Marine Management Organisation

Assessing Non-Lethal Seal Deterrent Options: Fishing Trials Technical Report (MMO1131)

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Report prepared by: ABPmer and NFFO

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Interactions between seals and fishing gear include depredation of fish catches by seals and entanglement of seals in fishing gear. Throughout England, predominantly in the south-west, north-east and east, depredation is an issue for static net fisheries in particular, that leads to economic costs from loss of commercial catch, gear damage or increased gear handling time. The Marine Management Organisation (MMO) Marine Conservation Team is required to provide advice on the implementation of and compliance with the Conservation of Seals Act (1970) in regard to seal and fishing gear interactions. Defra policy is that prior to shooting under the Conservation of Seals Act (1970), non-lethal methods of deterrent should be tried and shown to be ineffective at resolving the problem. However, effective non-lethal seal deterrent alternatives to shooting are currently limited for application from fishing vessels in sea fisheries.

As part of a project to better understand the interactions between seals and fishing gear and non-lethal deterrent options, at-sea fishing trials were undertaken to test a non-lethal seal deterrent. This technical report provides detail of the design, methodology and results of the fishing trials.

A mackerel fishery in Torbay was selected for undertaking the trials, involving two vessels using gill nets. An early prototype Acoustic Startle Device (ASD) developed by Genuswave, which uses Targeted Acoustic Startle Technology (TAST), was selected for use in the trials. On each fishing trip, each vessel deployed a ‘control’ net that was fished normally without any ASD, and a ‘test’ net with one or more ASD to test the effectiveness of the device at reducing seal depredation compared with the control net. Test nets were deployed with one to three devices set on separate anchors as close to the net as possible; the combined duty cycles of devices (percentage of time that the device emits a sound) deployed with test nets was between 1.2% and 4.2%. Some technical problems occurred in the prototype ASDs throughout the trials, resulting in reduced source levels, and/or truncated (shorter) pulses for some trials. These errors were accounted for in the data analysis where possible.

The results indicate that, despite the range of technical errors that occurred, deployment of the ASD shows promise for reducing seal depredation in fisheries in inshore waters, although testing has only taken place in a limited range of conditions and gears types (water depth, net length etc). Generalised linear mixed models (GLMM) (with logarithmic link function) estimates indicate that even when no other factors are considered, the use of the ASD resulted in a 74% increase in catch (weight) in the test net compared with the control. However, the data also indicate that an appropriate adjustment of the duty cycle and the number of deployed units could allow this positive effect in catch to be increased further.

There was a very high variability in the effectiveness of the device; in some cases the increase in catch was marginal and at a level that would not be noticeable on an individual level. This likely reflects variability in fishing and the presence or absence of fish in the area, individual variability in seals’ behaviour and hearing (motivation for feeding on fish from nets, and hearing sensitivity) as well as device technical errors that occurred during the trial.

Other issues identified that may affect the applicability of the ASD to reduce seal depredation in static net fisheries include the handling of the device, which is currently difficult due to its modular set-up, the robustness of the device; and the cost for individual inshore fishers. Therefore, for the prototype device to become market-ready and to be considered a viable non-lethal deterrent option in wild capture fisheries, further work is needed to:

I. ensure the robustness of the devices for regular handling and deployment at sea
II. adapt the configuration of the devices for ease of handling and deployment
III. optimise the duty cycles of one or multiple devices for an optimum level of deterrence whilst minimising noise input to the marine environment
IV. carry out further development and testing in a wider range of fisheries to confirm its effectiveness for a range of locations, target species and gear types.

The cost of the devices, and the number of devices to be deployed per net, would also have to be considered and it may not be economically feasible (particularly if multiple devices are required to ensure coverage of the full net) for static net fishers in England. There may be a need for funding support, or efficiencies in production to bring the price to a level that is accessible for application to inshore fisheries.

1. Introduction

Interactions between seals and fishing gear include depredation of fish catches by seals and entanglement of seals in fishing gear. Throughout England, predominantly in the south-west, north-east and east, depredation is an issue for static net fisheries in particular, that leads to significant economic costs from loss of commercial catch, increased gear handling or gear damage. Seal-fishing gear interactions can also lead to seal mortality through either legal shooting ('Netsmen's Defence') or as a result of accidental bycatch.

The Marine Management Organisation (MMO) Marine Conservation Team is required to provide advice on the implementation of and compliance with the Conservation of Seals Act (1970) in regard to seal and fishing gear interactions. Defra policy is that prior to shooting under the Conservation of Seals Act (1970), non-lethal methods of deterrent should be tried and shown to be ineffective at resolving the problem. However, effective non-lethal seal deterrent alternatives to shooting are currently limited for application from fishing vessels in sea fisheries.

In order to improve the specificity of advice, the MMO commissioned this project to understand the interactions between seals and fishing gear and to examine non-lethal deterrent options such that the MMO is better able to offer advice that can reduce the need for shooting. This may have secondary positive effects for conservation and fisheries by reducing seal by-catch and net-based feeding.

The project explored the following seven objectives:

I. understand how seals take fish from nets and what factors assist them (for example, location, visual cues etc.)
II. identify what factors influence depredation behaviour (for example, opportunistic, or specialist)
III. identify the breeding populations of individuals undertaking depredation
IV. review non-lethal deterrent measures currently available that may be appropriate for reducing the seal–gear interactions at sea
V. review what modifications to fishing gear or fishing tactics may mitigate seal depredation and bycatch
VI. clarify potential impacts and benefits and risks to the fishing industry, managers and seals of implementing non-lethal measures, gear modifications or tactics identified through V) and VI) and prioritise a sub-set of mitigation measures for testing
VII. design and undertake testing in collaboration with the fishing industry of the most promising depredation deterrent measures.

As part of objective VII, this technical report provides an overview of the technical design of the fishing trials, results and statistical analysis of trials data, and recommendations for non-lethal seal deterrents emergent from field experience. This report follows a literature and data review (MMO, 2018), and a stakeholder engagement report (MMO, 2019) as part of the same project. A summary report presents the key findings of this and the previous two reports under this project

1.1. Aims and Objectives for Trials

The aims and objectives for the trials follow from the recommendations of the literature and data review (MMO, 2018) and the stakeholder engagement report (MMO, 2019) that in summary were to:

- test startle-eliciting Acoustic Deterrent Devices (ADDs) making sure they are robust and do not significantly interfere with normal fishing operations
- test the ADD in an area with high rates of depredation
- involve the fishing industry in the trial to increase transparency and trust
- design the trials to control for environmental variables (as much as possible)
- explore opportunities for photographic identification (Photo ID) to gather evidence of seal depredation.

The following sections detail how these have been achieved within the design of the trials.

2. Methodology

2.1. Fishery Selected for the Trials

The literature and data review (MMO, 2018) and stakeholder engagement activities (MMO, 2019) helped to identify fisheries suitable for the trials. Fisheries in the east of England and in Cornwall initially showed promise as suitable locations due to overlaps of seal distribution with net fisheries, static net fisheries reported to be suffering depredation, and fishermen willing to be involved. However, some fishermen were eventually reluctant to be involved in the trials, and issues including depth, soak time and location presented technical challenges in obtaining a suitable deterrent device for the trials (see Table 1).

During the stakeholder engagement phase of the project, both a fisherman from Torbay and the Devon and Severn Inshore Fisheries and Conservation Authority (DSIFCA) made contact with the Project Team to raise the issue of seal depredation in Torbay and discuss how this project may help. Whilst recent survey data on seal distributions in Torbay is limited (see Russel et al., 2017), information from DSIFCA suggested seal populations had increased in recent years and local fishermen were suffering losses of catch as a result.

Therefore, a mackerel fishery in Torbay was selected for undertaking the trials following a favourable assessment of fishing methods and overcoming the potential challenges to implementing the trials (Table 1).

Two vessels (Rachael of Torquay PZ736 and Thankful BM488, Figure 1) were involved in the trials. The first vessel belonged to the fisherman who initially made contact with the Project Team and the second vessel was recommended by the fisherman for the trials, based on fishing with similar gear and in a nearby location.

Figure 1 The vessels involved in the fishing trials

Rachael of Torquay, PZ736

Thankful, BM488

Generally, nets are set in the evening and left to soak overnight, then hauled the following morning. Specific details of the fishery are provided below:

- target species: mackerel
- fishing location: inshore, around Torbay (Babbacombe Bay, Hope's Cove, Torquay, Paignton, Brixham, St. Mary's Bay, Man Sands)
- vessel size: 7 metres
- two fleets of gill nets (set separately from each other)
- net length: 150-200 m
- mesh size: 70 mm
- water depth: approximately 10 m
- soak times: overnight (~9 hours).

Table 1 How the features of the Torbay mackerel fishery respond to the challenges of selecting a trial fishery

Aspect	Challenge	Feature of Torbay Mackerel Fishery
Soak time	Battery needs to power the device throughout the soak.	Relatively short overnight soak, with nets set in the evening and hauled in the morning.
Length of net	ADD needs to provide some level of coverage along the length of the net.	Nets are 150-200m long – ADD should provide some level of coverage along the net.
Water depth	Equipment (ADD, speaker, battery) need to be waterproofed to the depth of deployment.	Fishery occurs in approximately 10 metres water depth. Equipment is already tested at this depth.
Other vessel traffic	Nets/ADDs may be dragged away during soak by other vessels, particularly if near busy shipping lanes.	Fishery is not near busy shipping lanes. Inshore fishery, nets are set close to the shore and clearly marked.
Level of seal depredation	Depredation level needs to be sufficient to detect a possible reduction with the ADD.	Anecdotal information from fishermen suggested regular seal-gear interactions. The greater numbers of individual fish likely to be caught in the mackerel fishery (compared to a monkfish fishery for example) mean that the chances of observing evidence of depredation of catches in control nets is maximised.

2.2. Non-lethal Deterrent Selected for the Trials

The literature review (MMO, 2018) and stakeholder workshop (MMO, 2019) concluded ADDs to be the most promising non-lethal deterrent option available to reduce seal depredation. The Genuswave Acoustic Startle Device (ASD), which is based on the Targeted Acoustic Startle Technology (TAST), was selected for use in the trials. This is a type of ADD (but with systematic differences) that has been developed by researchers at the Sea Mammal Research Unit (SMRU) at St. Andrews University, and evidence suggests it is particularly effective at deterring seals over time and does not present other risks, such as causing hearing damage in marine mammals or habitat exclusion in non-target species (such as harbour porpoise) (Götz and Janik, 2015; Götz and Janik, 2016).

The ASD harnesses the acoustic startle reflex, an oligo-synaptic reflex arc that is mediated in the brainstem. Repeated elicitation of the startle reflex has been shown to cause sensitisation, i.e. increased responsiveness of flight and avoidance behaviour (Götz and Janik, 2011); seals become less likely to forage on a simulated food source and show signs of fear conditioning. A majority of animals exhibit sensitisation (Götz and Janik, 2011), replacing or reducing the prevalence of habituation observed with conventional ADDs (Götz and Janik, 2010). It also operates in a lower frequency band (~1 kHz) compared with most ADDs (usually ~10 to 40 kHz). This is a frequency band at which pinniped hearing is more sensitive than odontocetes (Götz and Janik, 2014, Götz and Janik 2015). Furthermore, it operates at reduced duty cycles[1], signal durations, and lower maximum source levels (sound pressure levels at 1m distance). As such, the ASD does not pose a risk of causing temporary threshold shifts in non-target or target species in realistic exposure scenarios, removing the risk of hearing damage (Götz and Janik, 2015).

The Genuswave ASD emits isolated sound pulses (200ms duration) that have rise-times shorter than 5 to 10 milliseconds (ms). The ASD used in the present study operated at a source level (i.e. the sound pressure level at 1m distance from the source) of ~180-182 dB re 1µPa (rms).

2.2.1. Application in wild capture static net fisheries

This is the first time the Genuswave ASD has been used in wild static net fisheries in its current form; previously tests have been conducted on fish farms in Scotland (Götz and Janik, 2015; Götz and Janik, 2016) and an Irish gillnet and jigging fishery with the device deployed from the vessel (Gosch et al., 2017; Gosch et al., 2018). Methods of deploying the devices at sea with static nets have therefore been developed for this trial (see Section 2.4), with the aim of achieving a ‘proof of concept’, rather than to find a viable solution to seal depredation at this stage. Previous project phases identified no device of higher technical readiness for the project objectives. Thus development would have be required for any device progressed for project trials.

The device set-up is modular (see Figure 2), and comprises a control unit (‘pod’), battery supply within a pelican case (not shown), a dual transducer array (‘speaker’) and cables to connect the pod to the speaker. The dimensions of the pod are 35cm (height) by 14cm (diameter) and the weight is 9.5kg. The dimensions of the pelican case, which houses the 12 volt battery, are approximately 25cm by 20cm by 15cm. Before the trials began, a test deployment of the device from Rachael of Torquay PZ736 was undertaken. The objective was to trial at-sea deployment and configuration of the device. Through this, it was agreed to deploy the pod, battery

[1] The ‘duty cycle’ is the percentage of time that the device emits a sound. A duty cycle of 1% means the device is making a sound 1% of the time; over one minute, the device would be making a sound for 0.6 seconds in total, made up of multiple short bursts of 0.2 seconds each, randomly spaced throughout the minute.

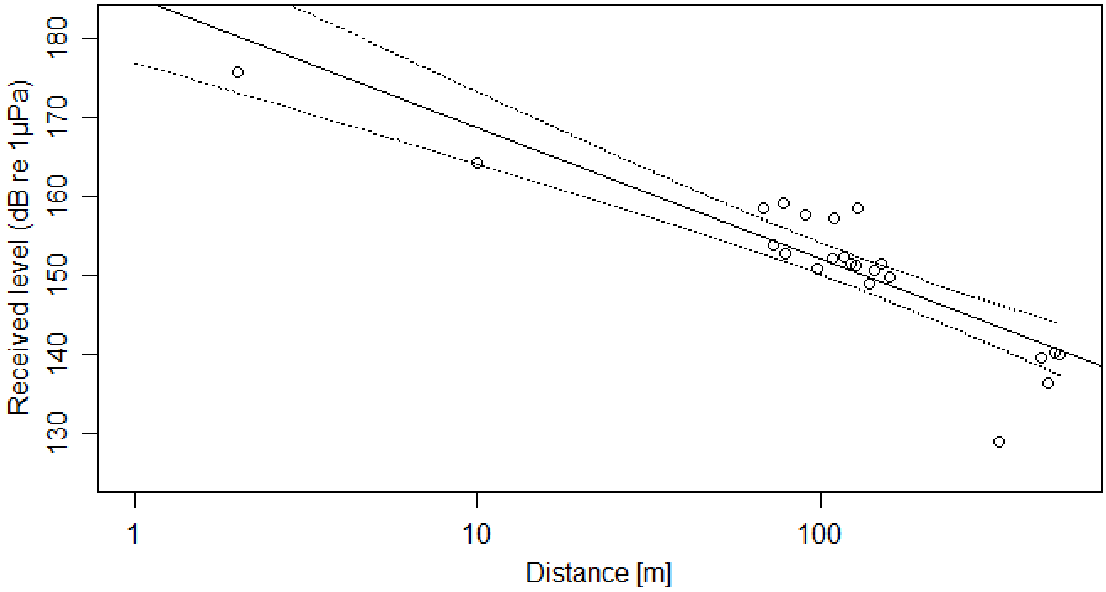
and speaker array on a buff (surface marker buoy) with its own anchor, separate from but in proximity to the net itself (see Section 2.4 and Figure 4).

Figure 2 Genuswave pod (left) and speaker (top right) and cable (bottom right)

Prior to the trial the source level of the device was measured in two separate calibrations as ~181dB re 1 µPa. During this trial deployment, a series of hydrophone recordings were made at distances up to 500m from the device to determine the sound propagation (Figure 3). Transmission loss was ~16*log_{10} of distance. This was less than previously encountered in the fish farm experiments (~17 or ~18log_{10} of distance) meaning the sound travelled further (see Götz and Janik, 2015; Götz and Janik 2016). However, it is in line with that expected in a shallow water coastal environment. The received level at 500m distance was ~140dB re 1 microPa; a level at which startle responses are less likely (or unlikely) to occur. Therefore, a distance of 500m between the control and test nets was used in the trial protocol where practicable[2], to minimise the potential for the device to affect the control net.

[2] In some instances nets were unable to be set 500m apart due to the location of other fishing gear, expected mackerel runs, and coastal morphology.

Figure 3 Sound propagation from trial at-sea deployment (received level against distance from the device)



2.3. Experimental Design

The trials took place during June, July and August 2019.

Three Genuswave ASDs were available for use in the trial which influenced the experimental design. The devices were labelled and were programmed with the following duty cycles (amount of time a device emits sound in a period of time):

- 'Device 1' – duty cycle 0.6%, and later increased to 1.2%. Labelled with 1 RED cable tie
- 'Device 2' – duty cycle 0.6%, and later increased to 1.2%. Labelled with 2 YELLOW cable ties
- 'Device 3' – duty cycle 1.2%, and later increased to 1.8%. Labelled with 3 BLUE cable ties.

On each fishing trip, each vessel deployed a 'control' net that was fished normally without any ASD, and a 'test' net with one or more ASD to test the effectiveness of the device at reducing seal depredation compared with the control net.

Test nets were deployed as either 'test-single' with one device with the net, or 'test-pair' where two devices were deployed with the net (to give greater coverage along the length of the net). As the trials progressed, a 'test-tri' configuration was also used where all three devices were deployed with one test net. This configuration was considered to offer the greatest potential protection to the net and therefore, of the options available, most likely to result in a significant reduction in depredation. This is because coverage of the net would be increased whilst benefiting from the more frequent pulses from the higher overall duty cycle associated with use of multiple pods. Under the test-tri experimental design, only one vessel at a time could be used for trials deploying the test-tri net and a control net fished normally.

The duty cycles of each device were pre-programmed (see above). Test-pair nets always used Device 1 and Device 2 which operated at lower individual duty cycles. Test-single nets used Device 3 that was set at a higher duty cycle to compensate for single operation. However, there were some instances when Device 1 or 2 was used in the test-single configuration due to malfunctioning devices prior to deployment.

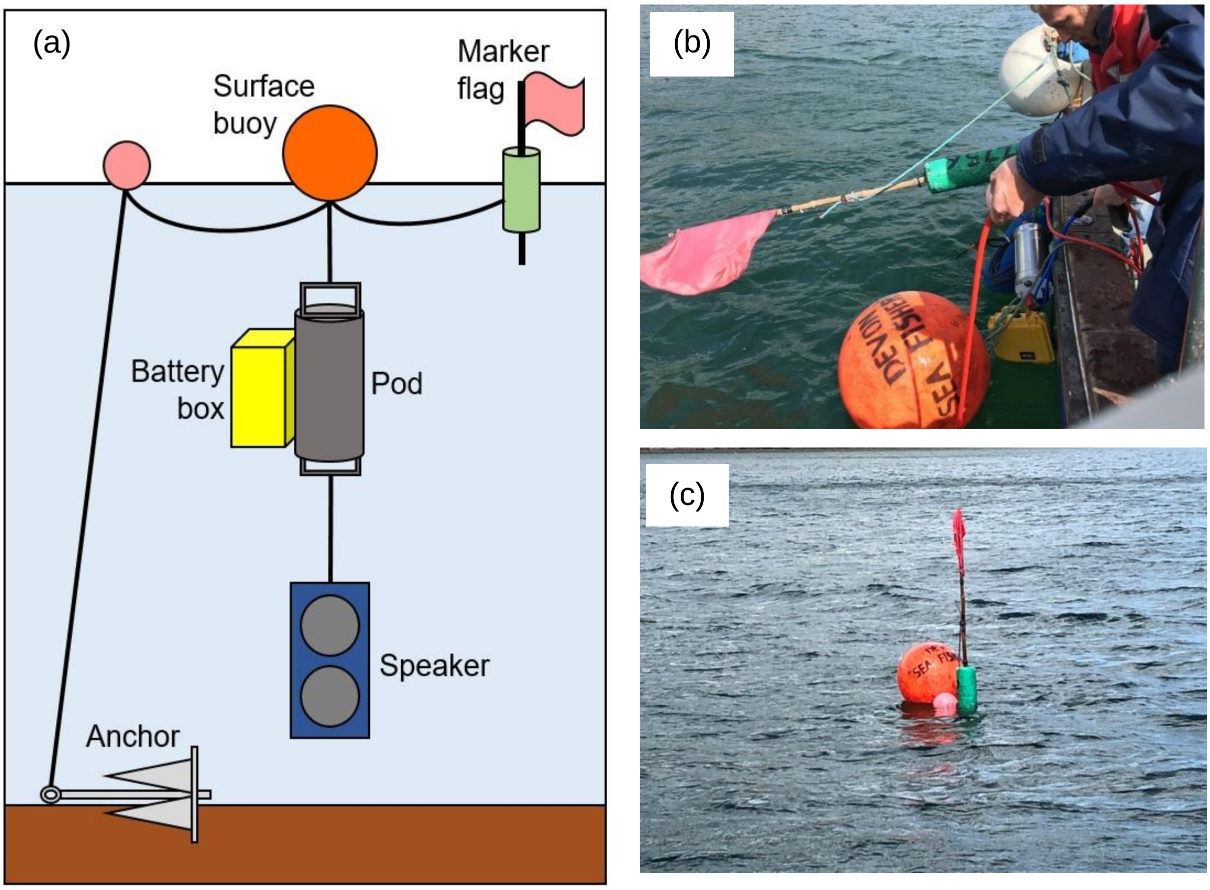
The test-single, test-pair and test-tri deployments were alternated between vessels and among nets. This enabled a comparison of the protection offered by one device vs. two devices vs. three devices, independent of the influence of the vessel or net.

The number of devices and overall duty cycle was incorporated into the statistical analysis to understand the effect of using multiple ASDs and of the higher overall duty cycles on the results (see Section 2.5).

2.4. Trial Protocol

The pod was attached to a pelican case containing the battery and floated below the surface by a buff. The device was marked with a flag and pick-up buoy, and moored to the seabed by an anchor, separate from the net itself to prevent hindrance when shooting and hauling. This also allows acoustic protection during hauling. The speaker was suspended from the pod and also attached to the buff (Figure 4).

Figure 4 Device set up and deployment: (a) device set-up independent of the net; (b) pod and battery box being deployed; and (c) device deployed on a surface buoy during calibration testing



The set-up and positioning of the devices with the nets is shown in Figure 5 and Figure 6.

Figure 5 Setup on test net for one device (test-single configuration)

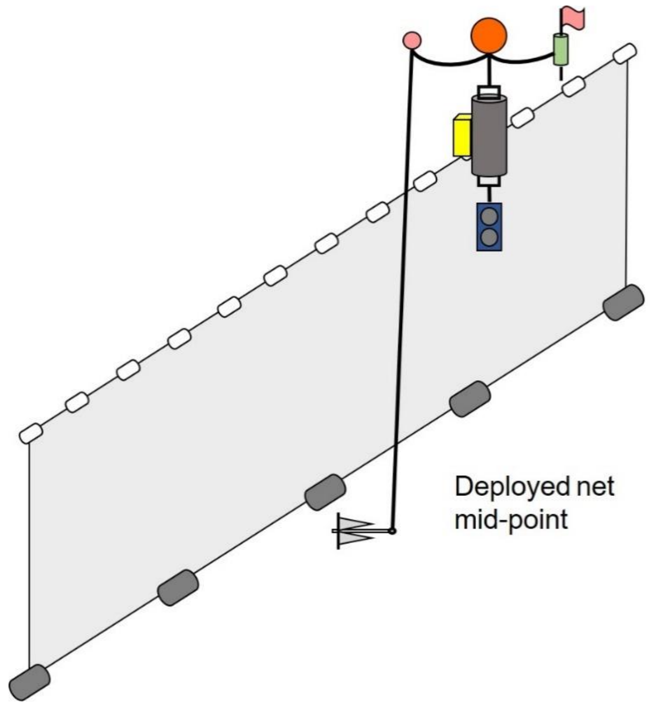
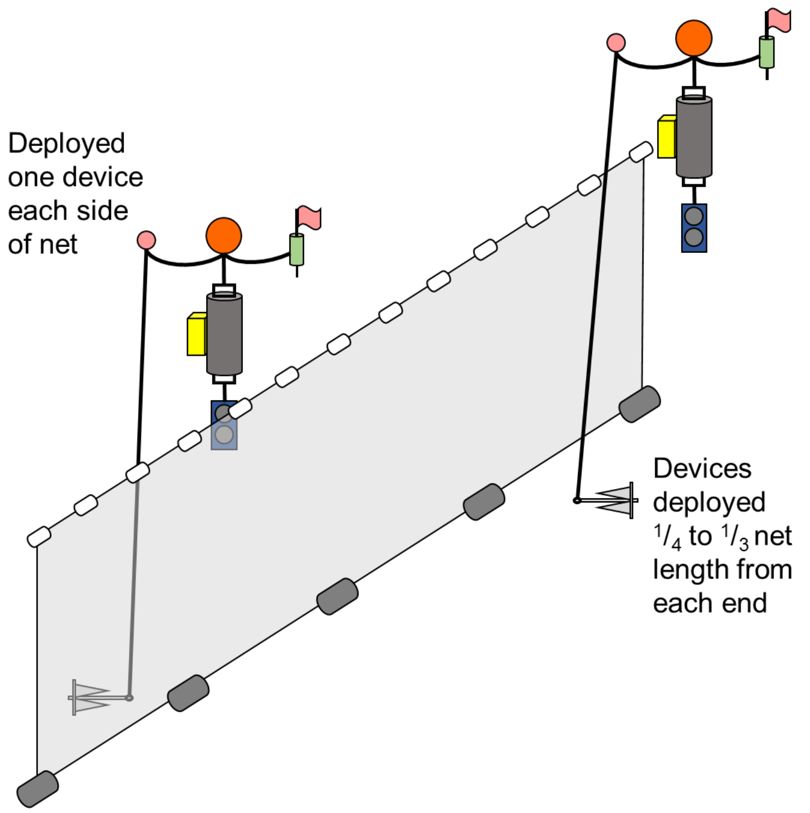


Figure 6 Set-up on test net for two devices (test-pair configuration)



2.4.1. Trial implementation

Table 2 presents a summary of the fishing trips that were undertaken as part of the trials by each vessel, and the devices that were deployed.

Table 2 Summary of fishing trips per vessel and devices used

Landing Date	Thankful		Rachael of Torquay	
	Trial Number	Device Used	Trial Number	Device Used
13 June	1	3🟦		
14 June	2	3🟦		
16 June	3	3🟦	4	1🟥 + 2🟨
17 June	5	3🟦	6	1🟥 + 2🟨
18 June	7	3🟦	8*	1🟥 + 2🟨
20 June	9	1🟥 + 2🟨		
21 June	10	1🟥 + 2🟨		
22 June – 2 July	All devices returned for service and duty cycle adjustment			
3 July	11*	1🟥 + 2🟨		
	Pod 2 faulty and returned for servicing			
4 July	12	1🟥 †	13	3🟦
5 July	14*	1🟥 †	15	3🟦
6 July	16*	1🟥 †	17	3🟦
7 July			18*	3🟦
8 July			19*	3🟦
9 July	20*	1🟥 †		
10 July	21	3🟦		
11 July	22	3🟦		
12 July	23*	3🟦		
17 July			24	1🟥 †
18 July			25	1🟥 †
21 July			26*	1🟥 †
22 July	Pod 2 received after service			
23 July			27	1🟥 + 2🟨
24 July			28	1🟥 + 2🟨 + 3🟦
25 July			29*	1🟥 + 2🟨 + 3🟦
26 July	30	1🟥 + 2🟨 †		
27 July	31*	1🟥 + 2🟨 †		
29 July	32	1🟥 + 2🟨 †		
1 August	33	1🟥 + 2🟨 + 3🟦		
4 August			34*	1🟥 + 2🟨 †
5 August			35*	1🟥 †
7 August			36	1🟥 + 2🟨 †

* Trip discarded from analysis due to device malfunction, auction recording error, or zero catch (see Section 2.5.2)

† One or more devices faulty so not deployed as planned

2.4.2. Setting the gear

The nets were set at the normal time for the fishery (evening). The device(s) on the test net were deployed, activated and left to soak with the test nets. The control nets were set in the same area, but with a separation of approximately 500m or more from the test net, where practicable, to minimise interference between the control and the test net (with device(s) active).

The net the device was deployed with (test net), and the order in which the nets (test and control) were deployed, were varied to remove potential influences of specific nets or deployment order on seal depredation.

2.4.3. Hauling the gear and landing the catch

Nets were hauled at the normal time for the fishery (sunrise). For the test net, the net was hauled before the devices were brought on board as the stakeholder engagement report identified that depredation by seals may occur as nets are hauled.

Once the nets were hauled, fish were cleared from the net, noting any damaged fish (see Section 2.5.1). The undamaged catch from the test and control nets were collected into separate boxes and labelled accordingly.

Undamaged catch was landed and sent to Brixham fish market for auction the following day. Catches from the test and control nets were kept separate and labelled as ‘Landing 1’ and ‘Landing 2’, respectively, for each vessel. Mackerel catch was graded by size prior to auction and weight recorded (see Section 2.5.1).

There was no auction on Saturdays or Sundays, therefore any fish landed on a Friday, Saturday or Sunday were amalgamated and sold at Monday’s auction. Consequently, in order to separate the landings from each day fishing, counts of fish (and weights if possible) were taken as the fish were landed on these days (see Section 2.5.1).

2.5. Data Recording and Analysis

2.5.1. Data recording

The position of the start and end of the nets and position of each device, were recorded, along with the time when the gear was set and hauled, water depth, and numbers of damaged fish in the net. Other ancillary information that might be important to note was also recorded, such as seal behaviour (e.g. seals present at nets when setting or hauling), observation of any other marine mammals, dispersion of catch in nets (indicative of seal depredation), non-landed catch and gear damage.

Any damaged fish were counted and recorded as nets were cleared, including whether damage appeared to have been inflicted by seals, or by other means (crab/other scavengers, heat-damaged). This enabled seal depredation count data to be recorded. Examples of seal depredation observed in the trials, as well as damage to fish that was *not* caused by seals, are shown in Figure 7.

Figure 7 Examples of seal damage, and non-seal damage, observed during the trials

Seal damage (clean bite marks)

Not seal damage (flesh gnawed at, eyes removed)

Auction data were provided by the fish market detailing the weight of fish per species and per grade where appropriate.

Where possible, DSIFCA also conducted market inspections and collected data before the fish were sold. This acted as a data quality control to cross check the on-board and auction data. Market inspections included counting fish from each grade and recording the lengths and weights of individual fish. The average weights per grade allowed the number of fishes to be estimated from the total weight recorded for the auction where direct counts were not taken, and vice versa.

Counts of fish (and weights if possible) were also taken as the fish were landed on Friday, Saturday or Sunday to allow separation of amalgamated auction data over the weekend.

The on-board data recording sheet is provided in Appendix A. One sheet was completed for each net set (i.e. two per trip for each vessel).

2.5.2. Data processing

Raw data were inputted to Microsoft Excel, matching on-board data with auction and market inspection data. Data that were recorded as fish were landed (to account for lack of auction over the weekend) were also matched and inputted and used to allocate the auction data across the relevant days' fishing.

Trial exclusion

Trials in which more than one unit was not functioning on retrieval of the net were excluded from the analysis, as they did not allow a comparison of a functioning ASD on a test net with a control net. In addition, trials in which the catch was zero for both the control and test nets were excluded from the analysis. The rationale behind this was that on these occasions, catches were low because no or few fish were present in the respective areas, rather than the alternative, which would have been that fish had been caught in the net but removed by depredation. The former is considered to be the most likely explanation and was also confirmed by the fishermen's perceptions. If 'zero catch' had been the result of extremely high seal depredation then a large number of depredated fishes in both nets would have been expected, which was generally not the case. However, even in the less likely event that depredation played a minor role in occurrence of 'zero catch' in both nets, the 'zeros' do not contain particularly useful information in the context of a paired design study that relies on comparisons between a control net and a test net.

Technical problems and error variables

A range of technical problems occurred in the prototype ASDs throughout the trial. During the early stages of the trial, this was the result of damage to the electronic components in Devices 1 and 2, incurred during transport or handling. This had the effect of a reduced source level as one speaker in the dual speaker-array went offline. In addition, one speaker was found to be partly faulty, resulting in that array producing a 3 dB lower source level than expected. Other errors included a truncated (shorter) pulse as a result of power limitations due partly to depleted batteries and some software issues.

Where possible, error modes were reconstructed for individual trials based on reports from the fishermen, recorded usage of the units, results of engineer investigations of the devices and post-experiment calibrated sound recordings. Therefore, this is associated with some uncertainty. These error modes were coded in a simple binary error variable (factor) of either:

a) no obvious relevant error; or
b) error with some potential to impact effectiveness of the device.

An error state (b) was assigned if all devices deployed on the net were operating at a source level that was lowered by 3 dB or more. It was also awarded if just one unit had a reduced output in a multi-unit deployment, but an additional problem occurred (such as pulse truncation). All other conditions were scored as 'no error' (a).

Other variables

The following variables were disregarded prior to the model selection process:

- soak time (could have been included as an offset variable)
- location (potential random effect)
- distance between nets (potential fixed effect).

These variables were disregarded as data for these variables were missing from some trials, e.g. no entries on the on-board data sheet. Hence, their inclusion would have required the removal of all trials that were data deficient for these variables from the analysis, which would have further reduced the sample size of the data set.

Lower sample size was deemed to have a larger impact on statistical power than unconstrained variation from disregarded variables. Soak time was plotted and assessed qualitatively prior to the model selection process for the catch weight data for which information is available. This indicated that soak time did not vary dramatically across most trials (some outliers) and any possible correlation with catch did not appear to be particularly strong.

2.5.3. Statistical analysis and model selection

All statistical analysis was conducted in R 3.6.0. (R Core Team, 2019). Generalised Linear Mixed Models (GLMM) with logarithmic link function were calculated using the 'glmmTMB' package (Mollie et al., 2017). This approach allowed the use of a range of error distributions which can deal with over-dispersed data[3] or skewed distributions[4] (e.g. negative binomial), account for zero inflation[5] in the data (whenever needed) and consider random effects (Bolker et al., 2009). Random effects account for variation in the dataset but are not of interest as a primary predictor variable in the context of a study (Bolker et al., 2009). They can also be used to structure variance to reflect a paired study design, similar to traditional 'repeated-measure' statistics (comparing test and controls). Catch weight data were analysed with a model using a negative binomial error distribution and depredation count data were analysed using a model with a Poisson error distribution.

A three-step model selection process was carried out and the models with the lowest, second order Akaike Information Criterion (AICc) were selected. This enables the identification of the model that best fits the observed data whilst minimising the number of variables included to explain the variance. The more variables included in the model, the better the model fit, but the greater the chance of a Type I error (a false positive result). The procedure follows recommendations by Zuur et al. (2009) and Bolker et al. (2019) and was used in Götz and Janik (2016).

In a first step, the optimal specification of the model, i.e. the need for a zero-inflation argument and type of error distribution (e.g. negative binomial I vs. II) was tested using the fully populated model. In a second step, the optimal combination of random effects was determined in the 'beyond optimal' model that includes all crossed fixed effects (see Zuur et al., 2009). In a consecutive third step the best random effects combination determined in the second step was chosen and the optimal combination of fixed effects was determined (Zuur et al., 2009). If the AICc values were very close (~ within 1), results from the 2nd best model are also shown. Confidence intervals were calculated using the Wald method and the 'confint' function. Model coefficients and confidence intervals were exponentiated and are presented on the scale of the response variable for ease of interpretation (see Section 3).

The response variables used in the models were 'all catch (landed and non-landed)', also referred to as 'total catch' (Section 3.1) and 'all catch (landed)' (Section 3.2), also referred to as 'landed catch'. The former comprised the weight of all species landed and sold at auction, plus the catch that had been damaged other than by seals (e.g. by crabs, or damaged from exposure to the sun whilst clearing the nets,

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[3] Where the data are more variable than would be expected with a given statistical model.
[4] E.g. many low observations and few high observations.
[5] Zero inflation refers to a data distribution with frequent zero-valued observations.

and therefore not landed to the auction). The damaged catch was recorded as counts and was converted to weights based on average weights per fish for each species. The landed catch comprised the weight of all species landed and sold at the auction. Depredation count was also analysed separately as a response variable (Section 3.4).

Interaction terms between all fixed effects were assessed. The fixed effects included:

- treatment: 2-level factor (categorical variable), test (‘sound’) vs control
- duty cycle (% of time sound is emitted): covariate (continuous variable)
- number of devices deployed: covariate (continuous variable)
- error variable: 2-level factor (categorical variable), a) no obvious relevant error, or b) error with some potential to impact effectiveness of the device.

The following random effects were assessed:

- trial: a unique identifier for each trial, for which both a control and test (‘sound’) net were set. This random effect structures (random intercept) the variance to reflect the paired study design (control vs sound)
- trip number nested within vessel: nested random effect structure with trial nested within vessel
- trip and vessel as separate simple random effects with a random intercept (non-nested random effect structure).

Model assumptions were validated visually by plotting residuals against fitted (predicted) values, plotting residuals against covariates, a histogram of residuals and plotting qq (quantile-quantile) plots. The optimal model for ‘all catch (landed)’ and the second-best model for ‘total catch (landed and non-landed)’ initially showed a skewed histogram of residuals. The models were therefore refitted with the zero-inflation term specified which addressed the problem. A slight to moderate problem with patterning of residuals was also spotted in the depredation count model meaning that coefficients should be interpreted with caution.

The effect on the analysis of ‘outliers’ in the data was also examined separately to understand if they unreasonably influence the model estimates (coefficients and confidence intervals). Details of the method used, results and discussion are presented in Appendix B. It should be noted that any removal of data from the analysis, perceived ‘outlier’ or not, should be exercised with caution and must be based on objective criteria (as detailed in Section 2.5.2).

3. Results

There was a high variability in catch weights during the trial, reflecting the variability in fishing and the presence or absence of fish in the area. The impact of the biggest outliers on results was assessed (detailed in Appendix B) but did not alter conclusions. Outliers were therefore not removed. In the majority of trials, there were higher catch weights in the test nets with the ASD(s) compared to the control nets (see Figure 8, Figure 9 and Figure 10).

This effect was maintained throughout the experiment even though the overall catch weights decreased in the last few trials. The latter was mostly the result of low numbers of fish in the area (Figure 8 and Figure 9). The effect of the ASD(s) on catches in the test net can also be seen in the cumulative catch across both vessels throughout the whole experiment (Figure 10). The cumulative total catch (landed and non-landed fish) was approximately 79% higher in the test net (705 kg) compared with the control net (395 kg).

Figure 8 Total catch weight (landed and non-landed) in control and test nets per trial. Only trials included in the analysis are given.

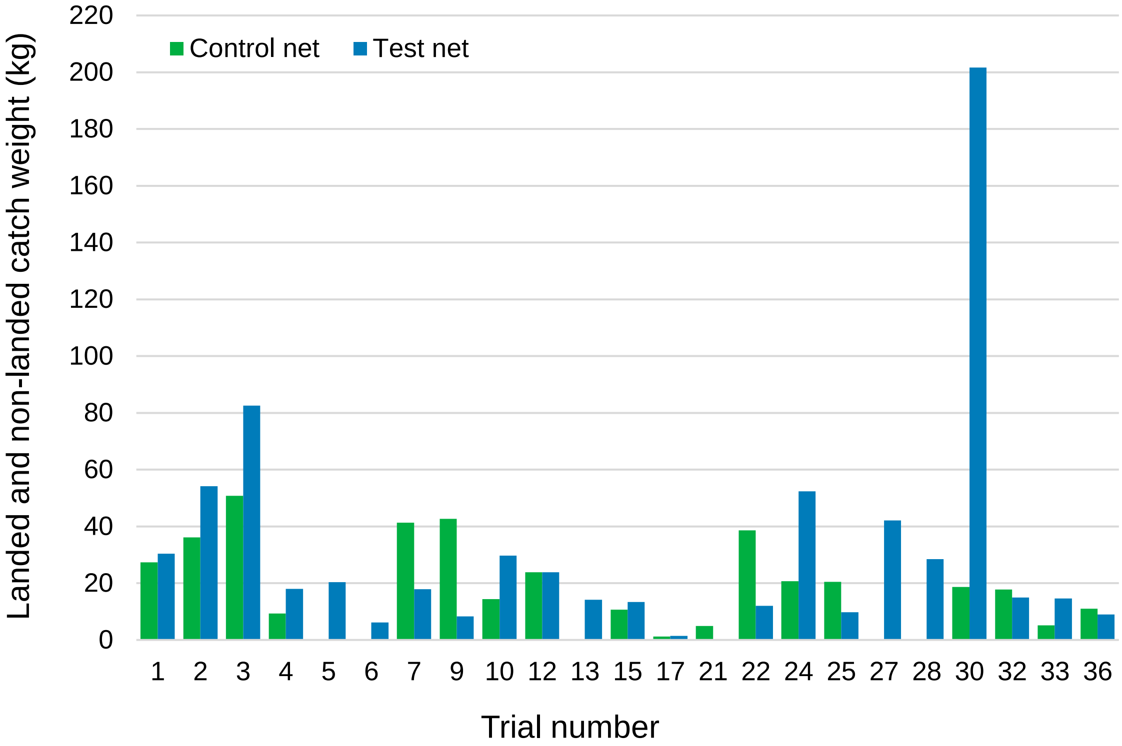


Figure 9 Landed catch weight in control and test nets per trial. Only trials included in the analysis are given.

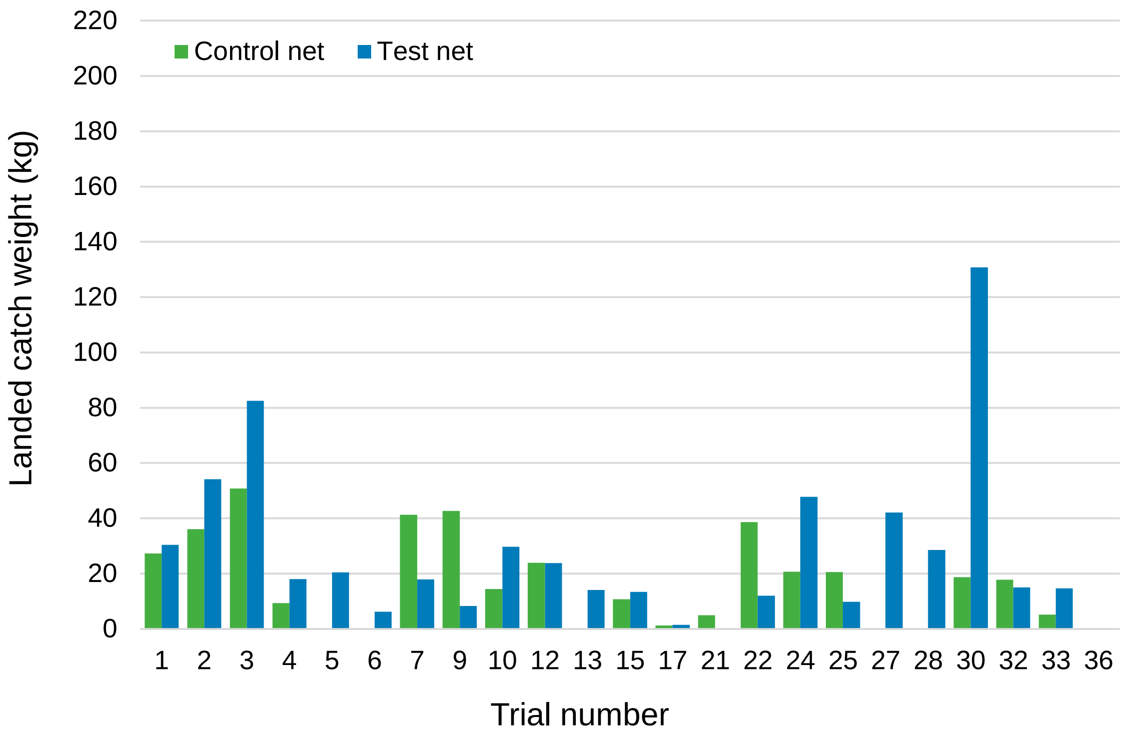
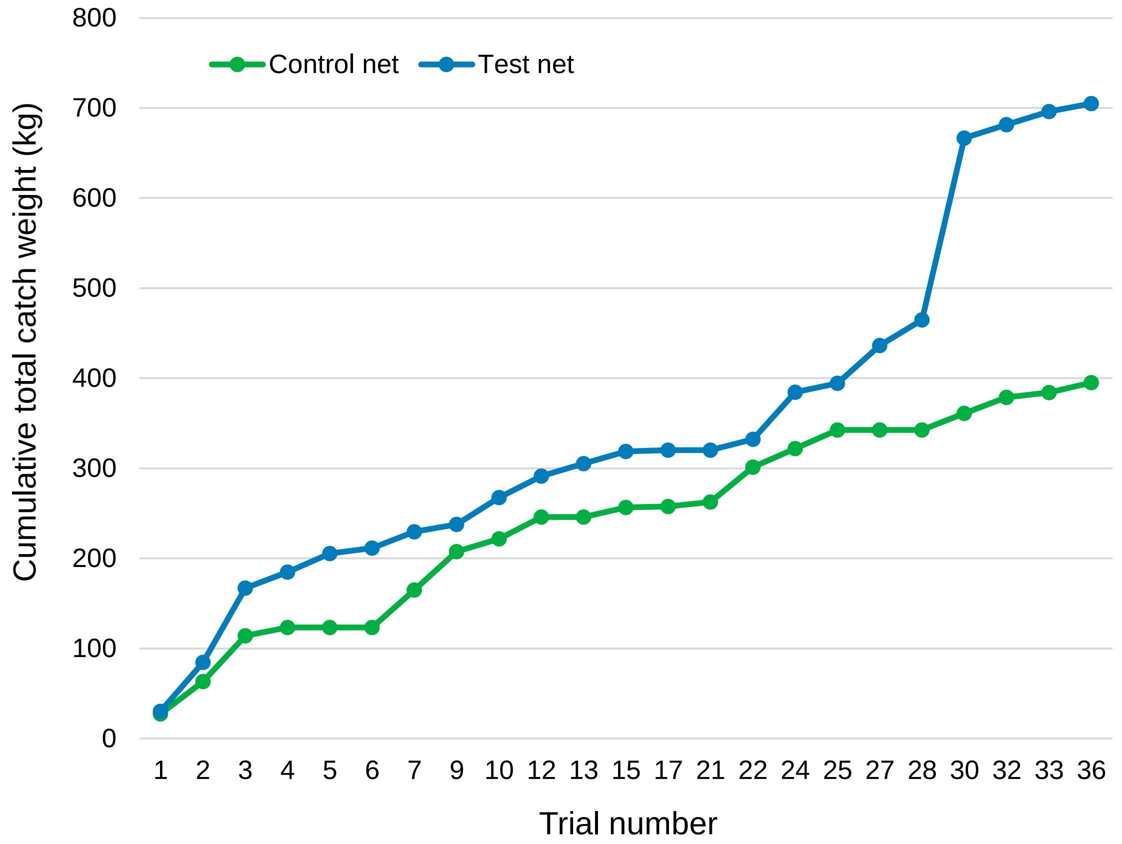


Figure 10 Cumulative total catch weight (landed and non-landed) over trials in control and test nets. Only trials included in the analysis are given.



3.1. Total Catch Weight (Landed and Non-landed) Analysis

The optimal model (lowest AICc) for the total catch weight (landed and non-landed) included treatment (test vs. control net) as the only predictor variable and trial as a random effect (reflecting the paired design). The significant effect of treatment (p=0.03) and the model coefficient (estimate) indicate that deployment of the ASD(s) increased total catch weight in the test net by 74%, or a factor of 1.74 (Figure 11, Table 3).

The 95% confidence interval for this estimate was large and ranged from 5% (factor of 1.05) to 189% (factor of 2.89) increase in the catch of the test net (Table 3). The optimal model (lowest AICc) did not retain any other predictor variables such as unit malfunction (error), number of units, or duty cycle.

Table 3 Total catch weight analysis (landed and non-landed) – optimal model with lowest AICc includes treatment as a fixed effect and trial as a random effect (random intercept)

Model Output	Coefficient	Confidence Interval		p Value
		CI: 0.025	CI: 0.975	
Intercept	15.180	9.002	25.597	<0.001
Treatment (Sound)	**1.744**	1.054	2.887	**0.030**

The model with the second-lowest AICc is also presented here and contained two predictor variables (treatment, and number of units deployed per net) and the interaction term between the two variables (Table 4).The interaction term only approached significance (at p=0.05) but the model coefficient hints at an increase in catch in the test net by a factor of 2.35 (135%) for each additional unit that is added to the net (providing better coverage along the length of the net).

Table 4 Total catch weight analysis (landed and non-landed) – model with 2nd lowest AICc includes treatment, number of units deployed and the interaction terms between the two variables and trial as a random effect

Model Output	Coefficient	Confidence Interval		p Value
		CI: 0.025	CI: 0.975	
Intercept	47.037	15.595	141.866	<0.001
Treatment	0.472	0.136	1.639	0.237
No of units	0.467	0.205	1.064	0.070
Treatment (Sound) * No of units	**2.350**	0.985	5.605	**0.054**

3.2. Landed Catch Weight Analysis

The optimal model for the data that only included the catch that was landed to auction included treatment, duty cycle and the interaction term as fixed effects and trial as a random effect (Table 5). The interaction term between treatment (sound) and duty cycle was significant (p=0.036)[6]. The coefficient indicates that the catch in the test net increased by a factor of 2.1 (110%) with each 1% increase in the duty cycle across all deployed units, for the range of duty cycles tested (Figure 11, Table 5).

The second-best model included only treatment as a predictor variable. Similar to the best model for ‘total catch weight (landed and non-landed)’, the effect of the ASD(s) was significant (p=0.031). The coefficient indicates a 72% increase in the catch in the test net (Table 6, Figure 11).

Table 5 Landed catch weight analysis – optimal model with lowest AICc includes treatment, duty cycle and the interaction as fixed effects and trial as a random effect

Model Output	Coefficient	Confidence Interval		p-Value
		CI: 0.025	CI: 0.975	
Intercept	55.700	18.666	166.206	<0.001
Treatment	0.428	0.140	1.306	0.136
Duty Cycle	0.491	0.250	0.966	**0.039**
Treatment (Sound)* duty cycle	**2.095**	1.051	4.174	**0.036**

Table 6 Landed catch weight analysis – model with 2nd lowest AICc includes treatment

Model Output	Coefficient	Confidence Interval		p Value
		CI: 0.025	CI: 0.975	
Intercept	14.568	8.857	23.961	<0.001
Treatment (Sound)	**1.724**	1.052	2.826	**0.031**

3.3. Measures of Effects Size

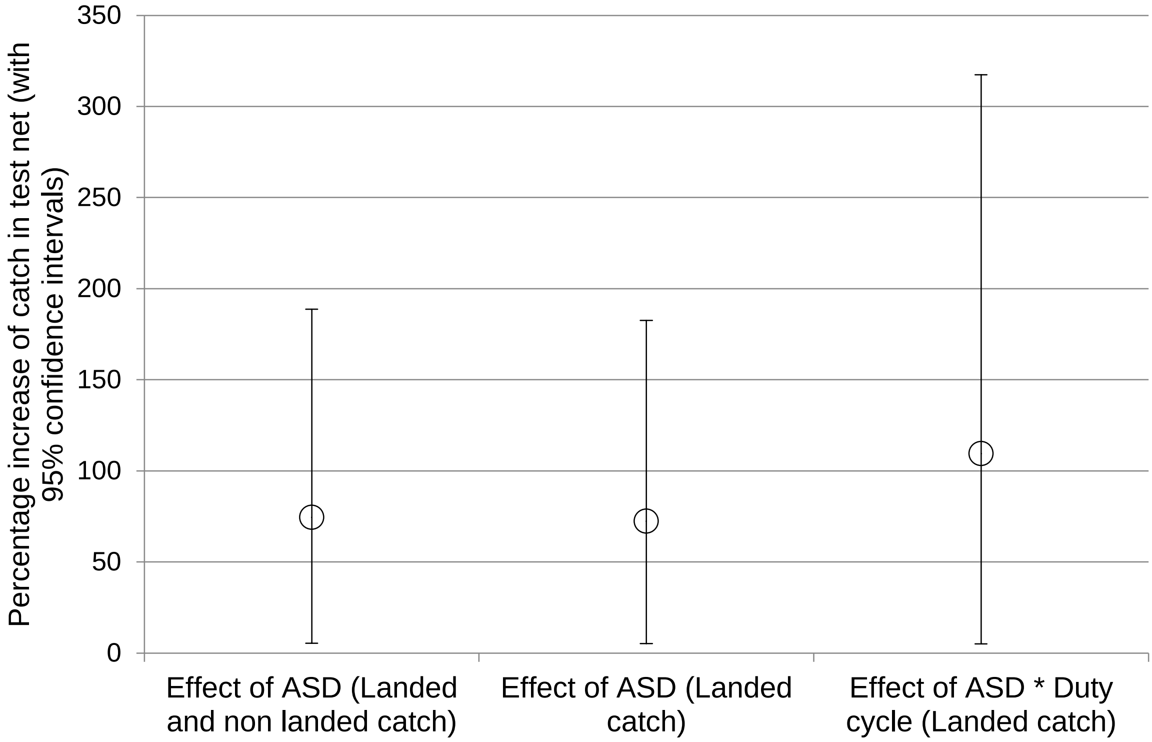
The effect size, i.e. the increase in the catch in the test net and associated 95% confidence intervals of the most important predictors (at p≤0.05) from the models explored for total catch weight (landed and non-landed) (Section 3.1) and for the landed catch weight models (section 3.2), is shown in Figure 11. Confidence intervals are large, indicating significant variability across the data. However, all parameter estimates that are significant (at p≤0.05) are positive, showing higher catches in the test nets compared with the control nets across all three models.

The coefficients and confidence intervals for the refitted models using the total catch weight (landed and non-landed) data in which the biggest outliers in the residuals were removed (between one and five outliers) are detailed in Appendix B. Results showed that while removing specific observations with outliers in the residuals influences the model estimates, this appears to occur in a stochastic manner, and is largely in line with results presented in Section 3.1. Therefore, the best

[6] The interaction term represents the effect of the duty cycle at a specific treatment level, i.e. ‘test net’ vs control net. Where an interaction term is significant, it is advisable not to interpret the significance of individual terms that make up the interaction.

representation still seems to be the model using the full data set with no removal of outliers.

Figure 11 Predicted percentage increase (with 95% confidence intervals) in catch weight in nets with ASD



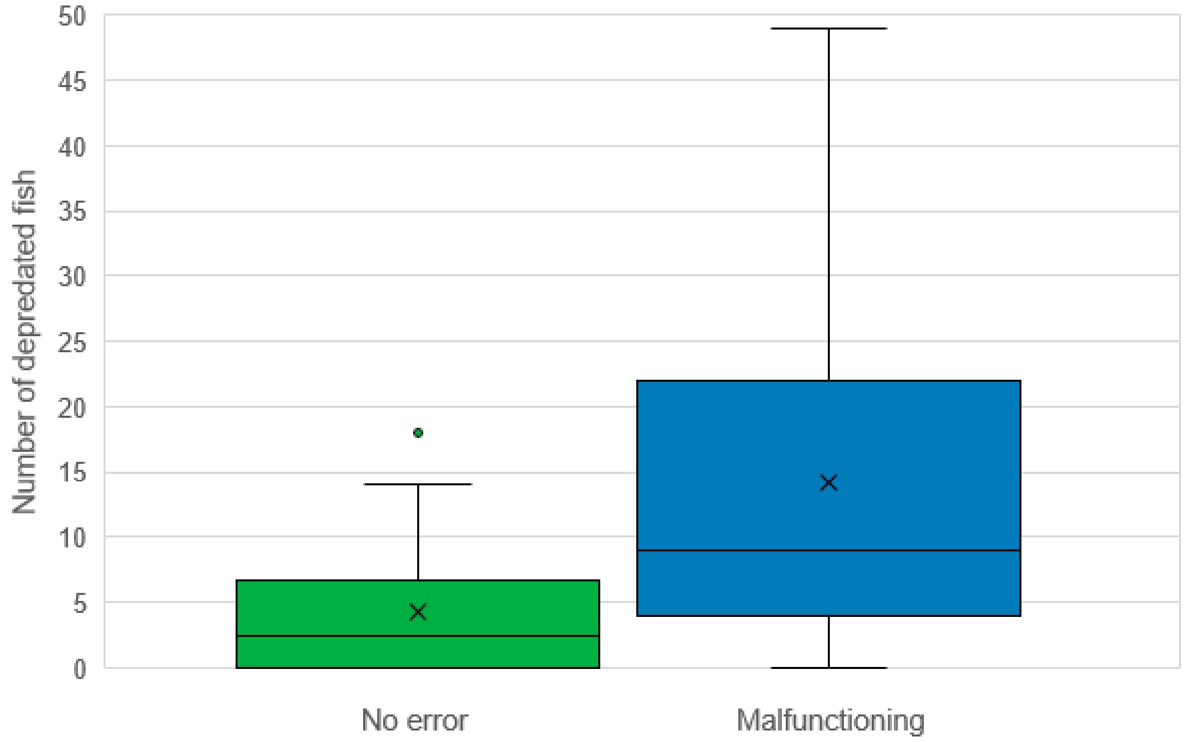
3.4. Depredation Count Analysis

The optimal model for the depredation count data only included treatment and the error variable but no interaction term (Table 7). The effect of treatment was not significant (p=0.705) but interestingly the effect of the error variable was (p<0.003). The model suggests that 3.4 times more depredated fish occurred in both nets when ASD units were malfunctioning (Table 7, Figure 12).

Table 7 Depredation count analysis – optimal model with lowest AICc includes treatment, duty cycle and the interaction as fixed effects and trial as a random effect

Model Output	Coefficient	Confidence Interval		p Value
		CI: 0.025	CI: 0.975	
Intercept	2.554	0.922	7.070	0.003
Treatment	0.946	0.795	1.126	0.705
Error variable	3.412	1.248	9.329	**0.003**

Figure 12 Number of depredated fishes in nets when ASDs were malfunctioning



4. Discussion

4.1. Effectiveness

The results indicate that deployment of the ASD showed promise for mitigating seal depredation in the inshore fishery in Torbay. The model estimates indicate that even when no other factors are considered, the use of the ASD resulted in ~74% increase in catch weight in the test net compared with the control. However, the data also provide evidence that an appropriate adjustment of the duty cycle and the number of deployed units should allow this positive effect in catch to be increased further. The interaction term between treatment and duty cycle indicates that operating the device on a duty cycle between 2-3% is likely to increase the catch in the test net by 100% compared to the unprotected control net.

There was considerable variability in catch weight across the trial and this likely reflects variability in fishing and the presence or absence of fish in the area, as well as some technical errors with the devices (Section 4.3). For example, the 95% confidence intervals from the model for total catch (landed and non-landed) indicate that increases in catch in the test net can be anywhere between 5% and 188%. Hence, in some cases the increase in catch with the ASDs can be minimal and may not be perceptible to fishers, and/or would not compensate for the additional handling time involved in using the devices.

The use of the ASDs did not have a significant effect on the number of depredated fish in the nets, with depredated fish sometimes found in both the test and control nets. This is likely to have been related to the errors in device operation, because there were significantly more depredated fish present in both test and control nets when the ASDs were malfunctioning. It should also be noted that seals may completely remove fish from the nets, therefore the level of depredation may be higher than the number of depredated fish in the nets.

It is important to highlight that the predicted increases in catch (model estimates) in this study may not be generalisable to different locations or fisheries. Therefore, further investigation is needed to confirm the efficacy of the ASD as a viable solution to seal depredation in English static net fisheries with differing circumstances (e.g. net length, depth etc.). The prototype ASD would need to undergo further technological developments before this could be completed (see Section 4.3).

In previous studies using TAST, a duty cycle of only ~1% was sufficient to cause behavioural exclusion of seals from a fish farm (Götz and Janik, 2015) and reduce depredation by 91-97% (Götz and Janik, 2016). The fish farm scenario differs from inshore fisheries as the tensioned cage nets effectively separate salmon from their marine predators. Therefore, seals have to spend significantly more time underwater manipulating the net with their flippers and jaws to obtain fish. Seals are also able to decrease their exposure to the noise by simply swimming on the surface (in contrast to cetaceans), where received sound levels can be dramatically reduced compared to underwater. This effect depends on how high they keep their head above the water but can be significant.

A seal attempting to predate on a fishing net has to dive but relatively short dive times may be sufficient to damage the catch or remove fish from a net in shallow water (~10m depth). This means that the duty cycle may have to be somewhat higher in an easily-accessible shallow water fisheries scenario where fish are easy to predate. This is because the pulse interval per unit must be kept within a range that does not allow the animal to successfully predate on the net and achieve sufficient underwater exposure to induce a flight and avoidance response.

Apart from duty cycle there is some evidence that the number of units deployed around the net also had an influence on the increase catch weight. This result can be explained by a range coverage effect, i.e. depending on net length a single unit may not be sufficient to protect the whole net. This is also supported by observations from the fishermen that fewer depredated fish and higher catches occurred in the net close to where the ASDs were deployed, while more depredation or lack of fish occurred in the periphery, away from the ASD (towards the ends of the nets in the test-single deployment).

Actual deterrence ranges are species-specific but also depend to some extent on the hearing sensitivity of individual seals, which in turn is dependent on age and genetic factors. There may also be some context-dependency in different environments. Deterrence ranges for earlier versions of the ASD in previous studies were approximately 250 metres around an inshore fish farm (Götz & Janik, 2015), but ranges were much smaller close to haul-out sites (approximately 60 metres) (Götz, 2008). In the context of the present study it should also be acknowledged that even though different pairings between the number of units and the overall duty cycle of the setup were tested, there is mild collinearity between the two variables, i.e. with more units deployed on a net, the duty cycle increases due to the combined sound from multiple devices.

The error variable (i.e. malfunctioning of the ASD units) was not retained in any of the optimal (and second-best) models for the catch weight data. This is unexpected, however, there was some uncertainty associated with the coding of this error variable and it may not always accurately present actual error states or the magnitude of an error throughout the experiment. Interestingly, unit malfunction did have a significant effect on the number of depredated fishes in both nets, with higher numbers of depredated fish when the units malfunctioned. One possible explanation may be that the units deployed on the test net also had an effect on the control net on some occasions. This is possible because it was not always practicable to set nets 500m apart and sometimes nets had to be shot closer together. Therefore, unit malfunction may have led to more depredation in both nets. This may have also resulted in a reduction of the measured effects sizes in the catch weight data. Alternatively, the malfunctioning devices may have allowed any seals present to continue to depredate on the fish in the nets, as the sound emitted by the devices was not sufficient to cause a startle response in the seals.

4.2. Balancing Environmental Effectiveness and Environmental Impact

The challenge for a practical commercial application will be to find an optimal combination of the number of units and duty cycle for the whole setup. There is likely to be a trade-off between ‘ease of use’ for the fishermen and the number of units deployed to give adequate coverage of the net. However, more importantly, the overall noise dose emitted by any device needs to be carefully balanced against any adverse environmental effects ASDs may cause. Most ADDs that are currently on the market operate at relatively high duty cycles (between 8% and 100% in multi-unit deployments) with a source level up to 196dB re 1Pa. Such devices and deployment protocols have been shown to cause large-scale habitat exclusion in protected species such as the harbour porpoise (Johnston, 2002; Götz and Janik, 2013). In addition, some ADDs also pose a significant risk of causing injury in the form of permanent hearing damage in both, target and non-target species of marine mammals (Findlay et al., 2019; Götz and Janik, 2013). In terms of hearing damage, the harbour porpoise is of particular concern as its auditory sensitivity is high in the frequency range where most current ADDs operate.

The ASD tested in this study differs from ADDs as its source level (180-182 dB re 1 µPa) and duty cycle (tested at 1% and 3%) are much lower. Furthermore, the signals are transmitted in a frequency band where the hearing sensitivity of porpoises is lower than in seals. This has been shown to reduce adverse behavioural effects and the risk of hearing damage in target and non-target species (Götz and Janik, 2015; Götz and Janik, 2016). During the trials, the fishermen observed the presence of cetaceans, and reported they did not seem to be affected by the ASD. The data from the present study suggest that it should be possible to find acoustic parameters that balance effectiveness while not posing a significant risk to target and non-target species when using the targeted acoustic startle technology. The modelling data suggest that a two-unit ASD setup operating at an overall duty cycle of 2-3% will lead to an increase in catches. There is scope for further optimisation of the setup with regard to determining the optimal duty cycle and number of units in subsequent studies. However, very large increases in the overall duty cycle (across all units) should be avoided in any acoustic device (ASD or ADD) for environmental reasons (noise pollution, see Goetz & Janik 2013).

4.3. Technological Challenges and Development

The range of technical errors that occurred in the units affected 11 out of 23 trials, and there is some uncertainty around the accuracy of the assigned error states in the data analysis (see Section 2.5.2). This has most likely contributed to the large variability in the effect of the ASD and the fishermen involved sometimes questioned the effectiveness of the devices. This large variability is reflected by the large confidence intervals for effect size (Figure 11). These errors are also likely to have reduced the effectiveness of the ASD in the trial. This view is also supported by the effect of the error variable on the number of depredated fish found in the nets.

There are currently no other devices on the market that have been comprehensively tested in a fully submerged setup (i.e. battery box and unit deployed below the water surface) or in wild capture fisheries. Genuswave considers the trial to have been beneficial from a technology development point of view. The units were initially designed for stable deployment on sea cages but ‘floating’ applications that involve much manual handling and regular deployment and retrieval cause a much higher strain on the components.

The trial has highlighted a number of developments and modifications to the equipment that would be beneficial, to improve its robustness, make it easier to handle, and extend its application to other fisheries:

- changes to the mechanical frames that keep the electronic components in place inside the pod, to make them more robust to manual handling and regular deployment and retrieval at sea in sometimes rough conditions
- more robust connectors on the cables connecting the battery, pod and speaker array, to withstand currents and waves during at-sea deployment
- integration of the battery and pod into a single unit, to reduce the complexity of deployment; there is also potential to integrate this into a floating dhan buoy to enable it to be floated on the surface with only the speaker array submerged
- need for update of the control software
- extension of depth rating of speakers by means of a pressure compensation system, to allow them to be deployed in deeper waters
- modification of speaker system to minimise size as far as possible, to improve ease of handling (although potential is limited due to frequency and energy conversion requirements – see below)
- further testing in other fisheries (e.g. different geographical locations, different depths, different gear types and target species) would also be beneficial to test the effectiveness of the ASD in a range of situations.

Genuswave has already implemented a number of these improvements (changes to the mechanical frames in the pod, and update of the control software) in the commercially-available product. Future development could explore other options outlined above to increase the ease of use of the device in wild capture fisheries and its potential for use in different conditions.

Nevertheless, there is an inherent need for the ASD (or any seal-specific ADD) to remain relatively large. This is because the minimum size of speakers required is partly determined by wavelength which is inversely correlated with frequency which needs to be relatively low to target seals (see Section 2.2). The efficiency of the speaker to convert electrical energy to acoustic energy (sound) is also more favourable in larger speakers. Therefore, unlike gillnet pingers designed to reduce cetacean by-catch, which are integrated on to the net itself, seal-specific ASDs will remain large and the potential for significant modifications to streamline its deployment will likely be limited. Inevitably this results in a time-related cost to the fishermen associated with deploying and retrieving the ASDs. Additionally, depending on the net length, multiple ASDs are likely to be needed to provide adequate coverage of the net, increasing the handling requirements and also the costs involved. However, it may be possible to include a ‘gillnet pinger capability’ in the ASD to avoid the need for separate gillnet pingers and further cluttering of the net.

4.4. Views of the Fishermen

The fishermen involved in the trial were supportive of the ASD and felt it was ‘on the right track’ for addressing the seal depredation problems they are facing. At times during the trial they perceived a positive effect, and when the devices were working as they should, they noted that there were higher catches of mackerel and fewer depredated fish in the net close to the ASDs. They recognised that seals tended to be better deterred by devices with higher duty cycles.

The technical errors that occurred and resulting variability in the results observed, together with the presence of seals in the vicinity of their nets at times, and significantly more depredated fish in both test and control nets when the units were malfunctioning, led them to question the effectiveness of the ASD. They also felt that the seals may be able to put up with the noise if they were hungry enough, and/or there may have been sufficient time between pulses (particularly at lower duty cycles) for seals to depredate on the nets, given the shallow depth at which they were set.

Addressing the technical issues encountered (to avoid device malfunction) and making the devices easier to handle (as far as possible), to facilitate deployment and hauling for single-handed operations, would increase the potential for their use as deterrent measures in shallow-water inshore fisheries.

Additionally, the cost of the devices, and the number of devices that would need to be deployed per net, would have to be considered against the potential increase in catch that the fishermen may achieve, for them to make a decision about whether it would be a cost-effective investment for them to make.

4.5. Views of the Acoustic Startle Device developer

Genuswave expressed a commitment to developing a solution that can be used for inshore water fisheries. The results from the trial show that in spite of the technical problems that occurred, the ASD led to a 74% increase in catches in the protected net compared to a control net. Genuswave believe that Acoustic Startle Technology could be critically important to the fisheries; it might even ensure ongoing commercial viability of such fisheries. Genuswave expect units to be commercially available early next year.

The technical problems that occurred in the fisheries trial have led to changes in design, i.e. improvements to the mounting frame of the electronics and software updates. Furthermore, Genuswave plan to develop the ASD so that the battery is incorporated into the main pod and deployment depth of the transducers is extended by means of a pressure compensation system. The transducers currently can be deployed to about 20 metres and with current deterrent range should be effective to 120 metres or more. The best results, of course, would be when the unit is in close proximity to the net.

Genuswave’s general approach is to provide a technology that will increase the user’s revenue, reduce user expenses and enable each fishery to generate more profits.

5. Conclusions

The trials tested the effectiveness of an ASD by Genuswave in deterring and reducing the level of depredation by seals in an inshore static net fishery in Torbay. A number of technical challenges were encountered during the trials, which reduced the effectiveness of the devices and therefore the overall outcome of the trial. Despite this, the ASD was shown to have a positive effect, i.e. a 74% increase in overall catch. However, there was a high variability in the effectiveness, and for the prototype device to become market ready and to be considered a viable non-lethal deterrent option in wild capture fisheries, further work is needed to:

I. ensure the robustness of the devices for regular handling and deployment at sea
II. adapt the configuration of the devices for ease of handling and deployment by fishermen
III. determine optimal duty cycles of one or multiple devices for an optimum level of deterrence whilst minimising additional noise input to the marine environment
IV. carry out further development and testing in a wider range of fisheries to confirm its effectiveness for a range of locations, target species and gear types, as well as potential for habituation to the devices by seals.

The cost of the devices, and the number of devices to be deployed per net would also have to be considered. Provision of funding support, or the creation of efficiencies in production to bring the price to a level that is accessible for inshore fisheries, would support the potential for its adoption. There is also likely to be a trade-off between ‘ease of use’ for the fishermen and the number of units deployed to give adequate coverage of the net.

In its current state of development, the ASD (and other ADDs) is not market ready for many wild capture fisheries and may not be economically feasible (particularly if multiple devices are required to ensure coverage of the full net) for individual static net fishers in England. Further improvements and testing are required for it to be considered a viable non-lethal deterrent, however this project has demonstrated that it shows promise and such further development should be explored.

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7. Abbreviations and Acronyms

ADD	Acoustic Deterrent Device
AICc	Akaike information criterion
ASD	Acoustic Startle Device
DSIFCA	Devon & Severn Inshore Fisheries Conservation Authority
GLMM	General Linear Mixed Model
GPS	Global Positioning System
MMO	Marine Management Organisation
NFFO	National Federation of Fishermen’s Organisations
PLN	Port Letter and Number
SMRU	Sea Mammal Research Unit
TAST	Targeted Acoustic Startle Technology

Appendix A – Onboard Data Recording Proforma

Vessel name:	PLN:
Departure date and time:	Landing date and time:
Departure sea state / weather conditions:	Landing sea state / weather conditions:

Net ID (i.e. T, C)	**Net length**	**Test (with device(s)) or Control (without device(s)) net? (please '✓')**		**Device operating on deployment? (please insert '✓', 'x', or 'N/A')**			**Device operating on retrieval? (please insert '✓', 'x', or 'N/A')**		
		Test (fill in Device boxes →)	Control (without device)	Device 1	Device 2	Device 3	Device 1	Device 2	Device 3

GPS location (lat, long)					Time net set	Water depth (m)	Time net hauled	Water depth (m)
Start net	End net	Device 1 (if test)	Device 2 (if test)	Device 3 (if test)				

Depredation (no. of fish)	Species:	Species:	Species:	Species:
Body removed	no.	no.	no.	no.
Bite to body	no.	no.	no.	no.
Skin removed	no.	no.	no.	no.
Other (specify)	no.	no.	no.	no.

Fish undamaged (boxes to market) Note: Brixham Trawler Agents to provide fish grading and weights for test/control boxes	Species	Box IDs (i.e. T#, C#)

Notes e.g. seal presence and behaviour, presence of other marine mammals (harbour porpoise, dolphins), approximate proportion of catch/damaged fish in particular net panels, net damage/entanglement, photos taken etc.

Appendix B – Influence of Outliers in Model Estimates

Rationale and Methods

A series of measures were taken to examine whether 'outliers' in the data unreasonably influence the model estimates (coefficients and CIs). Any removal of data from the analysis, perceived 'outlier' or not, should be exercised with extreme caution and must be based on objective criteria.

In terms of the modelling approach chosen in this study (GLMM) the primary concern is related to outliers in the residual variance ('residuals')[7] which have some potential to bias model estimates. Hence, in addition to the previously-described model validation procedures (see Section 2.5.3), the residuals were plotted against their index number to determine the data points with the highest residual variance (i.e. each residual's deviation from zero). These were considered the prime candidates for exerting an 'unrealistic influence' on the model estimates.

The trials (test vs control pair) which contained at least one of these data points were then removed from the analysis and the model was refitted on the remaining dataset. These 'refits' were conducted in a stepwise process. First, the trial with biggest outlier in the residuals was removed (trial 30), then the two trials with the biggest outliers were removed (trial 30 and 3), then the three (trial 30, 3, and 9), the four (trial 30, 3, 9, and 7) and the five biggest outliers were removed (trial 30, 3, 9, 7 and 22).

The model coefficient and associated confidence intervals were then plotted on the scale of the response variable and were compared to the model fitted with the full dataset (no outliers removed). These refits were only conducted on the landed and non-landed catch which showed the most obvious outliers.

Results and Discussion

The coefficients and confidence intervals for the refitted models using the datasets in which the one to five biggest outliers in the residuals were removed are shown in Figure 13.

While the model estimates for the 'percentage increase in catch in the test net' vary across models, the overall analysis seems to be relatively invariant to the process of stepwise elimination of potentially 'influential outliers'. When trial 30 is removed, the predicted percentage increase in catch in the test net reduces (to ~54%), but it is still a positive result. When the subsequent trials are removed, the predicted percentage increase in catch in the test net increases. When the five biggest outliers are removed, the model indicates an increase in catch by ~108% in the test net.

The average of the model estimates (i.e. the percentage increase in catch in the test net for all five tested 'refits') is 76% and the median is ~73%. The latter is similar to the model estimate of 74% increase in landed and non-landed catch in the original model using the full data with no removal of outliers. Hence, while removing specific

[7] The residual variance is the difference between the observed value of a data point, and the value predicted by the model.

observations with outliers in the residuals influences the estimates, this appears to occur in a stochastic manner.

The average of the stepwise removal of the five potentially most influential observations confirms rather than contradicts the general findings of this study (see Figure 13). The best representation therefore still seems to be the model using the full dataset with no removal of outliers. However, one should note that the confidence intervals for all these estimates are high (see also Figure 11). This is most likely a reflection of the many poorly-controlled factors that could have influenced efficacy (e.g. unit malfunction, error modes etc.).

Figure 13 Predicted percentage increase (with 95% confidence intervals) in landed and non-landed catch weight in nets with ASD with outliers in the residuals removed