**Contribution to the Themed Section: 'Marine Mammal Bycatch and Depredation'**
## Original Article

# Testing a passive deterrent on longlines to reduce sperm whale depredation in the Gulf of Alaska

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In Alaska, sperm whale (*Physeter macrocephalus*) depredation on longline sets has increased since implementation of the Individual Fishing Quota programme in 1995. A collaborative effort (SEASWAP) between longliners, scientists, and managers has undertaken research to evaluate this depredation with a primary objective to develop and test a passive deterrent that would reduce depredation without reducing catch rate of sablefish (*Anoplopoma fimbria*). Commercial longliners, fishing for their own sablefish quotas during the regular season, deployed beaded gear (25 mm lucite beads attached to gangions) with control gear and set recorders to collect acoustic data. Beaded and control gear were randomly assigned by skate quad (672 hooks) with 5 quads in each longline set. Acoustic recorders were used to document sperm whale creak–pause events, representative of depredation of the longline gear. Although there were more sablefish per skate quad on the beaded gear and there was a decrease in depredation events on the beaded gear compared with the control, neither effect was significant ($p = 0.205$ and $0.364$, respectively). The SEASWAP project is testing other deterrent strategies including gear modifications and the establishment of a sighting network to improve avoidance.

**Keywords:** commercial fishing, depredation, Gulf of Alaska, longline, marine mammals, passive deterrent, sablefish, sperm whales.

## Introduction

In Alaska, sperm whale depredation on commercial sablefish longline sets has increased since the cessation of commercial whaling and the implementation of the Individual Fishing Quota programme in 1995 (Sigler *et al.*, 2008). In this context, depredation refers to the removal or damage by whales of fish hooked on commercial longline gear. The increasing frequency of depredation on the NMFS Alaska Fisheries Science Center's (AFSC) sablefish longline survey in the Gulf of Alaska may be starting to affect population indices derived from the survey (Hanselman *et al.*, 2014). Sperm whales have long been known to depredate commercial longline fishing gear in both hemispheres (Hill *et al.*, 1999; Hucke-Gaete *et al.*, 2004; Purves *et al.*, 2004; Sigler *et al.*, 2008). Five early studies of depredation globally, from the Gulf of Alaska to the Southern Ocean, showed that sperm whales take 1–3% of the

catch (Hill *et al.*, 1999; Sigler *et al.*, 2001, 2008; Hucke-Gaete *et al.*, 2004; Purves *et al.*, 2004). However, later studies revealed empty hooks can be caused by removal of a fish by a whale; hence, depredation is likely higher than estimated by earlier studies which used catch comparisons to estimate removal (Mathias *et al.*, 2009; Straley, 2012). To date, there is little evidence for effective deterrents to this behaviour. Net sleeves, socks, and monofilament "spiders" have been used with marginal success in reducing depredation in the Patagonia toothfish fishery in the southern hemisphere (Goetz *et al.*, 2011) and in pelagic longline fisheries for swordfish (Rabearisoa *et al.*, 2012), but fish catch was significantly reduced and the net sleeves are not practical for use in the Alaska longline fisheries due to different gear and vessel configurations. Hooks are close together and gear is coiled in tubs or on skate bottoms, making sleeves impractical to deploy.

Sperm whales make distinctive sounds for communication and to locate and navigate underwater. Some sounds are associated with depredation events in the Alaska longline fishery (Thode *et al.*, 2007a, b). These sounds are described as a series of creaks followed by a pause (Figure 3). A "creak" is a rapid series of clicks in short succession. This distinct creak sound is an echolocation signal used by sperm whales to locate prey, which indicates that the animal is honing in on a prey item, essentially an attempt at removal (Mathias *et al.*, 2012; Wild, 2013; Thode *et al.*, 2014).

A collaborative effort, Southeast Alaska Sperm Whale Avoidance Project (SEASWAP), involving the Alaska Longline Fishermen's Association (ALFA), the University of Alaska Southeast (UAS), the Alaska Department of Fish and Game, Scripps Institution of Oceanography (SIO), and the Sitka Sound Science Center (SSSC) in cooperation with the AFSC, has undertaken research to evaluate these depredation events and inform fishery managers (Mathias *et al.*, 2009, 2012; Mesnick *et al.*, 2011; Thode *et al.*, 2012; Schakner *et al.*, 2014; Straley *et al.*, 2014). Passive acoustic data collected during fishing provide a quantitative measure of sperm whale depredation of fishing gear. Physical signs of depredation (fish heads, lips, and straightened hooks) are difficult to assign to sperm whales and also do not account for whole fish removed by the whales (Mathias *et al.*, 2009). This study utilized creak–pause counts as a proxy for depredation events.

The purpose of the research was to develop and test a passive acoustic deterrent that could reduce depredation by exploiting the echolocation abilities of sperm whales through confusion or masking. SEASWAP partners, including longliners, discussed potential strategies for deterrents. The goal was to design an experiment that would evaluate the efficacy of a passive deterrent and was practical for the fleet to use. The original idea was to develop a deterrent that would inflate upon gear retrieval, thereby mimicking the swimbladder of a rockfish (*Sebastes* spp.). Rockfish are spiny fish with a closed swimbladder, and anecdotal information by the fleet and researchers indicates that sperm whales avoid interactions with these species. Because of their closed swimbladder, these fish inflate upon gear retrieval, creating a large acoustic target, making them readily identifiable by sperm whales echolocation. However, we were unable to design a device with this characteristic that was practical for deployment on each gangion/hook combination. In the end, we tested a variety of objects attached to gangions for their acoustic properties. The target strength of the 25 mm diameter acrylic bead was evaluated to have similar target strength (128 dB) as an average sablefish, $-27$ dB for a 71 cm sablefish (W. Au, University of HI, pers. comm.). We speculated that because each gangion would have a similar acoustic return, regardless of the presence of sablefish, the whales would be confused in their echolocation ability to isolate a single sablefish (i.e. the reward). Thus, the bead would be a deterrent. We designed and conducted an experiment to test this hypothesis. A second hypothesis was that the placement of an acrylic bead near the hook would not change sablefish catch per unit effort per skate quad (cpue).

## Methods

We conducted a field trial of passive deterrent gear using small acrylic spheres (called beads) attached near each hook on the gangion (Figure 1). The gangion is a nylon cord, 8 mm in diameter and 610 mm in length used to attach the hook to the groundline (mainline) of the longline set. Autonomous acoustic recorders attached to the buoy line at the second end of the longline were used to document creak–pauses with and without the deterrent present. Data from these recorders were downloaded after each set and analysed for sperm whale vocalizations.

The deterrent treatment was randomized to the skate quads within 24 longline sets. Each longline skate was 183 m, and stuck with a gangion every 1.07 m. There was a 1.82 m blank space at each skate end's eye splice. This results in 168 hooks per skate. The gangions were #60 weight soft lay and have been pre-cut to 610 mm. The hooks were #13 Mustad hooks. The experimental unit was a skate quad (four 183 m skates) with 5 skate quads deployed per set. Each skate quad was randomly assigned to be either beaded (deterrent) or unbeaded (control) gear. The reason for using skate quads as the experimental unit was that the quads were the amount of gear that would reach from the seabed to the surface upon retrieval, allowing us to correlate sperm whale acoustics with gear type. By knowing the time of retrieval of each skate within a quad, we could match the sperm whale acoustic activity associated with beaded and control quads. However, because we did not know the depth of the whales that were depredating, there were a few instances when creak–pause activity could not be assigned to control vs. beaded gear (Figure 2).

Usually, an observer was onboard the vessel and counted back the hooks in haul back order utilizing a field computer that captured time and location with each data point entered. Each hook (including catch) was recorded as it came over the roller, allowing for later correlation (by time) with the acoustic data. The time each quad emerged from the water was also recorded. In a few cases, vessels had electronic monitoring systems on board and the hook by hook counts and times were documented by Archipelago Marine Research biologists using video review.

Acoustic data were reviewed by a bioacoustician (Wild) trained in determining sperm whale sounds, including creaks and creak/pause events. These acoustic data were time stamped to allow for comparison of the catch data.

### Statistical analysis of the hypotheses

A known proxy variable for a depredation event is a creak–pause audio signal (Thode *et al.*, 2007a, b) recorded by hydrophone and interpreted by researchers thereafter. The effect of the deterrent
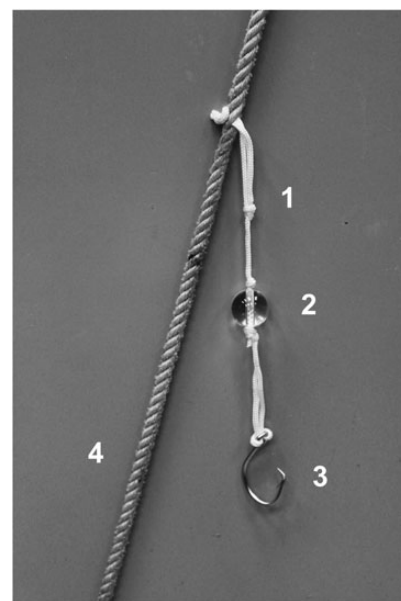


**Figure 1.** Beaded gangion being hauled back to vessel. 1, gangion; 2, bead; 3, hook; and 4, longline. Control gear is identical minus the bead.

**Figure 2.** Schematic of one 5 quad longline haulback illustrating how creak–pause activity is assigned to beaded vs. control. Creak–pause events in dashed box could not be assigned and were not used in the analysis.



**Figure 3.** Spectrogram of a sperm whale creak followed by a pause, recorded during a depredation event.

was assessed with a *t*-test (Rice, 1995) comparing the mean number of creak–pauses per skate quad with and without the deterrent, in the presence of sperm whales:
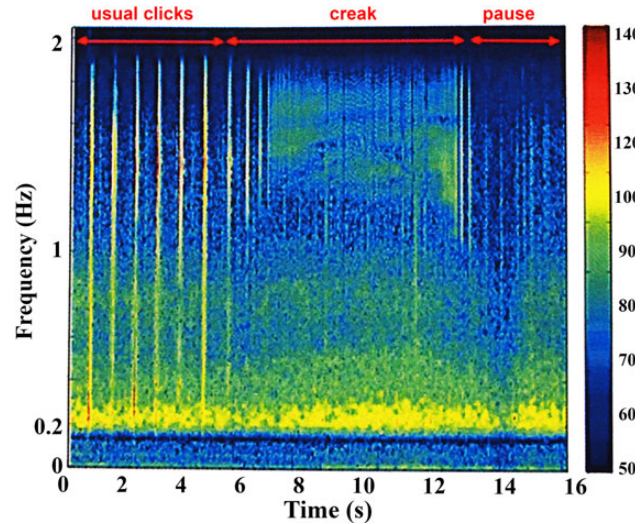
$$t = \frac{\bar{y}_{11} - \bar{y}_{12}}{\sqrt{(s_{11}^2/n_{11}) + (s_{12}^2/n_{12})}}, \qquad (1)$$

where $n_{ij}$, $\bar{y}_{ij}$, and $s_{ij}^2$ are the sample size, mean, and variance, respectively, of the *ij*th cell. This is a test of a simple effect within two levels of the whale present row.

A secondary hypothesis is that the deterrent does not influence cpue in the absence of whales. This is also assessed with a *t*-test [Equation (1)] except the comparison is between the mean cpue of skate quads with and without the deterrent but in the absence of whales. This is also a simple effect within the whales absent row.

The deterrent and the whales are both either present or absent, yielding four combinations of treatments. These are (i) whales present and deterrent present; (ii) whales present and deterrent absent; (iii) whales absent and deterrent present; and (iv) whales absent and deterrent absent. The effects of interest are both simple effects within the whale present row and whale absent row. The simple effect within the whale present row estimates the effect of the deterrent on reducing depredation. The simple effect within the whales absent row confirms the non-effect of the deterrent on cpue.

We conducted a power analysis (Rice, 1995; Kuehl, 2000) to determine the total sample size as well as how to apportion the sample size to the four treatment combinations. Power depends on the size of the effect, the standard deviation, the sample size, the significance level, and which statistical test is used. If power exceeds 0.9, the experiment should be successful in detecting the treatment effect if it exists. If power is <0.6, it would not be favourable to the success of the experiment. We assumed a significance level of 0.05, meaning that if a *p*-value is <0.05, then the effect will be said to be significant.

We used acoustic data collected from the F/V Ocean Prowler NMFS sablefish longline survey to estimate sperm whale depredation events per skate quad under normal operating conditions. These data were collected from the survey during 2009−2011 and 22 of these longline survey set hauls were used to evaluate the number of creak–pause counts. An example of the F/V Ocean Prowler data is as follows: 3, 8, 12, 20, 8 where the creak–pause counts indicate depredation events per skate quad. The creak–pause counts are in order as the longline is hauled. There is a readily observed pattern to the counts such that the number of depredation events starts low and increases as the haul progresses. We fitted a simple regression model to the creak–pause per skate quad vs. the order within the longline set to preserve this pattern in the simulated creak–pause counts. We randomly reassigned the residuals to the fitted values for each iteration of the bootstrap simulation (Efron, 1988; Manly, 2001). We obtained 1000 bootstrap iterations for sample sizes of 12, 18, 24, 30, and 36 longline sets. We computed a *t*-test statistic [Equation (1)] assuming that the deterrent would reduce creak–pauses by an assumed effect size. We then computed the proportion of iterations wherein the *p*-value of *t*-test statistic [Equation (1)] was smaller than 0.05. This provides an estimate of the power of *t*-test for that sample size and the assumed effect size. We plotted power curves vs. sample size for deterrent reduction effect sizes of 2, 2.5, 3, 3.5, 4, and 4.5 creak–pauses per skate quad (Figure 4).

The effect of the deterrent was assessed with a *t*-test (Rice, 1995) comparing both the mean number of creak–pauses per skate quad and sablefish cpue, with and without the deterrent, in the presence of sperm whales:

$$t = \frac{\bar{y}_{11} - \bar{y}_{12}}{\sqrt{(s_{11}^2/n_{11}) + (s_{12}^2/n_{12})}},$$

where $n_{ij}$, $\bar{y}_{ij}$, and $s_{ij}^2$ are the sample size, mean, and variance, respectively, of the *ij*th cell. To confirm that the deterrent does not reduce sablefish cpue, we conducted a similar *t*-test with the column means.

We made 25 experimental sets in 14 trips on 9 vessels between March and August 2012. Twenty-two sets, with a total $n = 103$
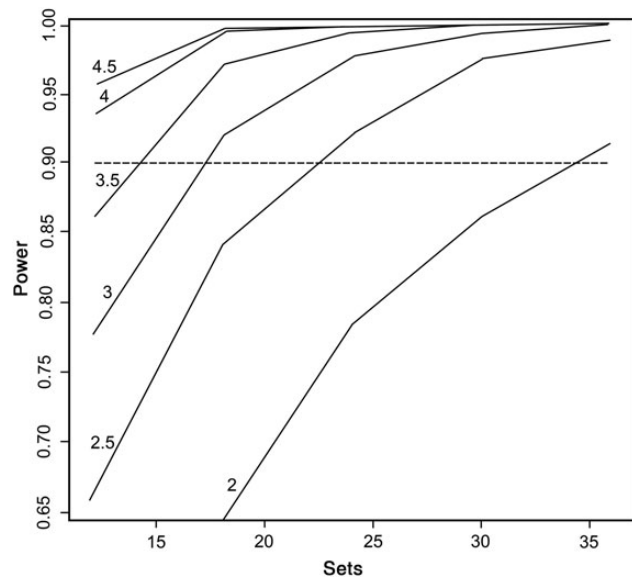
**Figure 4.** Prospective power analysis: power curves show the probability of finding a deterrent to have a significant effect (reductions in creak–pause per skate quad shown on curves), 24 sets (120 quads) will yield power of 0.90 with 2.5 less creak–pause events.

skate quads (800 m), were used in the analysis. Three sets with a total of 15 skate quads had failures of the acoustic recorders and were not usable in the analysis. The opening weeks (March) of the sablefish season always yield the largest cpue's and coincidentally during this experiment, there were no whales present at the gear during these days. Therefore, the longline sets fished on the first week of the opening (33 quads) were excluded when estimating the depredation effect. These data were instead used to test the hypothesis that the deterrent does not reduce sablefish cpue.

An estimate of cpue lost to sperm whales was obtained by constructing 95% confidence interval (CI) for the difference in cpue with and without whales present for all remaining quads (70 quads). Finally, an estimate of the proportion of quads that are depredated by sperm whales was obtained with the cell counts. A retrospective power analysis was also conducted once the actual deterrent effect size on the creak–pause counts and on sablefish cpue was established.

## Results, evaluation, and conclusions

*Hypothesis* 1: The passive deterrent does not influence catch per unit effort of sablefish in the absence of whales: 33 skate quads fished during the season's opening week, when whales were not present, were used to test this hypothesis. Although the beaded gear caught more fish than the control gear (mean = 310 sablefish per quad beaded vs. 260 sablefish per quad un-beaded), the difference was non-significant ($p = 0.137$).

*Hypothesis* 2: The passive deterrent (acrylic bead) does not significantly reduce depredation: Of the remaining gear, 32 skate quads were retrieved when whales were present. Based on acoustic data analysis, these sets had between one and three whales involved in depredation during haul back.

Sablefish cpue and creak–pause counts (available only when whales are present) do not have significant linear correlation ($r = 0.125$, $p = 0.49$). With whales present at the gear, the difference in

**Table 1.** Vessel effects for vessels that had beaded and control gear with whales present: CP, creak pause; SF, sablefish.

| Vessel | Difference in CP Beaded vs. control | Difference in SF per quad Beaded vs. control | % Difference Catch vs. quad (%) |
|---|---|---|---|
| V1 | −0.83 | 11 fish per quad | 7 |
| V2 | −3.25 | 46 fish per quad | 30 |
| V5 | −0.75 | 4 fish per quad | 5 |
| V6 | 0.17 | −7 fish per quad | −14 |

the mean number of sablefish caught between beaded and control quads was estimated as 14.82 sablefish per quad with 95% CI (−21.01, 50.65), which was not a significant difference ($p = 0.21$). The difference in the mean creak–pause count between beaded and control gear, with whales present, was −0.4667 creak–pause per quad, with 95% CI (−3.19, 2.26). Although this indicates a decrease in depredation events, it was not a significant effect ($p = 0.36$).

### Vessel effects

Differences in fishing success between vessels may have influenced results. The catch per unit effort of sablefish per quad (cpue) varied considerably between vessels, ranging from an average of 185 to 30 sablefish per quad. This does not include fishing on opening week when there was an average of 286 sablefish per quad. Four vessels had both beaded and control gear retrieved in the presence of sperm whales (Table 1). For three of the four vessels (V1, V2, V5), sablefish/skate quad was greater on beaded gear than control gear. The difference varied from 4.11 fish per quad to 45.50 fish per quad depending on vessel (5–30% of sablefish per quad), but none were significantly different. The number of creak–pause events was also lower on these vessels when fishing beaded gear, but the difference was also non-significant. For the fourth vessel (V6), beaded gear had lower catch rates than control gear (difference of −7.33 fish, 14% of sablefish per quad) and higher creak–pause events, although again these differences were non-significant.

### Other results

The difference in the mean cpue between sets with whales present and sets with no whales present was −10 sablefish per quad, with 95% CI (−31, 11). The negative indicates that actually more sablefish were caught when whales were present, although the difference was not significant ($p = 0.166$). This result is comparable to earlier work by Straley (2012) that indicates whales are more likely to depredate vessels with higher cpue. There was an estimated 3.38 creak–pause count per quad when whales were present with 95% CI (2.08, 4.67) which suggests a minimum number of fish taken from the gear. A 95% CI for the proportion of quads (0.31) that were depredated by sperm whales is (0.22, 0.39).

### Retrospective power analysis

The true power to detect the observed deterrent effect size was only ∼0.32 when compared with 0.90 power in the prospective power analysis. The retrospective power analysis made use of the actual sample size ($n = 103$), the newly estimated mean creak–pause counts (3.38 creak–pauses per quad), variance of same (12.89), as well as the estimated effect size of the deterrent (−0.4667 creak–pauses per quad). The sample size would have had to have been as large as $n = 2182$ quads to have the power to find a deterrent

effect of this size to be significant. If the experimental variance could have been reduced to 0.604, then the sample size ($n = 103$) would have yielded power closer to 0.9. Alternatively, if the deterrent effect (perhaps with an altogether different deterrent) could be increased to 2.5 creak–pauses per quad, then an experiment with this design would have the desired 0.9 power.

## Conclusions and discussion

The experiment did not detect a difference between beaded and unbeaded fishing gear. This was due primarily to a lack of power in the experiment that determined the deterrent ineffective. The reasons for the lack of power stem from the nature of the field study design.

We worked from commercial vessels in an active fishery using commercial fishing quota. The cpue between boats varied considerably even in the absence of whales. This was not unexpected as vessel effects on cpue are well documented and may be attributed to experience, area, depth, and season among other factors (Hinton and Maunder, 2004; Maleo and Hanselmen, 2014). Ideally, utilizing a single vessel during a discrete period would be much preferable but is unrealistic. In this limited access fishery, no single vessel holds sufficient quota in the study area to conduct the entire experiment. Therefore, the real-world nature of the experiment created difficulty in increasing sample size and reducing variables.

Another issue with the sample design was the use of quads instead of sets, making it necessary to remove some creak–pause event data from the analysis that could not reasonably be assigned to treatment type. Depending on the random placement of treatment quads, and the arrival and activity of whales, there were times that creak–pause activity could not be assigned to a treatment and had to be excluded from the analysis. We had considered including blank quads with no hooks between treatments; however, this was untenable to the fleet, whom were actively fishing. Blank quads increase setting and haul back time with no benefit to them and might have served to increase sperm whale access to the gear during haul back by slowing the retrieval process. Alternatively, we considered using the entire set instead of a quad as the treatment. Because we could not predict the presence of whales at a set in advance, the set treatment must be assigned randomly and this had the real potential of not having comparable sample sizes between treatments. In the future, we may consider smaller scale deterrent testing to gauge initial results then work with the fleet to engage in research with a large enough sample size to statistically test deterrent effects.

The unpredictability of depredation events makes deterrent testing challenging and whales have different behaviours around vessels. Some whales are extremely adept at removing fish from a longline and others are either not as focused or adept at this behaviour. Our experimental design before fieldwork suggested that 33% of the sets would have whales present. In fact, 31% of the gear did have whales present during the deterrent testing experiment. However, there is no effective way to yet predict when and where whales are likely to depredate. Additionally, there are significant unknowns associated with whale behaviour during depredation, including lack of knowledge of recent interactions with other vessels and competition behaviour among whales depredating concurrently, and it is likely that not all sperm whales present near longlines depredate gear (SEASWAP, unpublished data).

Sablefish are extremely valuable, currently bringing an ex-vessel value of over 10 UK£s per kilo ($7 US per lb) to the fishers ex-vessel. This means that for every depredated fish, the crew losing 218 UK£s in straight revenue, not considering increased real cost in bait and fuel to make additional sets to catch their quota and ecological costs in increased bycatch created by additional sets. Developing a low-cost, practical deterrent that reduces these interactions will provide benefits to the fleet and the resource, as well as reduce the possibility of whale entanglement. Additionally, our long-term partnership with the fishing fleet was developed as a means to reduce whale/longline interactions, and deterrents would provide longliners with a tool to meet this objective.

We are working to develop other deterrent or avoidance devices including a modification of the device used in the Fijian Tuna fishery developed by Hamer *et al.* (this journal issue) and a widespread sighting network, alerting longliners to the presence of sperm whales during fishing.

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