Scottish Aquaculture Research Forum

Assessment of the impacts and utility of acoustic deterrent devices

SARF044

A REPORT COMMISSIONED BY SARF
AND PREPARED BY

Sea Mammal Research Unit, Scottish Oceans Institute,
University of St Andrews, and Ecologic.

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Project Code: SARF044

A Report by

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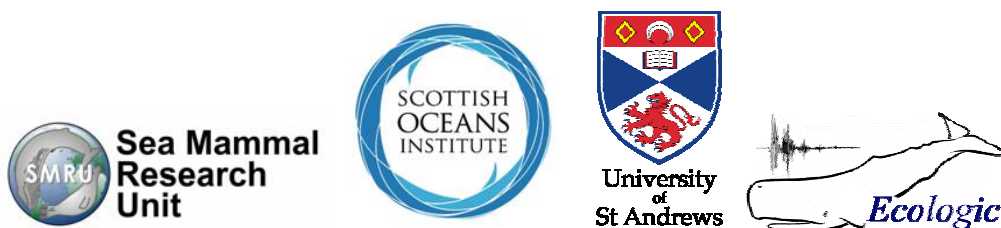
Commissioned by:

August 2010

Report Citation:

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Acknowledgements

Authors' address

Sea Mammal Research Unit
Scottish Oceans Institute
University of St. Andrews
St. Andrews
Fife KY16 8LB

Executive Summary

This project aimed to determine the extent to which Acoustic Deterrent Devices used at Scottish salmon farms affect harbour porpoise distribution, and how effective ADDs are at deterring seals from causing damage to nets and to farmed stock.

The interactions between seals and salmon farms were also examined through direct observations of seal activity around two sites and by examining trends in numbers of seals in relation to their distance from farm sites throughout Scotland.

Porpoise reactions to ADD signals in the short term and close proximity

Passive acoustic monitoring of harbour porpoise echolocation clicks was used to infer changes in the behaviour and distribution of porpoises in areas where ADDs were being used.

Self contained porpoise click loggers ('T-Pods' – made by Chelonia Research) were deployed at two farm sites that were using ADDs, ranging from 200m to 8km from the sound source. The two ADDs were both made by Airmar, but their acoustic signals differed slightly. Deployments covered about 6 months and 6 weeks at the sites in the Sound Of Mull and Loch Sunart respectively. During these periods the ADDs were on and off for various periods of time.

Ten T-pods were deployed and two were lost while one more did not record anything. Analysis of the number of minutes per day during which one or more porpoise click trains was detected (click-positive-minutes), for each day of deployment, showed a substantial reduction in the number of click positive minutes at all the adjacent monitoring stations when ADDs were active (although the T-pod at 8km recorded no data). Nevertheless, some click trains were still detected at all sites when ADDs were active, including those closest the sound source, demonstrating partial rather than complete exclusion of porpoises from the affected areas.

The highest levels of porpoise activity recorded whilst an ADD was active were recorded at 200m from one of the sites, suggesting the exclusion effect is voluntary rather than obligatory. Porpoise clicks detections recovered almost immediately after ADDs were switched off at both locations.

The sound field of the two ADDs tested was also quantified to examine the signal propagation losses and to describe the signal in more detail. The ADD signals were consisted of a series of ~2 msec pulses with a centre frequency of 10 kHz repeated every 46 msec. Each transmission was made up of a burst of pulses lasting for 2.6 seconds with pauses between transmissions. Temporally overlapping signals occasionally increased average power by as much as 3db. One of the two devices tested also emitted a 7.4 kHz pulse, though this may be a fault in the signal production. Secondary peaks in power above 10 kHz were also recorded. We used published audiograms of harbour porpoises, bottlenose dolphins and harbour seals to determine sensation levels at each of the secondary peaks, and concluded that in all cases the secondary peaks were at a lower sensation level than was the primary 10 kHz peak and should therefore be perceived as being less loud than the primary peak. Mean received power levels were mainly lower than predicted by spherical spreading at all the Pod sites.

Main findings here were that:
- **Porpoises avoid areas where ADDs are active.**
- **Porpoises return to areas almost immediately after ADDs are switched off.**
- **Porpoises are not totally excluded from areas where ADDs are being used.**
- **Porpoises were detected (feeding) even at about 200m from an Airmar ADD source.**
- **Porpoises, dolphins and seals are most sensitive to the 10 kHz peak in the Airmar ADD signal.**
- **ADD signals are not uniform.**

Porpoise reactions to ADDs in the longer term and at a wider spatial scale

Standardised calibrated acoustic recordings made routinely by the Hebridean Whale and Dolphin Trust and collected between 2006 and 2008 were analysed to determine sound levels associated with ADDs over a wide survey area on the west coast of Scotland. Custom software allowed an automated analysis to identify ADD sound sources; a smoothed surface of ADD received levels was calculated by interpolation between values over a 1km spatial scale to produce "sound maps" of ADD received levels for the Sound of Mull and Loch Linne. ADDs could be detected up to 14.7 km from the sound source and were detected throughout most of the Sound of Mull. Propagation losses were also plotted and showed considerable variability between sites, though generally, propagation loss was found to be similar to or greater than the rate of 20 Log (Range) expected with spherical spreading

The same data from the HWDT were also used to examine how the introduction of an ADD at a new site during 2008 affected porpoise distribution in the Sound of Mull in that year compared with 2006 and 2007. The Sound was divided into four areas, one of which contained the site at which an ADD was introduced in 2008. A comparison of porpoise detection rates before and after ADD introduction in each of the areas showed significantly fewer detections in the area with the introduced ADD. However, the reduced detection rates were lower than those recorded in other parts of the Sound where ADDs had been in use for much longer. Possible explanations for this might relate to variation in habitat quality, with individuals more motivated to remain in higher quality habitat in spite of disturbance from ADDs, or to a degree of tolerance to ADDs within particular areas when animals have become habituated to the noise levels.

The same acoustic monitoring data were also used to develop descriptive models of porpoise distribution using a General Additive Modelling approach. Porpoise distribution was modelled using a number of covariates that might be expected to influence distribution or detection, one of which was ADD received level. Seabed slope and seabed depth were both significant predictors of porpoise distribution, but ADD received level was not. This suggests that at these spatial and temporal scales, which are large compared to those of other studies on the effects of ADDs, ADD received levels were not having a statistically significant effect on porpoise distributions here.

Main findings were that:
- **Acoustic signals from ADDs can be detected at more than 14km from the sound source.**
- **Acoustic propagation losses are site specific and quite variable**
- **Porpoises appeared to avoid one area where ADDs had recently been installed.**
- **Porpoises appeared to be less averse to other areas where ADDs had been used for several years**
- **Within the Sound of Mull, habitat modelling links porpoise distribution most closely to water depth and seabed slope, while ADD received levels were not a significant predictor of porpoise distribution.**

Assessment of ADD use and seal damage

We were unable to analyse detailed company logbook data, but conducted interviews around much of the coast, including the Northern and Western Isles, to gauge the levels of seal damage, and to better understand what practices are considered most effective in dealing with the problem.

Over the course of the project we interviewed 49 individual people with responsibility for over 136 different sites. We found that seals are regularly reported at salmon farm sites, where they usually present few problems. Porpoises are also seen relatively frequently. Reports of damage were more often attributed to grey seals than common seals.
About 23% of sites reported an occasional or regular serious problem with seal damage, while 49% of sites were reported to have only minor problems and 26% reported no problems. A third of all respondents claimed that the problem had become less acute in recent years due to changes in management practices

The main ways of dealing with seal attacks were reported to be adequately weighted and tensioned nets, regular removal of dead fish, and the use of seal blinds at the bottom of net cages, as well as lower stocking densities and larger cages. Only one site reported using anti-predator nets, which are generally considered difficult to manage and likely to entangle wildlife, moorings and boat propellers.

ADDs were used at roughly half the sites, with Airmar and Terecos being the two most popular types of device. There appears to be a trend towards increasing the number of transducers in place at each site. Survey respondents indicated that ADDs are sometimes used at sites continuously and sometimes only when seal damage begins; less frequently ADDs are only switched on once the fish have reached a certain size, and less frequently still when seals appear to be taking a more active interest in the caged fish. There was no consensus about how effective ADDs are, but most respondents reckoned they could be effective at least some of the time. There was a wide variety of opinions on how and why ADDs do or do not work. Several respondents thought that failures occurred due to poor maintenance or flat batteries, others thought that hungry seals would put up with the noise, or that seals get used to the noise, while others reported that when the devices are used, seals move away.

A majority of respondents thought that most damage was caused by large individuals rather than young seals, and by rogue individuals, because removal of individual animals normally resolves the problem. A majority also reported more damage during the winter months and also more problems when fish were larger or more densely stocked.

Very little information was obtained on how seals attack caged salmon. Most respondents believed that seals attack from underneath, using a rush and grab tactic and biting or sucking fish through the cage netting, but only two people reported having actually witnessed such an attack. Much remains to be learned about how seals attack caged salmon.

Main findings were that:
- **Seals were commonly reported at salmon farm sites without causing damage.**
- **Less than a quarter of farm sites reported a major problem with seal depredation.**
- **Seal depredation was reported to have declined over the past decade or more due to improved management measures.**
- **Net tensioning, mort removal, lower stocking densities and seal blinds were all reported as important in minimising the risk of depredation.**
- **Most respondents thought that rogue individuals cause most damage.**
- **ADDs appear useful in some cases but are not always effective.**
- **Very little is known about how seals attack salmon in cages**

Observations of seal attacks.

One farm site (Fiunary in the Sound of Mull) was the subject of an intensive photo-identification study of seals. 1326 images of seals were taken at this site during two study periods in August 2008 and February 2009. All but three sightings were of common seals. Due to a combination of adverse weather conditions, the long range at which animals were photographed, a conservative scoring system and the partial submergence of many animals, the vast majority of images were of poor quality, with only 112 being selected as useful for photo-identification. 20 individuals were positively identified from left-side images, with 15 individuals identified by right-side images. Eight individuals were subsequently identified using images of both sides. Six animals were photographed on separate days, with the longest gap in between identifications being almost four months (22/08/08 – 19/02/09). Although there were many individuals around the sites at these times, and at least some habitually visited the site, there were no reported seal attacks over this period.

This work has demonstrated that photo-identification is possible at fish farm sites and shows promise as a means of exploring the behaviour of individual animals and could help establish

behaviour patterns of individuals and perhaps identify 'rogue' individuals and link these to specific haul out locations.

Another site at Loch Na Keal was also studied. Here we observed that during a period of persistent seal attack the fish appeared to have been damaged in a stereotyped manner. We were able to determine tooth spacing of the animal involved, but the incident stopped before we were able to do so systematically. Given enough data of this type it would be possible to investigate the size and likely species involved and provide a lower estimate of the number of seals involved in the incident.

We also deployed an underwater video camera and captured images of a grey seal at night time close to the camera. Limited underwater visibility restricted our ability to study the behaviour of this animal, but we believe that regular deployments of UW video devices at pens with a persistent seal problem could help to develop an understanding of how attacks are being perpetrated.

Main findings were that:
- **Individual seals can be identified using photo-id at farm sites**
- **The same individuals may be habitual residents of the farm site**
- **Damaged fish can be used to obtain some information on the individual seals responsible**
- **Under-water video systems could help understand the behaviour of seals engaged in attacking nets.**

Effects of salmon farms of local seal haul out numbers

As an additional objective we also examined the trends in seal haul out numbers in relation to the proximity of haul out sites to salmon farms sites. This work was suggested because common seal numbers have been in decline in some regions of Scotland, and concerns have been raised that the salmon farming industry might be implicated in this decline.

The SMRU has collected aerial survey counts of common seals hauled out during their moulting season since the 1980s. We have calculated the distance between each haul out location and the closest fish farm site using MS Access. We then allocated haul out location to be within 10km of a fish farm site, within 5km of a fish farm site or within 1km. The number of seals recorded, by region, for each year in which a survey had been made, and also the numbers of seals that had been recorded within 1, 5 and 10km of a fish farm site were determined for each survey year.

We fitted quasi-binomial generalised linear models to the proportions of animals counted within 1, 5, 10 km of fish farms for each survey year and by region. We wanted to know if proximity to a farm site might be related to proportional decline in seal numbers.
In Shetland, Highland and Orkney, there was no disproportionate decline in numbers of seals at those haul out sites closest to farm sites. In Strathclyde the models suggested a proportional decline in numbers close to salmon farms (ie a progressively smaller proportion of the total number of seals in the region were counted close to salmon farms), but this trend was most marked within 10km and within 5km of a fish farm site, and less so within 1km. The possible reasons for this are unclear as there has been no major overall change in common seal numbers in the area, but it may reflect a shift in seals overall towards more exposed locations and the islands, and away from the mainland shore where most fish farms are located.

Main finding:
- **Declines in common seal haul out numbers are not obviously affected by proximity to salmon farm sites.**

The report concludes with some guidelines to industry and suggestions for further research.

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1. Introduction

This project investigated two parallel questions: firstly to what extent do the Acoustic Deterrent Devices (ADDs) most frequently used in Scottish fish farms exclude or affect the distribution of cetaceans, especially harbour porpoises, and secondly, how effective are ADDs in preventing seals from damaging fish pens and damaging farmed fish or allowing fish to escape? A more general question was to investigate the management of interactions between seals and salmon farms.

These questions are important to fish farm managers and regulators because under the Nature Conservation (Scotland) Act of 2004, and under the the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended in Scotland), ADDs may be deemed to represent a deliberate or reckless disturbance of cetaceans and could constitute an offence. The use of ADDs is thus a balance between their value in allowing an important commercial activity to be prosecuted effectively in Scotland and their potential costs to other components of Scotland's marine environment. To be able to judge this balance of conflicting needs it is important to have better information on the extent to which these devices really disturb cetaceans, and, on the other hand, to try to clarify the extent to which ADDs can actually reduce the risk of depredation.

The overall objectives were as follows:

- To measure received sound levels and the degree of disturbance and exclusion caused by commercial and widely used ADD devices on cetaceans over a range of temporal and spatial scales up to several kilometres.

- To investigate sound fields and the effects of ADDs on porpoises at greater spatial and temporal scales by analysing acoustic data on porpoise distribution and mapping ADD received levels collected during regular acoustic surveys in the Hebrides.

- To assess, through interviews and where possible through analysis of existing log books, how ADDs are used on a representative sample of Scottish salmon farms, and to assess how their use affects the pattern of seal attacks at fish farms.

- To collect data directly from salmon farms during seal attacks and make observation of the effects of ADDs as part of management activities.

- Suggest guidelines for best usage based on these data and their analysis.

The report can be divided into two research focus areas, one addressing interactions with porpoises, the other those with seals. Objectives 1 and 2 address complementary aspects of the same general question, that is, what effect do ADDs have on porpoise distribution. Objectives 3 and 4 were intended to address a broader range of questions about the interaction between seals and salmon farms, an area of research that has so far barely been looked at.

This report addresses each of these objectives in turn and explores the extent to which each has been met. We describe any problems that arose during implementation and how we overcame these problems. We stress the importance of Industry trust and collaboration that is necessary for any such work to be taken further.

2. Research Focus A: Interactions with Porpoises.

In exploring the impacts of Acoustic Deterrent Devices on porpoises, we used passive acoustic monitoring equipment to monitor porpoise activity around sites where ADDs were being used, and also measured received levels at these sites to help relate observed reactions to received levels. These two aspects are considered in turn.

2.1 Objective 1: Porpoise reactions to ADD use

Here we studied differences in porpoise activity when ADDs were present or absent at two fish farm sites on the west coast of Scotland.

2.1.1 Methods

We used self contained ultrasonic click detectors, T-Pods (Chelonia Marine Research), to monitor activity levels of porpoises in the vicinity of fish farms with active and inactive ADDs. T-Pods consist of a transducer (hydrophone element), an analogue click detector, a digital timer and a duration logger. They are powered by 6 or 12 D-cell batteries and can be deployed for several weeks at a time. Porpoise-like clicks are detected by comparing the output from two analogue filters centred at 130Khz and 90Khz respectively. The ratio of energy levels detected from the output of these two filters is the primary criterion for detecting porpoise clicks, which are known to have most energy around 130Khz. Once the T-Pods are retrieved, data are downloaded from each via a USB port or parallel cable to a computer where proprietary software analyses the sequences of clicks recorded and, based on various acoustic characterisitics of the clicks, ascribed clicks to trains that are: highly likely to be from cetaceans ("Cet-Hi"), may be from cetaceans ("Cet-Lo"), doubtfully (?) or very doubtfully (??) from cetaceans. A further category of boat/sonar clicks is also identified where trains of relatively long clicks with fairly constant repetition rate are detected. Previous research (Thomsen *et al.* 2005) has shown that the software is fairly conservative in its classification of porpoises, such that false positive results among the Cet-Hi click trains are unlikely, while one might expect a fairly high proportion of Cet-Lo and "?" category trains to be of cetacean origin. Nevertheless we also made a visual inspection all of the detected click trians to identifyany that appeared (on the basis of having a constant repitition rate) as though they might have been mechanical rather than biological in origin.

We used 6 version 5 T-Pods and 5 version 4 T-Pods. The version 5 T-pods were cross calibrated at Arboath in June 2008 and were found to be consistent with one another. The Mark IV T-pods were calibrated at Loch Sunart in May 2009, and were more variable individually.

We monitored the echo-location clicks of porpoises around fish farms that were using ADDs as part of their normal activity. We hold that using existing farm sites is an important aspect of the experimental procedure, as the reactions of animals to such noises are likely to be context specific. We know that porpoises in these parts of Scotland have been subject to ADD signals for decades (several porpoise generations), and that animals are still present in fairly high densities in coastal waters (0.39 animals per km^2 according to aerial survey estimates from the SCANS-II project). Fish farm operators have told us that they regularly see porpoises even when ADDs are being used. It seems reasonable to assume that these mammals will know their individual habitats and will be used to specific noises coming from specific sites. We wish to examine how those noises, rather than novel ones in new locations, might effect porpoise distribution. We therefore tested the effect of two ADDs – both made by Airmar, but one of which was louder than the other, at two different sites.

The basic experimental procedure was to deploy T-Pods at a range of locations away from each site and either to ask the site operator to turn their devices off for short while, and measure the effect, or to wait until such time as the devices were to be removed as a part of the fish production cycle. We chose two sites, at Fiunary in the sound of Mull and at Laga Bay in Loch Sunart. One is operated by Scottish Sea Farms, the other by Marine Harvest.

We also attempted simultaneous visual sightings at a cliff top location overlooking Pod sites B and C, but during 12 days of observation by a team of two observers only 2 animals were sighted. This methodology was not pursued as we concluded it would have lacked the statistical power to detect any changes in distribution, is expensive and requires low wind speeds for porpoises to be seen.

The use of porpoise click detectors to determine porpoise activity relies to some extent on the assumption that porpoises will echolocate most or all of the time. While there is some evidence that this is true (at least in captivity – Verfuss et al 2005), echolocation is an

important if not essential part of foraging and navigation so that a silent porpoise is severely constrained in its ability to forage successfully. In all of the discussion below, therefore, we assume that changes in click detections reflect changes in the foraging potential of porpoises in the vicinity of the Pods, but we cannot exclude the possibility that silent animals may be present when no clicks are detected. Pod detections are taken as a proxy for animal density.

2.1.2 Deployments

At Fiunary we deployed T-Pods at five locations up to 3km ("A" to "E" at 200m, 500m, 1000m 1500m, and 3km respectively) from the farm site at Fiunary in the Sound of Mull. To try to avoid the T-Pods being towed away by scallop dredgers that routinely trawl this area, we moored the devices about 200m offshore, running in a line in one direction away from the farm site parallel to the shore, with a clear line of sight to the farm site from each (see map, Figure 1). Pods were deployed to the north west of the site to avoid interference with ADD signals from the Fishnish A and B sites on the opposite side of the Sound of Mull, which also had operational ADDs during this period.

Anchors and chains were used with polypropylene ropes attached to well-marked and highly visible red buoys, with T-Pods deployed on short strops of about 2m set about 4-5 m above the sea bed. We were advised that the dredgers tend to work outside of this near shore zone, further into the Channel. The closest device was at 200m from the site and was in 60m water depth. The more distant T-pod locations were all in shallower water of between 20m and 30m in depth. ADDs were audible from above water at 200m or thereabouts from the site, and calibrated recordings of the ADDs were taken on the same day as we deployed the T-Pods (see below).

We deployed the T-Pods at Fiunary on the 12th August 2008, and retrieved them for the first time on 31st August 2008. Initial inspection showed that the number of detections was low on all PODs. We were informed that the fish would be harvested soon and we therefore re-deployed the T-Pods on 7th September. They were retrieved for a second time on 2nd November 2008, while the ADD had remained in place. We redeployed the devices for a third time on 25th November and the fish and ADDs were finally removed from the site on 27th November. The T-Pods were left in place until 27th January. One T-Pod was lost during the November-January deployment, presumably towed away, and has not subsequently been recovered. Therefore, no data are available for site E after 2nd November.

After some analysis of the data, we decided to redeploy the T-Pods again, on 3rd March 2009. This is because after the ADDs were removed we found that porpoise echolocation clicks increased markedly at the site, but then diminished to lower levels before the end of January. In the meantime we discovered that an ADD being used at another site on the other side of the Sound of Mull (Fishnish), was removed on the same day as we had removed the T-Pods (27th January). As the two sites are only 5km apart it was conceivable that the ADDs at Fishnish might have an influence on porpoises around the Fiunary site.

In Loch Sunart we deployed five T-Pods deployed on 15th June 2009 at depths of between 27 and 29m, and at distances of between 200m and 8km (240m, 1.1km, 1.7km, 3km, 8km) from the Laga Bay farm site, at which an Airmar device was being used. A second site at Invasion Bay, further up Loch Sunart, was also using an Airmar device at the same time. The locations of the T-pod deployments and the farms sites are shown in Figure 1. The topography of Loch Sunart meant that it was difficult to arrange the T-pods in a straight line away from the site, so we chose sites at different distances from the ADD, with similar water depths where mooring seemed possible. Laga Bay and Invasion Bay were the only two operational sites in Loch Sunart at the time. Loch Sunart is a long deep loch with a narrow entrance that leads into the northern end of the sound of Mull. We assume therefore that the two sites were the only audible source of ADD signals within the Loch.

The T-Pods were left to record levels of porpoise activity whilst the ADDs were active, from 15th June to 8th July, on which date both sites turned off their ADDs for a pre-agreed duration of three weeks. ADDs were redeployed at both sites on July 30th and the T-pods were retrieved on August 5th.
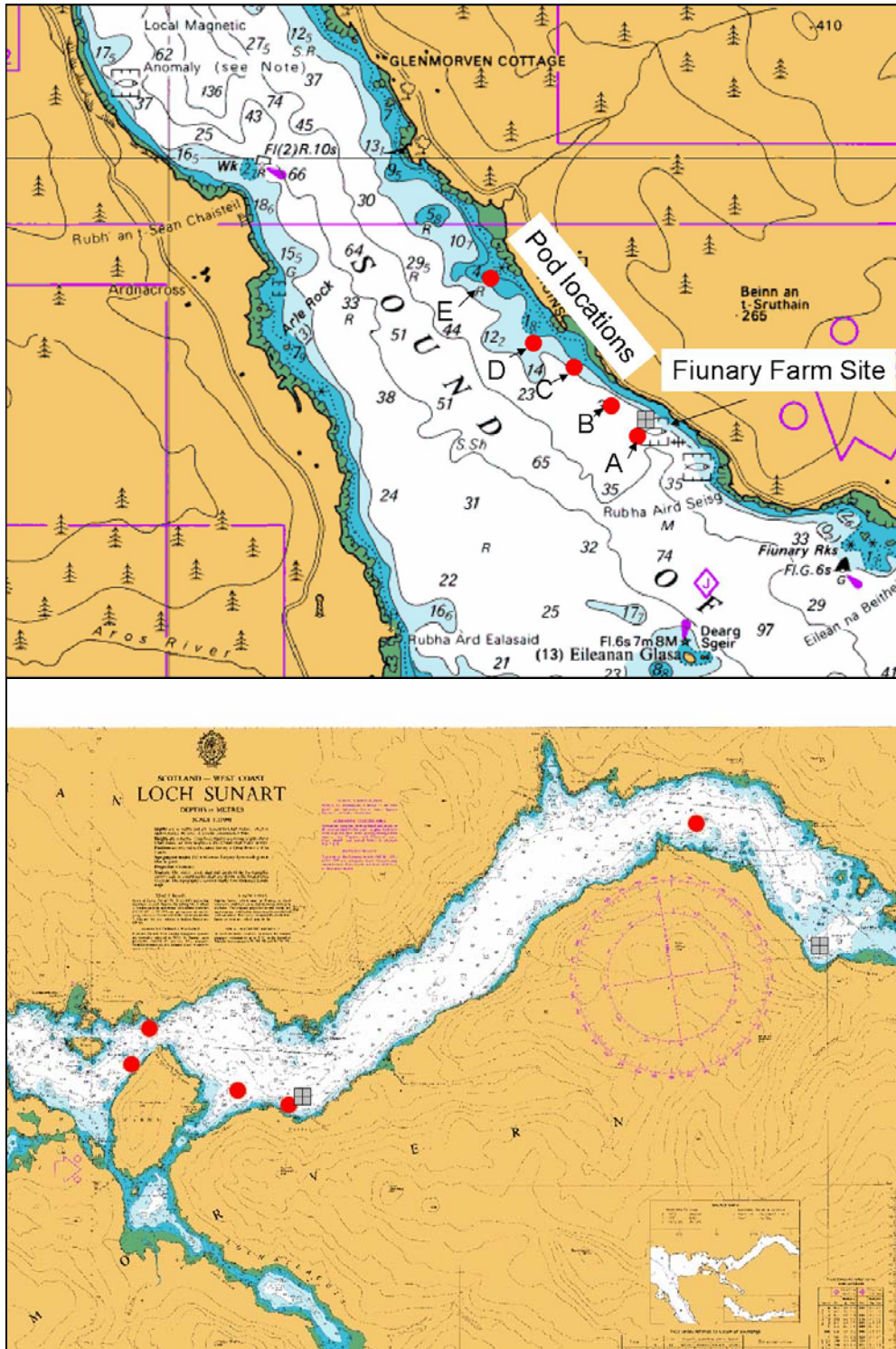
Figure 1 Pod deployment locations and fish farm sites: Sound of Mull & Loch Sunart

One T-Pod (no 313 at site C, 1.7km from the ADD) had been lost, and another (no 258, 8km from Laga Bay, up the Loch) had malfunctioned and no data could be recovered. The remaining three T-Pods held data for between 43 and 50 days. We had intended to ask the site operators to turn the devices off for a second time, but during the period in mid July when the devices were switched off, the site at Laga Bay began to experience growing levels of seal damage. Given the fact that the data from the T-pods recovered on 5th August appeared to give a clear picture of porpoise activity, there seemed little point in pursuing the original plan with the risk of eliciting another seal predation problem.

2.1.3 Results

We have used the number of porpoise click train detection positive minutes (DPM's) per day as a metric to describe, or as a proxy for, the relative density of porpoises. This is the number of minutes in each day that one or more porpoise click trains ("detections") was recorded.

Firstly, we found evidence of porpoises feeding (click trains with rapidly increasing click repetition frequency) within 200 metres of 10 active ADD transducers at Fiunary, which shows that such devices do not completely exclude all porpoises from their vicinity. We also observed a porpoise surfacing a few metres from the boat during T-Pod deployment at site C (1000m from the site) while the ADDs were active.

At Fiunary one unexpected finding was that the T-pod location with the highest number of clicks was the one closest to the fish farm (Site A). This was also the site with the greatest water depth. A visual examination of the click trains recorded at site A had found that there were some false positive readings at this site, but their inclusion does not materially affect the conclusions presented here. Previous calibration of the devices showed that they had similar sensitivity indicating that this difference is real and is not due to differences in Pod sensitivity. As soon as the ADD was removed from the Fiunary site there was an increase in the number of porpoise click trains detections. The increase was greatest at Site A, and less pronounced at B and C, while no click trains at all were detected at Site D after the ADD at Fiunary was removed. The T-Pod at site E was lost.

The number of click positive minutes per day are shown in Figure 2,**Error! Reference source not found.** with site A being closest to the farm site and site E furthest away. Much of the increase in activity at site A after November 27th was apparently short-lived. Figure 2 shows an immediate increase in detections for about a month after the ADD was switched off, but after this time DPMs per day fell away to much lower levels towards the end of January. DPMs were lower for most of the final deployment (March to May) than in January, except for the final few days in May at Site A, where there seemed to have been increased porpoise activity.

A very similar result was obtained at Laga Bay (Figure 3), where porpoises were detected at the site when the device was active, but at relatively low rates. The number of DPMs per day increased by factors of 7, 4 and 9 at the three sites (0.2, 1.0 and 4km from the source respectively) when the ADDs were switched off.

2.1.4 Discussion

Previous studies have shown that acoustic deterrent devices such as those used at fish farms will scare porpoises away from sites at which they are deployed to distances of 3km or more (Olesiuk et al 2002). Our data show a rather more complicated picture.

We found that the click detection rates generally decreased with distance from the Fiunary farm site (Figure 2). This may be because these sites, and site D in particular, may not have been a particularly favourable habitat, whereas Site A was in deeper water as the fish pens themselves were deployed in an underwater depression, or area of high relief, where deep water of about 60m comes close to shore. It is also possible that wild fish associating with the fish farm site are attractive to porpoises. T-Pods also record temperature and we found that the T-Pod at Site D that did not record any cetacean activity after November 25th also recorded some very low temperatures, around 3°C, compared with temperatures of around 9°C at other the sites. We speculate that this may be due to the proximity of a fresh water runoff source which may have influenced porpoise activity in its adjacent sea area during winter spates. Once the ADD was removed from the Fiunary farm site there was an immediate increase in porpoise click detections recorded (Figure 2). This was also evident at sites B and C (though not at D). Overall, there was an increase in the average number of click positive minutes at all sites from 0.12 per day per site to 1.58 per day per site. This might be interpreted as indicating that porpoises are 13 times more numerous within the study zone when the ADDs are switched off, but much of this increase was due to a relatively short lived increase in activity at the sites closest to the farm site for the 3 – 4 weeks immediately after

the device was switched off. As the device had been active for about 11 months during 2008, one interpretation could be that as soon as the noise disappeared, porpoises moved in to explore what may have been a novel feeding area. Once the 'novelty' had worn off, activity levels subsided to what might be considered normal background levels, as shown during March to May when DPM values were around 0.8 per day; this is 6 times more frequent than when the ADDs were on.
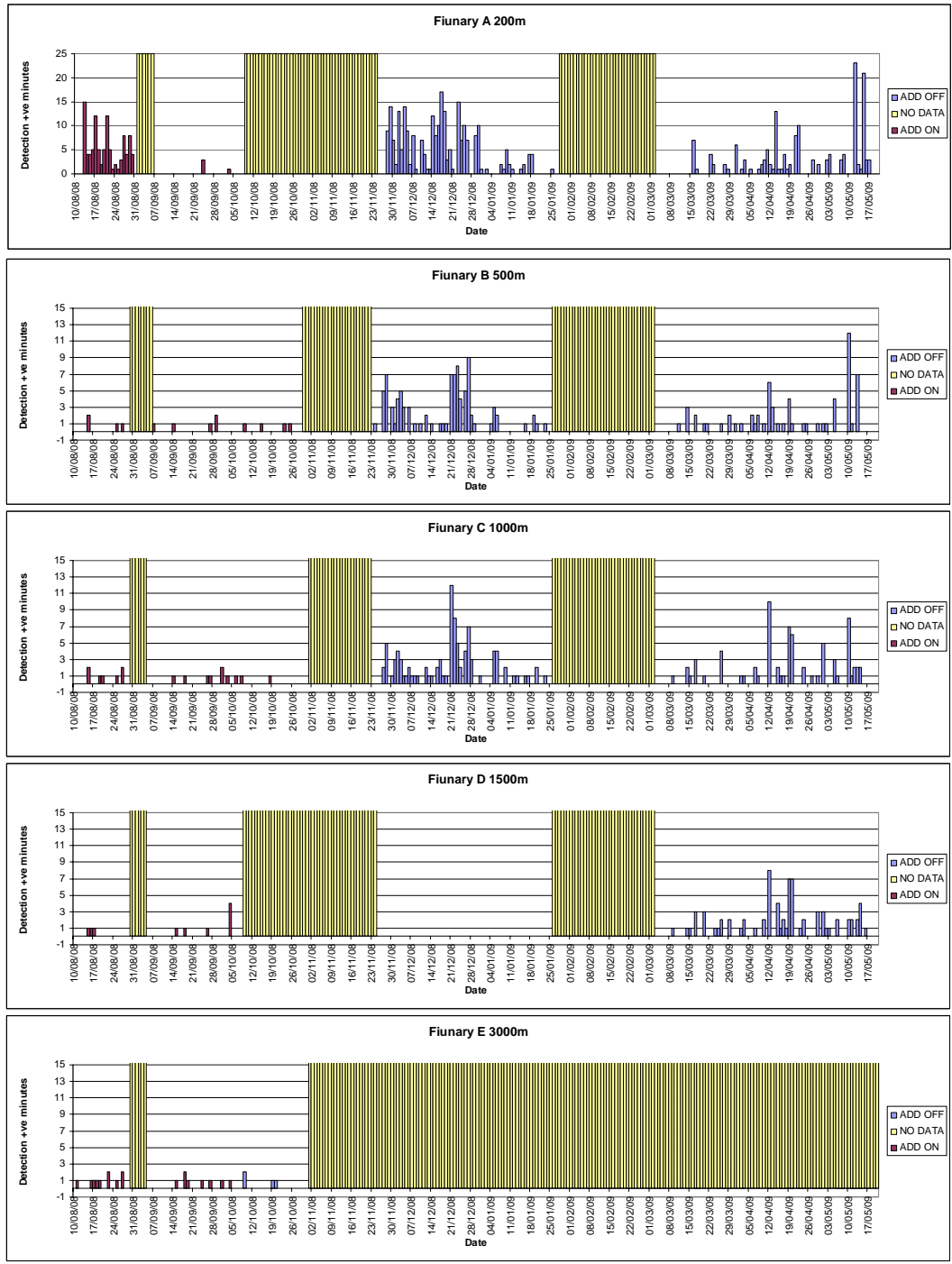
Figure 2. Plots of porpoise positive minutes for each day at POD locations ranging between 200m and 3km from the Fiunary site. Note Y-axis range –detection positive minutes– differs at site A compared with the rest.

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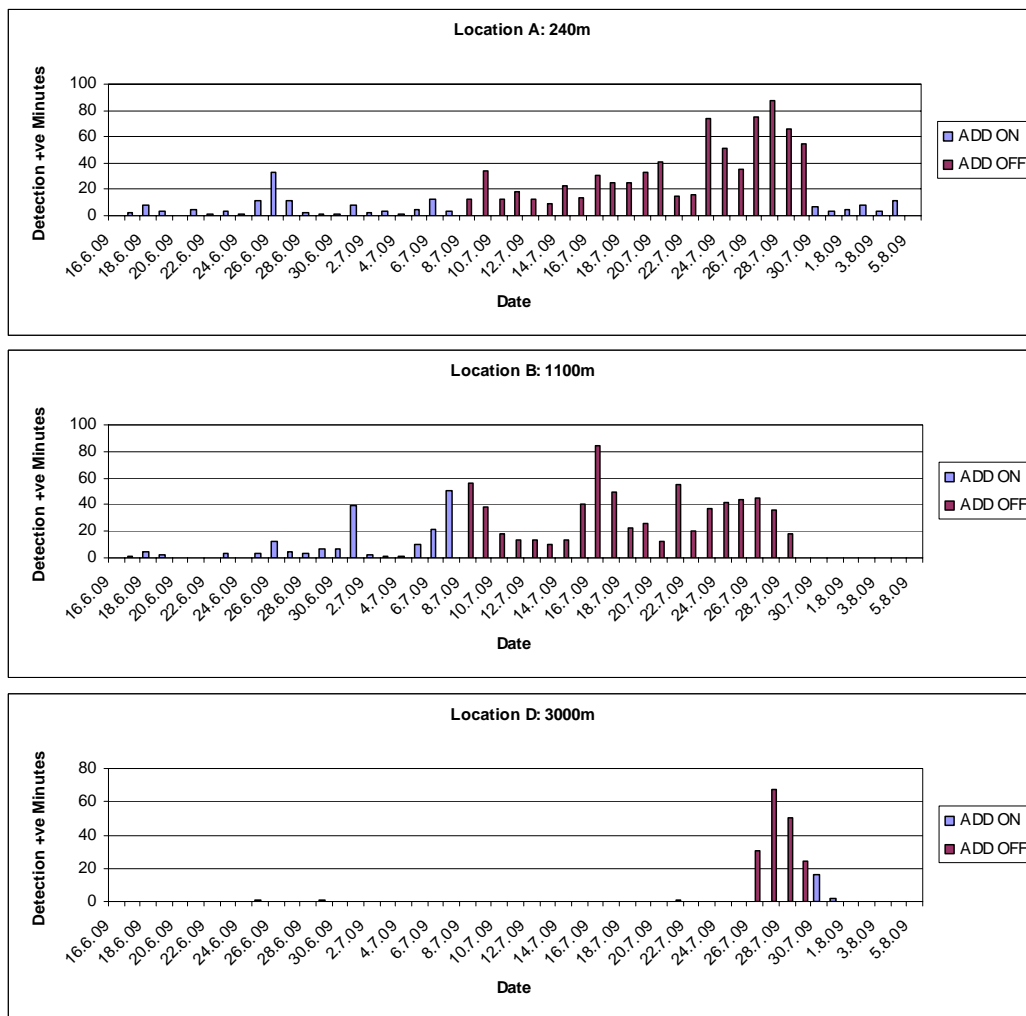
Figure 3 Plots of porpoise positive minutes per day at the three locations in Loch Sunart from which useful data were retrieved. The colour of the bars indicates whether ADDs were on or off.

These results demonstrate one fact that is already well known, which is that porpoises avoid sources of loud noise. They also the reveal a pattern which is not as straight forward as that shown in earlier Canadian studies. Some porpoises seem tolerant of the noise of ADDs and are able to forage quite close to such sound sources. This conclusion supports observations made by farm site managers over many years. We speculate that our observations may in part be due to the fact that several generations of porpoises have now experienced the noise made by ADDs along much of the west coast of Scotland. They may to some extent have grown accustomed to the noise, as other animals have been shown to become accustomed to traffic and other anthropogenic noise sources. In addition, it is possible that fish farm sites are in fact attractive to wild porpoises in that they are thought to aggregate wild fish species. Previous observations from Canada, showing clear cut exclusion in response to ADDs, had measured shorter term exposures and were not made at fish farm sites so that any potential attractive effects of farms sites would have been missing. The extent to which this degree of exclusion may have significant effects on the foraging success or the conservation status of porpoises remains a question to be answered. We also note that porpoises are not ubiquitous in the absence of ADD noises, and some sites still had no or very low encounter rates even when ADDs were off.

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2.2 Measuring the Sound Field of ADDs in Use

2.2.1 Methods

Calibrated recordings were made at each of the POD mooring locations at both the Fiunary and Loch Sunart Sites. The recording system used for this consisted of a calibrated Reson TC4033-1 hydrophone deployed at a depth of ~10m and a Reson VP2000 amplifier. Recordings were made on a laptop computer using an Edirol UA30 USB sound card. The sound card was calibrated by plugging in a Horita PT3 signal generator into the UA30 in place of the hydrophone. Calibration tones at 1 kHz and 10 kHz were recorded. The Tape Recorder function in the Logger software suite was used to make all recordings analysed here.

Analysis was carried out using the Raven Pro 1.4 Bioacoustics Analysis Program (Cornell Bioacoustics Laboratory, Cornell University, N. Y., USA). A 1/3 octave band pass filter centred around the ADD signal's centre frequency of 10kHz was applied to all recordings. Sections of ADD pulses of approximately 1 second duration which were not overlain by other noise were selected by hand and a range of measurements, including average acoustic power were calculated using the measurement function in Raven.

Airmar ADDs usually consist of a signal generator unit connected to four separate transducers. A transmission of approximately 2 seconds is sent to each transducer in turn. By spacing the transducers around the fish farm site the volume ensonified to a high level is increased. At Fiunary four units were in operation. Two of these had 4 transducers each and one had two transducers making a total of 10 transducers on site. Scottish Sea Farms provided accurate GPS locations for all ten transducers. Ranges from each POD location to the closest ADD transducer were calculated.

2.2.2 Results and Discussion

Recordings made at Fiunary Pod Location A – range ~200-400m approx have been analysed in detail to provide information on the acoustic parameters of the signal. The ADD signal consisted of a series of ~2 msec pulses with a centre frequency of 10125 Hz repeated every 46msec. Each transmission was made up of a burst of pulses lasting for 2.6 seconds with pauses between transmissions. Because more than one unsynchronised unit was in operation pulses were received irregularly and the effective duty cycle was higher than the 50% expected from a single unit. Occasionally pulses overlapped each other, when they did the average power was, as expected, 3db greater during periods of overlap.
Acoustic characteristics of signals from Airmar ADDs have previously been reported by (Lepper et al., 2004). Our observations are generally in good agreement with these although at 2.6 seconds transmission length observed here was substantially longer than the 2 second transmission length reported by Lepper et al.

The occurrence of one of more units producing 7.4 kHz pulses at the Sunart site was unexpected. Subsequent enquiries confirmed that the device was a standard Airmar device, so we assume some minor distortion or malfunction of the transducer may have been responsible for the unusual signal. We do not know how commonly such distortions occur.

Figure 3 shows a spectrum of a typical 10 kHz ADD transmission (sample size 1024 Hann Window 135Hz bandwidth). Most energy is at ~10 kHz but there are distinct secondary peaks at higher frequencies. For a species, such as odontocetes, which have more sensitive hearing at higher frequencies it is possible that these secondary peaks could be further above their hearing threshold at that frequency than the 10 kHz primary peak is above the threshold at 10 kHz, and could therefore be perceived as being louder than the primary peak.

In the levels at each secondary pulse are measured and standardised to the level at 10 kHz. These are compared to the sensitivity levels at the appropriate frequencies for harbour porpoise, bottlenose dolphins and harbour seals using values from published audiograms to derive a value for received sensation levels of secondary peaks relative to received sensation levels at 10 kHz. In all cases the secondary peaks were at a lower sensation level than was

the primary 10 kHz peak and should therefore be perceived as being less loud than the primary peak.

Frequency	Received level dB(Relative)	RL difference to 10kHz	Harbour Porpoise Sensitivity Level	Harbour Porpoise SL Difference re 10kHz	Bottlenose Dolphin Sensitivity	BND SL Difference re 10kHz	Harbour Seal Sensitivity Level	Seal SL Difference re 10kHz
10272	65.1	0	55	0	58	0	65	0
20164	35.3	-29.8	40	-14.8	52	-23.8	63	-27.8
30690	34.2	-30.9	37	-12.9	49	-21.9	62	-27.9
47366	33.8	-31.3	36	-12.3	48	-21.3	72	-38.3

Table 1 Comparison of relative sensation levels of different frequency peaks for harbour porpoise, bottlenose dolphins and common seals. Levels above sensitivity level, sensation levels (SL) are shown standardised against SL at 10 kHz   Sources for audiograms for harbour porpoise, common seal and bottlenose dolphins respectively (Kastelein et al., 2002, Mohl, 1968, Johnson, 1967)

Table 2 and Table 3 show mean and standard deviation for average power values for recordings made at pod locations at Fiunary and Sunart. In Figure 4 and Figure 5 these are plotted against range from the fish farm along with expected levels at each POD location, assuming spherical spreading and a 192dB source level (as reported by Lepper et al., 2004). This indicates that at both sites propagation conditions are somewhat worse than would be expected by spherical spreading (20LogR) and are also somewhat variable between locations. At Fiunary propagation is poor to locations B and D while in Sunart levels are very low at site 3, where the direct path to the fish farm is obscured by the island of Càrna. Propagation will be affected by water temperature and salinity, and the nature and shape of the sea bed.
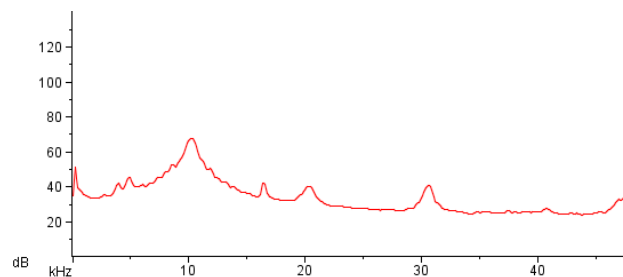
Figure 3 Spectrum of Airmar ADD transmission, sample size 1024 Hann Window 135Hz bandwidth

Pod	Mean Received Level (dB)	N	Standard Deviation	Range(m)
A	136.9	17	2.121	217
B	126.1	31	2.20	481
C	123.4	45	2.67	1016
D	110.7	16	3.56	1511
Total		109		

Table 2 Mean and standard deviation of average power levels (dB re 1µ Pa) in the 1/3 octave bands around the mid frequency for 10kHz and 7.4kHz ADDs at POD locations around the Fiunary site.

Frequency	POD Location	Mean Power (dB)	N	Range (m)
10kHz	1	145.559	58	240
	2	128.885	13	1107
	3	99.729	17	2922
	5	105.022	23	8021
	Total		111	
7.4kHz	1	138.538	63	240
	2	131.276	17	1107
	3	101.404	23	2922
	5	97.418	11	8021
	Total		114	

Table 3 Mean and standard deviation of average power levels (dB re 1µ Pa) in the 1/3 octave bands around the mid frequency for 10kHz and 7.4kHz ADDs at POD locations at Loch Sunart

Error Bars: 95% CI
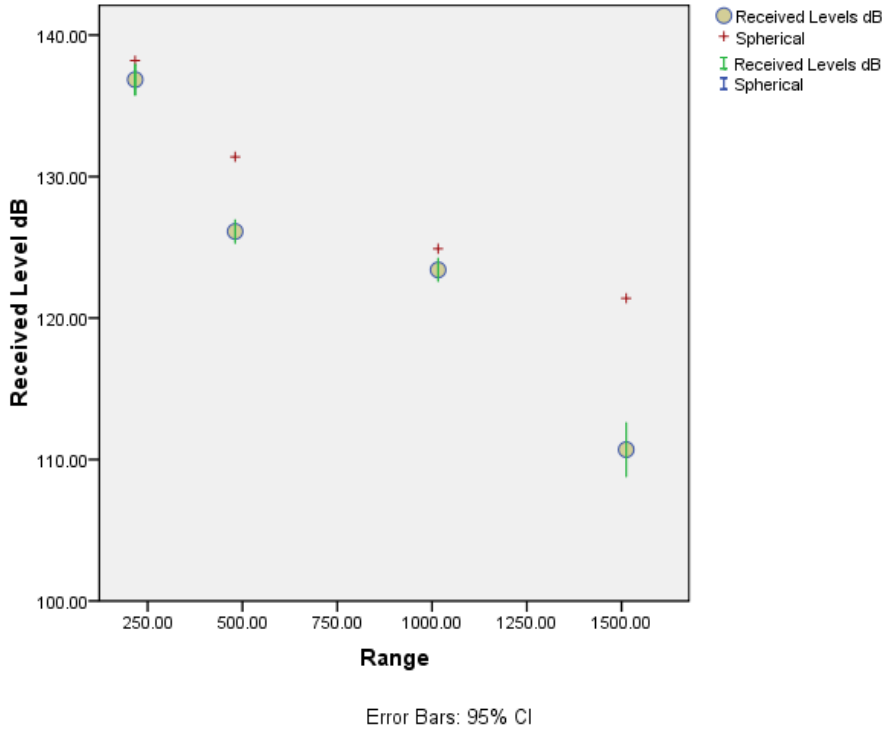
Figure 4 Plot of mean received average power in the 10kHz 1/3 octave band (db re 1μPa) levels and 95% confidence intervals at locations of Pods A to D and predicted levels. Predicted levels at locations are based on a source level of 192dB and an assumption of spherical (20 Log R) propagation loss.

Error Bars: 95% CI
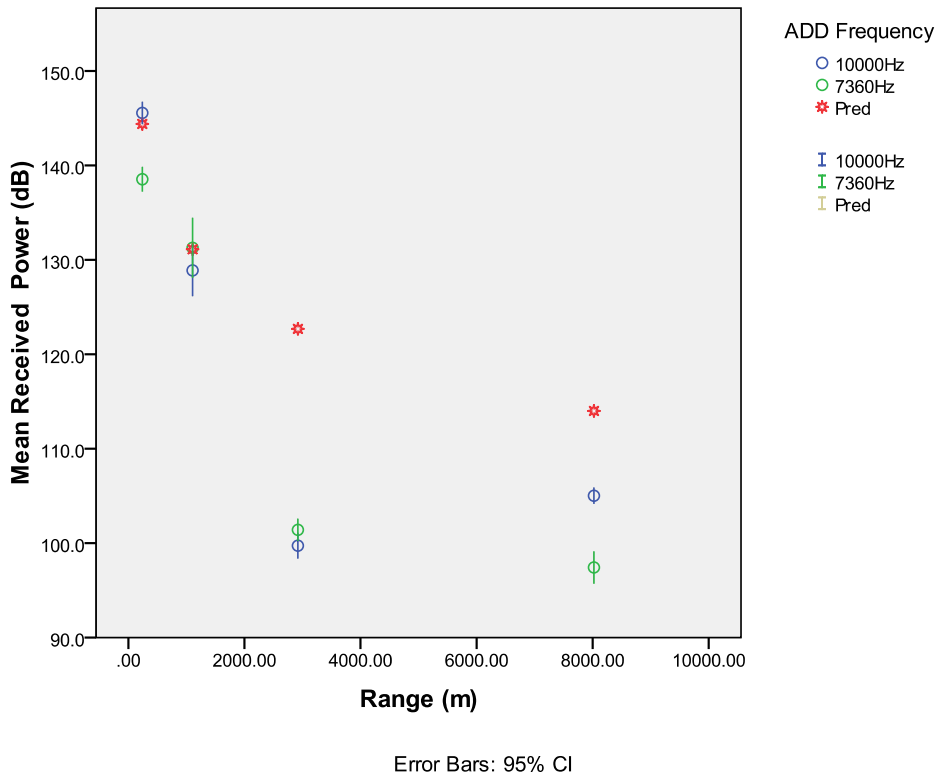
Figure 5 Plot of mean received power (db re 1μPa) and 95% confidence intervals in the 1/3 octave bands centred on the peak frequency of the ADD signal for 10kHz and 7.4kHz ADD signals recorded at POD locations in Loch Sunart

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2.3 Objective 2. Analysis of Acoustic Data from Towed Hydrophone Recordings

2.3.1 Methods

To investigate levels of ADD signals in the Hebridean marine environment at greater spatial and temporal scales we have analysed recordings made from the Hebridean Whale and Dolphin Trust's research vessel Silurian in the course of their regular cetacean surveys. Silurian is an 18 m motor-sailing vessel which has been used by HWDT to conduct standardised cetacean monitoring surveys on the west coast of Scotland (55º 10' – 58º 40' N, 5º 0' – 8º 35' W; approx, see Figure 6), between April and September of each year from 2003 to 2008. (Surveys continued in 2009 but we have not used these data here.) Silurian deploys a towed hydrophone system during all surveys. This is monitored continuously, principally for porpoises, using automated cetacean detection software. Standardised acoustic recordings are made on a fixed schedule and operators also monitor the hydrophones carefully for one minute every 15 minutes and note any cetacean signals as well as anthropogenic and natural noise levels.

Data analysed here were collected between 2006 and 2008, years in which a particular effort was made to collect standardised calibrated recordings of ADD signals. In these years, continuous broad-band recordings were made during any period when ADD signals could be detected by operators.

The towed hydrophone system included a streamer-section containing two 12.7mm spherical ceramic hydrophone elements connected to broadband preamplifiers which provided 35 dB of gain and incorporated a 2 kHz high pass filter (Seiche UK Ltd). The hydrophone preamp units had a near flat response between 2 – 140 kHz and highest sensitivity at 150 kHz. Hydrophones were mounted 25cm apart in a 5m long, 35mm diameter oil-filled polyurethane tube. This "streamer section" was towed on a 100m strengthened cable. Signals from the hydrophones were received by a Seiche buffer box, which provided an additional 8.9 dB of gain and split the signal into two buffered outputs. An unfiltered output was digitised at 96 kHz using an M-Audio Quattro USB sound card. A 20 kHz high pass filter was applied to a second output and this was digitised at a rate of 500 kHz per channel by high frequency National Instruments 6251 DAQ card. These high frequency channels were analysed for porpoise click vocalisations using the Rainbow Click program. The analysis of ADD sound fields described here uses the unfiltered signal. A Horita PT3 signal generator was used to calibrate the sound card by recording 1 kHz and 10 kHz tones at the beginning of each day. The towed hydrophone was calibrated by the Wraysbury Acoustic Calibration Laboratory, in May 2008. The characteristics of the Seiche Buffer box were determined by bench-testing at the Sea Mammal Research Unit, University of St Andrews.

During surveys, the Logger program was run continuously and the tape recorder facility in Logger was used to make recording. Logger allowed operators to enter information on environmental conditions and results from acoustic monitoring sessions. The Logger program interfaced to the ship's GPS and navigation system and the ship's position was recorded every 10 seconds and at the start of each recording. Thus, the hydrophone's location could be determined accurately at any time in any recording.

Most of the sound recordings analysed here were obtained in the course of HWDT's ongoing survey program. However, as part of this project, the "Silurian" was chartered to conduct a dedicated sound mapping survey of Loch Sunart in the early summer of 2009.
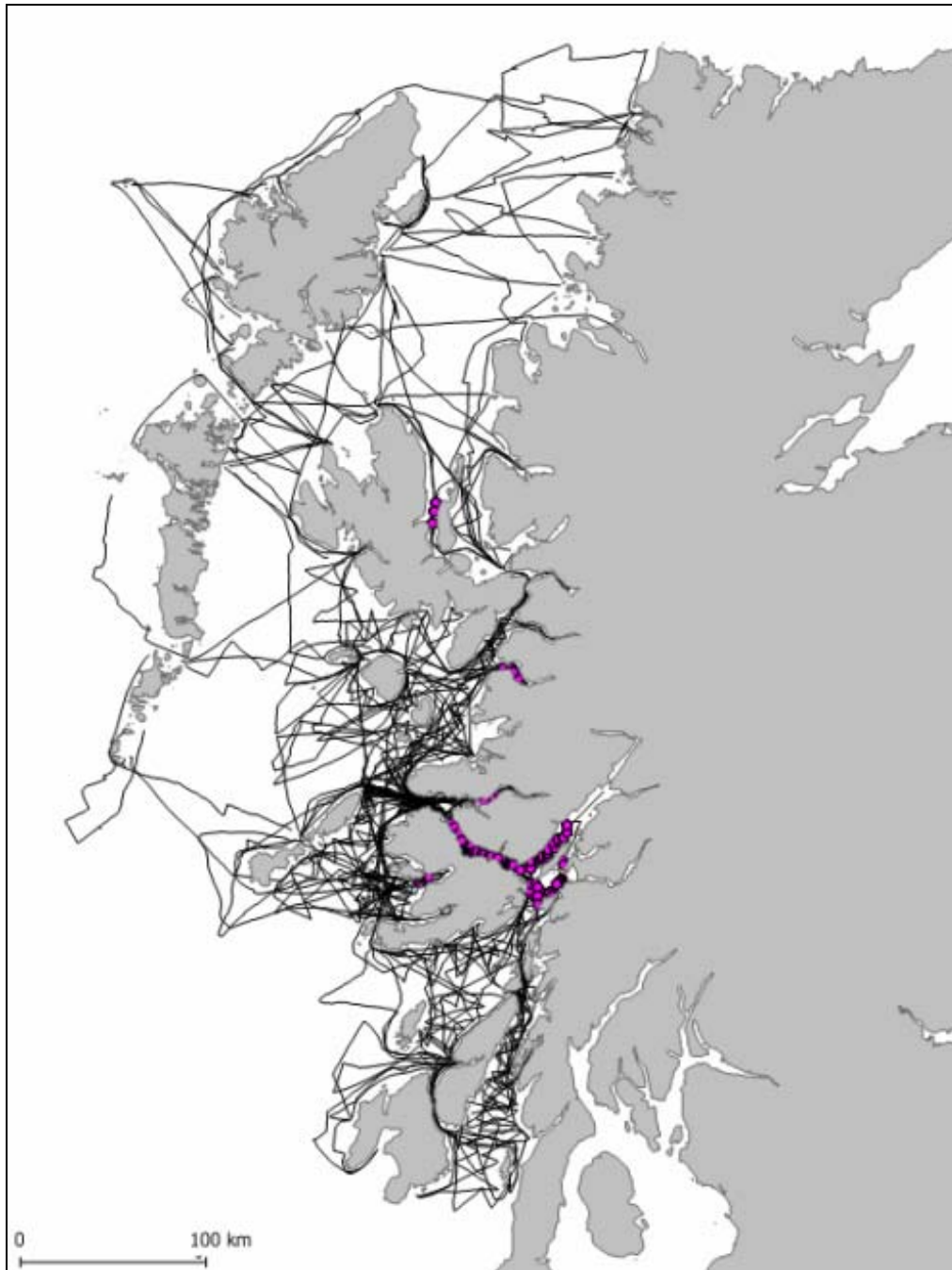
Figure 6. Study area off the west coast of Scotland showing tracks of Silurian in 2007 and 2008. Location of all sites at which operators reported hearing ADDs are shown by the dots.

The large number of recordings collected required an automated approach to analysis using programs specially written in Matlab. Recordings lasting greater than 1 minute were split into sub-recordings of one minute or less duration. Each recording file was then band-pass filtered between 9 and 11kHz.
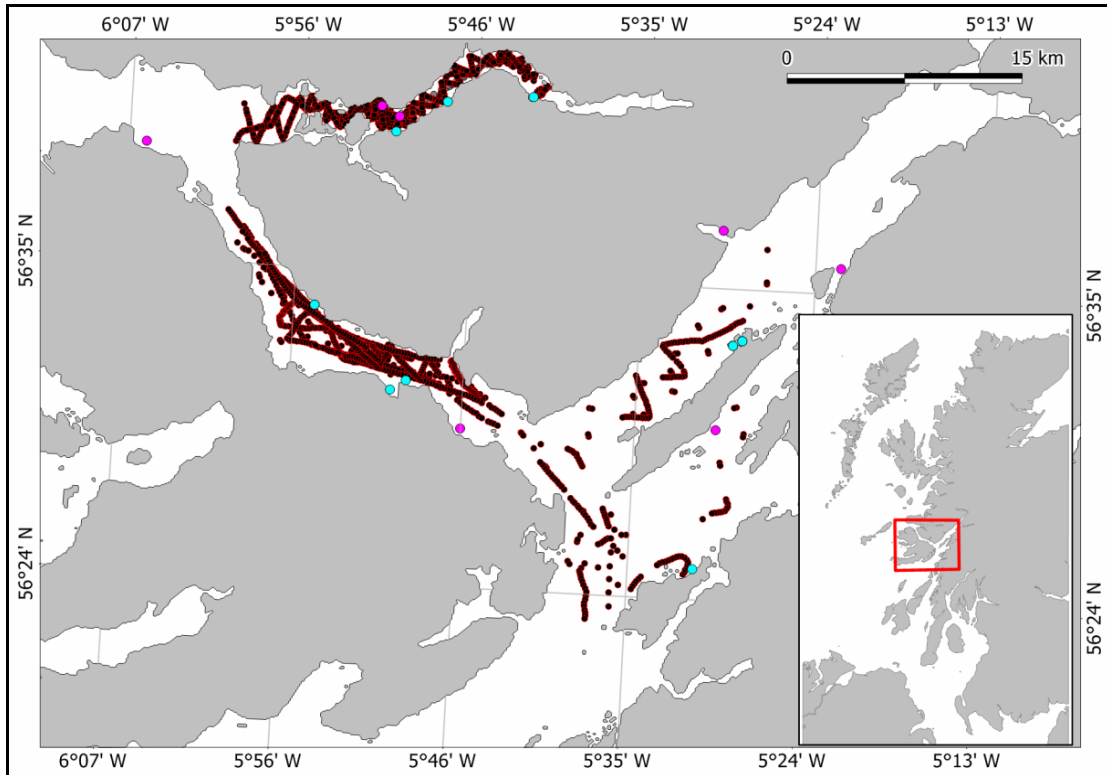
Figure 7 Detailed view of the Sound of Mull Loch Linnhe area showing tracks of the research vessel Silurian and the acoustic monitoring stations at which ADDs were recorded. Active ADDs are shown in blue and fish farms without ADDs are shown in pink

The intensity in sections of 512 samples (5.2 msec) was then calculated. A histogram of the intensities of these sections for recordings with an ADD present would be expected to be bimodal with a lower mode summarising intensities in sections of the recording without ADD pulses present and a distinct upper mode representing sections which had an ADD pulse present. After inspecting many examples of histograms it was decided that the upper 99th percentile provided a good measure of the level of the ADD signals and the lower 10th percentile a good representation of background noise (e.g. Figure 10).
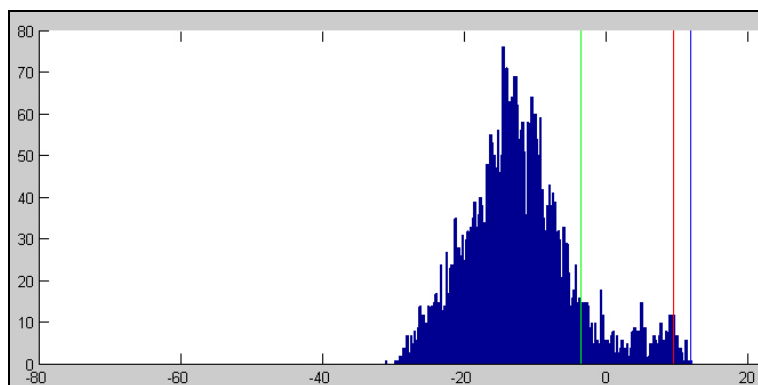
Figure 8 Histogram of acoustic intensity (dB relative) for 5.2msec samples from a 9-11 kHz band passed field recording of ADDs. Red line shows the 99% percentile which is taken as being the received level of ADDs at this location.

These measures were only accepted from a recording if there was a 10dB or greater difference between these two values.

The hydrophone location at the mid point of each recording was calculated from GPS locations stored in the associated Logger database. A smoothed surface of ADD received levels was calculated by kriging interpolation between values over a 1km spatial scale to

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produce "sound maps" of ADD received levels using Manifold GIS. The range from the mid-point of each recording to the closest active ADD was calculated and these were used to explore propagation loss.

2.3.2 Results

Results are described separately under Sound Fields and Propagation Losses.

2.3.2.1 Sound Fields

Figure 9 shows a map of ADD received levels in the Sound of Mull in 2008. It is clear that received levels were elevated well above background at ranges of many km from fish farm sites. From this and from Figure 9 its clear that ADDs can be detected at ranges of up to 14.7 km and that with several fish farms using ADDs there, ADDs can be detected through most of the Sound of Mull. Previous studies of the effects of ADDs on porpoise distributions have not measured received levels directly however research in the Bay of Fundy (Johnston, 2002) estimated that porpoises would be excluded from an ADD at received levels of 125dB.

2.3.2.2 Propagation Loss

Figure 10 shows plots of received levels of ADD signals with range from active ADDs for four fish farm sites in the Hebrides. Considerable variation in propagation conditions (such as temperature, salinity and bathymetry) is evident both within and between sites suggesting that different patterns of effects of ADDs on porpoise distributions might be expected at different sites. Generally, propagation loss was found to be similar to or greater than the rate of 20 Log (Range) expected with spherical spreading.

Figure 9 interpolated sound fields of the main cluster of ADDs observed on the west coast of Scotland in 2008. Light blue dots show the position of the ADD sites.
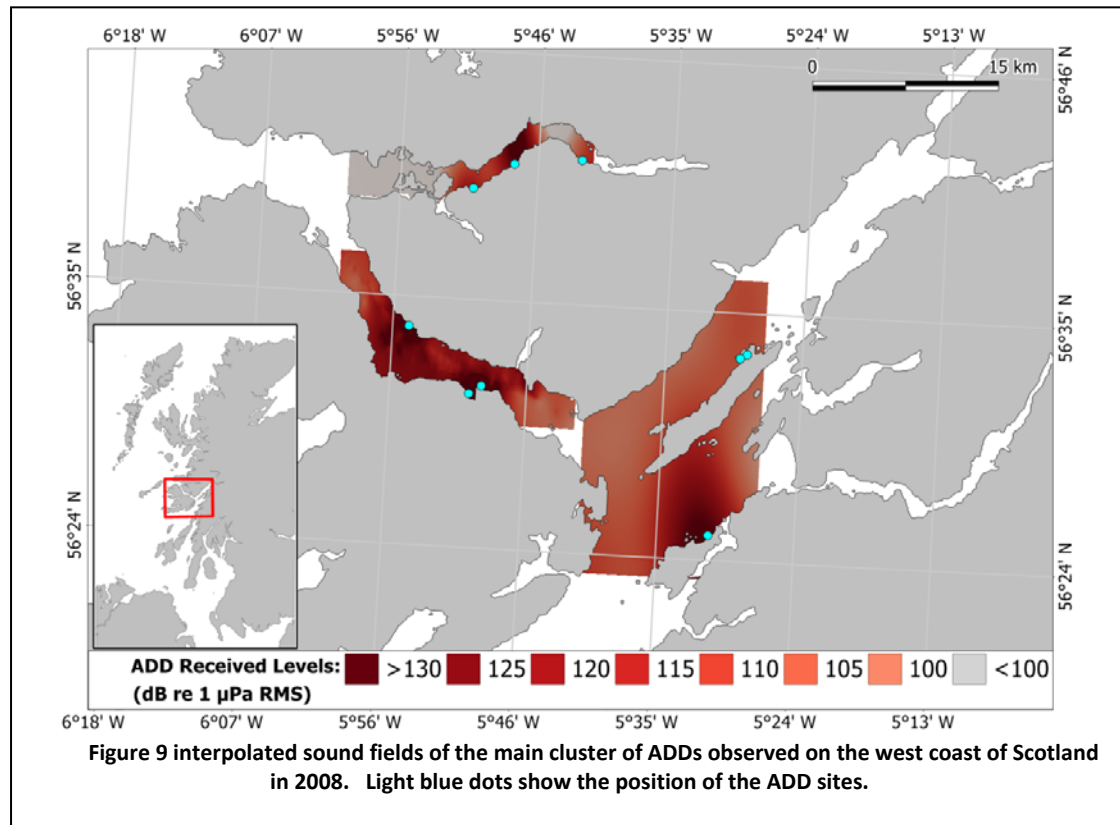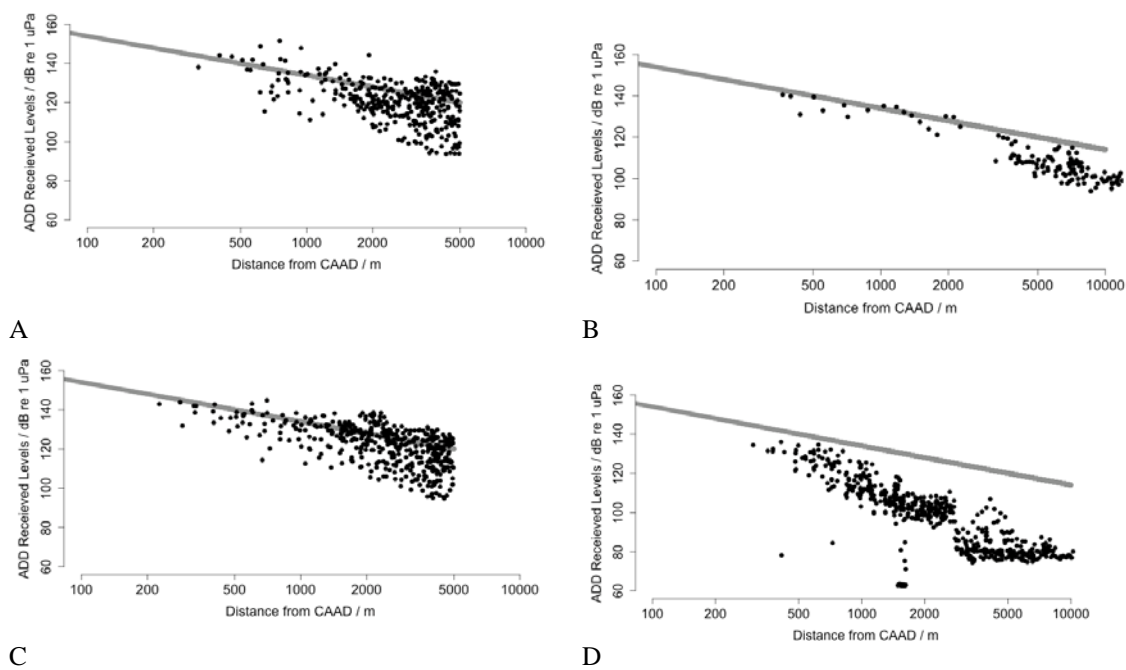
Figure 10 Plot of Received Level (RL) against distance for active ADDs at four sites in the Inner Hebrides: (a) Fishnish B (in the Sound of Mull); (b) Kerrera; (c) Fiunary (in the Sound of Mull) and (d) Loch Sunart. The received levels of ADD signals are represented by the black dots and the expected propagation loss under a spherical spreading model with a source level of 192 dB re 1 μPa is shown by the grey line

2.4 Effects of ADDs on Porpoise Distribution

Two approaches to investigating effects on porpoise distributions have been explored using the data collected on the HWDT survey vessel. The first was a case study involving a comparison of distributions and densities in years before and after a new ADD was introduced in the Sound of Mull. The second is an investigation of whether ADD levels were a significant predictor within a spatial model of relative porpoise densities incorporating a variety of habitat and environmental parameters.

2.4.1 Case Study: Before and After ADD Introduction

Detailed and consistent data on porpoise densities and ADD received levels were collected in the north western section of the Sound of Mull between 2006 and 2008 with some 801kms of acoustic survey completed. Over this period, Airmar ADD devices were operating at two adjacent fish farm sites, Fishnish A and B, while at a third site, Fiunary, a new Airmar ADD system was fitted for the first time in 2008 (Figure 11). Based on this pattern of ADD use, the sound of Mull was divided into four subareas which experienced different levels and histories of ADD exposure (Figure 11). These survey blocks, interpolated sound fields and the vessels survey tracks and the locations of porpoise detections are shown for 2006,7 and for 2008 in Figure 13 and monitoring effort and detection numbers are broken down by year and areas in Table 4. A reduced detection rate is evident in 2008 in the survey blocks close to and to the north of Fiunary, the site at which the new ADD equipment was installed. The number of acoustic encounters was significantly lower in the Fiunary area in 2008 than expected (p < 0.05, χ^2 = 4.82, df = 1) and no porpoises were detected within 4300m of the ADD site during that period.
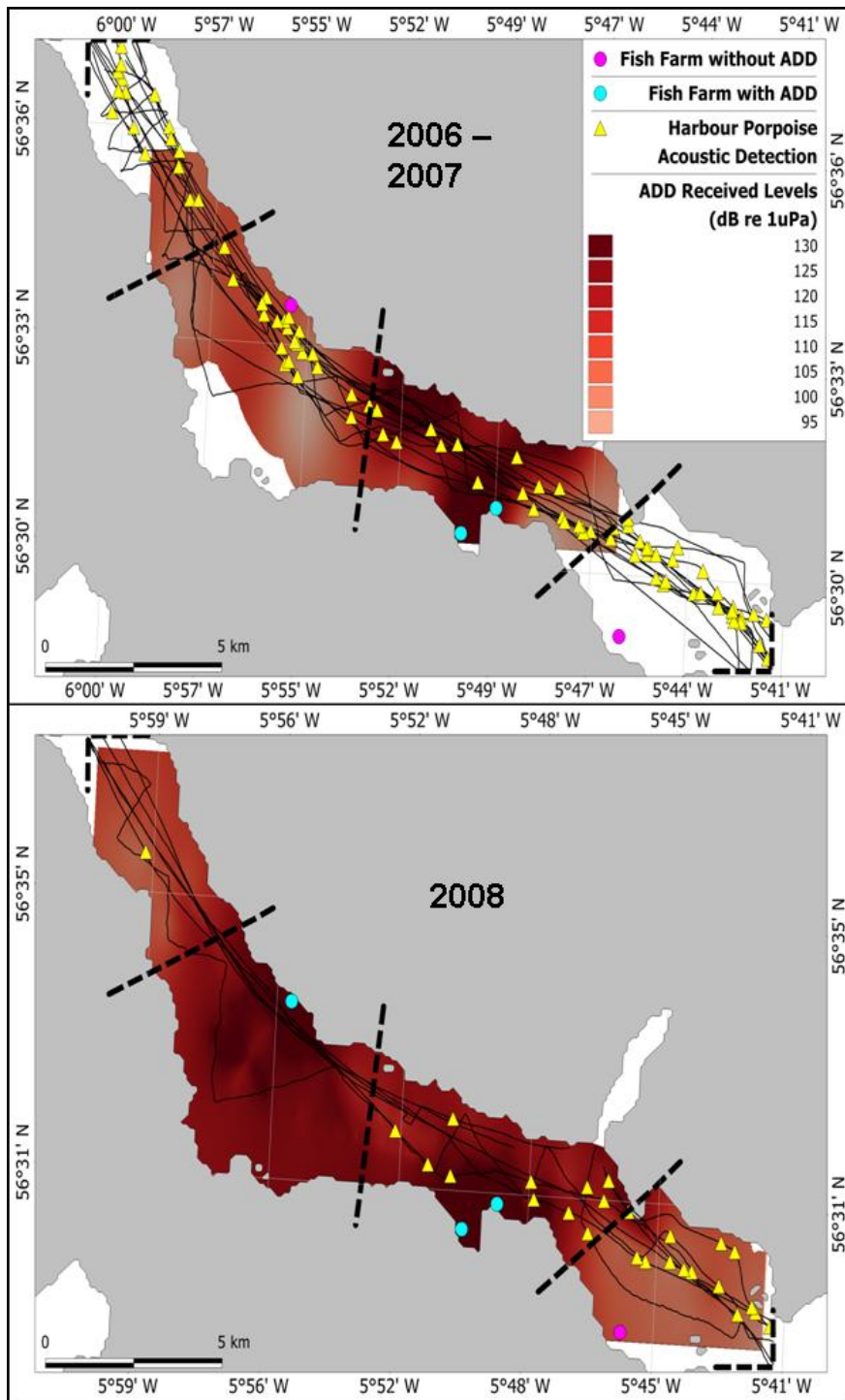
Figure 11- Distribution of acoustic survey effort (black lines) and acoustic detections of harbour porpoise (yellow triangles) in 2006-7 and 2008. Locations of active ADDs are shown as pink dots, farms without active ADDs are shown as blue dots. The boundaries of the areas considered in the analysis are shown. Sound field levels are shown in legend.

While this result seems quite clear some qualifications should be noted. Although this is based on a substantial amount of monitoring effort it still represents a single trial. Thus, while there is good support for the indicated changes in densities we can have less confidence in the factors that caused them. It may be the case that some other unrecorded factor caused a shift in porpoise distributions that coincided with the installation of the ADD. While porpoise densities seem to have been reduced within several kilometres of the new ADD we know from POD monitoring that they were not completely excluded from the area and it also seems to the case that the same degree of displacement is not evident at the Fishnish A and B sites

which have had active ADDs throughout. Possible explanations for this might relate to variation in habitat quality, with individuals more motivated to remain in higher quality habitat in spite of disturbance, or to a degree of tolerance to ADDs within particular areas or by particular individuals (although it seems very likely that individual seals would move between these different areas within the Sound).

Year	Statistic	Area 1	Area 2	Area 3	Area 4	Total
2006	Effort	27.6	46.2	73.6	52.8	200.2
	Detections	5	7	6	15	33
	Det. Rate	0.18	0.15	0.08	0.28	0.16
2007	Effort	85.6	104.7	100.2	63.5	354.0
	Detections	11	15	17	21	64
	Det. Rate	0.13	0.14	0.17	0.33	0.18
2006 & 2007	Effort	113.2	151.0	174.1	115.5	553.8
(combined)	Detections	26	22	23	36	107
	Det. Rate	0.14	0.14	0.13	0.31	0.19
2008	Effort	50.7	59.2	77.8	67.2	254.9
	Detections	1	0	11	14	26
	Det. Rate	0.02	0	0.14	0.21	0.10

Table 4 Summary of effort (in km), detection frequencies and detection rates (acoustic detections per km) each study area in each year.

2.4.2 ADDs as a Significant Predictor within models of Porpoise Distribution

The acoustic monitoring data collected by HWDT have been used to develop descriptive models of porpoise distributions in the Inner Hebrides during a NERC funded PhD studentship at the University of St Andrews (Booth 2010). This work was extended under the present project to include data on ADD received levels as a potentially important co-variate. .

A General Additive Modelling (GAMS) approach has been followed but with the statistical significance of covariates within models being tested using General Estimating Equations (GEEs) (e.g. see Panigada, et al. 2008 for an example.). One of the advantages of this approach is that it provides a method for accommodating spatial and temporal autocorrelation in the data avoiding inflating statistical significance. The potential effects of and densities of a wide range of covariates on porpoise distributions were tested, generally with consistent results. Covariates considered are summarised in Table 5 Covariates considered in the porpoise distribution modelling process. Some of these, such as sea state, are likely to affect the detection process itself, while others, such as water depth, are more likely to influence porpoise distributions directly. One of the covariates considered was ADD received level.

Covariates Considered Likely to Affect Detection	Covariates Considered Likely to Affect Distribution	
Boat Speed (knots)	Year and Month	Chlorophyll
Time from Sunrise	Spring Tidal Range	Water Temperature
Position in Lunar Tidal Cycle	Current Speed (m/s)	Percentage Gravel (%)
Position in Daily Tidal Cycle	Distance from Land (km)	Percentage Sand (%)
Noise Level	Water Depth (m)	Percentage Mud (%)
Engine Status	Slope (degrees)	ADD Received Level (dB)

Table 5 Covariates considered in the porpoise distribution modelling process.

Model fitting used stepwise model selection based on the quasi-likelihood information (QIC) statistic (Pan 2001). For all models, each covariate was permitted to be present in the model

as a spline fitted with knots placed at the mean for each covariate, as a linear term or was removed from the model. Factor variables were permitted to be included as either a factor, a linear term or omitted entirely. Reduced models were created manually with one of the covariates being omitted at each step. Each model was then compared to the relevant full model using a simple anova.glm method. For each dataset, the retained terms were then fitted in order of significance and investigated using the sequential anova.geeglm to determine the final 'best' model.

Models were constructed over a range of spatial and temporal scales.

To investigate whether ADD received levels were a significant factor in determining distribution a model was fitted to the areas within the Sound of Mull (56° 40' 31" N 6° 11' 5" W to 56° 24' 27" N 5° 36' 9" W). In this model, water depth and seabed slope were the only covariates retained as significant predictors of relative densities. The highest detection rates were observed in regions of > 50 metres water depth, and in regions with seabed slopes > 2°. Received ADD level was removed from the model selection process during the 'anova.glm' stage, as the model with 'received ADD level' removed was not significantly different to the relevant full model (p > 0.4). This indicated it was not a significant predictor of porpoise distribution at the scale investigated. This suggests that at these spatial and temporal scales, which are large compared to those of other studies of the effects of ADDs, ADD received levels here were not having a statistically significant effect on porpoise distributions.

3. Research Focus B: Interactions with Seals

The use of ADDs as a means of controlling predation at salmon farms should properly be seen in the broader context of seal depredation at aquaculture sites. Scientific studies on this subject have been lacking, yet seal predation is considered a significant issue by; industry, regulators, consumers and various animal welfare organisations. There is a need to better understand how and why seal predation occurs. Research in this area must rely on industry collaboration, and this requires trust to be established between researchers and industry. .

3.1 Objective 3. Assessment of ADD Use and Seal Damage

3.1.1 Introduction

Although there has been little or no scientific study of seal depredation at salmon farms, there is a wealth of largely anecdotal information on this topic available through the practitioners who observe such events on a regular basis during their work. Site managers and workers will often have detailed observations or theories about seal damage, and will often also have opinions on whether or why ADDs work or do not work. We aimed to speak to as many site operators as possible during the course of this project in order to tap into the body of knowledge held by the industry. We were particularly interested in observations on whether or why ADDs might work, but also asked about a wider range of predator issues, to try to gain some perspective on the issue.

Initially we also hoped to have direct access to company logbooks to be able to quantify some of the observations that have been made by those involved at the site level, but this proved to be more problematic than we had anticipated. Although most companies maintain logbooks, it proved difficult to access these records directly, though some summary information was made available. In some cases we were told that this was because they were not in any easily retrievable format, but our overall impression was that there was some concern about the possible implications of allowing us to have access to such records, from a commercial perspective. This is an understandable concern, but from a research perspective it is frustrating that a wealth of data exist that cannot readily be queried. We hope that enough trust can be built up in future that such records might be made fully available for impartial research to be conducted in this area. The main area of work undertaken to address this task was to conduct interviews with as many site managers as possible.

3.1.2 Methods

An initial meeting with nine Scottish Sea Farm site managers allowed us to test out a draft questionnaire which then revised in the light of discussions we had with SFF. This was subsequently used to interview as many site managers as possible right around the country. Interviews were conducted in Shetland, Orkney and the Western Isles, as well as along the length of the west coast mainland (Highland and Strathclyde) and several of the Inner Hebridean islands. Geographical coverage was therefore good.

Semi-structured or qualitative interviews (Warren 2001) were conducted, whereby the interviewer held a series of specific questions in mind, but conducted the interviews as discussions or conversations. The interviewer then asked for clarifications to try to obtain answers to the specific list of questions but in the interviewees' words. The aim was to enable interviewees to answer the questions from their own perspectives. Such an approach is intended to prevent the interviewer's categorisation of the issue being forced on the informant, and should help solicit a broader range of possible answers, although it can pose problems in codifying answers afterwards (Platt 2001).

The list of questions that the interviewer attempted to cover is given in Annex 1. We have coded the answers and have used our coded values to try to summarise views within the industry. Because of the way the interviews were conducted, not all questions were answered by all interviewees, so the total number of responses varied for each question. We have construed questions and answers by farm site wherever possible, though some individuals gave the same answer to cover all the sites for which they were responsible and, based on the question, judgement had to be exercised as to whether such answers could be used to inform on all sites or whether they represented a single response.

A full report of the interviews will be written up for publication in a suitable journal and will augment previous such studies by Ross (1988) and Quick et al (2002). Here we summarise some of the main findings.

3.1.3 Results

Over the course of the project we interviewed 49 individual people with responsibility for over 136 different sites.

Seals were reported to be seen frequently at most salmon farm sites, and in the majority of cases on a daily basis. All except 2 respondents reported that seals were present routinely, and at 75 out of 83 sites, seals were reportedly seen on a regular basis without any cause for concern. Porpoises were also reported to be seen 'daily' at 18 sites, 'weekly' at 15 sites and 'monthly' at 19 sites. They were seen occasionally, annually or never at a further 26 sites. Porpoises are less conspicuous than seals, and are generally more shy of people, so these reports suggest that porpoises are, generally speaking, quite common around farm sites. Reported levels of sightings of other wildlife species are shown in Table 6.

Frequency reported	Porpoises	Dolphins	Whales	Basking sharks	Otter	Mink
Daily	18	1	0	0	27	
Weekly	15	1	0	1[1]	23	4
Monthly	19	12	3	4	3	
Yearly	6	25	5	15	2	
Occasionally	8	28	29	21	9	8
Never	12	14	43	40	14	66
Don't know	0	2	1	1	1	1
Missing data	6	1	4	3	1	5
Variable	1	1	0	0	1	

Table 6 Wildlife reported around farm sites

When we asked about the scale of the problem posed by seals to salmon farming operations, about half of respondents (49%) reported only a minor problem, while 23% reported occasional or continual major problems and 26% reported no problems. It is also worth noting that 33% of respondents claimed that the problem had become less acute in recent years due to changes in management practices.

How big a problem are seals?	No of sites	%
Major problem	**10**	12%
Sometimes major	9	11%
Minor problem	42	49%
Not a problem	22	26%
Not answered	2	2%

Table 7: Assessment of the scale of problems with seals

When asked about the anti-predator measures used, most respondents listed a range of measures that are taken. The measures adopted included the use of ADDs, but much more emphasis was put on other aspects such as adequately weighted and tensioned nets, the regular removal of dead fish ('morts'), and the use of seal blinds at the bottom of the net cages. It was also often stated that lower stocking densities and larger nets helped in these procedures, as did the use of plastic circle nets rather than the older-style steel cages; the former, it was said, being easier to keep well-tensioned. Overall 62 sites were reported to be using plastic circles and 23 using steel framed rectangular cages.

The use of anti-predator nets was reported by only one respondent, and such nets are clearly now rarely used. Indeed several respondents noted that they are difficult to manage, foul easily on mooring lines and boat propellers, and may catch and drown wildlife including marine mammals and birds.

Despite the fact that respondents noted the presence of both common and grey seals, most often on a daily basis, and in roughly equal proportions (77:65 accounts of grey:common seals daily/weekly/monthly), the majority attributed damage mainly to grey seals rather than commons. Grey seals were reported to be the main perpetrators at 34 sites, with commons seal damage reported at only 4 sites, and no information on species for a further 35 sites.

When asked about the age or sex of seals responsible for damage, 'large' animals were reported for 43 sites, while both older and younger animals were found at 22 sites, and mainly young animals at only 5. At the vast majority of sites (61) seal attacks were thought to be perpetrated by single 'rogue' animals. This opinion was often supported by the observation that when individual seals are removed, attacks often ceased for some time. The few that disagreed (8 sites) felt that any seal could be causing the problem, while several more respondents did not know.

There was less consistency concerning the seasonality of attacks. At a majority of sites (51 among 83 sites for which answers were supplied) winter was reportedly the worst season, but there was no apparent pattern at 22 sites, while other seasons were reported for 10 sites. A slightly higher proportion of sites (66 of 82) were thought to have more problems when fish were larger or more densely stocked, with only 5 reported to have more damage to small fish and 11 reported as having no pattern within the production cycle.

Attacks were reported to be more frequent at night at 53 of 83 sites, while at 20 there were said to be no diurnal patterns and more attacks reported at 10 sites during daylight. When asked about meteorological or tidal correlations, or whether the use of underwater lights affected seal attack rates, no clear patterns of opinion emerged. Respondents thought sick fish increased the likelihood of attack at 45 sites, while there was disagreement on this point for 21 sites; dead fish however were thought to increase the risk of seal predation at 60 sites, compared to 10 sites at which this was not thought to be true.

Seal attacks were described similarly by most respondents. Most thought that seals attack from the bottom of the cage, though the only reason for this perception seems to be that this was assumed to be where the net is least tensioned. Fish are grabbed through the meshes, sometimes leaving just the head and tail, sometime sucking out just the liver. Seal attack episodes often start with a few fish and then increase in severity over time. Only two respondents claimed ever to have seen a seal ramming a net to grab fish through the meshes. Fish are thought to react by leaping out of the water. The process of such attacks remains unclear however.

ADDs were reported to be in use at 40 sites and not in use at 41 sites. Most sites using ADDs were using Terecos (17) or Airmar (14) devices. A few older Ferranti Thompson (2), Ace Aquatec (4) or other (3) devices were also reported. At several sites there seems to be a move towards fitting several Airmar systems, each of which has four transducers, where in the past a single unit would have been fitted. Such a trend would increase the acoustic energy introduced into the environment by such sites. Several operators noted that in recent years units have become more robust and reliable and that with the provision of AC electricity on cages becoming more common it was easier to maintain correct battery voltage.

Several modes of ADD use were reported reflecting different views on the way seals might respond to them. At 16 of the 40 sites ADDs are used continuously. Here the intention was to discourage seals from ever learning to become interested in the cages. At 12 sites ADDs are only switched on when the fish become large enough to be considered at risk. At 4 sites ADDs are switched on when seals are seen close to the cages, which might indicate increasing interest, while at 21 sites ADDs are only used when seal damage begins to be noted. ADDs, when in use, are usually left running all the time. Managers operating in these more responsive modes often suggested it this would avoid seals becoming habituated to ADDs as well as reducing noise input into the environment.

Predator triggers had been used at 27 sites, but at none of these had they been deemed a success, with many people reporting that they had been set off too easily by the fish, and that the acoustic deterrent then did not work. Habituation to ADD signals was considered a problem for 41 sites, but not at a further 10. There was much equivocation about the effectiveness of ADDs. Most people that used them reckoned that they reduced seal attacks without eliminating them, and at 15/20 sites they were judged overall to have some preventative effect, and not at 5. There was a wide variety of opinions on how and why ADDs do or do not work. Several people thought that failures occurred due to poor maintenance or flat batteries, others thought that hungry seals would put up with the noise, or that seals get used to the noise, while others reported that when the devices are used, seals move away. There was no overall or majority view.

3.1.4 Discussion

These results, together with the comments and observations noted during interview, provide some very useful insights into the issue of seal depredation at salmon farm sites. It appears that seal depredation has been addressed over the years largely by changes in practices and, in particular, in new designs and measures that have been adopted to maintain net tension. There are still clearly problems which are worse at some sites than others. Commercial sensitivity prevented us from exploring this as we would have liked. About half of all sites were reported to be using ADDs, and this agrees with the study of Quick et al (2002) who found that 51% of farms were using ADDs in 2001, suggesting little change since then. Quick et al also reported that 81% of farms reported problems with seal attacks in 2001. These authors did not distinguish between occasional and serious levels of damage, but our results suggest that improved management measures may have reduced the levels of seal damage since 2001.

Seals are clearly regular residents around almost all salmon farm sites, and usually have little effect on operations. When seal attacks occur, many people believe a single rogue animal is involved. Attacks often begin at low level, and then as the animal or animals involved gain experience they can escalate to hundreds of fish per day. The usual mode of attack appears to be to charge the net and grab fish through meshes. Most people believe this is done at the

bottom of the net. Dead or ill fish seem to encourage this behaviour. Often there is little or no noticeable damage to the net though sometime seals may deliberately chew nets resulting in holes, which are the worst scenario for the producers. Regular dive inspections can help minimise the risk of this. ADDs are just one of a range of measures that are taken. Most people believe they have some effect, but none considers them to be completely effective. Some people believe their efficacy wears off through time.

The lack of any detailed observation of how seals attack cages is noteworthy. Two individuals claim to have observed a seal attack on net camera systems. We believe this is an area that warrants further attention to better understand exactly how seals manage to achieve the high levels of damage that we have seen, and had reported to us, by little more than a rush and grab tactic.

3.2 Objective 4: Observations of Seal Attacks

3.2.1 Introduction

This objective was highlighted in our proposal as being the most aspirational and high risk component of the project, and the one most likely to be difficult to deliver. In part because there are very few examples of successful research in this area on which to build. However, we believe this to be the most important aspect of the problem to understand in resolving seal depredation.

Under-water video monitoring has been tested elsewhere and could provide a useful tool to explore the issue of seal depredation. Konigson (2006) managed to film several seal interactions with set fyke nets in Sweden, and was able to demonstrate that one individual in particular was a 'repeat offender'. Although we heard of the existence of a film clip of a seal attacking a salmon pen in Scotland, we were unable to track this down. The technical issues in monitoring a large fish pen to study seal attacks by camera are formidable. Seal attacks often though not always occur at night. Underwater lighting is therefore required. Even in good light the field of view is limited, and it is very hard to know where a seal attack might occur within a cage system

A major difficulty in studying seal interactions is being able to get to a farm where an attack is taking place in time to make observations. Learning that an attack is underway requires a high level of support and trust from fish farm managers. It is understandable that with the best will in the world they won't relish the extra complication of observers at their sites when they are trying to deal with a difficult and costly situation. It is also the case that once attacks begin, a process of management actions is implemented to terminate the attacks, and there is often little time available to respond.

In spite of these difficulties we made two concerted efforts to investigate seal interactions in the field.

3.2.2 Photo-identification: Methods

The first was at the Scottish Sea Farms Fiunary and Fishnish sites in the sound of Mull (see Figure 11) where our focus was on using photo-identification methods to identify individual seals surfacing close to a fish farm site. Fieldwork was conducted between late August 2008 and February 2009. Images were taken from the shore using a Canon EOS20D, Minolta D7, and a Sony A700, with a 600mm telephoto lens and 1.4x teleconverter. In total 1326 images were taken and analysed for possible matches, with the intention of determining a rate of individual resighting, a minimum number of animals involved and some measure of individual site fidelity.

3.2.3.1 Photo-identification: Results

Almost all seals photographed were common seals, with just three sightings of grey seals, only 1 of which of was photographed well enough for identification. Images which contained no useful information or which were duplicates were discarded from analysis, and the remaining photos were separated into sightings events (a period of time at a particular site). Remaining images were categorised by left and right sides, image quality (1 – poor, 2 – reasonable & 3 – excellent), and pelage 'uniqueness' (1 – unrecognisable, 2 – some pelage potentially useful for recognition and 3 – clear, unique pelage markings). Due to a combination of adverse weather conditions, the long range at which animals were photographed, a conservative scoring system and the partial submergence of many animals, the vast majority of images were of poor quality, with only 112 being selected as useful. Of these images 32 were of right sides, and 73 were of left sides, with the remainder showing mainly the animal's face. 20 individuals were positively identified from left-side images, with 15 individuals identified by right-side images. Eight individuals were subsequently identified using images of both sides. Of the 35 animals identified in total, 6 were photographed on more than one day, with the longest gap in between identifications being almost four months (22/08/08 – 19/02/09). Although there were many individuals around the sites at these times, and at least some habitually visited the site, there were no reported seal attacks over this period.

3.2.3.2 Photo-identification: Discussion

This work has demonstrated that photo-identification is possible at fish farm sites and shows promise as a means of exploring the behaviour of individual animals and could help establish behaviour patterns of individuals and perhaps identify 'rogue' individuals and link these to specific haul out locations. Although this can initially be viewed as a trial, there is already evidence that a substantial number of seals regularly visit fish farms over several days, during periods when ADDs are active. This has significance for the risk that animals will experience an adverse effect on their hearing, including a permanent or temporary threshold shift. One of the main limitations of photographing seals from the shore is the range at which a useful image can be obtained. With the current land-base technique, only those sites where a good vantage point is available from which the majority of the site is visible (such as un-wooded cliffs or rocky outcrops) are suitable. It is likely that better results would be obtained from photographers operating from the cages, feed barge or from drifting vessels, as the photographer would be much closer to the seals. We argue that a better understanding of the behaviour associated with seal "attacks" to help address the broader issue of depredation

3.2.4: Direct Observation of Attacks

Our second substantial field effort was at the Lighthouse Caledonian Farm at Loch Na Keal, Mull. Here we were able to make some observations in the course of an ongoing seal attack.

We were provided with photographs of a few of the large number of dead salmon removed (e.g. Figure 12). All of these had been damaged in the same very characteristic manner with their stomachs apparently torn out from below. This suggests a stereotyped attack behaviour by the seals. From these images we were able to make measurements of the likely canine spacing of the predators. Given enough data of this type it would be possible to investigate the size and likely species involved and provide a lower estimate of the number of animals. On this occasion though the incident stopped before we could arrange to collect such images.

We also deployed a video recording device (Tritech seacorder - autonomous video recording system) overnight at this site during a period of seal attacks. Although we did not observe a seal attacking the nets concerned, we did observe a grey seal (possibly more than one individual) on three occasions swimming close to the camera. It is interesting to note that all of the seals seen and photographed at the surface close to the cages and at near by haul out sites were common seals. The seal that investigated the camera had a yellow/orange stain on either side of its mouth (see Figure 13), suggesting possible marking of the animal by antifouling on the net meshes. This could prove a useful way of identifying individual animals engaged in this activity. We believe that regular deployments of UW video devices at pens with a persistent seal problem could help to develop an understanding of how attacks are

being perpetrated, and could help identify the individual responsible. More work in this area would be required and will need the full co-operation of a fish farm company and the site managers.

We also deployed hydrophones to make continuous UW recordings at this site through a night when seal attacks occurred. No seal vocalisations were recorded.

Figure 12 Salmon mortalities showing characteristic patterns of injury,

Figure 13 Frame captured from UW video of grey seal investigating net. Orange staining, possibly from net antifouling seems to be present around the seal's mouth.

3.3 Supplementary Objective: Effects of Salmon Farms on Local Seal Haul Out Numbers

3.3.1 Introduction

Declines in common seal numbers have been reported in several regions of the UK (Lonergan et al. 2007) including the East of Scotland, Western Isles and Shetland. The greatest declines have been reported in Orkney, where summer moulting season counts have gone down from over 7000 animals in 1997 to around 3000 in 2007. The causes of this reduction are unknown but at least one Animal Welfare organisation (the Seal Protection Action Group) has claimed that the shooting of seals by salmon farmers has been a major factor behind the animals' decline, while Mark Carter, of the Hebridean Trust, was reported on the BBC to say that he believed the general decline in seal numbers was particularly noticeable in the areas surrounding fish farms (http://news.bbc.co.uk/1/hi/scotland/7981598.stm).

Any causal link between fish farms and declines in common seal numbers is not immediately obvious. Declines in common seal numbers have been noted in the East of Scotland where there are no salmon farms, while in some areas such as the Highlands where farms are numerous, no such declines have been noted. Nevertheless we agreed to address this point at the Annual Review meeting of the present project in April 2009 as a supplementary objective.

3.3.2 Methods

The SMRU has counted common seal numbers at haul out sites around the Scottish coast since 1988. Counts are made by aerial survey during the moulting season (usually the first three weeks of August) when a large proportion of the population is hauled out around each low tide. Not all regions are surveyed every year, so a patchwork of surveys covers the coastline from year to year. Haul out locations are recorded as accurately as possible during each survey and many tens of thousands of haul out locations have been recorded since 1988. Fish farm sites are also recorded during surveys. We have used locations of any farm sites detected during SMRU surveys and this may include some sites no longer in operation. However, because common seal population declines have been ongoing for some time it seems appropriate to consider all sites - past and present – as potential factors in influencing changes in seal numbers.

We have calculated the distance between each of these haul out locations and the closest fish farm site using MS Access. We then allocated haul out location to be within 10km of a fish farm site, within 5km of a fish farm site or within 1km. The number of seals recorded, by region, for each year in which a survey had been made, and also the numbers of seals that had been recorded within 1, 5 and 10km of a fish farm site were determined for each survey year.

We reasoned that, if fish farms were implicated in the overall decline of seal numbers, then disproportionate declines might be expected in those haul outs closest to farm sites.

We fitted quasi-binomial (over-dispersed) generalised linear models to the proportions of animals counted within 1, 5, 10 km of fish farms for each survey year and by region. We discarded a few survey years when there had been only partial survey data collected in a region, and we did not include the Highland region since the observations here were highly variable from year to year (note also that overall numbers of common seals have increased in this region over the two decades of survey).

3.3.3 Results

The model outputs are shown graphically below. For the Strathclyde region, the best model fits for the 5km and 10km thresholds had a step around 1995. The best 1km model had a linear decline in Strathclyde. In all other regions the number of seals counted at haul out sites close to fish farm sites as a proportion of the total number counted in each region remained effectively constant. This suggests that even in areas like Orkney where there has been a dramatic overall decline in numbers, there has been no disproportionate decline in numbers of seals at those haul out sites closest to farm sites. The relative decline in seal numbers close to fish farm sites in Strathclyde requires some explaining. The overall numbers in Strathclyde have not declined noticeably, so the trends identified here should be seen in the context of an overall stable number of animals in the region.
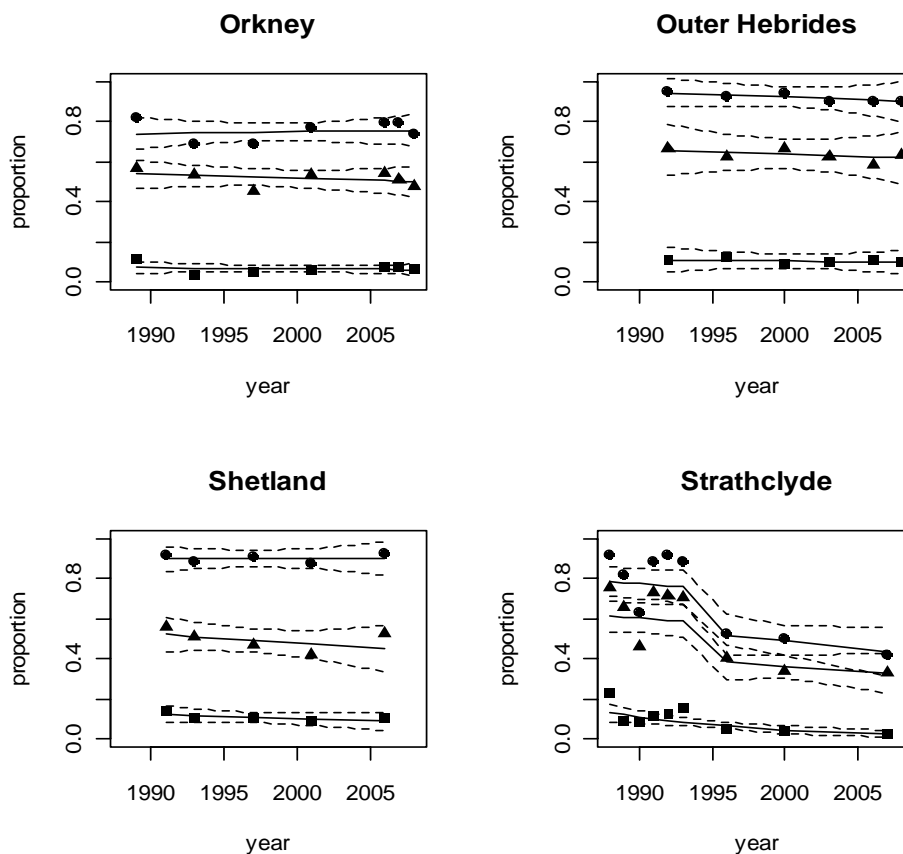

Figure 14 Trends in relative numbers of common seals at haul out sites within 1k, (circles), 5km triangles and 10km (squares) of fish farms sites for four Scottish regions based on the output of a quasi-binomial model general linear model.

3.3.4 Discussion

It is important not to over-interpret this result. Figure 15 shows that most of the haul-out sites that are close to farm sites are also in the relatively sheltered water areas of the Firth of Lorne and Loch Fyne. A decline in common seal numbers throughout inshore areas compared with those for example on the western extremities of Mull, on Islay or on Coll and Tiree, could be due to any number of other changes in ecosystem dynamics.

This analysis is the first to directly link seal haul out numbers to salmon farm sites, but should be regarded as only a preliminary attempt to describe trends over the past twenty years, and further and more detailed work will be required to fully explore this issue. However, there is no immediate support in these data for the notion that the decline in overall numbers, seen most acutely in Orkney, is associated with higher rates of decline around farm sites as has been suggested.
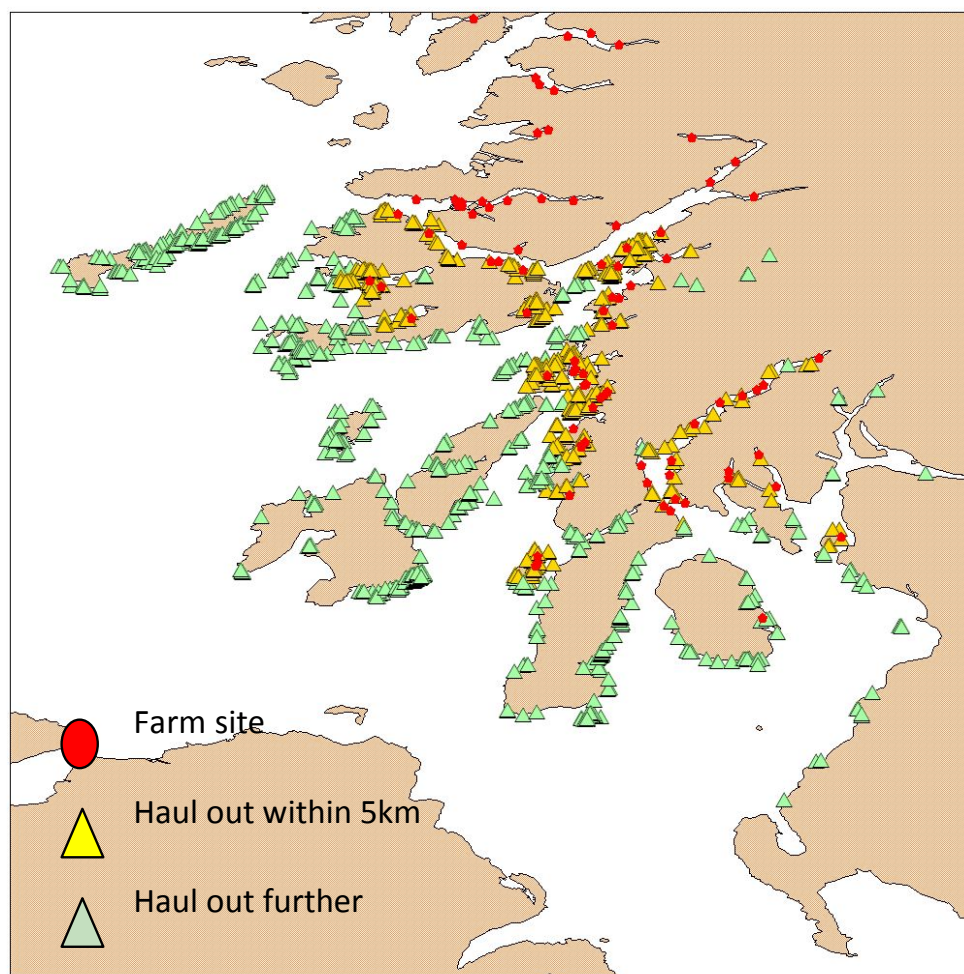

Figure 15 Location of fish farms, common seal haul out sites within 5km and more distant haul out sites in the Strathclyde region.

4. Industry Guidelines for Best Practice

Objective 5 was to suggest guidelines for best practice based on the data collected from industry and their analysis. Guidelines on the effective deployment of ADDs should seek to optimise the balance between the positive and negative aspects of their use. Positive aspects include the efficient operation of the aquaculture industry, improved welfare of farmed fish, a reduced requirement for less acceptable methods of managing seal interactions, such as lethal removal, and lowered risk of farmed fish escapes. Negative aspects relate to the potential for excluding porpoises and other cetaceans from important habitat and, potentially, the risk of inducing hearing damage and of course the cost of implementation.

As we have seen, we were not able to obtain or analyse appropriate log book data from industry. The experience and opinions of industry practitioners, garnered through interviews, has provided diverse and conflicting views on the efficacy of ADDs and how they can best be used. This diversity of opinion may well reflect the reality of a complex and variable phenomenon. Given this uncertainty, however, we feel unable to suggest a coherent set of guidelines based on new information though we can offer some suggestions for good practice.

If ADDs are to be used then it is important that they should operate effectively. For example, we were told of instances in which the failure of one transducer in a multi-transducer system provided a "chink in the armour" allowing a depredation event to become established. In a situation like this, with most of the other units operating fully, the overall acoustic output to the environment and any disruptive effect on cetaceans would likely remain high, while the system's positive protective function was compromised. Units need to be well maintained, batteries should be fully charged and performance should be checked regularly. An UW sound meter might be helpful to assess sound output.

This project did demonstrate effects on harbour porpoise distribution, though less dramatic than those shown by previous Canadian studies. As European Protected Species all cetaceans are protected under national and EU wildlife legislation. Specifically, deliberate or reckless disturbance of any cetacean could constitute an offence under The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended in Scotland). Advice on licensing requirements can be obtained from local Scottish Natural Heritage (SNH) offices. Licensing requirements may be influenced by the fact that SNH considers some sites to be more important to cetaceans than others. Specifically, these might include Special Areas of Conservation (SACs) with a cetacean interest; straits, sounds, and embayment's where cetaceans are frequently observed and where the presence of ADDs may cause a barrier to passage, and finally headlands and tidal upwelling areas that may be important for cetaceans' feeding.

This project underlines how little is known about how ADDs affect seal depredation and the most effective ways of using them to protect fish farms. To help achieve this understanding, and to be able to build a positive case to support their role in predator management, it is important that fish farmers collect relevant data on factors such as predator sightings and depredation events, as well as what management measures are applied and what their consequences may be. Arrangements should be made for these data to be appropriately analysed and for the results to be disseminated. It will be highly beneficial if this is an industry initiative coordinated coherently across the UK sector as a whole even though this will involve addressing questions of trust and commercial confidentiality.

An industry guidance leaflet has been prepared and is reproduced in Annex 2.

5. Recommendations for further research

Effects of ADDs on Cetaceans.

Our observations of the effects of ADDs, at two different sites, using static detectors and moving survey data have all investigated the effects of Airmar devices, and these were also the model investigated in earlier Canadian studies. However, about half the sites in Scotland use Terecos ADDs and, so far, no investigations of their effects on cetaceans have ever been made. As part of this study we did make arrangements to trial Terecos devices but operational problems at the farm sites prevented this within the time span of this project. A series of tests of the effects of Terecos devices would therefore be useful.

Several studies have now measured the effects that Airmar devices have on porpoise distributions with more or less consistent results. The requirement now is for an assessment of the consequences of this degree of disturbance for the conservation status of local porpoise populations and implications in the context of statutory requirements such as those laid down in the EU Habitats Directive.

Understanding and Managing Seal Depredation

Our work on this project has emphasised how little is known about the nature of seal depredations as a whole, including the role of ADDs as a management tool. A better understanding should lead to improved management of the problem and allow a convincing positive case for the use of ADDs to be made to set alongside their well proven negative effects.

An inexpensive and easily implemented first step would be for farms to keep appropriate records of aspects of seal occurrence, depredation and management actions and, most importantly, to agree a process by which these could be analysed and the results disseminated. Many sites already keep records and it is likely that much could be gained by analysing existing data. However, it may also be useful for industry and experts to agree a standard set of data which can be reliably and consistently collected. (This might include images of damaged fish).

Focused research at farm sites is also required to understand the nature of interactions. We suggest that research should go forward in two areas. One would be focused on gaining an understanding of the nature of seal interactions with fish farms. The second would test tools and procedures for managing seal interactions which seem to show promise. Our experience emphasises that it is essential that the industry is centrally involved at all stages in any research exercise and has a real sense of ownership of the process. Success is unlikely without this very high level of cooperation. Several approaches seem useful in terms of understanding seal interactions

- Photo-identifications studies can provide good information on the identity and numbers of seals frequenting farms sites, and allied with other data, should provide good information on the occurrence of "rogue" individuals.
- Underwater video should provide information on seal interactions with nets. Many farms now have their own very capable video systems and there would seem to be good scope for using these along with dedicated units.
- High resolution scanning sonar would be a useful way of imaging the movements of seals around cages in murky water and at night.
- Measuring the behaviour of fish within cages might indicate information on seal attacks and fish vulnerability and suggest ways of reducing risks by altering fish behaviour. This could be studied using both video and scanning sonar.

Potential alternative management tools to control depredation that might be worth exploring at this stage include:

- The use of conditioned taste aversion to condition seals to avoid salmon.
- Use of electrical fields to exclude seals from the immediate vicinity of nets
- Improvements in net design
- ADDs utilising sound sources that have fewer negative environmental consequences.

6. Bibliography

Johnson, C. S., (1967) Sound detection thresholds in marine mammals. In: *Marine bio-acoustics*: 247. W. N. Tavolga (Ed.). Pergamon, Oxford, U.K.

Johnston, D. W. (2002) The effect of acoustic harassment devices on harbour porpoises (Phocoena phocoena) in the Bay of Fundy, Canada. *Biological Conservation,* **108,** 113.

Kastelein, R. A., P. Bunskoek, M. Hagedoorn, W. W. L. Au & D. de Haan (2002) Audiogram of a harbor porpoise (Phocoena phocoena) measured with narrow-band frequency-modulated signals. *Journal of the Acoustical Society of America,* **112,** 334.

Konigson, S., M. Hemmingsson, S. G. Lunneryd & K. Lundstrom (2007) Seals and fyke nets: An investigation of the problem and its possible solution. *Marine Biology Research,* **3,** 29.

Königson, S. J., K. E. Lundström, M. M. B. Hemmingsson, S.-G. Lunneryd & H. Westerberg (2006) Feeding preferences of harbour seals (Phoca vitulina) specialised in raiding fishing gear. *Aquatic Mammals* **32,** 152.

Lepper, P. A., V. L. G. Turner, A. D. Goodson & K. D. Black, (2004) Source levels and spectra emitted by three commercial aquaculture anti-predator devices. In: *Seventh European Conference on Underwater Acoustics, ECUA 2004*: 6. Delft, Netherlands.

Lonergan, M., C. D. Duck, D. Thompson, B. L. Mackey, L. Cunningham & I. L. Boyd (2007) Using sparse survey data to investigate the declining abundance of British harbour seals. *Journal of Zoology,* **271,** 261.

Mohl, B., (1968) Hearing in seals. In: *The behaviour and physiology of pinnipeds*: 172. R. J. Harrison, R. C. Hubbard, R. S. Peterson, C. E. Rice & R. J. Schusterman (Eds.). Appleton-Century-Crofts, New York.

Olesiuk, P. F., L. M. Nichol, M. J. Sowden & J. K. B. Ford (2002) Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises (Phocoena phocoena) in Retreat Passage, British Columbia. *Marine Mammal Science,* **18,** 843.

Pan W, 2001. Akaike's information criterion in generalized estimating equations. Biometrics 57: 120–125.

Panigada, S., M. Zanardelli, M. MacKenzie, C. Donovan, F. Melin & P. S. Hammond (2008) Modelling habitat preferences for fin whales and striped dolphins in the Pelagos Sanctuary (Western Mediterranean Sea) with physiographic and remote sensing variables. *Remote Sensing of Environment,* **112,** 3400.

Platt, J. 2001. The History of the Interview. In: Handbook of Interview Research, Context and Method. Edited by Jaber F. Gubrium and James A. Holstein. Sage Publications, London

Quick NJ, M. SJ & A. JD, (2002.) The use of anti-predator controls at Scottish Salmon Farms. Fisheries Research Services Report No 03/02. Pitlochry, FRS Freshwater Laboratory, 16pp.

Ross, A., (1988) Controlling Nature's Predators on Fish Farms. 96. Marine Conservation Society, Ross-on-Wye.

Thomsen, F., N. van Elk, V. Brock & W. Piper (2005) On the performance of automated porpoise-click-detectors in experiments with captive harbor porpoises (Phocoena phocoena) (L). Journal of the Acoustical Society of America, 118, 37.

Verfuß, U., Miller, L., Schnitzler, H-U., 2005. Spatial orientation in echolocating harbour porpoises (*Phocoena phocoena*). Journal of Experimental Biology 208, 3385-3394

Warren, C.A.B., 2001. Qualitative Interviewing. In: Handbook of Interview Research, Context and Method. Edited by Jaber F. Gubrium and James A. Holstein. Sage Publications, London

SARF044 – Annex 1. Question prompts for interviewing fish farm operators.

Questionnaire:

Information about the Farm Site

(please fill in a separate questionnaire for each site)

Name and Location:

Number of fish and number and type of cages:

Management Area:

Timing of Production Cycle. (typical month smoults added, typical Month Harvest)

How frequently are marine mammals seen from the farm site

	Never,	Once a year	Once a Month	Once a Week	Daily
Grey Seals					
Common Seals					
Porpoise					
Dolphins					
Whales					
Otters					

How big a problem are predators (Seals, Cetaceans, Birds, Fish)
at this site

What anti-predator procedures are employed on this site

Seals

Species –
Which species are most often observed around the site?

Which species is most often involved in attacks?

Type

What is the age and sex of the individual seals most often involved in attacks

Are there instances when rogue individuals becomes a particular problem? If so, give details of species, age, sex etc

Are seals seen routinely from the farm

Are seals seen without there being a problem

Timing

Seasonality. Is there a time of the year when the problem is particularly difficult?

Production Cycle. Is there a time in the production cycle when more attacks occur

(Do you have any information that might help to disentangle these two.)

Diurnal. When in the day/night cycle do attacks tend to occur

Tidal. When in the tidal (high;low water) or lunar (spring/neap) do attacks tend to occur

Meteorology. Is there any association between particular weather conditions and attacks

Underwater Lights: Do you think the use of underwater lights affects the problem

Other Factors
Have you noticed associations with other factors
- Ill or disabled fish present
- Occurrence of Mortalities in the bottom of the net
- After net cleaning
- After grading
- Other ….

Observations of Seal Interactions
Have you observed seal attacks in the past

If so, please describe

Do you have photographs of these or of damaged fish,

About ADDs

What makes models are used at this site

At what stage do you employ ADDs?
- o When fish reach a certain stage
- o When seals are seen
- o When attacks start

How long do you continue to use them?
- o Until seal interactions cease
- o Until seals removed
- o Until harvest
- o For a set number of days
- o

Are they used day and night?

Do you use predator triggers?
- If so, what make and how effective are they

Do you have any evidence to suggest that seals (or cetaceans) become habituated to ADDs?

Effectiveness

Are ADDs effective in preventing attacks from starting

Are ADDs effective in alleviating a problem with seals once it has started

Do ADDs reduce the number of seals observed at the fish farm

Do ADDs reduce the number of cetaceans seen at the fish farm

Have you experienced variability in effectiveness of ADDs and if so why do you think this occurs.

Seals, Porpoises and Fish Farms: the question of acoustic deterrence

Background

This guidance note is to inform relevant stakeholders of some of the important results of a research project which was designed to assess the effectiveness of acoustic deterrent devices (ADD's) in preventing seal attacks on marine fish cages. The project also assessed the potential effect of such devices on the behaviour of porpoises. A detailed project report is available at: www.sarf.org.uk/downloads/SARF044 Final Report .pdf

Seals are part of the marine and coastal environment and healthy seal populations can coexist alongside aquaculture developments.

Seals are often seen close to fish farms without causing any problems but occasionally seal predation of fish in cages can become an issue. The level of predation may be low level but persistent. Sometimes large scale losses of fish occur, even when protective measures have been taken.

New licensing requirements, such as those within the Marine Act (Scotland), now mean that all management measures designed to prevent seal predation will be open to greater scrutiny. In particular, shooting of seals will be regarded as a last resort, subject to a new type of licensing, and licenses will need to be applied for in advance.

To obtain a license farm managers are likely to need to show that other management procedures have been tried and have failed, and that shooting would be effective, i.e. that individual seals causing the problem can be identified reliably and then safely and humanely removed.

The information outlined below is based on a survey of fish farm managers, together with field observations from fish farms to assess the effect on seals and porpoises of one type of acoustic deterrent device (ADD). Although the results are not definitive, they are offered as a general guide to the state of our understanding and to help inform decision making.

Severity of seal problem

No of responses (N=85)
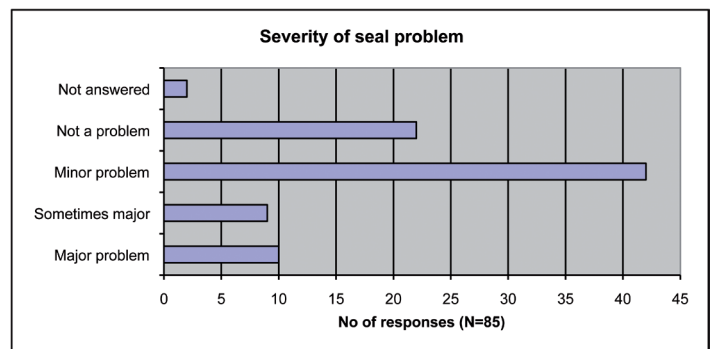
Recent Work on Seals, Fish farms and ADDs

An industry survey conducted by the Sea Mammal Research Unit (SMRU) suggests that seal predation reported by industry has decreased over the past ten years. This probably reflects improving management, fish welfare and containment practices.

Seal damage can result in direct fish mortality, escapes through damaged nets, fish stress leading to reduced growth and an increased susceptibility to disease.

A number of protective procedures are now routinely employed by industry and are widely reported to reduce seal interactions.

The survey of industry opinions showed that the regular removal of dead fish, and strong, correctly tensioned and well maintained nets are the two most effective ways of reducing damage to stock. Seal blinds on the bottom of nets can also help.

Separate anti–predator nets are generally not favoured because they can result in the entanglement and drowning of birds, seals and other wildlife, and may also become entangled in other equipment.

Acoustic deterrent devices (ADDs) are widely used but there is no consensus on their overall effectiveness, and no substantial studies have been conducted to show how effective they are or what the optimal deployment strategy might be.

There is concern in relation to the effect of ADDs on cetaceans, especially the harbour porpoise, a species that is widespread in Scottish coastal waters. As European Protected Species cetaceans are protected under national and EU wildlife legislation. Deliberate or reckless disturbance of any cetacean could constitute an offence under The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended in Scotland).
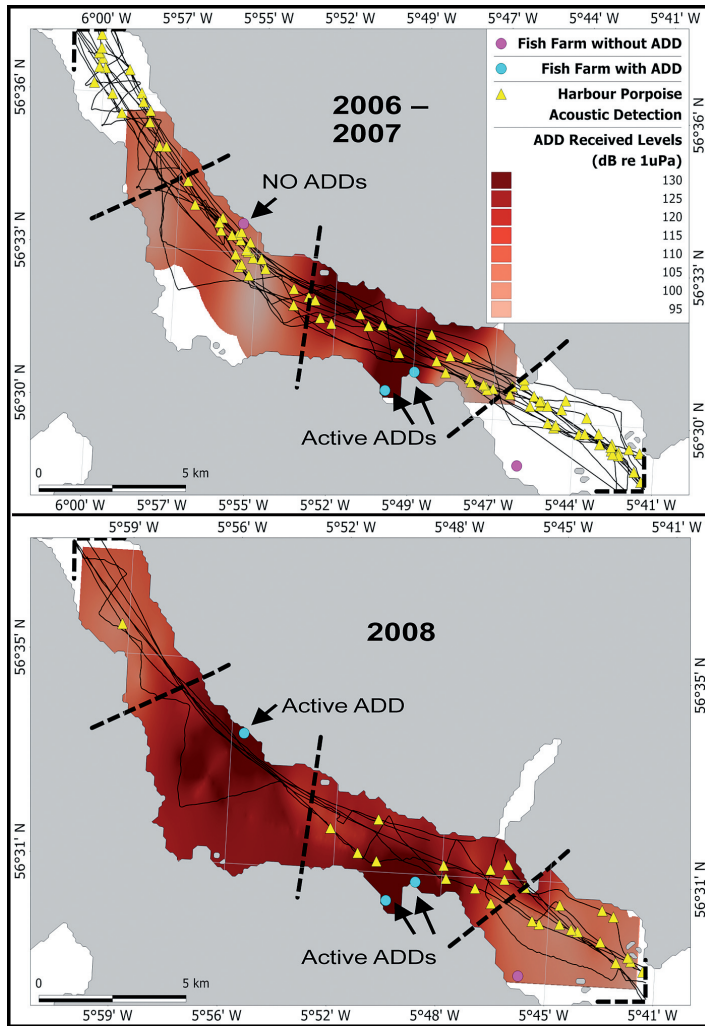
In 2006 and 2007 porpoises were frequently detected throughout the Sound of Mull where there were two sites using ADDs. When another site began using ADDs for the first time in 2008, detections of porpoises declined, but only in the area closest to the new sound source.

Effects of ADDs on porpoises: summary information

The ADDs tested (Airmar) were shown to be associated with decreased rates of porpoise detection over ranges of several kilometres from the source, as has been demonstrated previously in Canada.

Although some effect was noted as far as 4km from one site, the recent research revealed a pattern of porpoise behaviour which is not as straight forward as that shown in earlier Canadian studies. Porpoises were not completely excluded from ensonified areas even at short ranges, and some are capable of tolerating the noise of ADDs close to the sound source. Porpoise activity recovered within days of ADDs being switched off.

There were indications that porpoises developed a tolerance of ADD signals, with more sightings and acoustic detections in one area where ADDs had been in use for many years, compared with an adjacent area where they had been newly installed. Tests with other ADD's are recommended to confirm and elaborate these results.

It is an offence to recklessly disturb a European Protected Species and it may therefore be necessary to apply for a license to inflict such disturbance. However, the significance of ADD use as a potential conservation issue for porpoises is still hard to determine. The results show that they have an effect on porpoise behaviour but it may be temporary and porpoise density in western coastal Scottish waters as a whole remains high, even after decades of ADD use.

ADDs to manage Seal predation

Anecdotal evidence suggests that ADDs can be an effective response to seal predation. However, their efficacy seems to be variable and possibly site specific.

Within the limitations of this project, field evidence for the effectiveness of the ADD's tested was not conclusive.

ADDs should be used as part of a management strategy and, preferably, only if predation persists once other options such as tensioned nets and mortality removals, have been instigated.

The costs and benefits of using ADDs should be assessed on a site by site basis and the indiscriminate deployment of these devices at all sites is not recommended because of the potential impacts on cetaceans.

The decision to deploy ADDs should be made in the light of the potential benefits, in terms of reduced likelihood of fish predation or loss, and the impacts on local cetacean populations. Impacts on cetaceans are also likely to be site specific and will depend on the way that local seabed topography affects the propagation of sound around the site. Some sites may also be more important to cetaceans than others. Specifically, these might include Special Areas of Conservation (SACs) with a cetacean interest; straits, sounds, and embayment's where cetaceans are frequently observed and where the presence of ADDs may cause a barrier to passage, and finally headlands and tidal upwelling areas that may be important for cetaceans' feeding. The benefits of ADD use may also be site specific and individual balanced assessments should be made at each site. Advice on licensing requirements can be obtained from local SNH offices.

The Future

Acoustic signals that are more specifically targeted at seals while being less aversive to cetaceans have been developed and are currently being tested in the field as part of a research project sponsored by Marine Scotland.

University of
St Andrews