Effect of seal scarers on seals

Literature review for the Danish Energy Agency

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Summary

A number of studies have been conducted to test the effectiveness of seal scarers, or acoustic harassment devices. Most studies have focused on the application of seal scarers in fisheries, with the purpose of reducing depredation on catch and damage to fishing gear. Other studies, including a few on captive seals, have addressed the now widespread use of seal scarers as a mitigation tool, intended to keep seals away from potentially harmful noise generated by offshore construction activities, most notably pile driving of foundations for offshore wind turbines.

The different studies are very diverse with respect to methods used and specific questions addressed and are thus difficult to compare directly. Some conclusions relevant for mitigation can nevertheless be drawn across the studies:

- Of the different types of seal scarers tested, the Lofitech device appears consistently more effective at deterring seals than the other commonly used type, the Airmar dB II plus.

- No differences in response between harbour seals and grey seals were evident in the studies, although the sample sizes are too small to draw firm conclusions.

- Minimum deterrence distance for the Lofitech seal scarer is estimated to range between 200 and 600 m and for the Airmar dB II plus around 50 m.

The above distances relate only to use for the purpose of mitigation of hearing injury in connection with pile driving or other loud underwater noise. Within the context of fishery, distances are expected to be much smaller as there is a strong food incentive for the seals to tolerate high noise levels.

1 Background

This study is commissioned by the Danish Energy Agency to review and evaluate the current knowledge on effectiveness of seal scarers as a mitigation tool to protect seals from injury during construction of offshore wind farms. Seal scarers are used during construction of offshore wind farms to deter and hence protect marine mammals from exposure to loud noise levels capable of inflicting hearing damage. In the following, the available results from experimental studies are reviewed and evaluated in the context of using seal scares as mitigation tools.

Seal scarers, or seal scrammers, are devices designed to deter seals from fishing gear and aquaculture installations to avoid depredation on fish in fishing gear. They are often, together with acoustic alarms (pingers) used to deter small cetaceans from gill nets, referred to as acoustic deterrent devices (ADDs). As the seal scarers are significantly more powerful than porpoise pingers, the seal scarers are often also referred to as acoustic harassment devices (AHDs).

In addition to their primary purpose in relation to fisheries and aquaculture, seal scarers are also extensively used to deter marine mammals from loud and potentially dangerous sound sources, such as pile driving or underwater explosions. Sometimes they are referred to as acoustic mitigation devices (AMDs) in this context, although the difference is purely semantic. Mitigation is achieved by deploying an AHD prior to the main activity (pile driving, explosion etc.) such that marine mammals are deterred out to safe distances before the main event occurs.

1.1 Seal scarers (AHDs)

Seal scarers (figure 1.1) transmit short sounds in a frequency range of 10-40 kHz (often with main energy at 10-14 kHz), with source levels in the range 175 to 195 dB re 1µPa. In some models, the length of pulses and the intervals between them are randomised to decrease the potential for animals habituating to the sounds so that aversion effects can be maintained over time. Producers of AHDs include Ferranti Thompson, Terecos, Airmar, Ace Aquatec and Lofitech.

Figure 1.1. Two seal scarers: Left: Lofitech (Leknes, Norway), orange box contains the battery, orange cylinder is the transducer; right Airmar dB II plus (Airmar, Milford, NH, USA), black cylinder is the transducer.

As mentioned above, most of the AHDs emit sounds in the frequency range 10-14 kHz where pinnipeds, including harbour seals (*Phoca vitulina*), have their best hearing (Reichmuth et al. 2013). The ability of AHDs to prevent depredation has been the subject of several studies, but even so their effectiveness has been disputed (see Königson 2007). In sharp contrast to this are several studies of the effects of AHDs on harbour porpoises, which indicate reactions to AHDs at distances of several kilometres (e.g. Olesiuk et al. 2002, Brandt et al. 2012, Brandt et al. 2013).

The deterrence distance is critically important in assessments of the effectiveness of AHDs as mitigation tools to reduce the risk of auditory injury to seals. As auditory injury accumulates over time, the exposure to multiple pile driving noise pulses must be factored in as must the movement of seals away from the piling site as a reaction to the noise. If seals are closer than a critical distance at the start of piling, they will not be able to escape sufficiently far away before the accumulated acoustic energy exceeds safe levels, with increased risk of hearing damage (see Skjellerup et al. 2015). In order for an AHD to be effective as a mitigation tool in connection with pile driving, it must be able to deter seals beyond this critical distance (determined by factors such as source level of pile driving noise and sound transmission properties) before the pile driving operation begins.

1.2 Harbour seal and grey seal hearing

The underwater audiogram of harbour seals shows good underwater hearing within the range from a few hundred Hz to about 50 kHz (figure 1.2). AHDs usually produce energy at frequencies in the 10–20 kHz range, well within the range of good hearing of harbour seals. The hearing sensitivity of grey seals is not known but presumed to be comparable to the harbour seal.

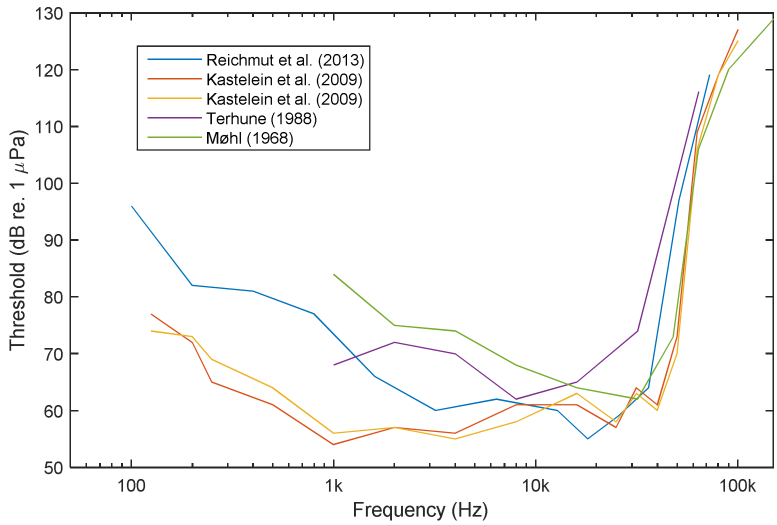


Figure 1.2. Different audiograms of harbour seals. Data compiled by Reichmut et al. (2013). Each line corresponds to one animal. Kastelein et al. (2009) thus obtained audiograms from two different individuals.

Comparatively little is known about behavioural reactions of harbour seals to underwater sound. They are generally, together with other pinnipeds, assumed to be tolerant of quite high noise levels (e.g. Blackwell et al. 2004), although most information on this is anecdotal. In the following, the current knowledge about the impacts of AHDs on harbour seals will be reviewed and discussed. Particular emphasis is on evaluating the effectiveness of AHDs in deterring seals away from pile-driving sites to minimise the risk of auditory injury or, in other words, to extract from the studies an estimate of the deterrence distance to be used in modelling of noise mitigation according to Skjellerup et al. (2015).

2 Studies testing responses of seals to AHDs

Thirteen studies were identified as relevant for the review. Most of these were conducted in real or simulated fisheries or addressed the interaction between seals and fisheries in other ways. Two studies were conducted on animals in captivity, and three studies targeted the use of AHDs as mitigation tools directly.

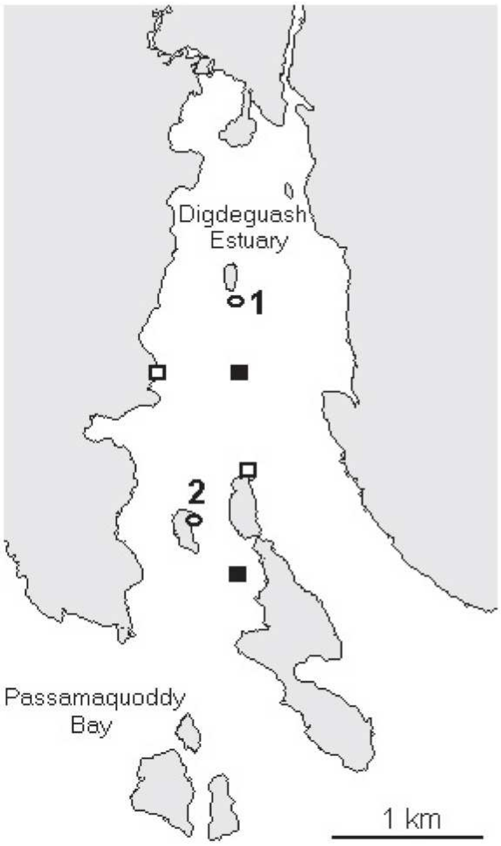
2.1 Field studies directly evaluating reaction distances

The following studies were designed to quantify the deterrence distance of AHDs in the field and thus provide results that can be directly used in an evaluation of the effectiveness of seal scarers for protection of seals against hearing damage.

2.1.1 Jacobs and Terhune (2002)

Jacobs and Terhune (2002) tested the effect of the Airmar dB plus II AHD around harbour seal haul-out sites in the Deer Island region, Bay of Fundy, Canada. The source level of the Airmar used was 178-179 dB re 1 μPa_{pp}. In the first behavioural trial, they flushed harbour seals into the water from a haul-out site with a research vessel and four Airmar transducers were turned on after a period of two minutes. Behavioural reactions were monitored by observers on the ship and distances measured with an optical range finder. No observable reactions by the seals to the AHD were noted in any of the trials. The closest distance between the research vessel and a seal at the surface while the AHD was turned on was 43 m, but the majority of seals were about 200 m away. In the second trial, seals had to swim through an ensonified area in a narrow estuary to reach the haul-out site up-river (figure 2.1). Counts were made from the shore or from the vessel where the active ADH was deployed. One seal was observed 44 m away from the vessel and a few were observed 45 and 46 m away after 17 minutes of operating the AHD. This suggests that the seals habituated to the sounds of the Airmar in the Deer Island region where a high number of these devices are employed within the salmon fishery industry, often throughout the year.

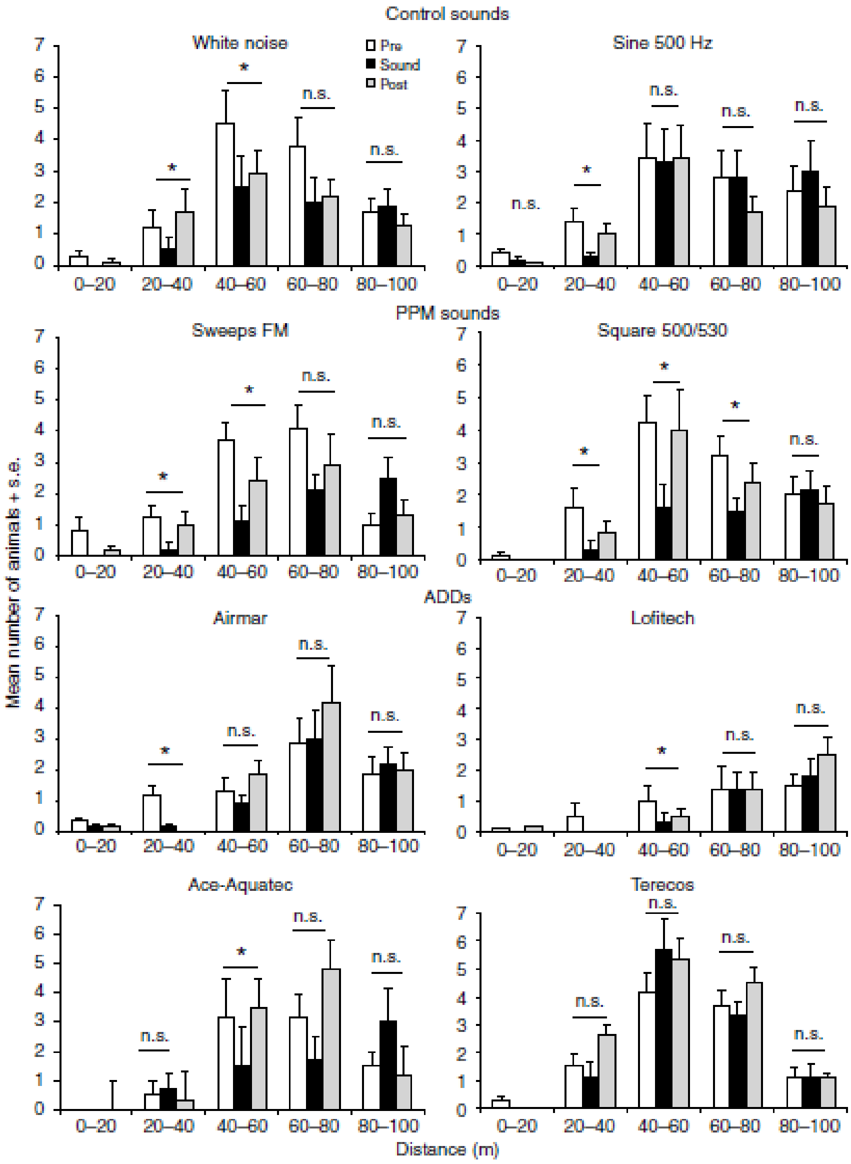
Figure 2.1. Experimental area used by Jacobs and Terhune (2002). Circles indicate seal haul-out sites, open squares land observation sites and closed squares ship observation sites.



2.1.2 Götz and Janik, (2010)

Götz and Janik (2010) tested the responses to different deterring sounds, including those of AHDs (Airmar dB plus, Lofitech, Ace-Aquatic and Terecos), by grey seals and harbour seals in captivity and by grey seals around a haul-out site at the mouth of the River Tay in Eastern Scotland. Although captive seals initially responded to playbacks of sounds at normalised received levels of 146 dB re 1 μPa_{rms}, the seals habituated rapidly to all sound types in the presence of food motivation. In the field, animals were subjected to different AHD sounds played from an underwater loudspeaker attached to a boat, every 15 min on 18 separate days (with maximum five exposures per day). Each AHD sound was only tested six times. Surface positions of grey seals were quantified relative to the playback boat within a 100-m radius using a laser range finder and compass. The response was measured by the number of surfacings. In the field, the deterrence range was approximately 60 m (figure 2.2), although only 40 m for the Airmar. No habituation was evident in the field trials (tested by the relationship between playback number and the count of seals). Based on sound recordings, the authors found that seals repeatedly avoided sounds at received levels of 135–144 dB re 1 µPa.

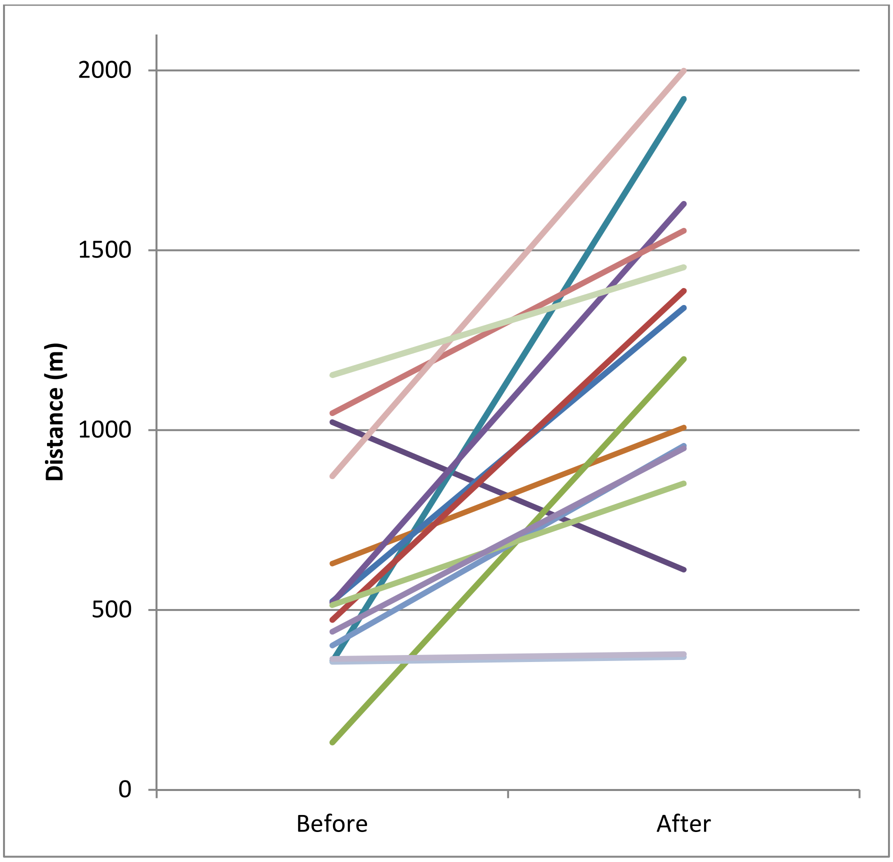
Figure 2.2. Reactions of seals to different sounds, including several AHD sounds, played back at reduced levels. Shown for each sound are numbers of observed seals before, during and after sound exposure, separated into distance intervals. Stars indicate a significant decrease from pre-exposure to exposure. From Götz and Janik (2010).



2.1.3 Hall et al. (2014)

Hall et al. (2014) monitored the behavioural responses of ten GPS-tagged harbour seals during exposure to a Lofitech AHD and to killer whale (*Orcinus orca*) sounds. Ten harbour seals were tagged with small Pathtrack UHF Fast lock GPS tags, allowing real time tracking (few minutes delay) of the seals via communication with three base stations. Seals were tagged in May 2013 around Kyle Rhea, Isle of Skye, Scotland, and the 16 exposures deemed "adequate" by the authors took place at the end of June 2013. The playback unit was deployed directly from the research vessel when seals were passing by the boat at distances from 132 m and upwards. In most cases, more than one tagged seal was within effective range. The most common response by seals during exposure was a change in behaviour, typically from travelling or area-restricted movement to moving close inshore. The greatest distance at which this inshore movement was initiated was at 1153 m for the Lofitech. Some form of response was evident in all of the 16 Lofitech exposures within 1000 m (Figure 2.3). However, one animal at 1022 m from the AHD at onset continued swimming towards the sound and reached a final distance of 612 m. Two animals were 356 and 364 m away, respectively, when the AHD started, and although they reacted to the sound, they did not move more than 13 m away from the sound. The lack of deterrence for these two seals could possibly be explained by their proximity to the coast, meaning that a) they were restrained in movement and b) had immediate access to safety on land.

Figure 2.3. Results compiled from Hall et al. (2014), showing distances of individual seals from the AHD before and after sound exposure



2.2 Studies on captive animals

Two studies have been conducted on captive animals on responses to AHD sounds. For obvious reasons, it is necessary to use reduced sound pressure levels (SPLs) in captivity studies when measuring reaction distances within the confinements of an enclosure. This raises issues on how to transfer results back to the real mitigation situation in the wild. However, a major advantage of captive studies is that the behaviour of the animals can be monitored closely, thus revealing finer details in responses.

2.2.1 Kastelein et al. (2006)

Kastelein et al. (2006) subjected five captive harbour seals to four series of tone pulses, spanning a broad frequency range (8, 16, 32 and 45 kHz). Pulse duration was 250 ms and pulse interval was 5 s. Each of the four sounds was made deterrent by increasing the amplitude. The seals reacted by swimming away from the sounds. The displacement effect of each sound was judged by comparing the surface positions of the animals and number of surfacings during ten 45 min baseline periods and ten 45 min test periods per frequency (one frequency per day in rotation, 40 sessions in total). The seals were displaced by all four frequencies throughout the 40 trial days (figure 2.4). Based on the movement of the seals to a presumed tolerable sound level area of the pool, averaged discomfort threshold SPLs were determined to be 130 dB re 1 µPa for 8 kHz, 119 re 1 µPa for 16 and 32 kHz and 129 re 1 µPa for 45 kHz.

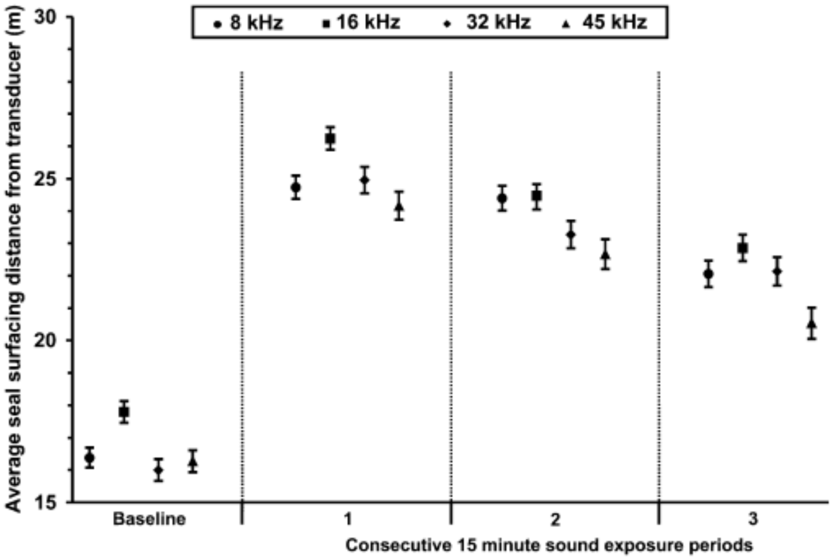


Figure 2.4. Surfacing distances for a captive harbour seal exposed to AHD sounds of different frequency. Note the pronounced habituation to the sound over the first three stimulus presentations. From Kastelein et al. (2006).

2.2.1 Kastelein et al. (2015)

Kastelein et al. (2015) investigated the responses of two captive harbour seals to the Ace Aquatech and Lofitech AHDs. The trained animals were exposed to lowered signals of the two AHDs. Sounds were projected underwater via a transducer placed 1 m below the water surface. The behaviour of the seals was filmed from above by a camera. Test sounds were recorded via a hydrophone at different locations to determine received SPLs. One to two experimental sessions, consisting of 30 min baseline followed by 30 min exposure, were conducted per day with each animal, five-six days per week, 15 sessions per AHD in random order, 45 in total during April-May 2010. The authors found that seals started to show small behavioural changes at received SPLs of 124 and 133 dB re 1 µPa for the Ace Aquatech and Lofitech, respectively. Seals hauled out more and spent more time with their heads above water at levels of 134 and 138 dB re 1 µPa and above for the two sound types, respectively.

2.3 Studies related to exclusion from fishery or foraging sites

The majority of studies on AHDs have tested their effectiveness in reducing damage to fishing gear and aquaculture and in reducing depredation on catch, the purpose for which AHDs were originally developed. The objective is different when an AHD is used to deter seals away from fishing gear compared to a mitigation setting, primarily because the deterrence distance as such is irrelevant. If the AHD is able to effectively deter seals from the net or aquaculture pen, it is not important how far from the net or pen they are deterred. Thus, the important measures in many of the following studies were changes in catch and/or reduction in damage to nets. Thus, only from some of the studies can additional information about deterrence distances be obtained.

2.3.1 Mate et al. (1986)

Mate et al. (1986) used sound to scare seals away from salmon and trout gill drift nets on the Colombian River between 2nd and 24th April 1982. The nets were deployed upstream and drifted freely for 90 min, first as a control drift and secondly with sound, on days with similar tide (in total 22 drifts). The transducer had a source level of 189 dB re 1 µPa at 12 kHz deployed from a boat (no sound measurements made). Significantly more fish were caught during experimental drifts than in control drifts and less fish were damaged.

Mate et al. (1986) also attempted to keep seals out of a hatchery area during Nov-Dec in 1980-1982 and 1984. A transducer was deployed in a creek channel with resulting source levels of 158 to 176 dB re 1µPa. An observer 30 m from the creek entrance recorded locations and time of seal surfacings and salmon captures during the 10 min exposures. They found that when the AHD was turned on, seals reacted immediately by swimming away from the creek mouth. Seals within 50 m of the transducers often had their heads above water, possibly a behavioural adaptation to reduce the received noise level. In general, significantly fewer seals were feeding in the area and fewer salmon were consumed, but the AHD did not completely exclude seals.

2.3.2 Geiger & Jeffries (1986)

Geiger and Jeffries (1986) examined the effectiveness of the AHD "Sealchaser" in Californian commercial gill net fishery. Tests were made in cooperation with fishermen during catch days in a single fishing season and area. The fishermen kept logs on drifts, control and experiments. The source level of the applied AHD was 195 dB re 1 µPa at sweeping frequencies of 11.9 to 14.7 kHz. The general result was less damage to drift nets with the AHD on and more salmon was caught, but the AHD was in no case completely successful in keeping seals away. One fisherman reported that on the fifth day of AHD harassment, one harbour seal was observed 50 m from the sound source, but most sightings were 100 m away. Another fisherman reported harbour seals within 60 m from one experimental boat and 30 m from another after 15 experimental hours.

Geiger and Jeffries (1986) also tested the effect of using AHD for herding harbour seals downstream Youngs River by sweeping with an AHD from a boat through the river, reaching a bridge with two or three fixed AHDs. Observers on the bridge or in boats reported that no harbour seals were seen upstream during sweeps (five in total). This led to lower fish damage in the experimental area above the bridge, but the effect was short term. The fixed AHDs on the bridge did not keep seals from swimming upstream. One seal was observed to swim with its head above water and several were seen by the nets during the experiments.

2.3.3 Yurk & Trites (2000)

Yurk and Trites (2000) tested the use of Airmar dB II plus to keep harbour seals from feeding on out-migrating salmon smolt under a bridge at night in the Putlet River, Courtenay, British Columbia, Canada. The Airmar was configured to produce broadband signals that pitched at 27 kHz and had maximum source intensity at 10 kHz (194 dB re 1 µPa). The experiments were conducted by two observers who counted the total number of harbour seals in the area every 30 min from the upper bridge decks with a red-filtered, 106-candlepower spotlight to illuminate the river. A total of 161 hours of observation were made over 23 days. The use of the Airmar AHD device yielded a significant decrease of the predation rate in seven successive trials. A mean of 0.4 animals was present during the acoustical tests (range 0–1) compared with a mean of eight animals on control nights (range 0–26). On most experimental nights, no seals fed within a 50 m radius of the AHD.

2.3.4 Fjälling et al. (2006)

Fjälling et al. (2006) tested application of modified Lofitech AHDs to reduce grey seal interaction in the Baltic salmon-trap net fishery. The Lofitechs used here had a source level of 179 dB re 1 μPa_{rms} and peak frequency at 15 kHz. The AHDs were deployed during three consecutive fishing seasons. Catches were significantly higher in traps with AHDs than in controls and less damage was done to the nets with AHDs. This effect lasted for several fishing seasons, but late in the season damage to the catches was common even in traps with AHDs. No specific deterrence distance was noted; however, variations were observed in the behaviour of the seals. Some seals seemed to learn to utilise the 1.5-min silent interval between the deterrence signals to approach the fish nets and to keep their heads above the water whenever the AHD was pinging. Some older male seals did not seem to respond to the AHD, either because of habituation or age-related hearing impairment.

2.3.5 Königson (2007)

Königson (2007) monitored grey seal behaviour around fishing gear with AHDs (presumably Lofitech or the modified Lofitech). When the AHD was deployed next to salmon traps, which were set in shallow water near the mouths of estuaries, trap catches increased and damage to gear decreased. However, damage levels did not decrease when the AHD was used in herring gillnet fishery in deeper waters, possibly due to technical problems. To test the dinner bell theory, more specifically that seals associate AHD sounds to areas with fishing nets, i.e. favourable feeding areas, they placed the AHD close to the coast, with an observer on shore, to see if any seals would be attracted to the sound, having gotten used to associating this with the fishing gear in the earlier experiments. On four out of five occasions, seals did indeed approach the AHD after only half an hour. The author suggests that seals make use of their hearing to localise the fishing gear.

2.3.6 Graham et al. (2009)

Graham et al. (2009) tested the effectiveness of the Lofitech AHD for excluding seals from Atlantic salmon rivers in Scotland in 2006. The Lofitech generated 500-ms pulses of ca. 15 kHz with randomised pulse emission patterns and a source level (SL) of ca. 189 dB re 1 mPa at 1 m. Sound recordings confirmed these parameters and also the presence of a second harmonic at ca. 30 kHz that was 15–40 dB lower than the fundamental frequency, and a third harmonic at ca. 45 kHz that was 20–50 dB lower. There was no energy below 5 kHz. The device was tested in two rivers (with depths of 2.5 and 3.5 m), with the intent to prevent seals from moving upstream. Observations were made from the river bank during a 4-month trial period and surveys were carried out within 2 h of high tide. The authors found an approx. 50% reduction of the number of seals upstream of the seal scarer. Seals were observed within 200 m of the AHD at the closest. The shallow water depth in the river and the bottom profile probably affected sound transmission; hence, the effective range off the AHD was likely shorter than AHD transmissions in larger water depths.

2.3.7 Harris et al. (2014)

Harris et al. (2014) tested the effectiveness of the Lofitech AHD at deterring seals away from Atlantic salmon net fishery in Scotland during 2009-2010. Sound recordings confirmed the specifications of the Lofitech (SL of ca. 189 dB re 1 mPa at 1 m). The AHD was effective at keeping seals away from the bagnet fishery and, in correlation with this, they found that landings increased when the AHD was turned on. Also, the number of sightings was significantly reduced as was the time seals spent in the area. Sighting data was collected by an observer during 93 hours in 2009 and 104 hours in 2010. Although the distance at which deterrence was achieved was not reported in the first year, no seals were seen within 80 m (max. sighting distance in dedicated observation area). In the second year, there were seven sightings within 80 m (mainly of one specific grey seal), suggestive of habituation to the AHD. Grey seals were more persistent at this site than harbour seals, both when the AHD was off and on (second year only), more grey seals being identified and their frequency of occurrence being higher than for harbour seals.

2.3.8 Götz & Janik (2014)

Götz and Janik (2014) tested the response of harbour seals (and harbour porpoises) to deterrence sounds around a fish farm. The deterrence sound had a peak frequency of 1 kHz and a source level of ~180 dB re 1 µPa. Visual observations were conducted over 16 days with and 16 days without sound (control). Seal numbers dropped sharply during sound exposure compared with control observation periods within 250 m of the sound source but were unaffected at distances further away from the farm (figure 2.5).

Figure 2.5. Results from Götz and Janik (2014), exposing harbour seals to narrow-band noise around 1 kHz.

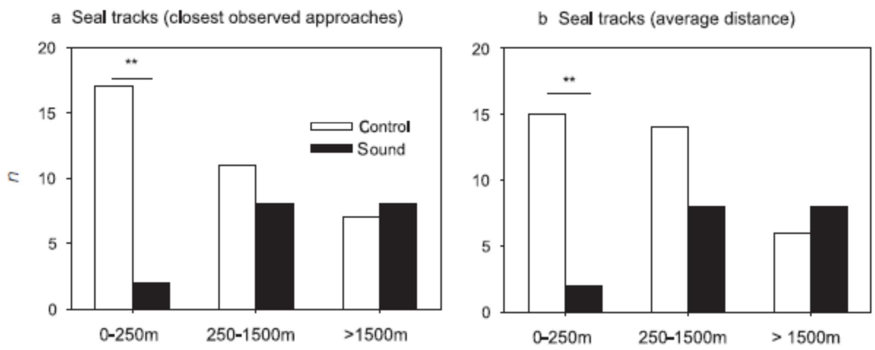


Table 2.1. Overview of studies that have assessed the effectiveness of seal scarers on harbour seals or grey seals. SL: source level 1 m from the source, RL: received level at the deterrence distance.

Study	Objective	Results	Sound
Studies testing responses of seals to AHDs			
Jacobs & Terhune (2002)	Behavioural reactions of harbour seals around two haul-out sites. Distances recorded by range finder.	No visible responses. Most seals > 200 m, few at 45 m.	Airmar dB II plus SL: 178-179 dB re 1 μPa_{pp}
Götz & Janik (2010)	Test of grey seal avoidance responses towards recorded sounds of Airmar, Lofitech and Ace-Aquatech AHDs. Surface positions of seals measured with a laser range finder within 100 m radius.	Deterrence range was between 40 and 60 m.	SL: 172 dB re 1 μPa_{rms} RL: 135–144 dB re 1 µPa
Hall et al. (2014)	Monitored behavioural responses of 10 GPS-tagged harbour seals during exposure to Lofitech AHD. Tagged seals were exposed when passing the research vessel.	All animals < 1000 m responded. Deterrence not complete beyond ~350 m.	SL: 189 dB dB re 1 µPa
Experiments in captivity			
Kastelein et al. (2006)	Studied deterring effects of 8-45 kHz tone pulses on captive harbour seals. Responses captured by video.	Responses to all sounds at all frequencies and sound levels.	Discomfort threshold: 119-130 dB re 1 µPa
Kastelein et al. (2015)	Harbour seals exposed to Ace Aquatech and Lofitech AHDs. Behaviour recorded with digital camera.	Responses to both AHDs.	Changed behaviour at RL of 124 and 133 dB re 1 µPa, respectively
Studies related to exclusion from fishery or foraging sites			
Mate et al. (1986)	Harbour seals deterred from a hatchery area. Visual observations of responses.	Seals were deterred out to at least 50 m.	SL: 158-176 dB re 1 µPa
Geiger & Jeffries (1986)	Test of responses of harbour seals to AHD in commercial gill net fishery. Visual observations by fishermen and observers.	Closest seals (as estimated by fishermen) were found at 30, 50 to 100 m from the AHD.	"Sealchaser" SL: 195 dB re 1 µPa
Yurk & Trites (2000)	Attempt to deter harbour seals away from area with out-migrating juvenile salmonids with the Airmar dB plus II AHD. Two observers counted seals from upper bridge.	On most days no seals closer than 50 m.	SL: 194 dB re to 1 Pa
Fjälling et al. (2006)	Tested responses of seals to modified Lofitech AHDs in salmon trap-net fishery. Visual observations of behaviour and evaluation of damage to fishing nets and catch rate of fish.	No distances reported. Increase in catch when AHD was active.	SL: 179 dB re 1 μPa_{rms}
Königson (2007)	Studied deterrence of seals around fishing gear with AHDs. Visual observations from shore and evaluation of damage to fishing nets and catch rate of fish.	No distances given. Observed attraction to AHD (dinner bell effect).	-
Graham et al. (2008)	Lofitech AHD deployed in river to exclude harbour seals from salmon rivers. Dedicated observations made from river banks. Approx. positions based on landmarks.	Closest observations about 200 m.	SL: 189 dB re 1 µPa
Harris et al. (2014)	Lofitech AHD deployed at salmon fishery 80 m offshore to keep harbour and grey seals away. Dedicated observations made from shore.	No observations first year within 80 m (observation range), second year some within 80 m.	SL: 189 dB re 1 µPa
Götz & Janik (2014)	Deterrence of harbour seals with AHD sound (narrow band noise around 1 kHz) at a fish farm site. Visual observations by two observers from shore, tracking with theodolite.	Few seals within 250 m.	SL: ~180 dB re 1 μPa_{rms} with peak frequency of 950–1000 Hz

3 Discussion

It is difficult to directly compare the selected studies in a meaningful way as they are very different with respect to sound types, methods of evaluation and context (wild vs. captive, fishery vs. haul-out or foraging sites). However, some consistent patterns emerge across the studies (see figure 3.1). First of all, the Airmar AHD appears to be less effective at deterrence than other AHDs, such as the Lofitech device. The three studies with Airmar AHDs (Yurk and Trites 2000, Jacobs and Terhune 2002, Götz and Janik 2010) all reported minimum deterrence distances around 50 m. Comparing the studies where the Lofitech was used is more difficult as one study (Götz and Janik 2010) used lower source levels than the others (Graham et al. 2009, Hall et al. 2014, Harris et al. 2014) and, therefore, not surprisingly found lower minimum deterrence distances than the studies using maximum sound output. The minimum deterrence distance for the reduced Lofitechs was 60 m, whereas the ranges reported in other studies were larger, up to beyond 1000 m (Hall et al. 2014). The study by Harris et al. (2014) stands out as very short deterrence ranges of less than 80 m were reported, although a normal Lofitech device was used. However, this study was conducted in a real fishery where there likely was a strong food incentive for the seals to tolerate the sounds. This interpretation is supported by the fact that one grey seal individual was that with most sightings at close range; all during the second year of the study. This could be indicative of habituation or increased tolerance by this particular seal, and this is in line with observations from other fisheries where singular "trouble-animals" were highlighted as being responsible for a large part of the depredation from fishing gear (Königson 2007).

The methods used by Hall et al. (2014) were likely the most sensitive means of detecting responses (gps tags on individual seals, allowing high resolution, fine-scale analysis of changes in behaviour), and it is thus not surprising that they were able to detect reactions at the furthest distances. Most significant in respect to deterrence (in contrast to just reaction, which is a much broader category of behaviours) was that no seals were observed within 350 m of the sound source. This is in good correspondence with the results of the third study (Graham et al. 2009) where a minimum deterrence distance of about 200 m was reported.

The difference in reactions between the Airmar AHD and the Lofitech AHD is likely explained by differences in source level and signal structure of the Lofitech and the Airmar. The Lofitech produces relatively long signals (hundreds of ms), whereas the Airmar produces numerous, but very short signals.

If we focus on the Lofitech AHD, as it apparently is the most effective of the two, the results are consistent, with a minimum deterrence distance corresponding to received levels of noise in the range 136 to 143 dB re.1 μPa_{rms} (assuming spherical spreading loss and ignoring the single "trouble-animal" of Harris et al. 2014). This is considerably higher levels than those reported for captive animals where the levels needed to induce behavioural responses were 119-133 dB re. 1 μPa_{rms} (Kastelein et al. 2006, Kastelein et al. 2015). More than anything, this difference likely reflects the higher ability to detect minute behavioural changes on video-monitored animals in captivity vs. relying only on surface sightings in the wild.

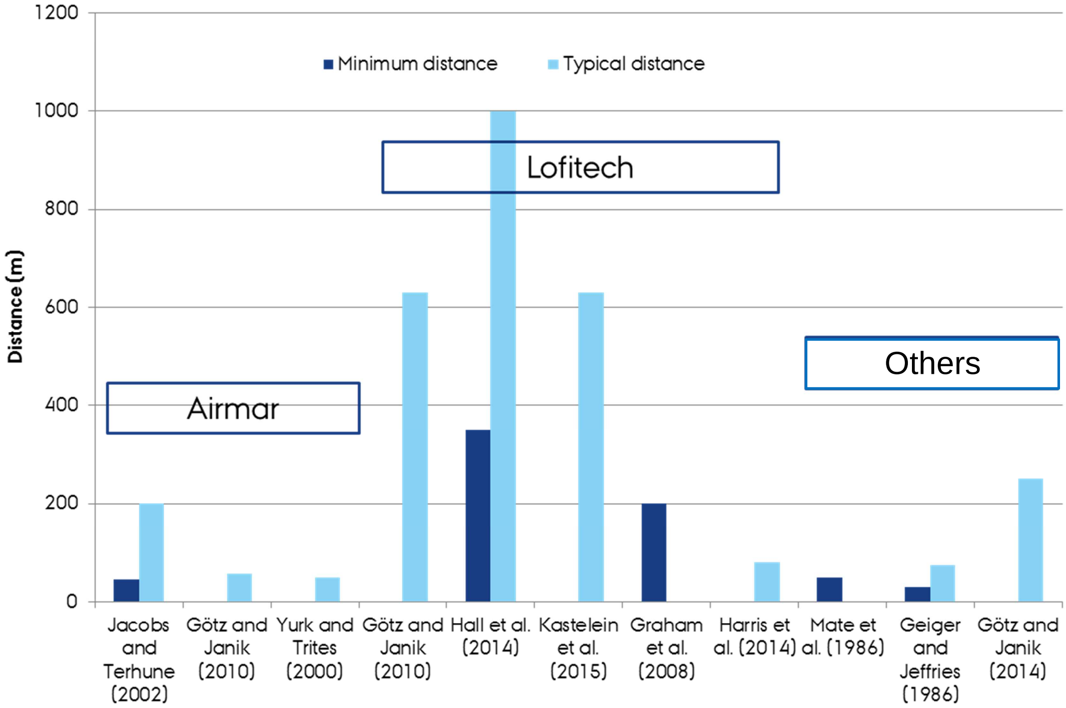


Figure 3.1. Overview of deterrence distances extracted from the different studies described above. Distances are separated into "minimum distances", reflecting the shortest range where seals were observed, and "typical distances", reflecting the range where the majority of seals were deterred. Actual ranges from Götz and Janik (2010) and Kastelein et al. (2015) have been adjusted to compensate for the reduced source level used in these studies.

Three other studies used other types of AHDs/sounds with highly different results. The small deterrence distance of about 50 m in Mate et al. (1986) is likely explained by the lower source level of the sound (158-176 dB re. 1 μPa_{rms}), whereas the similarly low deterrence distance of Geiger and Jeffries (1986), who used a very high source level (195 dB re. 1 μPa_{rms}), remains unexplained. The reason could be a combination of high motivation for the seals to approach the area, as it was in a real fishery, and the fact that distances were not measured but reported by the fishermen, and although these are undoubtedly skilled seamen, it is notoriously difficult to judge distances accurately at sea without measuring aids of some sort. The last of the three studies (Götz and Janik 2014) is interesting too, but for the opposite reason. The authors used lower source levels than the Lofitech (180 dB re. 1 μPa_{rms}), yet reported a minimum deterrence distance of 250 m, which is in line with the Lofitech. With only one study it is difficult to conclude why, but the sound was markedly different from the Lofitech, being a bandpass-filtered noise at lower frequencies, around 1 kHz.

Thus, when summing up, the minimum deterrence distance for the Lofitech AHD derived from the above studies is estimated to range between 200 and 600 m, and for the Airmar dB II plus the distance is considerably lower, around 50 m,.

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