possible "false" porpoise click detections. The buzz data was also visually inspected during the hours the fishing boat was known to have been in the study area for extreme values which could distort the results. The resulting buzz data was then compared between the control and experimental net. A Shapiro-Wilks test was performed to check if the data was normally distributed the result showed that the data is not normally distributed. As the data was not normally distributed a Mann-Whitney-Wilcoxon test was performed on the buzz data to see if any differences in buzz data between the pearl net and control net were significant.

# 3. Results

The video data confirmed the fisherman's notes in the protocol without any deviations including the absence of bycatch of harbour porpoise during the study. In period 1 all F-PODs recorded 900 hours of click data and during period 2 the F-PODs recorded 530 hours of click data.

## 3.1 Overall click loggings

To look at the overall click loggings for each F-POD in the two periods the F-FOD click files were run through the "Analysis" tool in F-POD.exe. This gives the total number of clicks in the FP1 file (before click classification in KERNO classifier, total number of clicks classified as porpoise clicks (Narrow Band High Frequency, NBHF) clicks in the FP3 file, the proportion of the overall quality for clicks either moderate and/or high quality where chances of "false" NBHF click detections decreases with quality, average NBHF clicks per day, total of number of detective positive minutes (DPM) with NBHF clicks and total number of hours recorded (Table 2 and Table 3). All the values are based on the entire click files which includes the hours with detections during hauling of nets which increases the amount of "false" click detections. The overall click loggings show that amount of clicks detected in period 1 is much greater than the amount of clicks detected in period 2 for all the click categories. It also shows a large variation in clicks detections between the F-PODs.

*Table 2. Overall click loggings for each F-POD in period 1. Number of clicks in the FP1 file is the total number of clicks before click classification in the KERNO classifier. Number of clicks classified as porpoise clicks (Narrow Band High Frequency, NBHF) in the FP3 file. The proportion of the overall quality for NBHF clicks, either moderate and/or high quality. Average clicks per day is the average NBHF clicks detected per day. Total of number of detective positive minutes (DPM) is the total number of minutes that contain detections of NBHF clicks. Total number of hours recorded is the total number of hours recorded by each F-POD.*

| **Period 1 F-POD id** | **C6178** (control) | **C6179** (control) | **P6180** (pearls) | **P6181** (pearls) |
|---|---|---|---|---|
| Number of clicks in FP1 file | 13,967,226 | 8,088,050 | 9,532,649 | 10,184,379 |
| Number of NBHF Clicks in FP3 file | 143,790 | 178,083 | 2,722 | 286,623 |
| Average number of clicks per day | 3,803 | 2,933 | 72 | 7,580 |
| Total number of DPM | 3055 | 362 | 55 | 3263 |
| Quality of clicks | Moderate | Moderate | Moderate/High | Moderate/High |
| Total number of hours | 907 | 907 | 907 | 907 |

*Table 3. Table 2. Overall click loggings for each F-POD in period 2. Number of clicks in the FP1 file is the total number of clicks before click classification in the KERNO classifier. Number of clicks classified as porpoise clicks (Narrow Band High Frequency, NBHF) in the FP3 file. The proportion of the overall quality for NBHF clicks, either moderate and/or high quality. Average clicks per day is the average NBHF clicks detected per day. Total of number of detective positive minutes (DPM) is the total number of minutes that contain detections of NBHF clicks. Total number of hours recorded is the total number of hours recorded by each F-POD.*

| **Period 2 F-POD id** | **C6178** (control) | **C6179** (control) | **P6180** (pearls) | **P6181** (pearls) |
|---|---|---|---|---|
| Number of Clicks in FP1 file | 2,035,081 | 2,249,637 | 2,872,280 | 1,549,592 |
| Number of NBHF Clicks in FP3 file | 11,877 | 19,849 | 1,204 | 587 |
| Average number of clicks per day | 538 | 901 | 55 | 27 |
| Total number of DPM | 75 | 306 | 23 | 15 |
| Quality of clicks | Moderate | High | Moderate | Moderate |
| Total number of hours | 530 | 529 | 529 | 530 |

## 3.2 Effect of pearls on porpoise click rates

The predictor variable pearls was significant meaning that the predictor variable pearls explained variation in average detective positive minutes per hour in all the GAM models, the model for period, the model for period 2 and the model combining the click data for both period 1 and period 2 (Table 4, Figure 4, 5 and 6). Where the click data showed significantly less average detective positive minutes per hour (DPM/hour) recorded when using pearls in both periods.

The GAM model that best explained difference in detective positive minutes per hour (DPM/hour) per date and diel phase for the nets in period 1 had a R-square of 0.336 and explained 25,6% of the deviance and included the predictor variables pearls, diel phase, day of period 1, wind velocity and wave height (Table 4 and Figure 4).

The GAM model that best explained difference in detective positive minutes per hour (DPM/hour) per date and diel phase for the nets in period 2 with a R-square of 0.125 and explained 15.8 % of the deviance and included the predictor variables pearls, diel phase, wind velocity and wave height (Table 4 and Figure 5).

The GAM model that best explained difference in detective positive minutes per hour (DPM/hour) per date and diel phase for the nets when combining the data for both period 1 and 2 had a R-square of 0.389 and explained 30.5% of the deviance and included the predictor variables pearls, diel phase, day of period, period and wave height (Table 4 and Figure 6).

*Table 4. Results of the different GAM models for period 1 and 2 and the GAM model for the combined data of period 1 and period 2. Deviance explained shows how well each respective model explains the variation in the dependent variable average detective positive minutes per hour (DPM/hour). $R^2$ shows the adjusted r-squared for the model. n shows number of data points for average DPM/hour used in respective model. Predictor variables shows the predictor variables which gave the best respective model and their respective significance in relation to variation the dependent variable average DPM/ hour. Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.*

| **GAMs** | **Deviance explained %** | **n** | **$R^2$** | **Predictor variables** | **P-value** |
|---|---|---|---|---|---|
| Model period 1<br>Family=<br>Negative binomial (0.836) | 25.6% | 417 | 0.336 | Pearls<br>Diel phase:<br>Day<br>Dusk<br>Night<br>Day of period<br>Wind velocity<br>Wave height | 0.000 ***<br><br>3.42e-07 ***<br>0,007 **<br>8.67e-07 ***<br>0.0024 **<br>0.0147 *<br>0.078 . |
| Model period 2<br>Family=<br>Negative binomial (1.632) | 15.8 % | 208 | 0.125 | Pearls<br>Diel phase:<br>Day<br>Dusk<br>Night<br>Wind velocity<br>Wave height | 0.018 *<br><br>0.05 *<br>0.499<br>0.00513 **<br>0.02164 *<br>0.00239 ** |
| Model combined<br>Family=<br>Negative binomial (0.954) | 30.5% | 625 | 0.389 | Pearls<br>Diel phase:<br>Day<br>Dusk<br>Night<br>Day of period<br>Wave height<br>Period | 9.69e-05 ***<br><br>2.93e-07 ***<br>0.03 *<br>1.93e-09 ***<br>0.00533 **<br>6.05e-05 ***<br>< 2e-16 *** |

The partial response curves for average detective positive minutes per hour (DPM/hour) in the GAM model for data of period 1 in relation to predictor variables shows that average DPM/hour increases with wind velocities up to 10 m/s and decreases with higher wind velocities (Figure 4). Average DPM/hour increases with wave height. Average DPM/hour decreases with days from start of the period. Average DPM/hour is significantly lower when pearls are used. Average DPM/hour is significantly lower during diel phase 2 (day) and diel phase 3 (dusk) and significantly higher during diel phase 4 (night).

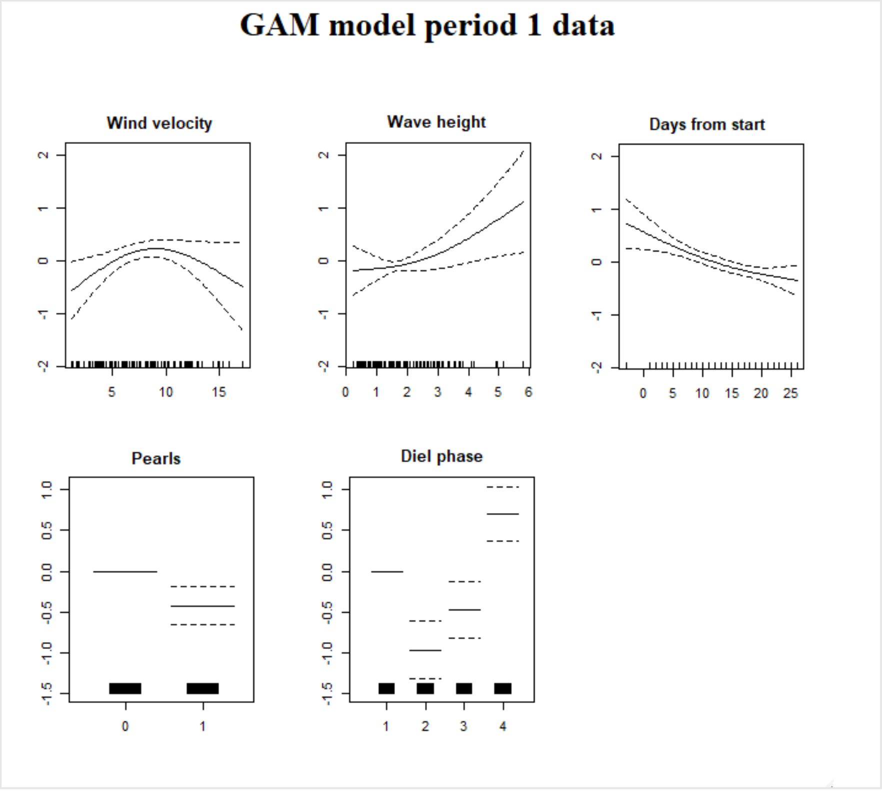


*Figure 4. Partial response curves for average detective positive minutes per hour (DPM/hour) in GAM model for data of period 1 in relation to predictor variables wind velocity, wave height, days from start, pearls and diel phase. Values above 0 indicate a positive effect of the respective predictor variable on average DPM/hour.*

The partial response curves for average DPM/hour in the GAM model for the data of period 2 in relation to predictor variables shows that average DPM/hour decreases with wind velocity (Figure 5). Average DPM/hour increases with wave height (p= 0.078). Average DPM/hour is significantly lower when pearls are used. Average DPM/hour is significantly lower during diel phase 2 (day) and diel phase 3 (dusk) and significantly higher during diel phase 4 (night).

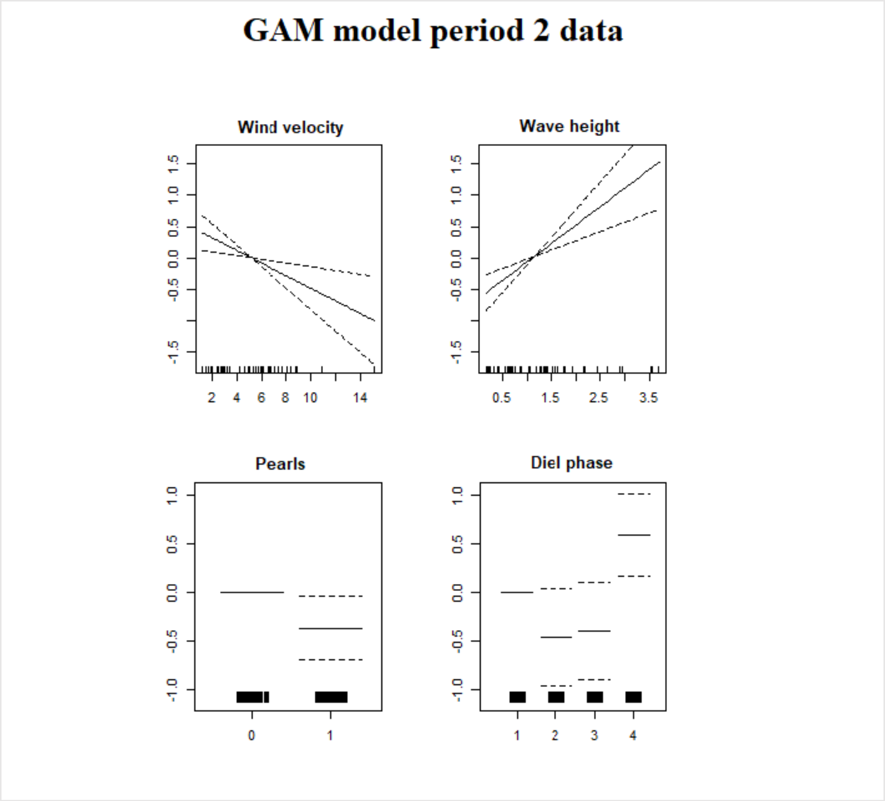


*Figure 5. Partial response curves for average detective positive minutes per hour (DPM/hour) in GAM model for data of period 2 in relation to predictor variables wind velocity, wave height, pearls and diel phase. Values above 0 indicate a positive effect of the respective predictor variable on average DPM/hour.*

The partial response curves for average DPM/hour in the GAM model for the combined data of period 1 and period 2 in relation to predictor variables shows that average DPM/hour increases with wave height (Figure 6). Average DPM/hour decreases with days from start of the period. Average DPM/hour is significantly lower when pearls are used. Average DPM/hour is significantly lower in period 2 compared to in period 1. Average DPM/hour is significantly lower during diel phase 2 (day) and diel phase 3 (dusk) and significantly higher during diel phase 4 (night).

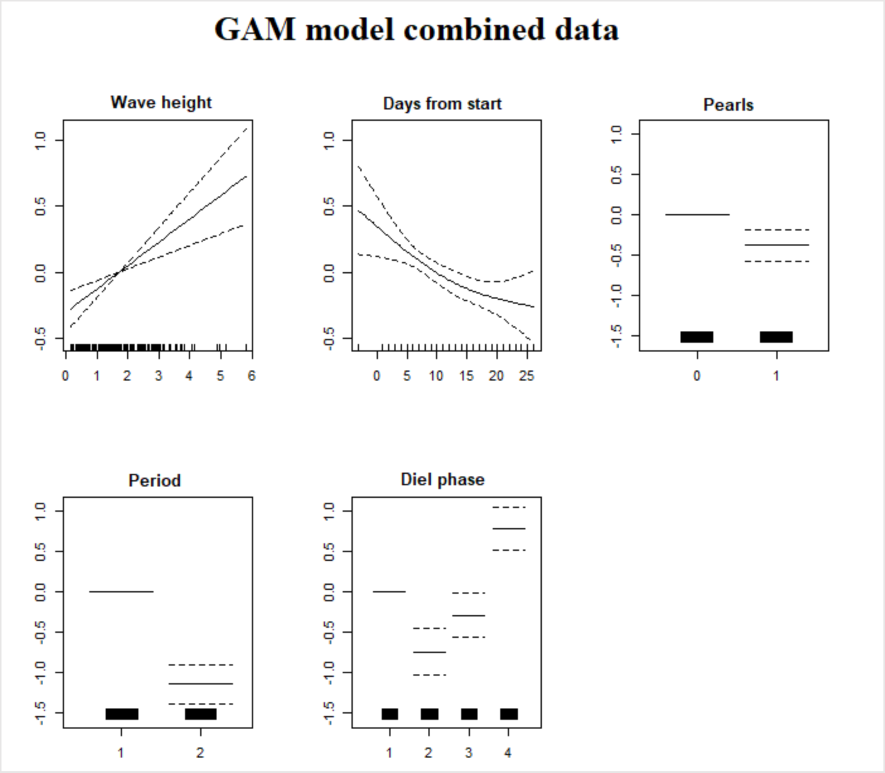


*Figure 6. Partial response curves for average detective positive minutes per hour (DPM/hour) in GAM model for combined data of period 1 and period 2 in relation to predictor variables wave height, days from start, pearls, period and diel phase. Values above 0 indicate a positive effect of the respective predictor variable on average DPM/hour.*

## 3.3 Effect of pearls on click behaviour

Mann-Whitney-Wilcoxon tests were used to compare average buzz ratio for each diel phase between all F-PODs in period 1 and in period 2 respectively and between diel phases in period 1 and period 2 for each F-POD. There was no significant difference between the average buzz ratio per diel phase for any of the F-PODs comparing period 1 with period 2. The only significant difference between the net with pearls and control net was found between F-POD C6178 (control net) and F-POD P6181 (experimental net) for diel phase day during period 2 where F-POD P6181 had a significantly higher average buzz ratio during diel phase day than F-POD C6178 (p= 0.0483). Doing the same comparisons for average buzz ratio per hour between the net with pearls and control net in period 1 and period 2 showed no significant difference.

### 3.3.1. Buzz ratio per diel phase

The data for average buzz ratio between each diel phase for each F-POD in period 1 showed a significant difference between all diel phases apart from between diel phases dawn and dusk (Figure 7). All the F-PODs displayed a similar distribution of buzz ratios with the highest buzz ratio during the day and the second highest during night. The values of average buzz ratios per diel phase during period 1 showed no significant differences between the control net F-PODs and experimental net F-PODs.

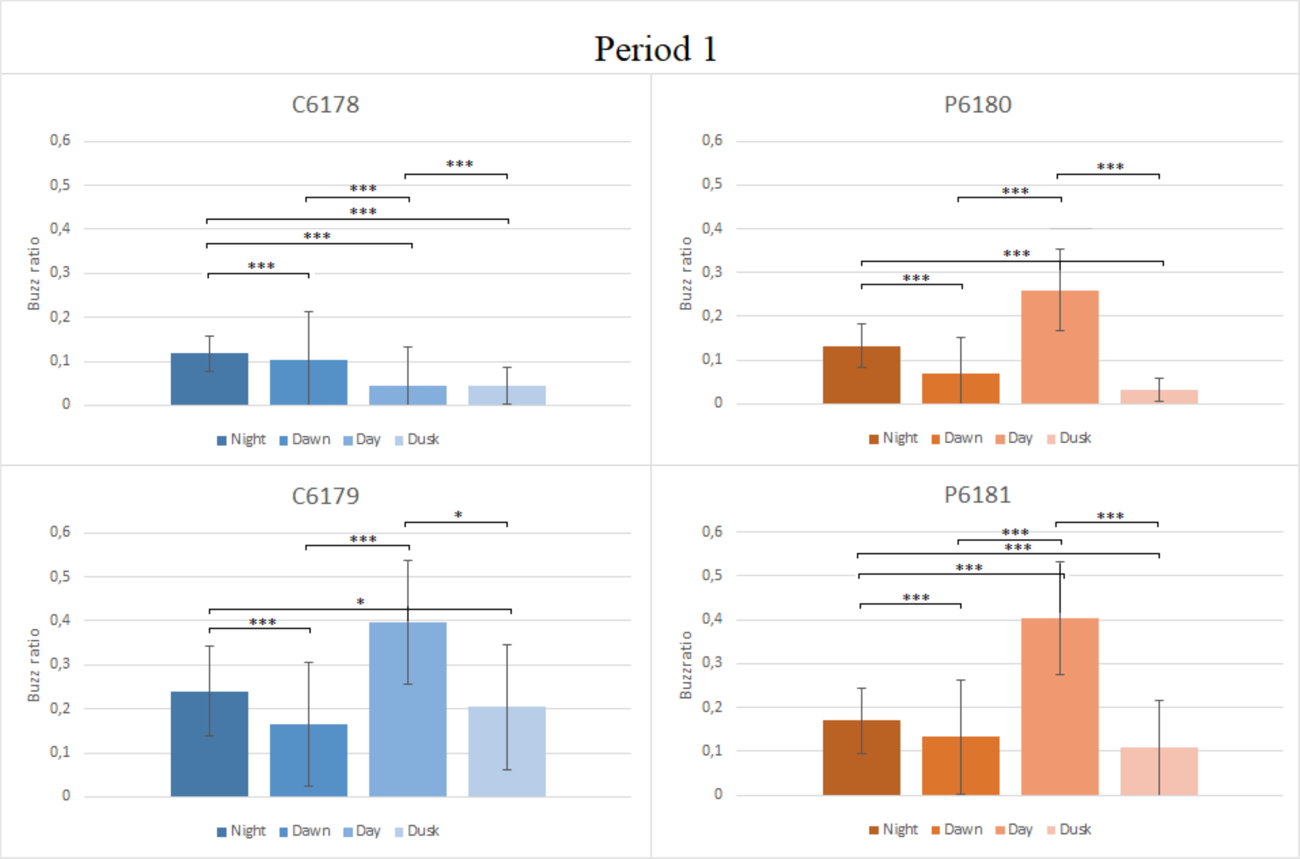


*Figure 7. Average buzz ratio per diel phase in period 1 for each F-POD. F-PODs C6178 and C6179 have been attached to the control net and F-PODs P6180 and P6181 have been attached to the experimental net with pearl s. The error bars display the 95% confidence interval. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.*

The data for average buzz ratio between each diel phase for each F-POD in period 2 showed a significant difference between all diel phases apart from between diel phases dawn and dusk (Figure 8). Overall the average buzz ratios per diel phase during period 2 are similar between the control net F-PODs and experimental net F-PODs. The only significant difference found between the net with pearls and the control net was found between F-POD C6178 (control net) and F-POD P6181 (experimental net) for diel phase day (p= 0.0483) meaning that F-POD P6181 (experimental net) had registered significantly more buzzes during the day than F-POD C6178 (control net).

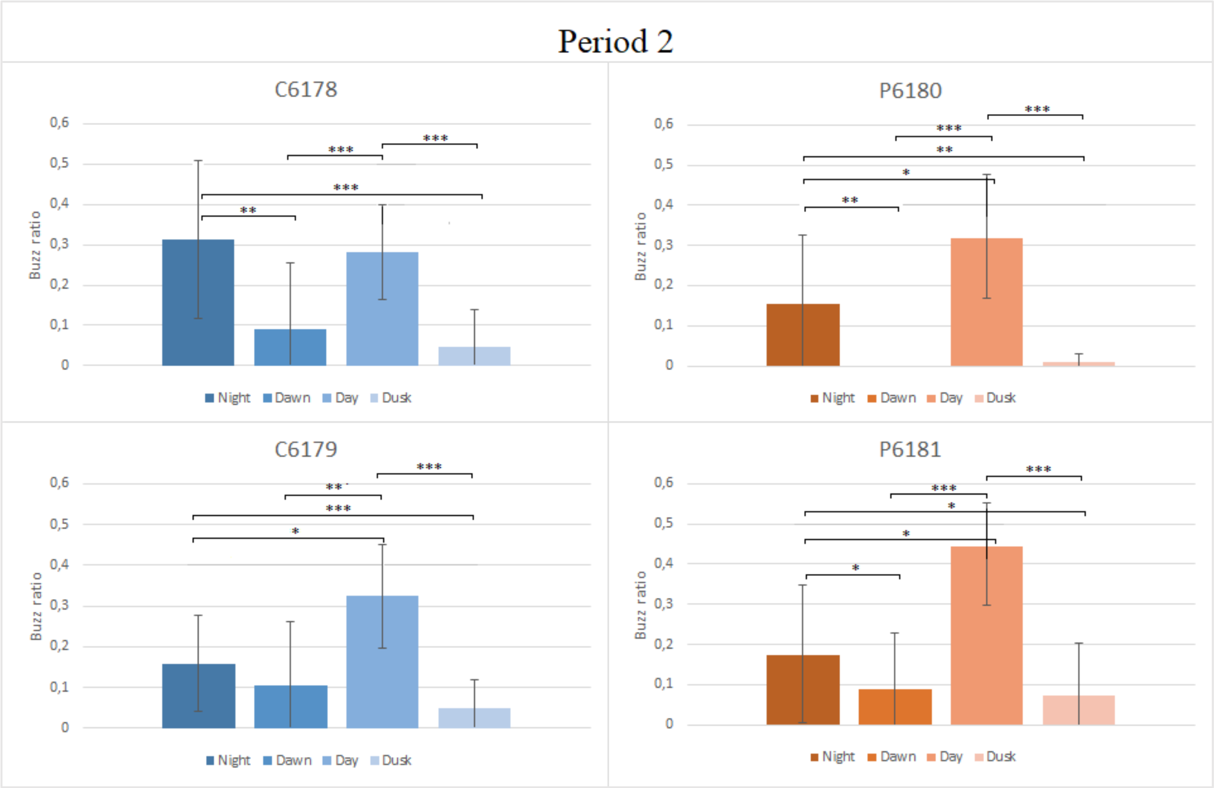


*Figure 8. Average buzz ratio per diel phase in period 2 for each F-POD. F-PODs C6178 and C6179 have been attached to the control net and F-PODs P6180 and P6181 have been attached to the experimental net with pearl s. The error bars display the 95% confidence interval. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.*

# 4. Discussion

The use of acrylic glass pearls as acoustic reflectors on a gillnet in this study resulted in significantly lower presence of harbour porpoises (detective positive minutes per hour). The 30 cm spacing between pearls also resulted in significantly lower presence compared to the 60 cm spacing. The use of acrylic glass pearls as acoustic reflectors on a gillnet as well as the spacing of the pearl also indicated changes in click behaviour. With significantly higher average buzz ratio for one of the F-PODs for the net with pearls (30 cm spacing between pearls) during the day than for one of the F-PODs on the control net.

## 4.1 Effect on porpoise presence

The use of pearls was significant in all three GAM models where the click data showed a significant decrease in average DPM/hour per diel phase recorded in relation the use of pearls in both period 1 and period 2 and for the combined data of period 1 and period 2 (Figure 4, 5, 6 and Table 4). This can perhaps explain the findings in the Kratzer et al. (2020) where a lower bycatch (not significant) of porpoises were seen in for the net with pearls. The pearls may affect porpoises in such a way that the porpoises stay far away enough from the net to not get entangled and this in turn leads to lower porpoise presence in vicinity of the net leading to less clicks being registered by the F-PODs. And the reason for this increased distance could be that the pearls make the nets more visible for a porpoise using echolocation as Kratzer et al. (2020) hypothesised and also saw when testing the net with pearls in a echosounder the pearls made the entire net more visible when using echolocation in comparison to the control net where only the lead lines were visible. That average DPM/hour is significantly lower during diel phase 2 (day) and diel phase 3 (dusk) and significantly higher during diel phase 4 (night) in the GAM models is probably due to the variation in porpoise activity during different parts of the day. Studies have shown that echolocation behaviour differ between diel phases (Carlström, 2005; Todd et al., 2009; Linnenschmidt et al., 2013). Porpoises have also been shown to be more active during night time (Carlström, 2005; Todd et al., 2009; Dähne et al., 2013; Linnenschmidt et al., 2013; Mikkelsen et al., 2013, Brandt et al., 2014; Kyhn et al., 2018). That porpoises are more active during night was also evident by looking at the click data where there often were many click recordings during at least four consecutive hours during diel phase night which was not seen during diel phase day or in the other two shorter diel phases dawn and dusk. That average DPM/hour decreases with wind velocity could be because wind velocity effects water movement and visibility in the water column which in turn affect porpoise distribution and presence either direct or indirect due to for example prey distribution. That average DPM/hour increases with wave height in the GAM models is surprising as wave height should correlate with wind velocity and effect water movement and porpoise presence in a similar way as wind velocity. Could it be that higher wave heights to a larger degree during night time when porpoises are more active or that wave height also depends on wind direction and certain wind directions increases prey availability and leading to an increase in porpoise presence and an increase in number of clicks being registered.

As it was discovered that the control net of the pearl study had only been set 450-500 m from a net with pingers for all deployments during period 1 the shortest distance from a net with pingers was calculated for each end of both the control net and the pearl net. And used as a variable for pinger distance in the period 1 models. This was done to see if pinger distance had a significant effect on the dependent variable DPM/Hour used as a proxy for porpoise presence as the pingers may have affected the results of the control net of the pearl study. No significance was found for the predictor variable for pinger distance in any of the GAM models regardless of combination of other variables. So the variable for pinger distance was excluded from the models. However this is no guarantee that the shorter pinger distance has not affected the average DPM/hour per diel phase for the control net during period 1.

The pinger type used in the other study in the same area was the future oceans netguard dolphin pinger (Future Ocean Ltd) with a frequency of 70 kHz and 145 dB with a recommended spacing of 200 m. As the effective distance, the distance that the pinger is effective in reducing porpoise presence, of this pinger have not been studied in any published study the information about effective distance had to be taken from studies on other pingers with a similar signal strength and frequency. In a study on harbour porpoise reaction to pingers by Kindt-Larsen et al. (2019) the Aquamark100 pinger (60-140kHz, 145 dB) was used to study the effects of this brand of pinger in 23 hour on and off cycles on porpoise presence at different distances in two areas. They found that the AQUAmark100 pinger gave a 2-fold decrease in number of clicks in trains per hour out to 400 m during cycles when the pinger was on in one area and a 3-fold reduction in the second area at 400 m during cycles when the pinger was on. Some studies have found that echolocation activity of harbour porpoises can decrease several kilometres away from an area with pingers (Johnston, 2002; Olesiuk et al., 2002; Kyhn et al., 2015). However in a study looking at the effect of the banana pinger (50-120 kHz, 145 dB) on porpoise detections they found that the pinger effect on detection rates decreased substantially only 100 m away (Crosby et al., 2013). The same was seen in a study by Königson et al. (2020) where they calculated the theoretical effective distance for the seal safe 70 kHz banana pinger which was found to be only 100 m. The effective distance of pingers has been shown to vary with depth, bottom type, and background noise levels, so the effective distance differ between different areas (Trippel et al., 1999; Hardy et al., 2002; Carlström et al., 2009; Larsen et al., 2013; Kindt-Larsen et al., 2019). Previous studies with 70 kHz pingers also suggest that different brands of pingers and different number of pingers may have different effective distances despite using the same frequency (Hardy et al., 2002; Kindt-Larsen et al., 2019). It is therefore unlikely that the pingers in the pinger study in the same area may have had on the results of this study. It would have been preferable to have performed the two studies in different areas. However for another study on porpoise bycatch mitigation it would be interesting to see what effects a combination of using both pearls and pingers on the same net may have on bycatch of harbour porpoise. As most pinger studies have some bycatch of porpoises and the previous study by Kratzer et al. (2020) using the same pearls with the 30 cm distance also had some bycatch of porpoises, perhaps the combination of the use of pearls and pingers may decrease bycatch even further or even eliminate porpoise bycatch altogether.

The lower significance for pearls in the period 2 model is surprising since the distance between pearls was half the distance between pearls used in period 1(Figure 4,5 and Table 4). The reason for this may be because of the smaller amount of data collected in period 2 as period 2 only lasted for 15 days which is about half the length of period 1 which lasted for 27 days. It can also be due to the fact that far less clicks were recorded during period 2 than in period 1 in total and per day which means a smaller amount of click data. The much lower quantities of clicks recorded in period 2 (Table 2 and Table 3) may be because the porpoises had left the area as porpoises show seasonal changes in distribution (Verfuss et al., 2007; Benke et al., 2014) Seasonal changes in distribution is often because of changes in for example prey availability and breeding (Edrén et al., 2010; Sveegaard, 2011; Sveegaard et al., 2012a and 2012b; Schaffeld et al., 2017). Period 1 of the pearl study took place in March while period 2 took place from the middle of May to the 1st of June. This corresponds to a 1,5 months gap between the two periods and as porpoise presence is seasonally correlated many of the porpoises in the area may have moved on to other areas. In Sveegaard et al. (2017) they also looked at click detections as a proxy for porpoise presence in an area in the south of Kattegatt called Store Middlegrund which is situated some distance south of the study area of the pearl study. Sveegaard et al. (2017) found that porpoise presence dramatically increased in Store Middlegrund during May until August. This suggests an increase in number of porpoises in the area coming from other adjacent areas. It is therefore possible that porpoises in the study area of the pearl study had migrated further south. That the only significant diel phase in the model for period 2 was night is most likely due to the fact that porpoises have been shown to be more active during night time (Carlström 2005; Todd et al. 2009, Dähne et al. 2013, Linnenschmidt et al. 2013, Mikkelsen et al. 2013, Brandt et al. 2014, Kyhn et al., 2018).

That the variable day of period had no significance in the period 2 model in contrast to the period 1 model may be because period 2 is just half as long as period 1 so there may not have been enough time for a significance to show for this variable (Table 2, 3 and 4). This may also be because of the lower numbers of clicks being recorded during period 2 leading to the differences being smaller between the days of period 2 and perhaps too small to be measurable with this amount of data.

The model for the combined data of period 1 and period 2 shows the same significant predictor variables as the model for period 1 (Table 4). This is not surprising as period 1 not only lasted twice as many days but had much more registered clicks than period 2 so the period 1 data effects the results to a greater extent than the period 2 data which probably only adds to the significance of the predictor variables that were significant for period 1 in the model for the combined data of period 1 and period 2. The significance of the predictor variable period which was added to see if there was a difference in effect between the 60 cm spacing and 30 cm spacing between pearls of period 1 and period 2 shows that there is a difference in effect on registered porpoise clicks. With significantly lower average DPM/hour detected for the 30 cm spacing in period 2. However to be able to confirm this a different setup deploying both a net with 60 cm spacing between pearls and a net with 30 cm spacing between pearls should be used to minimize sources of error and determine the effects of the different spacing between pearls.

## 4.2 Effect on echolocation behaviour

In period 2 the one of the F-PODs on the net with pearls had significantly higher average buzz ratio during the day than one F-POD on the control net. All the F-PODs displayed higher average buzz ratios during the day during both periods except for F-POD C6178 (control net) which had similar average buzz ratios during night and day (Figure 7 and Figure 8). Perhaps this is because the porpoises detect the nets to a greater extent during the day when they can use both sight and echolocation for object detection and the porpoises then inspect the nets leading to increased average buzz ratios during the day.

That the average buzz ratios appear slightly higher (not significant) for the pearl net in period 2 than in period 1 may be because the smaller spacing between pearls on the experimental net in period 2 catches the porpoises attention more than the net with 60 cm distance between pearls in period 1. It is also interesting to see that even though less clicks were registered in total for period 2 than in period 1 (Table 2 and Table 3) there is an indication of a higher proportion of buzz clicks during period 2. The highest average buzz ratios being registered during the day in this study contradicts the result of another study looking at buzz ratios where the highest ratios were detected during night (Amundin, 2020). The distribution of buzzes with the highest buzz ratio during night for one F-POD on the control net and second highest for the other three F-PODs however follows the trend of high activity during night time (Carlström, 2005; Todd et al., 2009; Dähne et al., 2013; Linnenschmidt et al., 2013; Mikkelsen et al., 2013; Brandt et al., 2014; Kyhn et al., 2018).

The significantly higher buzz ratio being registered during the day for the net with pearls during period 2 but not in period 1 could be that the combination of the smaller spacing (30 cm) between pearls on the experimental net in period 2 catches the porpoises attention in a larger degree and better light conditions. Both factors should make the net with pearls easier to see visually compared to the 60 cm spacing between pearls in period 1 and the control net. And if the net with 30 cm spacing between pearls is detected to a higher degree by porpoises perhaps this net is also inspected to a higher degree by porpoises leading to a higher buzz ratio for the net with 30 cm spacing.

## 4.3 Conclusion

This study shows that of the use of acrylic glass pearls as acoustic reflectors on gill nets decreases porpoise presence (detective positive minutes per hour) and indicates an increase in the porpoise click behaviour called buzz feeds (buzz ratio). These are preliminary results but they indicate that using acrylic glass pearls as acoustic reflectors on gillnets could be a promising new mitigation strategy for decreasing porpoise bycatch. Further studies should be carried out using a larger number of F-PODs attached along the entire length of the nets to increase the chances of registering clicks from porpoises echolocating towards the nets.

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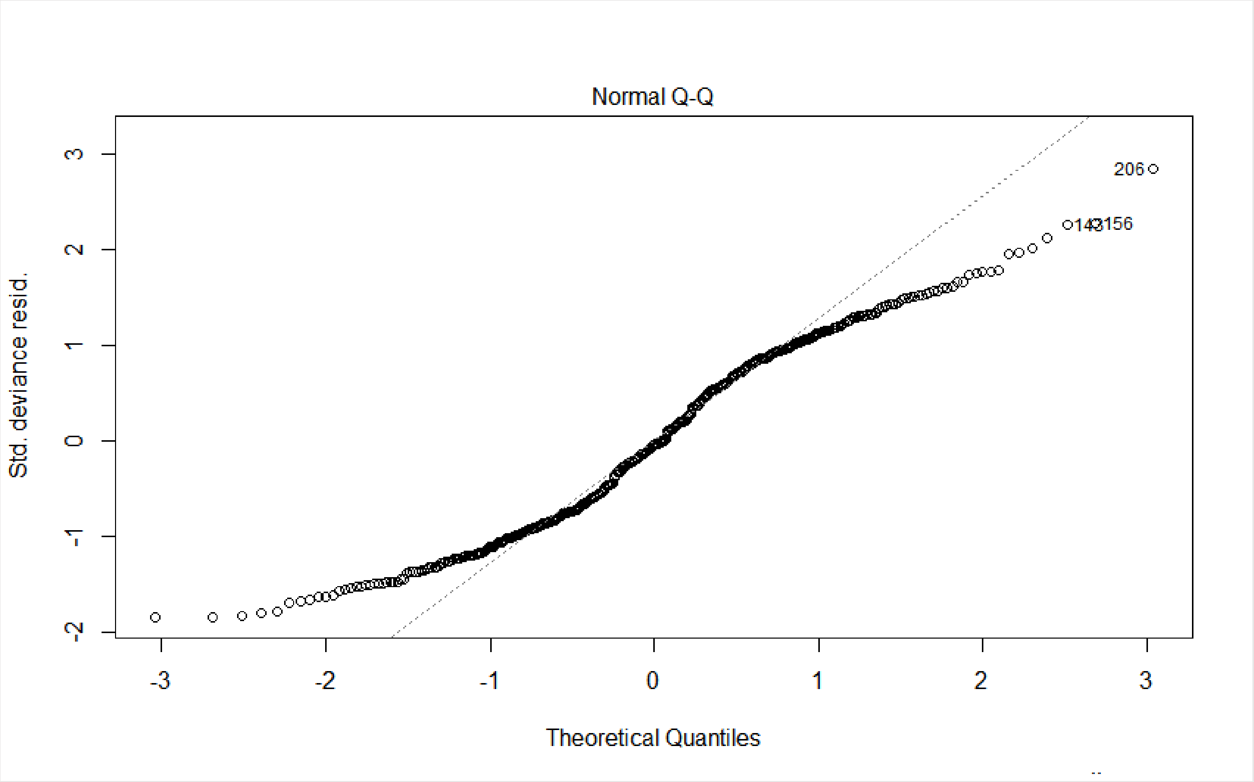
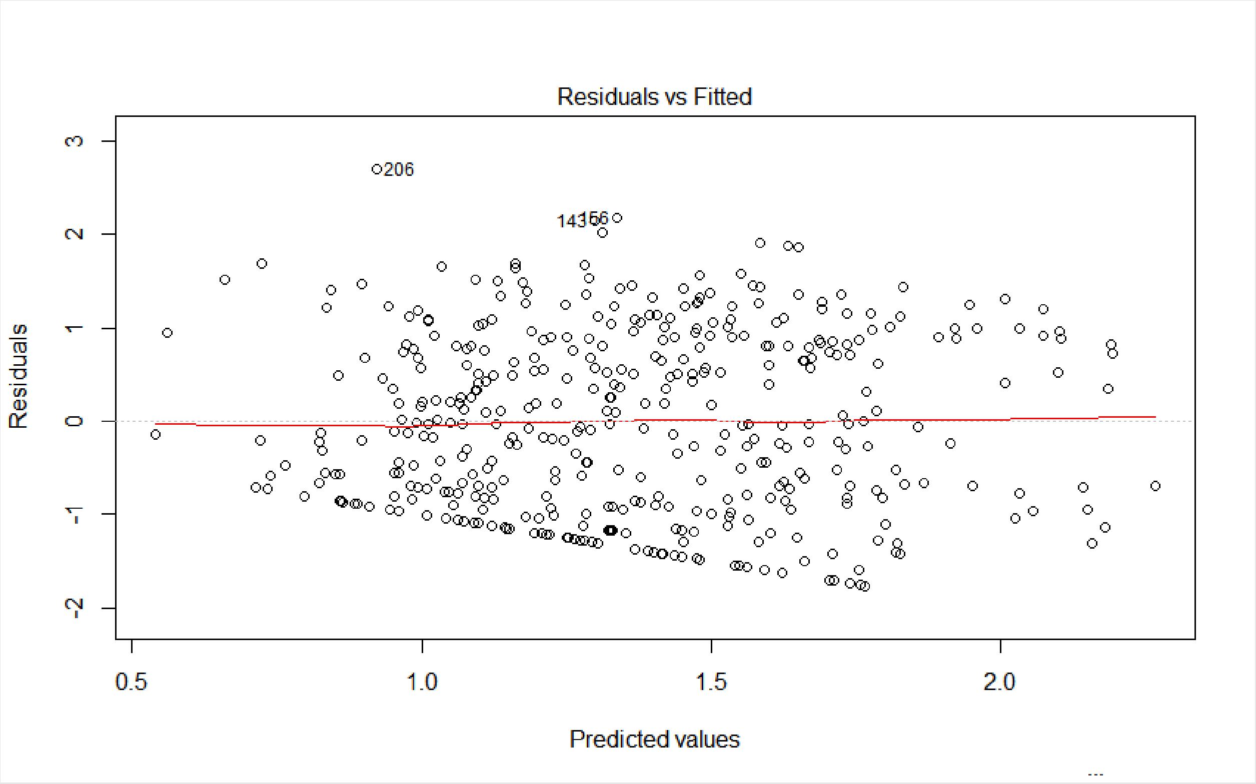
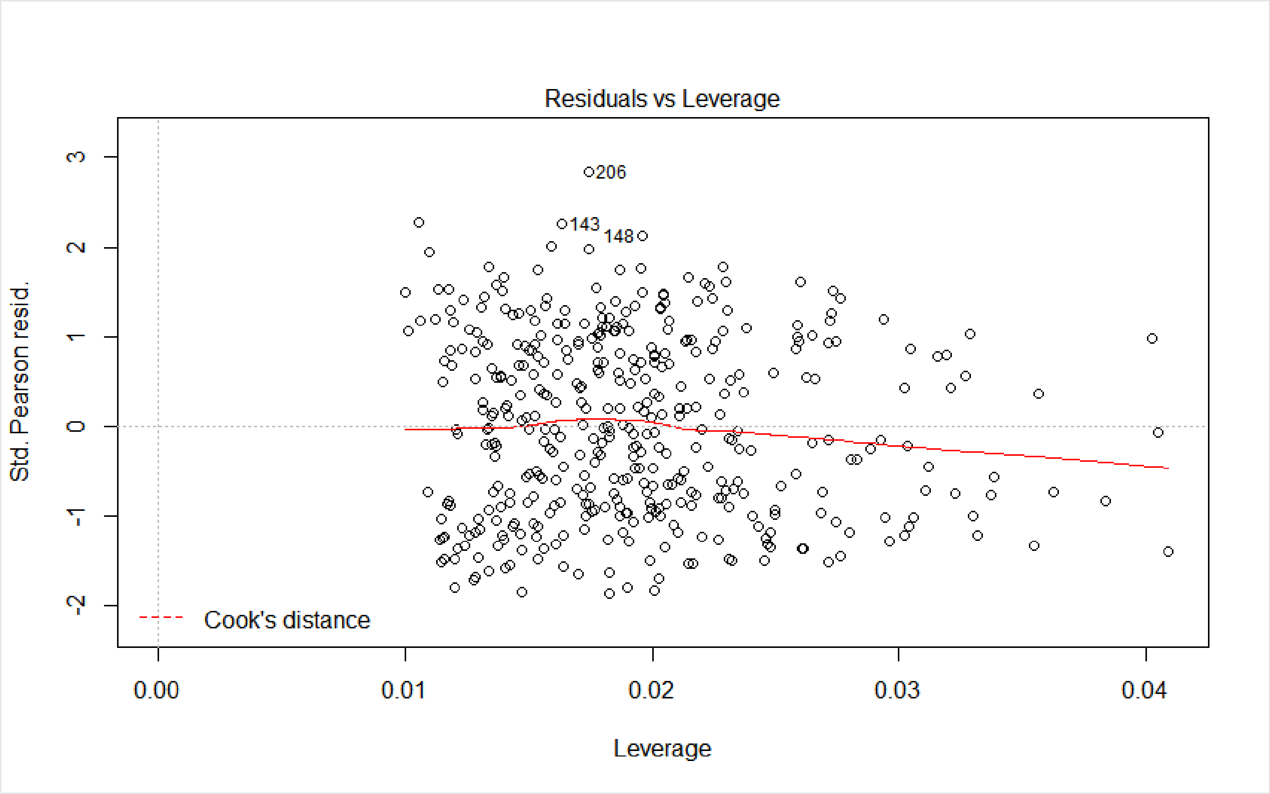
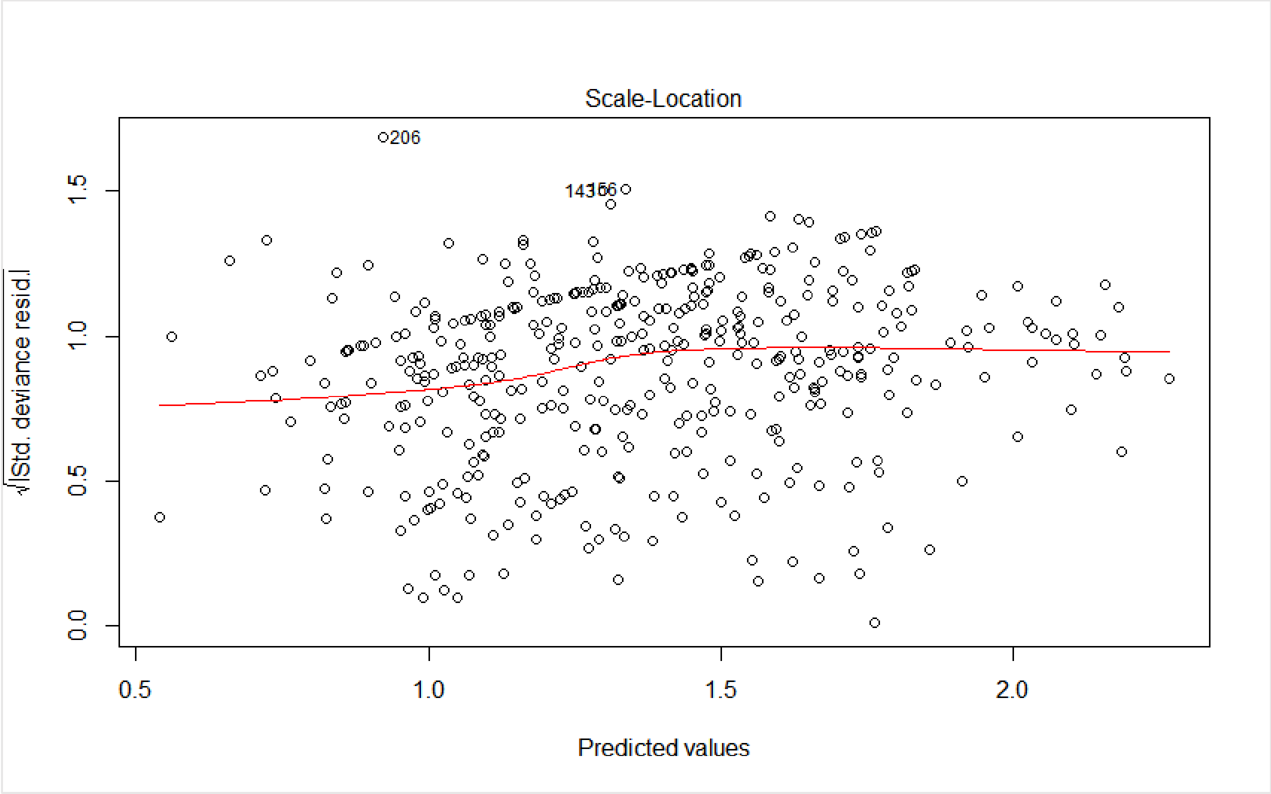
# Appendix 1

Examples of what the diagnostic plots looked like for the three GAM models.






Residuals vs Leverage
Std. Pearson resid.
3
2
1
0
-1
-2
206
143
148
Cook's distance
0.00
0.01
0.02
0.03
0.04
Leverage


Scale-Location
√|Std. deviance resid.|
1.5
1.0
0.5
0.0
206
143
148
0.5
1.0
1.5
2.0
Predicted values