# Investigations on Seal Depredation at Scottish Fish Farms

**Report to Marine Scotland**

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# EXECUTIVE SUMMARY

- The project has several overlapping objectives, with the overall aim of improving our understanding of seal depredation at fish farm sites, including aspects addressing mitigation of the problem.
- Specific objectives were to develop a photo-identification system for seals around a sample of salmon farm sites and interpret results, to develop a system suitable for underwater monitoring of seal behaviour around salmon cages, to explore aspects of cage design that might affect vulnerability to seal attacks, to use seal damaged salmon as a means of making inferences about depredation events, and to explore and analyse industry data on seal damaged salmon.
- During the course of the project we also adopted additional objectives to examine certain acoustic deterrent devices, to characterise their acoustic output and to examine the possible impact of one such system on the harbour porpoise, a European Protected Species (EPS) that is vulnerable to acoustic disturbance.
- Understanding more about the association of individual seals with farm sites close to their haul out sites will help us to understand the motivation for attacks on salmon pens.
- Thirteen fish farms in two areas, as well as ten nearby haul out sites, were subject to 66 photographic sessions, during which over 7000 digital photos were taken during 342 seal encounters.
- 48 seals were identified individually at fish farm sites, but only 17 were seen on more than one occasion, and mostly these were seen on consecutive visits, with very few seen repeatedly over a longer time period.  Among all the 72 identifiable seals (at farms and haul outs) only four were seen more than 3 days apart.  Two seals were seen 38 and 42 days apart respectively, at the same sites, while one seal was identified 3 years apart at two different sites 30km apart, and another seal was seen at two different farms 6km and 15 days apart.
- In general seals seem not to stay for long periods at farm sites or hauls outs. Other studies suggest a pattern of movement around and among an extended foraging range of some tens of kilometres.  We found no evidence of individuals specialising in feeding at any one site.
- We tested several underwater video systems and reviewed the advantages and disadvantages of these.  Ultimately we had our own system designed and built. This system is rugged and proved useful in the field, collecting many hours of good quality video recordings.  We recorded seals swimming around the cages, as well as diving birds, and the reactions of salmon within cages, but no depredation events were filmed.
- The key elements to a successful portable video monitoring system in this context are: a reliable and long lasting power supply; ease of removing video data for analysis without disrupting on-going recording;  a monitor attached by

umbilical to enable the camera to be positioned optimally; rugged housing and camera design.

- We provide a review of aspects of cage design and use that we consider important in minimising seal depredation, drawing on two previous studies and our own observations and discussions with industry.
- We note that holes in nets caused by seals are the single most frequent cause of salmon escapes from farm cages. It is generally agreed that very little is known about how such holes are caused, and what factors may increase or decrease their likelihood.
- The importance of reviewing the evidence after any serious depredation event is stressed, as only by learning from such events can we hope to understand the factors that make them likely to occur.
- We discuss the use of predator nets, seal blinds, false bottom cages and the removal of dead fish in minimising problems with seals. We note there are several problems with the implementation of predator nets, yet are also aware that such nets are still widely used in other countries.
- We note the existence of several new netting materials that have been or are being tested, though no comprehensive review of such trials is being undertaken.
- We discuss the importance of net tensioning and note that little information is available either on current practice or on optimal weight distribution or tensioning methods. We discuss the need for further research in this area.
- We studied the patterns of damage on many dead salmon, and attempted to obtain records from farm sites by providing operators with suitable cameras and recording kits. No pictures were returned, but our own examination suggests four main types of 'seal damage'. The most common appears to involve seals biting the belly of the fish through the meshes of the net.
- We measured a sample of such bite marks in an attempt to characterise the seal or seals responsible. We also made measurements of seal dentition from skulls and from live animals and were able to link inter-canine distance with the size of the animal. Although harbour seals generally have smaller inter-canine gaps, there was considerable overlap with those of grey seals.
- We were unable to unambiguously identify one or more individuals from a sample of seal bitten salmon from one net. Simulated bites on dead salmon using a seal jaw suggest that the dimensions of 'bite marks' can vary substantially even from the same pair of teeth.
- An analysis of industry data on seal damaged salmon covering 87 farm sites over a ten year period suggest that most sites suffer some depredation and on average some level of damage is experienced at each site in 36% of all months when cages are stocked. On average each site lost 264 salmon per stocked month. A notional annual loss of around £2.5 million would be expected if all fish had survived to harvest for these 87 farm sites.
- Taken together the data suggested there was a clear increase in predation rate over the first 6 or 7 months of the production cycle, with the greatest intensity

(most fish removed per month) at around month 9 or 10 of the production cycle. In general, the length of time that a farm had been active made no difference to the amount of predation.

- The proximity of the nearest harbour seal haul out site made no difference to the amount of depredation, though all sites were within 10km of a harbour seal haul out site. The number of harbour seals counted with 3, 5, 10 or 20km of a fish farm site made no difference to the amount of depredation.
- There was an unexpected positive relationship between the amount and frequency of depredation and the distance to the closest grey seal haul out site. Farms with grey seal hauls outs closest recorded less damage than those where grey seal haul out sites were further away (up to 11km).
- There was also less frequent damage at farm sites where there were larger numbers of grey seals counted within a 20km radius during August surveys than farms with less than 50 seals counted within a 20km radius. We cannot explain these findings as yet.
- There are clear geographic disparities in reported seal depredation rates. Farms sites in the Outer Hebrides typically have lower depredation rates than those around Loch Sunart, Loch Linnhe and the North/East costs of Skye.
- Tests on the effect of a Terecos Acoustic Deterrent Device (ADD) on porpoise echolocation frequency suggest that this device had only a very limited impact on porpoises in Loch Hourn. This is in contrast to previous studies that have shown widespread displacement of porpoises by another type of ADD.
- Calibrated hydrophone recordings of active ADD systems suggested that there was considerable variability in the acoustic output of the transducers, and it is suggested that regular measurements should be made at farm sites to ensure that transducers are all operating as intended.

# 1. Introduction

## 1.1 Background and rationale

Salmon aquaculture is one of Scotland's most important rural industries, producing more than 154,000 tonnes of salmon at 249 active sites in 2010, with a farm gate value of more than £539 million; it accounts for over one-third of Scotland's food exports by value. In 2010 the industry employed over 1000 people directly in production and between 4000 and 5000 in supporting sectors (Walker & McAlister 2010). Scottish Government supports industry aspirations to grow production of farmed fish sustainably to 210,000 tonnes by 2020[1] and to minimise the environmental impact of aquaculture (The Scottish Government 2009).

Salmon aquaculture cages often attract wildlife. Wild fish are attracted to the pens, often in large numbers (Carss, 1990; Dempster *et al*., 2009), probably because of the regular provision of food to the salmon, while birds and mammals may also be attracted either by the salmon themselves or by the associated fish or invertebrate fauna. Bird species may include herons, gulls and diving birds such as cormorants and shags, auks, and eider ducks. Mammals often associated with salmon farms include two species of seals (*Halichoerus grypus* and *Phoca vitulina)*, otters (*Lutra lutra*), minks (*Neovison vison*), dolphins and porpoises (*Phoceona phocoena*) (Northridge *et al.,* 2010).

In the majority of instances, the associations between wildlife and salmon farm sites are benign, and in fact farm sites may benefit the foraging opportunities of some wildlife. Occasionally, however, such associations can lead to conflicts where seals in particular have a direct impact on the salmon within the cages.

There are three ways in which seals can have a detrimental effect on salmon farms. Firstly, their presence around fish cages is said at times to frighten fish to an extent that they may stop feeding and fail to grow. This is a welfare issue for the fish, but is also an obvious economic issue for the farms themselves. Secondly, seals may attack salmon through the meshes of the net cages and kill or maim fish by taking bites out of them or clawing at them. Finally, on rare occasions, seals may actually breach the containing net itself, allowing fish to escape, sometimes in large numbers.

Quantifying the scale of these impacts is difficult. Farm sites routinely collect data on the number of dead fish on a daily or weekly basis, and most will also attribute causes of death (disease or seal damage for example), but these data are generally not made available (possibly for reasons of commercial confidentiality). There are consequently few records available in the public domain that quantify the numbers of fish killed or injured by seals. Quantifying the extent to which seals may scare fish is even more difficult, but under Part 6 section 110 of the Marine (Scotland) Act 2010, fish farms that profess a need to shoot seals must apply for a licence to do so, in

[1] http://www.scotland.gov.uk/Publications/2013/07/9185

order to “protect the health and welfare of farmed fish”. In 2012 some 30 licences were granted to shoot seals at 227 individual farm sites in order to protect the health and welfare of fish. Analysis of licence applications and returns may lead eventually to a better understanding of the extent to which fish welfare is affected by seals, but in 2011 242 seals were shot at Scottish fish farms[2], which gives some impression of the scale of welfare concerns. Escapes of fish that are attributable to seals are somewhat easier to quantify because under the Registration of Fish Farming and Shellfish Farming Businesses Amendment (Scotland) Order 2008 (and also under section 4.10 of the Scottish Finfish Farming Code of Good Practice[3]) any fish escaping from salmon farms must be notified to the Scottish Government within 24 hours of discovery. Companies are also obliged under the Fish Farming Businesses (Record Keeping) (Scotland) Order 2008 to maintain specific records relating to fish containment and breaches of containment, including details of net and mooring types as well as any anti-predator measures undertaken. In 2011 ten Atlantic salmon escape incidents were notified, involving 403,000 fish. Three of these incidents involving 21,000 fish were recorded as having been caused by predators – presumably seals. We return to this issue in Section 4 below, but note here that this aspect of seal damage is likely to be the least significant commercially, considering some farm sites are reported to have almost daily losses of fish to seals (Thistle Environmental Partnership, 2010b; Northridge *et al* 2010)).

Although it is not currently possible to quantify the full extent of the problem, the circumstantial evidence suggests that seals are a major problem for some salmon farm sites, and with pressure from the seal licencing system to reduce lethal control measures, there is a need to better understand the nature of this problem and to find the most effective ways to limit the more costly effects of seal behaviour.

## 1.2 Objectives

The present project sets out to address several objectives, all of which focus on trying to better understand the ways in which seals are able to attack fish cages, or aspects of the defence methods applied by site managers. The overall objective is to help understand how and why seals are able to cause damage to fish farm sites, in order to help develop acceptable methods to minimise such damage. To explore this objective we have focused on five sub-objectives as follows:

- To continue to develop a photo-identification database of seals around specific farm sites and at local haul out sites
- To test and expand use of underwater video and acoustic equipment to study the behaviour of seals around salmon cages
- To examine net structure and deployment with a view to better understand how seals may be able to damage caged fish
- To compare samples of seal-attacked salmon with seal dentition patterns

[2] http://www.scotland.gov.uk/Topics/marine/Licensing/SealLicensing/2011
[3] http://www.thecodeofgoodpractice.co.uk/index.php

- To examine industry data on seal damage that may explain underlying patterns of damage

One of the most prevalent methods used to deter seal depredation is the use of Acoustic Deterrent Devices (ADDs). There are several models used in Scotland. There are concerns that the use of these devices may have an unacceptable impact on echo-locating cetaceans that are generally much more sensitive to noise than seals. Several studies have shown that the widely used Airmar device may have an aversive influence on porpoise distribution to a distance of 3km or more (Olesiuk, Nichol, Sowden, & Ford, 2002; Johnston, 2002; Northridge *et al*., 2010). The effects of other devices, with very different acoustic signals, have not been studied. Indeed there is only one published study that even describes the acoustic signals of more than one of the devices concerned.

Two further objectives were therefore:

- To test how the widely used Terecos seal deterrent device might affect the distribution of porpoises.
- To describe the acoustic properties of a selection of ADDs that we were accessible for the project.

We will address each of the objectives in turn.

## 2. Photo-identification studies

### 2.1 Background

It is clear that seals are often present around salmon farm sites (Northridge *et al*. 2010), which seems likely to be due to the presence of wild fish that are usually found around farm sites (Dempster *et al*. 2009; Dempster *et al*. 2011; Uglem *et al*. 2009). It is often assumed that damage at fish farm sites is caused by individuals that learn how to overcome the defences in place, and then specialise in attacking caged fish. This view is held by many site operators because it is often stated that the lethal removal of a single individual will result in an immediate disappearance of seal-damaged salmon. However, some opinions also hold that on occasion many seals may engage in depredation at the same time (Northridge *et al*., 2010).

It is also sometimes asserted that the problems associated with seal damage at farm sites could be avoided if salmon farms were located away from seal haul out sites. While we address this issue from another perspective later in the present report (Section 6), there is an implicit assumption here that damage by seals is most likely attributable to the seals at the closest haul out site. That said, the association between individual seals at haul out sites and those at nearby farm sites has not been shown, and it remains to be demonstrated whether or not seals generally associate with farm sites closest to their haul out site, or whether individual seals learn both the location and reward of more than one site in their locality and visit several farm sites.

More generally we maintain that better information on the residence times of seals around farm sites, the species involved, the degree to which individuals associate with specific farms, and the numbers of individuals that associate with specific farms may help to understand the motivations and behaviour of seals that habitually forage around farm sites. This in turn may help explain some of the issues associated with seal damage to farm sites.

## 2.2 Methods

To explore these issues we have focused on two areas – one in Orkney and the other around the Firth of Lorne, Loch Linnhe and the Sound of Mull in Argyll– and attempted to identify individual seals present at several farm sites and associated haul out sites over the duration of the project. We have also incorporated some photographs of individuals collected under a previous research project (Northridge *et al* 2010) at sites around the Sound of Mull.

Two photographers were supplied with Sony digital SLR cameras (A550 and A700) each equipped with either a fixed focal 500mm or 600mm lens (Sigma and Minolta respectively). Photographs were collected on an opportunistic basis and in collaboration with site managers. Digital images were downloaded from flash memory cards and screened for quality. Images were managed in a bespoke seal pelage ID photo database that is being developed at the Sea Mammal Research Unit (SMRU) under a separate project that is examining individuals mainly at grey seal pupping colonies.

Usually a photographer would spend most of a single day at a site (a 'photo-session'), and collect photographs of as many seals as possible. Images were downloaded and stored in folders by site and date. Within each day/site images are stored by 'encounter', and then by seal. There may therefore be several photographs of an individual seal within an encounter, and several individuals within an encounter, but also several encounters of an individual within a single photo-session or day.

Each individual for which a good quality image was available was given a unique alphanumeric code. Images of each individual were examined by encounter, graded, and compared with all other images throughout the database to find matches. If no match was found a new individual identifier code was assigned, or the individual was tagged with a previously identified code.

## 2.3 Results

Photographs were taken at 13 fish farm sites, in Orkney and around Mull and Oban, and 10 haul out sites located close to those farms. There were 65 photographic sessions during which photographs were collected, involving 342 animal encounters. Over 7000 images were recorded, and after selection of the most useful images, 1597 were entered into the digital image catalogue.

The vast majority of seals that were photographed on the west coast were harbour seals (*Phoca vitulina)*, while in Orkney all the animals photographed at farms were grey seals (*Halichoerus grypus*). The numbers of seals encountered at farm sites are given by region and by species in Table 1.

**Table 1: Numbers of seals encountered at farm sites by region**

| Region | Grey seals | Harbour seals |
|---|---|---|
| Mull | 2 | 48 |
| Oban | 1 | 202 |
| Orkney | 6 | 0 |

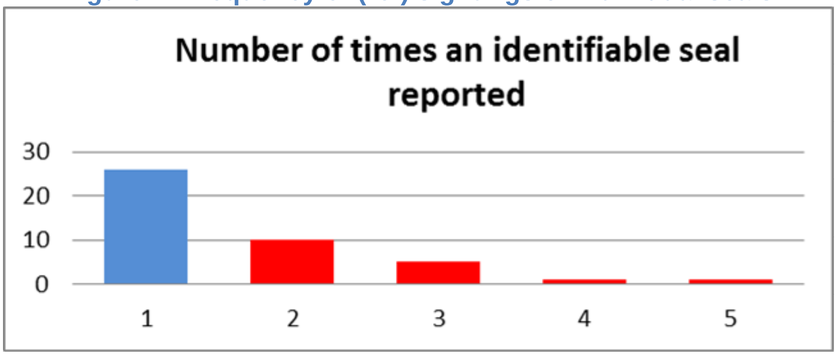
In total 50 photo sessions at fish farms (FF) resulted in 259 seal encounters, among which 48 identifiable individuals were recorded. A further 15 photo sessions at haul out sites (HO) resulted in 83 seal encounters of which 24 were identifiable individuals. Photo sessions at five locations (2 x FF, 3 x HO) resulted in no seal encounters. One haul out site also yielded 4 encounters in 2 days but none of the seals was deemed individually identifiable. On average each photo session resulted in 5.28 encountered seals and 1.25 identifiable animals. It is clear that some locations have more seal 'activity' than others: the fish farms at Lismore and Craignish for example yielded 49 and 40 encounters over just three and two sessions respectively, with 7 and 4 identifiable seals (see also Table 2).

Most of the 48 seals that were recorded at fish farms were only recorded once, but 17 were seen on more than one occasion (Figure 1: red bars). It is difficult to interpret this result with confidence, because sampling has been sporadic at all locations that we have visited, and because only about 1 in 4 or 5 seal encounters results in an animal being identified, but the data suggest that most seals at fish farm sites are transient, that is, they do not remain on site for long.

**Table 2: Detailed summary of seal encounters by site**

| Area | Site type | Location | Photo sessions | Encounters | Identified individuals | Encounters per Session | Identified seals per encounter |
|---|---|---|---|---|---|---|---|
| Mull | Farm | BB | 8 | 19 | 4 | 2.4 | 0.21 |
| Mull | Farm | FY | 10 | 31 | 11 | 3.1 | 0.35 |
| Oban | Farm | CBF | 1 | 7 | 2 | 7 | 0.29 |
| Oban | Farm | CGN | 2 | 40 | 4 | 20 | 0.10 |
| Oban | Farm | DSN | 2 | 11 | 3 | 5.5 | 0.27 |
| Oban | Farm | LC | 2 | 6 | 1 | 3 | 0.17 |
| Oban | Farm | LE | 3 | 49 | 7 | 16.3 | 0.14 |
| Oban | Farm | LL | 2 | 5 | 1 | 2.5 | 0.20 |
| Oban | Farm | PNC | 16 | 85 | 12 | 5.3 | 0.14 |
| Orkney | Farm | BH | 1 | 0 | 0 | 0 | 0.00 |
| Orkney | Farm | CNB | 1 | 5 | 2 | 5 | 0.40 |
| Orkney | Farm | MB | 1 | 1 | 1 | 1 | 1.00 |
| Orkney | Farm | ON | 1 | 0 | 0 | 0 | 0.00 |
| Mull | Haulout | SLN | 4 | 27 | 10 | 6.8 | 0.37 |
| Oban | Haulout | CB | 1 | 1 | 1 | 1 | 1.00 |
| Oban | Haulout | CBH | 2 | 4 | 0 | 2 | 0.00 |
| Oban | Haulout | EC | 1 | 0 | 0 | 0 | 0.00 |
| Oban | Haulout | ED | 1 | 22 | 7 | 22 | 0.32 |
| Oban | Haulout | ENC | 1 | 0 | 0 | 0 | 0.00 |
| Orkney | Haulout | BA | 1 | 1 | 1 | 1 | 1.00 |
| Orkney | Haulout | BFB | 2 | 21 | 4 | 10.5 | 0.19 |
| Orkney | Haulout | GH | 1 | 7 | 1 | 7 | 0.14 |
| Orkney | Haulout | HH | 1 | 0 | 0 | 0 | 0.00 |
| **TOTALS** and *Averages* | | | **65** | **342** | **72** | *5.3* | *0.27* |

**Figure 1: Frequency of (re-) sightings of individual seals**




However, it is also clear that some seals do attend sites repeatedly over long periods of time. One individual was seen three times at the same site in 2010 with 38 days between the first and last sighting, and another was seen twice at dates 42 days apart. More usually shorter ‘residences’ were apparent: of the 72 identifiable seals overall, only four were seen more than 3 days apart.

This suggestion that seals are most often transient at fish farm sites is supported by a closer examination of the encounters at one fish farm site, at Port na Cro, at which 14 photo sessions were made over 11 months, and where a steady progression of 'new' seals was identified throughout the sampling period. This is shown in Figure 2. Two harbour seals were sighted at more than one farm, one of which was resighted after more than three years and over 30km from the original sighting location. The other was seen at one site on two consecutive days, then fifteen days later was resighted at another farm approximately 6km away.

**Figure 2: Pattern of individual seal identification through time at Port Na Cro site**

| Port na Cro: identified seals by photo session date | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date / Seal** | **PNC1** | **PNC10** | **PNC11** | **PNC20** | **PNC23** | **PNC24** | **PNC25** | **PNC31** | **PNC32** | **PNC36** | **PNC40** | **PNC47** |
| 10-Nov-10 | * | * | | | | | | | | | | |
| 22-Nov-10 | | * | | | | | | | | | | |
| 15-Dec-10 | | | * | | | | | | | | | |
| 17-Dec-10 | | | * | | | | | | | | | |
| 18-Dec-10 | | * | * | | | | | | | | | |
| 12-Jan-11 | | | | * | | | | | | | | |
| 18-Jan-11 | | | | | * | | | | | | | |
| 28-Jan-11 | | | | | | * | * | | | | | |
| 02-Jun-11 | | | | | | | | * | | | | |
| 20-Jul-11 | | | | | | | | | * | * | | |
| 21-Jul-11 | | | | | | | | | * | | | |
| 16-Aug-11 | | | | | | | | | | | * | |
| 16-Sep-11 | | | | | | | | | | | | * |
| 27-Sep-11 | | | | | | | | | | | * | * |

## 2.4 Discussion

Sampling in Orkney was limited, mainly for logistical reasons, but all seal encounters at fish farms in this region were grey seals. Conversely, around Mull and Argyll we recorded predominantly harbour seals with very few grey seals identified at fish farm sites. Results from a questionnaire survey of salmon farm managers in the wider Argyll region (as reported by Northridge *et al* 2010) suggest that most were unsure which species of seal was responsible for most damage in this region. Our results here suggest that 99% of seals in attendance at farm sites around Mull and coastal Argyll are harbour seals, yet licence returns for the calendar year 2011 suggest that 58 harbour seals and 37 grey seals were shot in the wider western highland region on the basis of damage to fisheries or fish farming or to protect the welfare of farmed fish[4]. It seems that grey seals are in fact considered to be responsible for a greater proportion of damage to fish farm sites than their normal level of attendance at farm sites may suggest. It should be noted that we were not aware of nor told of any particular on-going problem with seals while we conducted these photo id studies.

[4] http://www.scotland.gov.uk/Topics/marine/Licensing/SealLicensing

Despite photographing seals at haulout sites adjacent to salmon farm sites whenever possible, we only found one match between those seals at haul out sites and those at farm sites. Two seals were seen to have moved between different farm sites, one over a relatively short period of time (fifteen days) and the other over a much longer period (over three years). It is possible that these individuals may specialise in feeding at farm sites, but given the low number involved this could also be put down to chance. Furthermore, the fact that there were no on-going predation events during the periods when these seals were sighted shows that if they have specialised in utilising fish farms sites in some way, it is not to predate on the farmed fish.

During the course of the project other members of SMRU were tagging harbour seals on the west coast as a part of another study, using satellite tags. One of these seals was noticed to have repeatedly visited a farm site over several days around 20km from the haul out site where it was tagged, before returning to the site where it was tagged (Figure 3 ). This demonstrates that not all seals seen around farm sites are necessarily to be found at local haul out sites, and agrees with previous satellite studies that have shown that while some 50% of harbour seal foraging trips are within a 25km radius of the haul out site at which they were tagged (with some seals travelling over 100km), only 40% of trips begin and end at the same haul out site (Cunningham *et al*. 2009). The overall impression is of harbour seals using several haul out sites within a ‘home range’ that may extend over several tens of kilometres in diameter.

Most individual seals at farm sites therefore appear to be transient, and may be taking advantage of locally abundant wild fish associated with the farm, usually for just a few days. There is no evidence at this stage to make a close link between animals at a haul out sites with those at nearby farm sites. Nor do we rule out the possibility that some animals may at times stay closely associated with a single farm for an extended period of time; in this study we have not seen this type of behaviour and it is clearly not widespread. It would be unwise however to read too much into a relatively small data set at this stage. So far our results should be seen as a pilot study into the feasibility of identifying individual behavioural responses to fish farms, and further analysis will be required to determine appropriate sample sizes required to answer questions about the range of individuals’ residences around farm sites, the relationship between animals seen around farm sites and those at local haul out sites, the degree to which individuals specialise in feeding at farm sites, and most importantly the degree to which damage may be attributable to specific individuals.

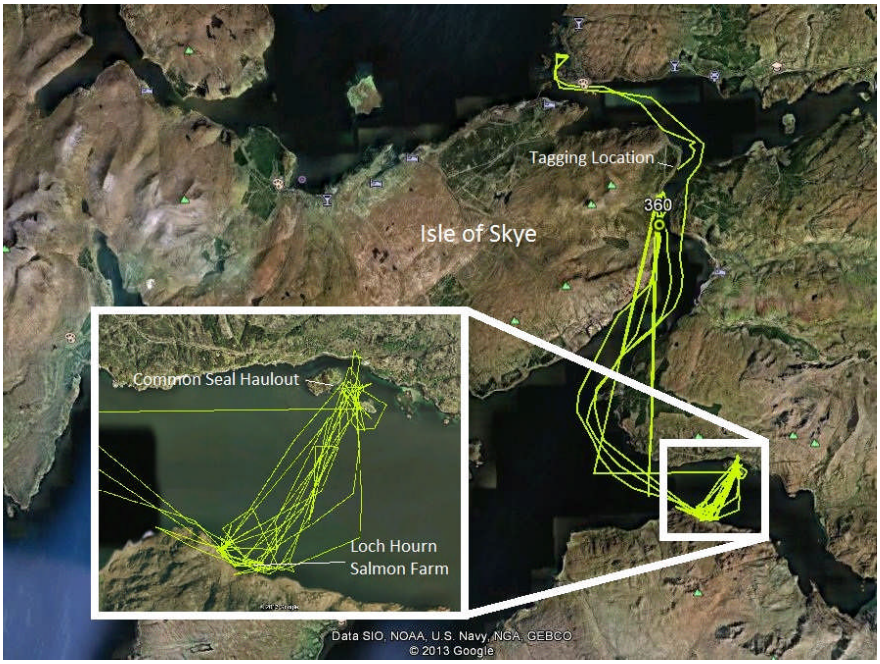



**Figure 3: Satellite track of harbour seal tagged at Kylerhea visiting farm site in Loch Hourn**

## 3. Underwater video monitoring systems to study seal behaviour around salmon cages.

One of the major obstacles to developing and improving measures to minimise seal damage at fish farms is the lack of understanding of how attacks occur.

Existing anti-predator practices are generally based on assumptions about seal behaviour and methods of attack, including the area of the net targeted and the number of seals involved. For example, seal blinds[5] and false bottomed nets are based on the assumption that attacks generally occur from below. These assumptions tend to be based on anecdotal evidence such as indirect observations of attacks. Direct observations are very rare, and generally go undocumented with very little empirical information available. However, during our work at farm sites we have occasionally heard anecdotes, usually second-hand, where attacks had been witnessed either by divers or via remote video cameras. These cameras are installed inside the fish cages in order to monitor the feeding activity of fish and provide a live video feed back to the barge. This gave us a starting point from which to gather information about attacks and we were keen to develop this as a means of collecting useful data.

We have examined existing in-pen camera systems at several sites, but conclude that they are not best suited for recording seal activity or depredation in the way that they are set up. Firstly, they are usually positioned in the centre of the cage facing upwards to get the best view of feeding fish in all light conditions. Some of the

[5] thicker netting material covering a few square metres of the centre of the bottom of the net to disguise dead fish that may accumulate there

newer cameras can be remotely rotated through 360°, allowing a view of the inside of the netting, but the camera is still at least 9-10m away from the side netting.

Additionally, any view of the net barrier is further reduced by low light levels when the camera is facing away from the surface and by particulate matter (and salmon) in the water column. Secondly, the cameras are needed for everyday operation of the farm, and in most cases it would not be practical to reposition them for any length of time. Power supply to these cameras is also generally limited to working hours when the generators are running. Even without these complications this is not a good angle for recording attacks as the net obscures the view of the seal.

We therefore began to experiment with different types of monitoring and recording systems in order to find a practical solution for recording attacks. Our progress so far is described below in five separate systems that we have investigated or developed.

### 3.1 System 1: Tritech Seacorder.

Initial attempts at making underwater recordings were made with a self-contained camera originally designed to be deployed on trawl nets[6]. The unit was very heavy and sturdy, and could easily be suspended below the fish farm cages. We had this unit modified so that an umbilical could be connected to a portable screen on the surface to enable us to adjust the angle and direction of the camera. The strength and weight of the camera meant that we were able to attach a length of chain to the base which helped to stabilise against the motion of the walkway on the surface. A ring of light emitting diodes (LEDs) is mounted around the lens which we hoped would allow recordings to be made at night. In one sense these proved useful as they were a point of interest for a seal to investigate, allowing us to get close-up images of the seal's head (Figure 3). This meant we were able to get a positive identification of species (*Halichoerus grypus*) and likely sex (female), which would otherwise have been difficult or impossible at night. Unfortunately the LEDs were not sufficiently powerful to illuminate the net from 3-4m away, which made recording of a night-time attack using this system unlikely. Furthermore, the battery life limited recordings to around 10 hours per deployment, and downloading the footage from the storage system to a laptop in the field was not straightforward. The seal that we recorded appears to have yellow staining around its mouth (Figure 3) which may suggest that the individual had netting material (coated with anti-fouling) in its mouth.

[6] This was a prototype of the now commercially available 'Seacorder' http://www.tritech.co.uk/product/tritech-seacorder-autonomous-video-recording-system

Figure 4: Close up of grey seal investigating camera system 1

## 3.2 System 2: Camcorder and housing

Our next recording attempts were made using a handheld video camera (Sony HandyCam HDR-SR12E) inside a custom built housing. Adaptations to the camera's power supply extended the recording time, but only to around 8 hours at a time. The great advantage of this system over the previous (Tritech Seacorder) was that we could easily download the data on-site, replace the battery-pack and rapidly redeploy for another day's filming. In this way recordings could be made semi-continuously over a period of days while a predation event was ongoing. The quality of video captured with this camera was also excellent, providing a very clear view of the net, fish and passing seals, even at depths below 10m where light is usually poor. This camera was relatively small and lightweight, which made it much easier to transport and handle on site. However, this also made the camera more fragile, and much more care needed to be taken when handling it in order to not damage it. This presents a problem in a fish-farm environment, where the risk of equipment getting knocked or splashed with seawater is high. Another disadvantage of using a camera in a housing like this is that you cannot see where the camera is pointing when it is deployed. Until the camera had been recovered and data downloaded, there is no way to tell whether you have an appropriate viewpoint. On one occasion divers working on the cages were happy to set up the camera in a good position, but clearly this would not be practical as a regular means of repositioning cameras.

Figure 5: Seal in daytime captured on system 2

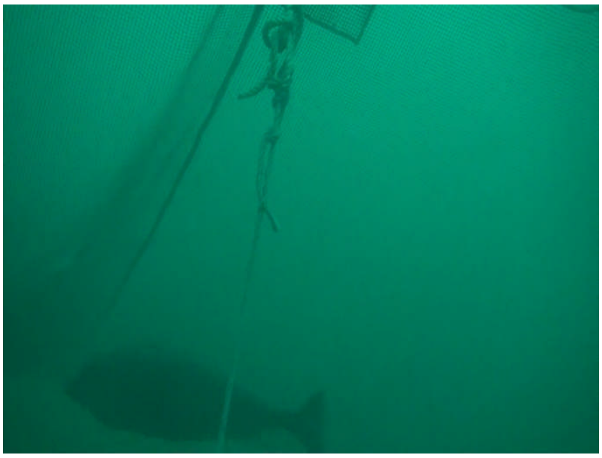


Figure 6: Seal in daytime captured on system 2

In total this system was deployed on five occasions, at three different locations. The timing of deployments was concentrated on late afternoon or early evening, as seals were suspected to be attacking during the evening/night. There were two encounters with seals recorded (Figures 4 & 5), both of which were in the late afternoon on the same site in Orkney. We saw no physical interaction between these individuals and the net system or the salmon, and it was not possible to identify positively whether the same animal was involved in both encounters, though it is thought to be unlikely - the second individual being clearly a grey seal, but the first being more likely to be common. We also saw instances of diving birds on these deployments, both shags (*Phalacrocora aristotelis*) and eider ducks (*Somateria millissima*), and multiple instances of salmon being startled by their diving behaviour.

### 3.3 System 3: Precision Aquaculture Portable Camera System

The main drawback of both previous systems was that battery and hard-drive size limited the length of recordings to around 10 hours per deployment. This hugely reduces the chances of collecting footage of an attack as it means the site needs to be visited every day to download data and recharge the battery. It was clear that in many cases it could be possible to exploit an available power supply on site, either as a continuous source or simply to charge a 12v battery while the generator was operating. By utilising the power supply on the sites, we were hopeful that we would be able to set up a recording system and leave it running over extended periods, and that this would be a much more efficient technique. Some video systems similar to this were found already to be in use by the industry, used for interim net inspections for instance. An aquaculture technology company agreed to lease us a prototype system on the arrangement that modifications could be made through the course of the project to accommodate our needs.

Initial tests were conducted with a 256 Gb hard drive machine which recorded four channels of video, large enough to record at least 2-3 weeks continuously. This system had an integrated monitor so that the video feed could be viewed whilst installing the cameras and could run from either a 12v or 240v power supply. Modifications and repairs of this unit were necessary after a brief trial, and a second system was supplied with a larger hard drive (1Tb) and fuses protecting critical components. This was tested over a one month deployment on a site where attacks were known to be occurring but technical problems meant that only 167 hours of footage was recorded on each of three channels. Here the recorder was attached to two deep cycle 12V batteries, charged by two solar panels.

There were several technical problems:

- One of the four cameras failed immediately
- Power consumption was relatively high resulting in cut outs.
- After a low voltage cut-out the recorder would remain dormant (not recording) until it was manually reset
- Extremely slow data transfer rate via USB made it logistically difficult to collect recordings
- Lack of access directly into the hard drive to bypass USB ‘bottleneck’.

Despite only recording for a fraction of the total deployment time, we captured multiple encounters with seals over this period. Interestingly, this site happened to be one where anti-predator nets (which are now rarely used in Scotland) are still employed. The cage at which the cameras were installed was fitted with a fully enclosed predator net which completely encircles the fish net on all sides and below. The anti-predator net was suspended from the walkway approximately 1m outside of the fish net, creating a second barrier between the seal and the fish.

Footage was captured at this site which clearly shows the seal in between the two nets (Figures 6 & 7). The only point of entry between the two nets was at the sea surface, where both nets are attached to the 'Polarcirkel'/tubular plastic walkway, meaning that the seal most likely crawled over the walkway to drop down inside the anti-predator net. This is a previously unidentified (or at least undocumented) problem with the design of anti-predator nets and is likely to increase the risk of seals becoming entangled and drowning. Seals were also seen outside of both nets (Figure 8).

Whilst this recording system was a significant improvement on earlier methods, the lack of flexibility of having a rented system highly restricted our data collection. Frequent malfunctions, slow repair/turnaround times and the inability to make fixes or small changes without returning to the manufacturer resulted in many recording opportunities being lost over the summer.



**Figure 7: Seal underneath inner cage**

**Figure 8: Seal inside anti-predator net system net**

Figure 9: Silhouette of seal outside fish net

### 3.4 System 4: Custom made camera system

Since none of the preceding systems proved ideal, we contacted a local underwater technology company with whom we have previously worked, to produce a video monitoring and recording system which meets our specific needs. The initial prototype of this new recording system was received in September 2011. This system is based on a commercially available recorder, selected because it has low power consumption and an easily accessible and interchangeable hard drive system. Initial field tests at one site during one day only suggest that this system will work very well. We have made a few minor improvements to make the unit as a whole more weatherproof.

This system is much more independent than previous models, requiring minimal input from either farm workers or researchers. We had hoped that one or more of these recorders could be set up at a site with an ongoing seal attack problem, but as of July 2012 we were unable to find a site willing to deploy the system. The system is designed so that it can be left to run continuously from a 12V power supply charged by solar panels, a wind turbine or a generator. If the power supply should fail for any reason a low-voltage cut out with hysteresis will turn the unit off – preventing possible hard drive damage and loss of data - until a point where enough power is available to run the unit safely, when it will revert to recording. During or shortly after an attack has been known to take place, the hard drive can be removed, replaced and sent for analysis. The unit can then be reset with an empty hard drive so no recording days are lost. This technique will also minimise analysis time, because only dates where fish were known to have been lost will be examined.

During our one short field test we collected video of fish inside cages (Figure 8), which suggests that salmon routinely swim within 2cm of the net. It seems likely that this behaviour could increase the risk of predation. The behaviour of fish in relation to the cage netting is another area we hope we can investigate with this system.

Figure 10: Salmon swimming within centimetres of the cage netting (System 4)

## 3.5 System 5:  Active Acoustic Imaging

When using video to examine underwater interactions, the availability of light is clearly a limiting factor.  Despite many recordings being taken at night, only a couple of seal encounters were captured outside of daylight hours.  Night-time recordings seem to be possible only when using some degree of underwater light, however, this could compromise the recording of attacks as lights  would likely affect the seal's (and potentially the fish's) behaviour.  Particulate matter in the water column would also be likely to obstruct the view of the net so while close-up images of seals could be collected, wider angle shots of interactions with the cage seem very unlikely.

One possible solution to this problem is the use of high definition sonar instead of traditional video.  To test the application of sonars to a fish-farm environment, a real-time multibeam imaging sonar (*Tritech Gemini*) was deployed for a day from a West coast fish farm.  The site was chosen because there was known to be a high likelihood of encountering seals and porpoises within short distances of the fish cages.  The sonar was fixed to the walkway so that it could quickly be rotated to face any seals sighted nearby.  A video camera was also attached to the transducer in an attempt to verify any images gained from the sonar, and photo ID was conducted in order to estimate the number of seals present.

Results from this preliminary experiment were encouraging.  Seals could be detected on the sonar screen up to a range of around 40m, much greater than through using video.  Seal tracks could be discerned on the screen because of the distinct size and speed of the target (Figure 10).  This could allow the possibility of using an automated program to detect seals in real time, as is being attempted elsewhere for tidal turbine instalments.  Ultimately, the potential to use such a system as an automated trigger for an acoustic deterrent could deserve further investigation.  However, the lack of detailed resolution may impede the utility of this tool in determining precise depredation tactics.

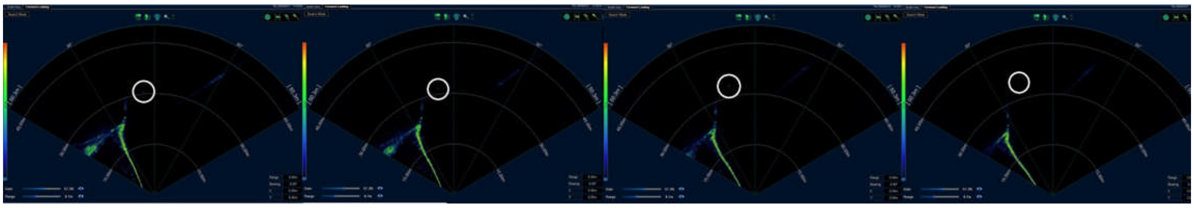


**Figure 11: Track of a seal moving away from the transducer (System 5: acoustic imaging); Circle encloses the seal image – but note that the image is much more obvious when moving than it is when viewed as a screen grab**

We also placed the sonar inside the fish cage briefly which showed that individual fish could be resolved (Figure 11). The frequency of the ultrasonic beam is far too high to be detected by fish, and the salmon showed no reaction. Such a system could also be used to monitor and assess the behaviour of the fish within the cage, as has been done elsewhere.

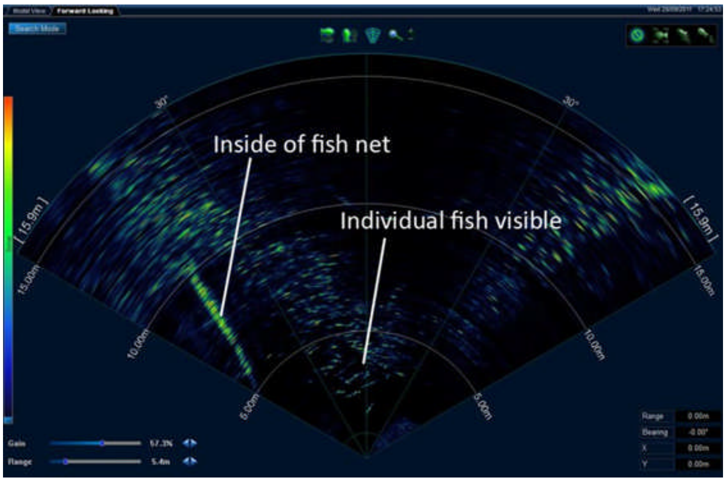



**Figure 12: View of individual salmon within the fish net**

## 3.6 Conclusions

The acoustic system we trialled does show some potential for tracking animals around fish farms, and could be a useful tool for exploring the movements of seals around cages, and possibly the movements of fish at the same time. It could also offer an option in the future for developing methods of triggering an anti-predator response – for example from an ADD. But although the range of the device was good, resolution is poor and this is probably not a useful tool for examining detailed aspects of seal behaviour, for which video systems are probably much more effective and practical.

Through trial and error we have found that the key aspects for a useful video tool in the present context are:

- A reliable and long lasting power supply
- Ease of removing video data for analysis without disrupting on-going recording

- A monitor attached by umbilical to enable the camera to be positioned optimally
- Rugged housing and camera design.

We believe that the system we have designed and had built fulfils these criteria. The unit is compact and easily transported, is robust and waterproof, has a ‘hot-swappable’ hard drive, good clear imaging, and a reliable power supply that will allow the camera and recording system to resume operation after a power interruption. Figures 12 to 15 show aspects of the system that we have developed. Table 3 shows some of the key features of the monitoring systems that we tested.

We will only be able to fully assess the utility of the device that we have developed once we have a found a site and a site manager willing to have such a device deployed next to his cages.

**Figure 13: the Entire four camera system and power supply fit inside a 60cm square box**

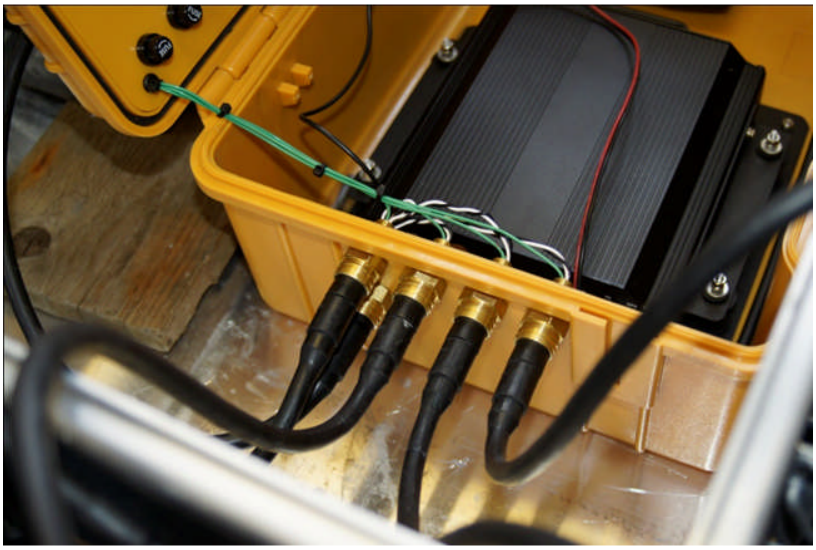


Figure 14: waterproof connectors for the four cameras and external power supply

Figure 15: In-box monitor to guide positioning each of the four cameras

Figure 16: Four external cameras for covering different parts of the cage; currently we use 30m of cable for each camera

**Table 3: Key features of monitoring devices that we tested**

| System | Number of channels /camera angles | Max. Recording time | Power supply (consumption) | Image resolution and frame rate | Live feed to surface? | Approximate Cost |
|---|---|---|---|---|---|---|
| 1 | 1 | 6 (-30) hours | 16.8V (130W) | 384 x 512, 25 fps | No | £11,500 |
| 2 | 1 | 10 hours | 6.8-7.2V DC (4.2W) | 1920 x 1080, 25 fps | No | £1500 |
| 3 | 4 | ~5 weeks | 12-24V DC (30W) | 288 x 352, 30 fps | Yes | £700 per month |
| 4 | 4 | Continuous | 8-48V DC (18W) | 720 x 576, 25 fps | Yes | £2000 |
| 5 | 1 | ~1 day | 18-75V DC (35W) | N/A | Yes | £20,000 |

# 4. Aspects of Cage Structure and Deployment

*"Whilst farmers had opinions and evidence about the nature of seal attacks, this was based on observation only and was not quantifiable or objective. It appeared that farmers did not have access to any research in regard to seal predation."* (TEP, 2010)

## 4.1 Introduction

Our objective in this section was to consider some of the practical aspects of cage structure and deployment in order to better understand how seals may cause damage to caged fish. This is an area which has been very poorly researched, as the suggested by the above quote (TEP, 2010). An important previous study, from which this quote is taken, was carried out by Thistle Environmental Partnership on behalf of the Scottish Aquaculture Research Forum (SARF) in 2009-2010 (Thistle Environmental Partnership 2010b; Thistle Environmental Partnership 2010a).

During the progress of the project, we also became aware that under the Scottish Government (Marine Scotland's) Initiative "A Fresh Start – the Renewable Strategic Framework for Scottish Aquaculture", the Improved Containment Working Group had been established, and had recommended a Scottish Technical Standard for Fish Farm Equipment, covering nets, pens and mooring systems. The development of protocols and best practice guidelines for containment was subsequently funded through SARF and a report has been published (Thistle Enviornmental Partnership 2012). This report deals with many of the technical aspects of cage design, and makes several recommendations for further research, some of which are focused on seal predation. A lack of any detailed relevant research limited the possibility of making anything other than general recommendations for controlling seal predation.

We have relied extensively on these reports to collate information on aspects of cage system design and usage, and on measures to minimise predator damage, augmented by our own observations. Our observations include not only those that we have made directly on sites, but also on discussions that we have had with site managers and with one net manufacturer. Where appropriate we have also drawn on other published literature. In this section we aim simply to explore some of the aspects of cage and net design that may be important in the context of seal damage, and raise a series of questions that it would be useful to explore further.

## 4.2 Understanding the nature of the problem.

From the perspective of containment, seal damage is one of several factors that may allow fish to escape. Fish farm operators are required to report escapes of fish within 28 days of occurrence, and these reports are published by Marine Scotland on their website[7]. Starting in 2002, such reports initially gave the number of fish escaping in each incident, but since 2009 a 'cause' for each escape has also been given.

Overall 1.8 million salmon have escaped into sea water since 2002, during 101 reported escape events (2002 until October 2012). The number of incidents has averaged 9 per year, though there is a clear decline in the frequency of escapes in recent years, since 2006 (Figure 17). An example of a predator hole is shown below.

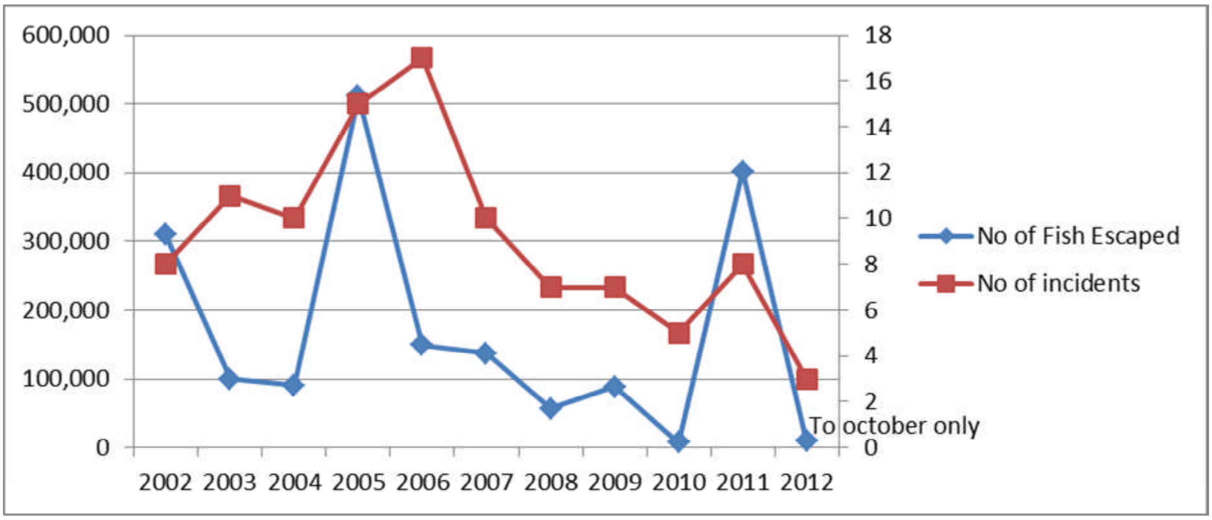



**Figure 17: Trends in salmon escapes to sea water, reported to Marine Scotland**

[7] http://www.scotland.gov.uk/Topics/marine/Fish-Shellfish/18364/18692/escapeStatistics

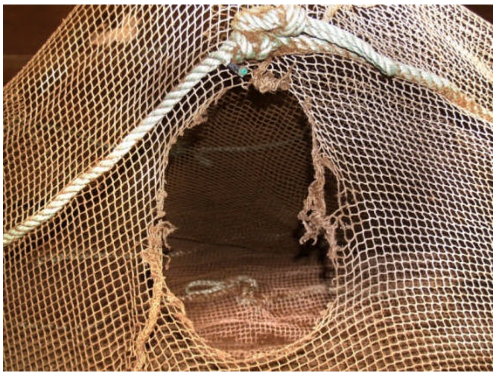


Figure 18: Typical predator hole in a net (photo credit: Knox Nets)

Since 2009 it is possible to determine how frequently each of five factors, including predators, has been responsible for fish escaping. Among 23 incidents reported from 2009 to October 2012, 5 (22%) were attributed in the government statistics to 'predators', while another 3 were attributed to 'holes in the net' of unknown cause. The biggest factor has been bad weather, but predators (presumably mostly if not all seals) were responsible for more than 88,000 salmon escaping over the past three and a half years (see Figure 19).

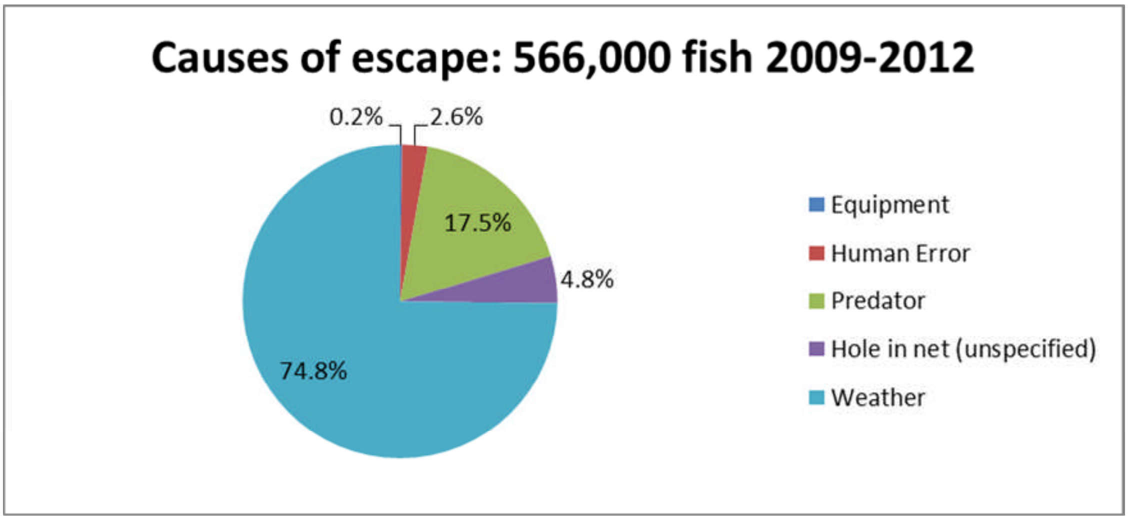



Figure 19: Causes of salmon escapes 2009-2012

It is clear from these statistics alone that predators are an important cause of fish loss, and unsurprisingly there are therefore several recommendations throughout both reports by TEP (2010, 2012) that relate to seals.

In fact, the official statistics may underestimate the impact of seals. SARF project report no 53 (TEP 2010) lists as its first objective "to identify and assess the contributory causes of a representative number of previously reported escape incidents in Scotland". This was achieved by informal consultations (face to face and by phone) and site visits. The report concluded that even the current "recording of escapes by Government is too generalised to give understanding of the real reasons behind different escape incidents and what should be done to prevent them". TEP augmented information on the returns sent to Government with consultations to identify both the underlying causes of fish escapes and any associated factors. This led to a much more detailed understanding of the sorts of problems that lead to fish escapes. For example, whereas information on the returns listed ‘human error’ as a cause, TEP was able to further refine this into three more detailed categories: 1) dropped fish, 2) wrong net used and 3) well boat collision. By visiting sites which had experienced fish escapes and by speaking with operators during the period of January to October 2009, when the Government scheme required reporting a cause for each escape, TEP found that 6 of 14 incidents (43%) could be attributed to predator damage, whereas only 3 incidents were recorded in the official statistics as having been directly caused by predation during this period (21%).

TEP recommended that more attention should be given to holes in nets and how they are caused, as this is the single most frequent cause of fish escape incidents, with predators (seals being by far the most important) being the predominant cause of such holes. They recommend tthat “all significant escape incidents and near misses should be investigated in detail on-site immediately after the event. This could be undertaken by independent companies, government officials or universities with appropriate technical knowledge and industry experience under the auspices of the Scottish Government Improved Containment Working Group”. Only by such detailed investigation can the underlying causes of fish escapes and associated factors be understood, and only by understanding the mechanisms by which escapes have occurred can remedial practices be implemented effectively.

In exactly the same way where other sorts of damage by seals are concerned, detailed on-site investigations are needed, for at least a representative selection of events. So far there has been little enthusiasm for such detailed investigation. We attempted to explore this method during the present project, but only managed to interview two site managers in the wake of significant seal damage incidents. Discussions at the SASWG suggested a lack of willingness to pursue this approach. We suggest that an adequate understanding of the problem of seal predation at fish farm sites cannot be achieved without a much more vigorous engagement by industry in trying to understand how and why such incidents occur, along the lines taken by TEP in exploring how escapes occur.

While the escape of salmon was the primary focus of the TEP studies that were funded by SARF, and remains the primary focus of the Containment Group, the issue of seal damage goes wider, and covers instances where seals bite caged salmon through the meshes of the cage, sometimes causing holes, but more often simply pulling or sucking parts of the fish through the meshes. It also covers the potential scaring of fish which is both a welfare issue for the fish and a commercial concern for the site managers if fish growth rates are affected. These concerns are of course linked, and the two SARF funded studies consider ways to minimise seal depredation in general, rather than ways to minimise fish escapes being caused by seals.

Previous studies (TEP 2010, 2012, Northridge *et al* 2010) have examined and discussed some of the methods used by fish farming companies to minimise seal depredation. These include the use of anti-predator nets, the use of seal blinds and false or secondary cage bottoms, increased tensioning of nets, changes in net shape and size, the use of alternative material, as well as the use of ADDs, which we discuss later. We consider each of the net and cage related issues in turn below.

## 4.3 Predator nets

Predator nets are widely used in other salmon producing countries but are uncommon in Scotland. Such nets may be of a curtain or skirt type, surrounding the entire cage system or individual cages, from surface to seabed. Alternatively predator nets may form a 'box net' with tensioned sides and a bottom that encloses the pens as a secondary cage.

There are several problems with predator nets which have made them unpopular. Firstly, they are difficult to install and manage and the nets themselves or their mooring ropes pose a hazard to boats manoeuvring around the site and may become entangled with other parts of the cage system. Secondly, they may reduce water flow to the cages and impact on water quality. Like the netting material of the cages themselves, predator netting may quickly become fouled, which will further reduce the flow of oxygenated water to cages themselves, and adds an additional burden in terms of net cleaning. Thirdly, they have a past history of entanglement of marine wildlife, with diving birds and mammals (we have been told) frequently found entangled in such nets. We have heard anecdotal accounts of porpoises becoming entangled and in one extreme case of thirty seals being drowned in one incident at one installation. Bird entanglements were most common, with cormorants, shags and other diving seabirds being most affected.

Part of the problem with predator nets appears to be the fact that large meshed nets have typically been used. Mostly predator nets appear to have been around 100mm square mesh (bar) which is equivalent to around an 8 inch stretched mesh. Smaller meshes might be less prone to entangle mammals at least, but with decreasing mesh size comes increased drag, more fouling and less oxygenated water reaching the fish within the enclosed cages. Smaller meshes can still entangle seabirds too.

Another problem appears to be that it is difficult to maintain the gap between the predator net and the cage itself, especially in areas of high tidal current. Thistle Environmental Partnership (2010) concluded that "research is required to try and identify more effective approaches to maintaining the separation of predator nets from cage nets, as well as making them easier to use".

It remains unclear why salmon farmers in Chile and Canada at least, deploy predator nets as standard practice. It is possible that they have established designs and net management regimes that work for them, but it may also be that wildlife entanglement is less of a concern in these countries. Thistle Environmental

Partnership (2010) recommends that an industry representative body should make a fact finding trip to Canada and Chile to find out how predator nets are used and how successful they are.

Notwithstanding the above, there are also questions about the effectiveness of predator nets. Despite their use in Canada and Chile, both those countries still have problems with predators. Limited data collected by TEP (2010) during their in depth investigations into the origins of fish escapes, found that among 28 incidents where holes had been caused in cage netting, 6 such incidents had occurred on farms where predator nets were in use (1 curtain type, 2 box type and 3 unknown type), while 10 had occurred at sites without predator nets.

Our own work suggests that predator nets are not widely used, though some farms do use predator nets in the Northern Isles where grey seals in particular are most numerous. However, we have recorded seals swimming between predator netting and the cage netting (see Figure 6 above), suggesting that these animals may routinely be able to evade such nets as they are currently used, which may also then pose a risk of entanglement for the animals themselves[8].

Despite the evident problems with the use of predator nets, campaigning groups continue to call for their re-implementation in Scottish fish farms[9]. The Recommendation by TEP (2010) that lessons should be learned from other countries seems sensible, at least to determine whether or not alternative net management and deployment strategies have been developed elsewhere that may overcome some of the problems currently associated with such nets in Scotland.

## 4.4 Seal blinds, false-bottomed cages and mort removals

It is often suggested that most seal attacks occur at the base of nets. We have been informed that some attacks also occur on the cage sides, and TEP (2010) also reported predator caused holes in nets at the sides as well as the bottom of nets. In their report, TEP state that their data suggest that “seal attack on the base of the net (13) is twice as likely as on the wall of the net (6 holes)”, that “two of the [reported] holes in the side wall were at or close to the bottom of the wall in the vicinity of the join with the base” and that “It is clear that seals attack the sides as well as the base of the net”.

Nevertheless most holes appear in or near the base of the cage, and of course only a minority of attacks result in actual holes. In most cases fish are bitten through the meshes of the net. Our observations (reported below in Section 5) suggest that most fish are bitten from underneath, again supporting the notion that most attacks occur from the base.

[8] Fifty one sea lions became entrapped in this way in a single incident in British Columbia in 2007 http://www.cbc.ca/news/canada/british-columbia/story/2007/04/20/bc-sea-lions.html

[9] E.g. http://www.gaaia.org/killing-farms

It has also been suggested to us and in several other sources, that dead salmon lying at the bottom of the cage can and will attract seals that then learn to take fish from through nets this way. For this reason as well as for fish welfare, the industry Code of Good Practice requires farmers to remove morts (dead salmon) on a regular basis. In fact there is no published research to suggest that seals are attracted by dead salmon. TEP (2010) suggest that “Research should be undertaken into the extent to which mortalities attract predation. Should this be considered significant, then the mandatory use of seal blinds or the daily recovery or fish mortalities should be required.”

Seal blinds are an area of the base of the net where thicker material is used in an effort to conceal dead fish from seals underneath. The blind is positioned at the lowest point of the net or around the ‘mort sock’ where dead fish will normally accumulate. Seal blinds are typically 3m by 3m up to about 5m by 5m squares of netting. In fact we learned that several companies have experimented with other measures to conceal dead salmon or strengthen the base of the cages, and some have also tried false bottoms, by installing a separate net below the base of the cage.

False bottomed cages were found to create additional problems because a lot of faecal matter and food got trapped between the two sets of meshes. One company also tried simply to put two overlapping nets on the bottom of cages, but abandoned this as impractical. Another tried at one time to use a tarpaulin with vents on the bottom, but this caught the tide and acted like a sail, causing serious problems.

It is clear that simply blocking the base of a cage is not a simple answer to the problem, as the base of the net needs to be permeable to allow waste material to escape and to prevent the net being distorted by the current.

It is also clear however, that not all nets behave as intended when in place. Tensioning the base of a net to ensure the netting is taught is not always straightforward, and again TEP (2010) report that “there appears to be little information available to fish farmers on the inability of weighting systems to effectively tension the base of a standard shaped net “, one of several factors they list as being crucial from a containment perspective.

Our own discussions with site managers during the present project included one observation that a serious depredation event may have been initiated when a pocket had formed in the base of a cage, into which dead fish had collected, and which had not been noticed during regular mort removals.

Protection of the base of the cage may therefore be an important area for further work.

## 4.5 Alternative net materials

Thistle Environmental Partnership (2010) recommend that research should be conducted into the role of the strength and construction of cages in deterring predator attacks. In this context, TEP reported that some manufacturers claim that high modulus polyethylene (HMPE – including Dyneema™) nets are “more resistant to predators”. Others suggest that PVC coated nets (Aquagrid™) will also “virtually eliminate fish loss due to attacks and escapes”. There are several other net types (e.g. Sapphire netting from Garware, India) that have also been described as being predator resistant. Some have steel or copper cores. Many such nets have been deployed and tested in Scotland but without any over-arching co-ordination that we are aware of, and without any impartial review of how they have worked. Part two of the scottish technical standard, commissioned by SARF, is currently underway and includes a review of background literature and available data.

Much of the discussion on new netting materials appears to focus on their increased strength, which makes breaking the meshes much harder for a predator, and which will therefore minimise fish loss through escapes due to holes in the net. However, most seal damage is caused by seals biting fish through the meshes without causing holes. The extent to which any new type of netting may inhibit such behaviour is not clear.

HMPE netting has been trialled in Scotland under an SSPO / Scottish Government funded project (TEP 2010), though we have been unable to find the report of this study. The trials apparently demonstrated handling problems with HMPE net panels, and a number of other concerns were mentioned to us. The netting used for example was knotless and this led to slippages, while being lighter and stronger meant that the twine diameter was thinner (an advantage from a water flow perspective), which also made the fish more visible to predators. TEP also reported that among their consultees it was noted that HMPE unlike nylon does not stretch and so will break when its peak load is exceeded, and also has poor abrasion resistance compared to nylon. So far was we know no company has adopted HMPE netting in Scotland as yet.

Although most discussion has focused on increasing net strength to minimise predator attacks, some thought has also been given to making nets more ‘repulsive’ – especially in the context of farming of fish that habitually chew, such as cod, which can chew through the meshes of a mesh given enough time. An idea brought forward at the SASWG is that such repulsive netting (perhaps impregnated with a strong tasting substance) could be tested with seals to find a way to deter animals from chewing on net meshes. So far this is only a suggestion for future work.

Given the number of trials that have been conducted in Scotland (and elsewhere) it would make sense for an overview study to review the results of such trials to better inform industry of the pros and cons of new netting materials, and specifically with respect to seal damage.

### 4.6 Net tensioning

Tensioning nets in aquaculture cages is essential to maintain net volume and structure, especially at high tidal energy sites. Net tensioning is also widely cited as being a critical issue in minimising seal depredation. The rationale here is that nets that are poorly tensioned may provide the opportunity for seals to makes holes more easily, may enable seals to deflect netting to a greater extent to grab fish within a cage, and/or may result in loose folds of netting that trap or restrict the movements of fish, enabling seals to grab them. In fact none of these rationales has been demonstrated, but there is nevertheless a widespread assertion that a taught net helps minimise seal depredation.

Within the Scottish industry there are currently two major types of fish cage in use. Older sites in particular use rectangular or square cages, typically made with a steel frame (typically 24-25m on each side) and each with its own mooring system. Increasingly however, farm sites are deploying circular pens (typically 80-100m, but up to 120m circumference) with plastic frames, and a mooring grid system, whereby pens are attached by buoy lines to a grid system of chains or ropes that is in turn anchored to a the seabed. The tensioning systems vary accordingly. In square steel cages weights are suspended from downlines to which the netting is attached, typically one or two lines at each corner and two or three along each side. The weights resist the effects of tidal currents and are intended to maintain the cage wall near-vertically. In circular pens the usual method of tensioning is to use a 'sinker tube' or 'weight ring' at the base of the net. A large heavy ring maintains the circular aspect of the base of the pen, and in so doing also helps maintain tension in the side walls of the pen. In both cases the base of the pen tapers conically to an area where dead fish accumulate. Often some additional weight may be added to the centre of the base to maintain the structure of the mort collecting area.

It appears that within the Scottish industry the amount of weight used has increased over the years. Whereas some years ago each vertical rope in a square cage might have held a 25kg weight, these are now more typically 80kg, and sometimes as much as 160kg may be suspended on an individual vertical rope. One of the reasons for this has been to minimise net deformation. The meshes of a sea cage, typically nylon with a twine diameter of perhaps 3mm and mesh size of 15mm or 25mm (depending on the size of the fish – smolts or growers respectively) results in a great deal of drag, which in turn lifts the net upwards and so decreases the volume of the cage and therefore increases the stocking density (see Figure 20).

One view of the consequences of this is that "salmon that are more heavily stocked [i.e. At a higher density] are more prone to injury from seals attempting to catch fish through the net wall ..." (Gregory & Grandin 2007) . We have found no evidence that this assertion is true, but it is a widely held belief. Nevertheless, regardless of any increase in stocking density with net deformation, it may well be that net deformations as indicated in Figure 20 may introduce net irregularities or near horizontal netting which may make taking a fish easier for a depredating seal. (If so, a large scale analysis of damage levels with respect to tidal/lunar cycles with more damage expected at spring tides would be revealing).

Although it is  a requirement of the Code of Good Practice for Scottish Finfish Aquaculture that “Nets should be adequately tensioned to minimise distortion” (5.2.5.7), TEP (2010) found that “no company [to whom they spoke] had any knowledge about the level of tension required to prevent predator attacks or any guidance on the optimum weight to be used”  Instead, it was reported, “these issues were approached in an experimental basis with some companies using much heavier weights than others, both for sinker tubes and individual weights”.

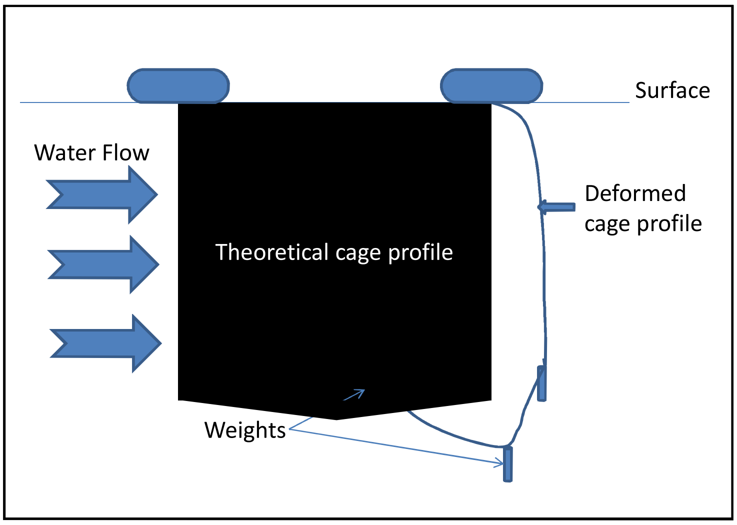



**Figure 20: Theoretical net deformation in a strong current**

Very little research has been conducted in this area.  One study (Lader *et al*. 2008) compared the net deformation in two sites with different weight regimes and with exposure to different current regimes in Norway and in the Faroe Islands.  At one site with square pens and with current speeds of 0.13ms$^{-1}$ (0.25 knots) there was an estimated 20% reduction in net volume, while in the other a 40% reduction in circular pen volume was measured when current speeds reached around 0.35 ms$^{-1}$ (0.68 knots).  The square pens were fitted with weights of 2x600kg, 400kg and 300kg at each corner and 2 x 125 kg weights on each of two sides and 2 x 80kg weight on each of the other two sides.  In excess of what we have been told is normal for Scottish sites, though we have not made a systematic study of the weight systems used at farm sites.  The circular pen was fitted with a sinker tube of 1700kg.  Neither of these current speeds are particularly fast.

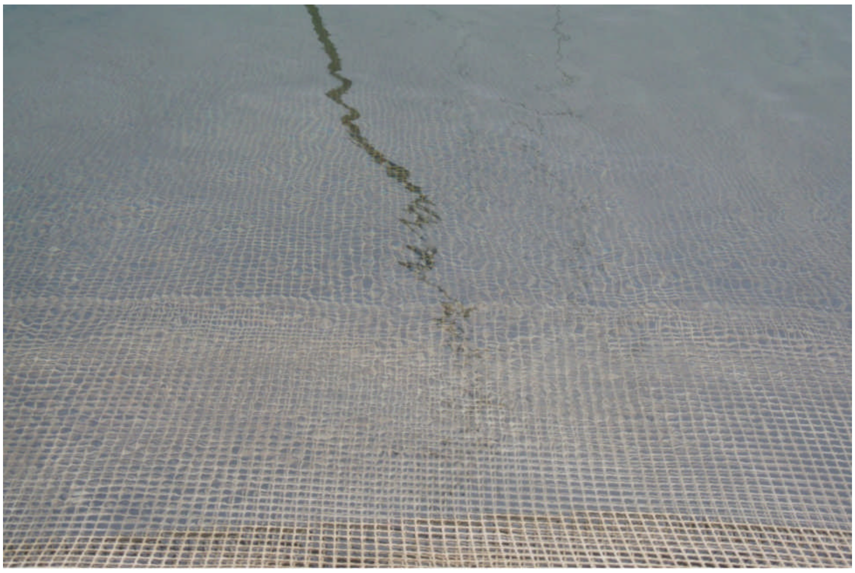


**Figure 21: Side panel of a square net cage displaced at peak tidal flow (Photo taken looking ~45$^{o}$ to surface)**

Our observations suggest that net deformation is not uncommon at Scottish farm sites. We have observed in at least one case one side of a cage almost horizontal at the surface, but we are unaware of the proportion of total sites where this may occur (see Figure 21).

TEP (2010) recommended that research should be undertaken into the ways that nets behave in different current regimes with different weighting systems so that advice can be given to farmers on the optimal tension required and how this might be achieved. They further recommended that research should be directed at the best ways to tension the base of a net.

The results of their detailed investigations of 28 fish escape incidents involving holes in the net are summarised below (from TEP, 2010b).

**Table 4: Number of predator hole incidents reported by type of weighting system used - adapted from TEP (2010b)**

| Weighting system | No of holes reported |
|---|---|
| Sinker tubes | 3 |
| Individual weights | 15 |
| Minimal or No weight | 1 |
| Unknown | 9 |
| Total | 28 |

These data suggest that nets with sinker tubes (i.e. Circular pens) are less likely to be associated with predator holes than nets with individual weights. Although we do not know what proportion of all sites use circular pens / sinker tubes overall[10], these

[10] Marine Harvest Scotland uses 25% steel and 75% plastic as of 2013 (Steve Bracken, MHS, personal communication)

are much more commonly being implemented now than square steel cages, and it is unlikely that they represent only 1/5$^{th}$ of the number of square cages as the numbers above would suggest if weighting system had no effect on the frequency of predator holes. Furthermore, as has been stated several times already, there is not necessarily a relationship between the number of holes found in nets and the amount of fish damage. Nevertheless these data suggest that circular pens *may* be less vulnerable to seals than square pens, and this is something that should be investigated further with industry data on damage rates.

TEP (2010) suggest that high priority research should focus among several other things on the level of tension required (i.e. the amount of weight per unit area of net in relation to tidal current) to deter predators, and also on determining how much net deflection would be expected at different sites. The latter at least is now relatively easy to address, given advances in instrumentation. In the former case, TEP (2010) also suggest that research is required to determine the best way to tension the base of a net (specifically of circular pens using sinker tubes) to avoid slack areas of netting developing. Research is underway for a SARF funded project (SARF092) addressing these knowledge gaps including experimental trials.

## 4.7 Discussion and Conclusions

Our own observations and the results of SARF project numbers 54 and 73 (TEP, 2010) suggest that the issues of cage design and net use have not been well explored. Net tensioning for example is cited as being an important tool in addressing seal depredation (see e.g. Northridge *et al*; 2010), but it is clear that there are no published data that support this assertion, and TEP (2010) found that no company had any knowledge of the level of tension required to prevent seal damage.

Indeed, in developing draft protocols for containment, TEP (2012- SARF 073) identified several of these issues relating to predation as being major knowledge gaps. In relation to the development of a Scottish Technical Standard (STS) on containment, they concluded as follows:

> *It is not proposed to include specific net measures from a design and construction perspective to protect against predation, since there is considered to be insufficient objective evidence on which to base such measures. Additional research is required on the way in which different freshwater and sea water predators breach net integrity and how effective possible defence measures might be. Whilst not essential to publishing a STS, it is highly desirable to include predation at the earliest opportunity as it is such an important issue in Scottish finfish farming.*
>
> *Although there is knowledge on seal 'attacks' at sea water sites most, if not all, appears to be anecdotal. Whilst all farmers consider that net tensioning is*

*effective, there appears to be no information on how tight such tensioning should be and whether higher net strengths (or indeed net materials) may provide greater resistance. Questions of particular interest include:*

- *How do seals actually breach nets – is this from a single bite, or are repeated bites required over a period of time?*
- *Are higher net strengths more resistant to seal attacks and, if so, which are most resistant and is it possible to quantify the reduced risk?*
- *Do different net materials offer greater resistance to seal attacks and, if so, which are most resistant and is it possible to quantify the reduced risk?*
- *Are different net treatments more resistant to seal attacks and, if so, which are most resistant and is it possible to quantify the reduced risk?*
- *Depending upon the findings to the above, are nets more vulnerable to attack during the life of the net?*
- *Do seals attack nets in a coordinated action involving more than one seal (there is anecdotal reports of such approaches)?*

Almost exactly the same set of questions could be asked about the more general question relating to seals attacking fish through the net. The issue of seals stressing fish through their presence or by grasping fish through the net has not been explored at all, and it is a moot point as to whether net or cage design might be a factor here too. These factors will hopefully be addressed in the second STS project, and amendments to the STS made as necessary.

Two further knowledge gaps identified by SARF073 (TEP, 2012) in the development of a draft containment STS protocol relate again to the lack of knowledge about net tensioning and what is required to deter predators (Knowledge Gap 12), and the need for better advice on best practice use of predator nets, especially through evaluating their effectiveness in Scotland and abroad (Knowledge gap 13).

While it is clear that more research is required to address these questions, it is also clear that fish farm companies possess a great deal of the information that would be required to address some of these points and to shed light on how seals cause damage and how this might most easily be addressed. Nonetheless, we agree with TEP (2010) who recommend (R3.3 in their report) better collection of information on seal attack events (they refer to escape incidents, we refer to all seal attacks). TEP suggest that "...all significant escape incidents and near misses should be investigated on-site immediately after the event", and we believe the same approach should be adopted after any major seal attack or series of attacks.

# 5. Evidence derived from seal-attacked salmon

## 5.1 Background

The bodies of deceased salmon (known as 'morts') are regularly collected by fish farm workers, allowing the examination of relatively fresh carcasses. In many cases these carcasses retain information about the cause of death and this is particularly true in the case of depredation events (it is thought to be quite rare for the entire fish to be eaten). We therefore hoped that details about the nature of attacks could be ascertained by the collection of data from these fish as well as discussion with fish farmers.

Conversations with farm site managers, combined with photographic evidence of seal damaged salmon seemed to imply that damage often falls into a few basic categories (listed below). Furthermore, in at least one such category, tooth marks are left in the abdomen of the fish which might usefully be measured in order to gain information about the seal responsible for the damage.

In this part of the study we attempted to characterise damage types by photographing seal-damaged fish at farm sites, and by asking site workers to collect photographs of samples of fish on our behalf. Our objective was initially to catalogue the damage types, but from that basis to try to make inferences about the behaviour involved in the predatory interaction, and also to see if the observed damage might be used to learn more about the nature of the attack such as the size or species of seal involved. We reasoned that the upper and lower canine teeth are most likely to be the cause of deep abdominal slashes observed on many fish, and that furthermore there is likely to be a relationship between the inter-canine distance and the overall size of a seal, and possibly some difference between grey seals and harbour seals in this respect.

Our investigation of seal damaged salmon was therefore an exploration of observations and photographs to try to make inferences about the predatory interaction, with a view to trying to define specific measurements or observations that might help further explain the process. We used photogrammetric images of seal damaged fish to examine wound dimension, and for comparison with these measurements we measured the inter-canine distance of samples of both grey and harbour seals from museum specimens, freshly dead and live animals. Where possible we correlated these with animal body length. A preliminary experiment was also undertaken to examine the formation of these types of wounds and to assess the consistency of the relationship between seal inter-canine distance and wound size.

## 5.2 Methods

### 5.2.1 Photography of morts

During visits to farm sites we made photographic records of fish that workers categorised as having been damaged by seals.  We used both known-size objects such as coins to provide a means of measuring wound size, but more generally photographed fish on a pale background beside a measurement scale.  We collected example photographs from as many types of seal damage as we could and also provided farm workers with waterproof digital cameras, slates and rulers to photograph seal damaged fish whenever possible.  Fish deemed suitable for measurement (Category 4 – see below) were classified as either fresh, near fresh, or old, allowing comparison between attacks occurring at different times. Photogrammetric measurements were taken in Adobe Photoshop, using the measurement tool which allows a custom scale to be set based on an object of known size.

### 5.2.2 Measurements of skulls

To make inferences about the size and species of seal by using measurements from damaged fish, we needed to first understand the relationship between seal size and inter-canine distance and whether or not some difference exists between grey and harbour seals.  Surprisingly, few suitable data were available to make this possible, so it was necessary to collect data specifically for the purpose.

When available, we measured inter-canine distances of seal carcasses that came through SMRU for necropsy, and also took measurements from seals in the field during routine SMRU tagging exercises.  This opportunistic sampling was not anticipated to result in a large enough sample size for a useful analysis so we also visited the archives of the Royal Museum of Scotland (RMS) and measured the inter-canine distances of grey and harbour seals skulls collected from Scottish and English waters.

Almost all of the skulls in the RMS had associated sex and species information, and most also had an age at which the animal had been collected.  Measurements were taken of the length of skulls with the intention of correlating this with body length or some more useful metric indicative of body size.  However, many of the skulls had at least one canine tooth missing and some had no associated lower jaw.  Callipers and rulers were used to measure the shortest distance between the inner lateral surfaces of each canine, or where canines had been removed for age investigation, from the inside of the canine alveolus.  All measurements were recorded to the nearest millimetre.

A very preliminary experiment was also conducted in order to gain an understanding of the process of bite wound formation.  Using the jaw of a cleaned and prepared grey seal skull kept at the SMRU, we broke the skin of a large fresh salmon in several different places.  These ‘bites’ were done with the fish held at several different angles and positions, simulating the movement of the fish inside the net during an attack. Photographs were taken of this fish allowing measurement by the same photogrammetric methods as were used on fish farm sites, but the exact measurement of the wounds were also taken with callipers so that the accuracy and precision of the photogrammetric method may be assessed.

## 5.3 Results

### 5.3.1 Photos collected

Calibrated slates and waterproof cameras were made available to three different sites, plus one group of fish-farm divers and one fish health manager who regularly visit about ten different sites. Unfortunately, no images or information came back to us through these arrangements. The reasons for this lack of cooperation were not clear, but could be related to an absence of motivation to continue data collection beyond our occasional site visits.

More than 400 photos of seal damaged salmon were collected from eight site visits in total; one sight over four occasions, one sight over three occasions, and the rest on just one occasion.

### 5.3.2 Categories of damage

The types of damage we have seen can broadly be classified into one of four categories, but it is possible that there are other types of damage that we have not yet seen.

Category 1 – At two sites, fish were found that had been entirely eaten except the head, sometimes with a part of the spine left intact (see example in the background of Figure 22). This is probably because the head contains the least amount of flesh and is therefore less attractive to the seal. Both large and small fish were found in this condition. Interestingly, these fish would be likely to have been classified as ‘predator-’ or ‘seal kills’, despite there being little evidence to show whether they were actually killed by the seal or simply chewed post-mortem.

Category 2 – At four sites we saw examples where the posterior half of the fish had been cut off, leaving the anterior half intact (Figure 23). This was only seen at sites where fish were relatively small (up to roughly 1kg). Additionally, at one site clear evidence was seen of fish having been ‘sucked’, tail first, through the mesh of the side netting. According to divers’ reports, these fish were sometimes left sticking through the netting despite the back end of the fish having been eaten. Figure 23 shows a fish with this type of injury, showing the marks left from having been caught in the mesh. This type of injury is thought to be more common when the fish are small.

Category 3 – At two more sites, fish were seen with multiple gashes along the flank (Figure 24). These gashes most often appeared to run dorso-ventrally, with depth and spacing that did not seem consistent with being caused by a seal’s teeth.

In these cases there are usually multiple parallel breaks in the skin, generally not extending below the muscular layer.  It is thought that injuries of this type are most likely to be caused by the fore-flippers, as seals are known to use these to grip fish whilst eating them on the surface.  Again, it is not certain whether these types of injury are caused pre- or post-mortem, but the fish would likely be recorded as having been killed by a seal.

Category 4 – Perhaps the most common, and certainly the most recognisable type of injury, especially amongst larger fish (greater than 1.5kg) is shown in Figure 25.  Here the abdomen of the fish has apparently been bitten from below by the seal, leaving two clear punctures in either side of the fish and usually associated with a large chunk of missing flesh.  We have seen this type of damage on at least four sites, but it is sometimes difficult to distinguish from category 3.  This type of wound always seems to be positioned immediately behind the gill flaps at roughly the widest part of the fish.  We repeatedly heard from fish-farmers that this type of damage is caused by the seal targeting the liver of the salmon, as this is thought to be the most 'nutritious' part of the fish.  However, our examination of these wounds at one site found that in many cases the liver was left intact, suggesting that either the liver was not the sole target of the attack or that the seal had regularly missed its target.  This was the category of damage that we suspected would be most amenable to further investigation regarding tooth spacing.

**Figure 22: Type 1 Damage: Spine and head left**

Figure 23: Damage Type 2: Tail removed through meshes

Figure 24: Damage Type 3: Multiple parallel gashes - possible flipper damage

Figure 25: Damage Type 4: Typical "belly bites" from larger salmon

### 5.3.2 Results from Edinburgh NMS skulls, live specimens, and heads

We examined and measured the dentition of 134 seal skulls (46 Harbour, 85 Grey and 3 unknown) from the Royal Museum of Scotland's collection. For grey seals, the majority of specimens were complete with data including the sex, age and location of the seal. These data were unfortunately unavailable from most of the harbour seal specimens. No reliable relationship between skull length and body size has yet been determined, and so we are unable to use these measurements to compare animal sizes.

The dentition of thirteen live harbour seals were measured during SMRU tagging operations in Orkney, five males and eight females. Associated length, girth and mass measurements were also recorded for comparison. A good positive correlation was found between body length and both upper and lower inter-canine distances (Figure 26). Interestingly, one of the males had previously broken its lower mandible which had reset in an unusual position, causing the inter-canine distance of its lower jaw to be greater than that of the upper jaw. This individual was excluded from analyses.

In addition, the dentition of seven dead grey seals were measured, four female, one male and two unknown.

The combined data from both skulls and whole head measurements is presented in Figure 27 divided into species to allow comparison. It is striking that the ratio of upper to lower inter-canine distances is consistently smaller for Harbour seals across the whole range of measurements, and that the linear relationships seem to hold between the two groups (skulls and complete heads). However, there is also a degree of overlap between the two species, which obviously prohibits the drawing of firm conclusions regarding species based solely on estimated inter-canine distances.

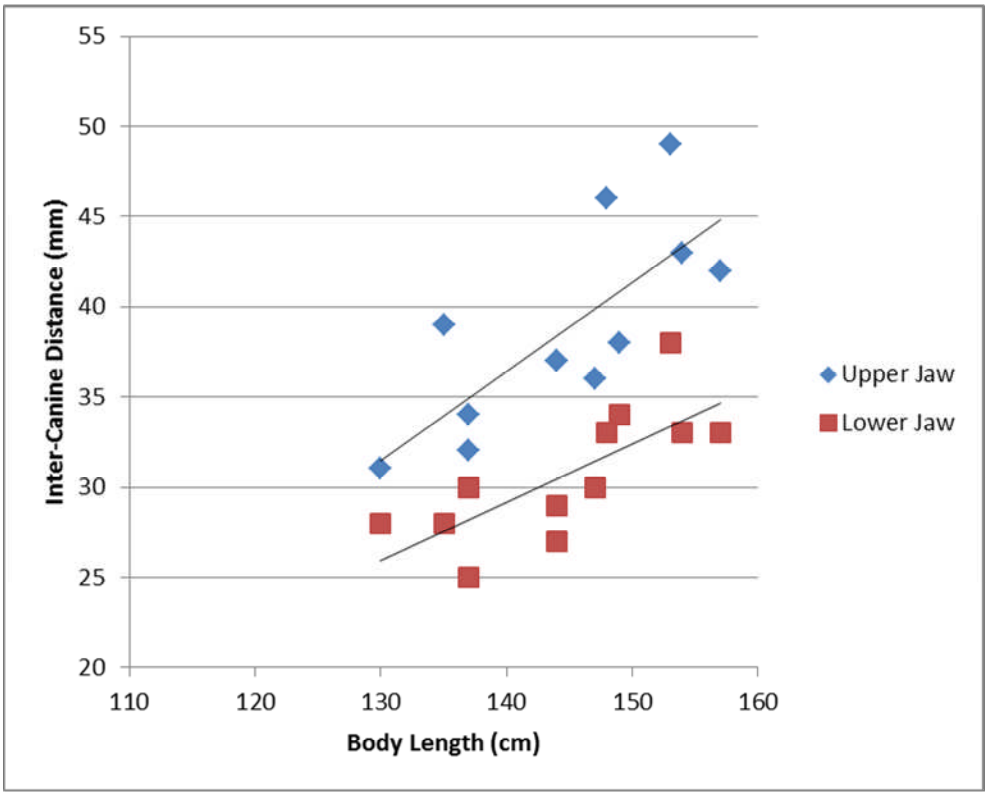



**Figure 26: Relationship between body length and inter-canine spacing - 13 live harbour seals**

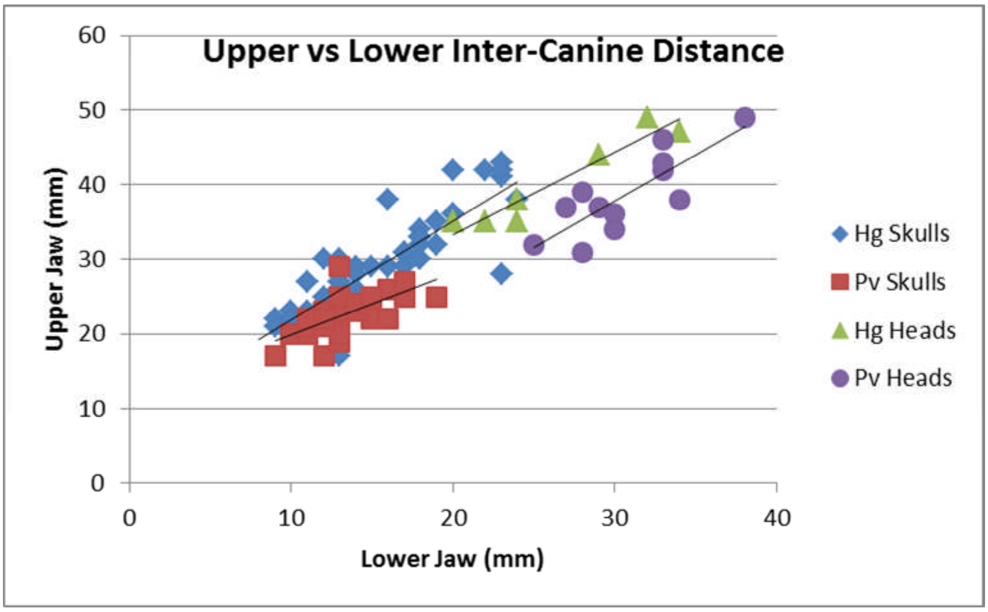



**Figure 27: Upper and lower jaw inter-canine distances - live and museum samples**

### 5.3.3 Measurements taken from dead salmon

Photogrammetric measurements were taken from 51 fish in all, but we limited our analysis to 28 fish all of which came from the same net. Of these, 21 were categorised as 'fresh', 3 as 'near fresh' and 4 as 'old'. Measurements were taken from both sides of each fish, with the smaller measurement being taken to represent the lower jaw inter-canine distance. The average difference between the two measurements was 9.3mm, much closer to the observed average difference of 7.5mm (range 4-13mm) found in complete Harbour seal heads than to the 14mm (range 11-17mm) average difference for Grey seal heads. A scatter plot comparing upper and lower inter-canine measurements does not appear to show any mono-modal or multi-modal clustering (Figure 28) as might have been expected if one or several animals of different sizes were responsible left consistent bite marks on the fish. A slight bimodality is apparent when the data are clumped and viewed as histograms (Figure 29), but the relative proportion of the two modes does not seem to correlate between upper and lower jaw measurements (i.e. If the two modes were caused by two different seals the relative numbers of one to the other should be similar in both the upper and lower jaw measurements). From looking at the broad spread of these data it seems likely either that there were a large number of seals involved in the attack, or that there is a significant source of error somewhere in our methodology. This error could be introduced by inaccuracies in our photogrammetric measurement (e.g. Introduced through perspective error in photographs) or alternatively, could be caused by some source of variability in wound formation, such as the stretching of the salmon's skin during or after the attack.

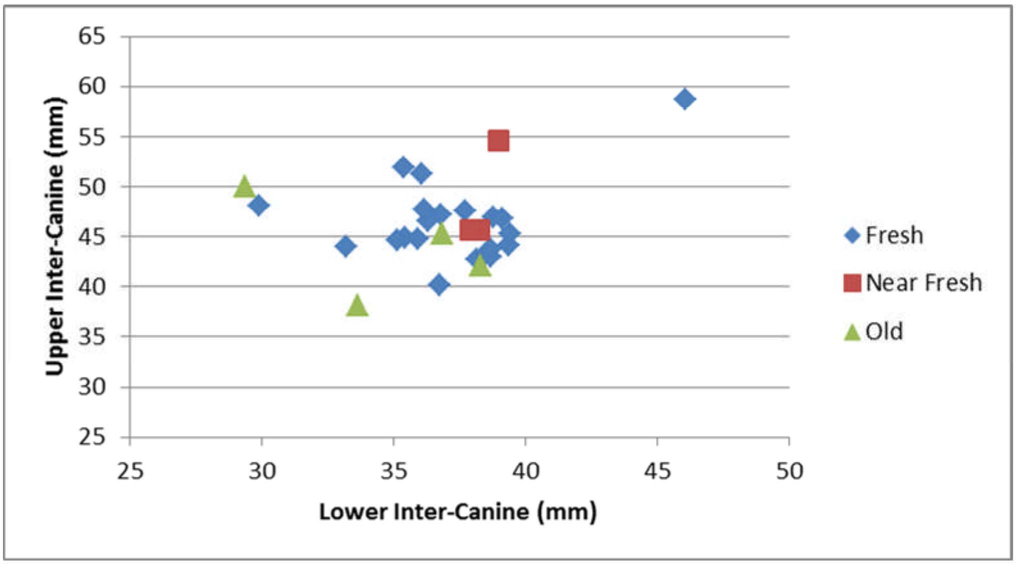



**Figure 28: Measurements of distance between paired wounds taken from salmon farm morts (see text).**

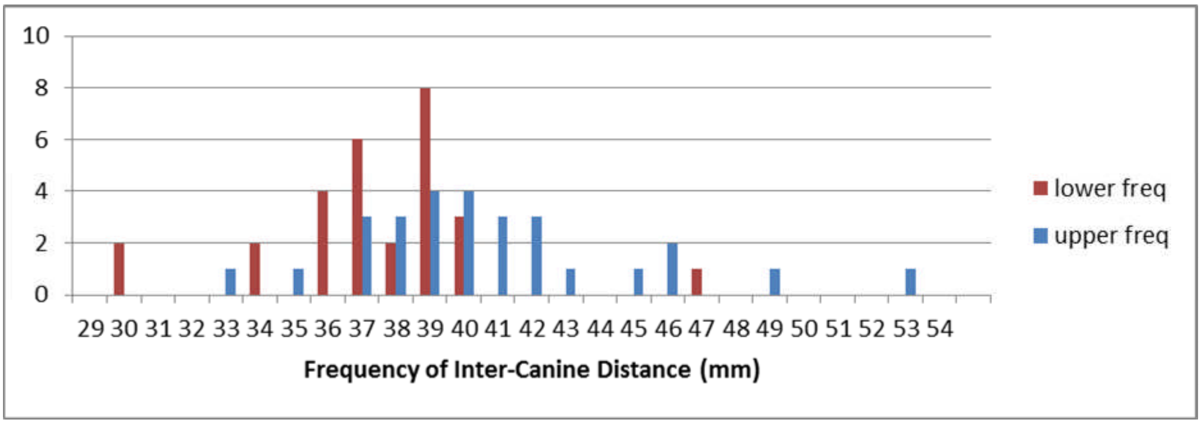



**Figure 29: Histogram of 'bite' mark spacings on dead salmon**

The results of our work using a seal jaw to puncture the skin of a dead salmon suggest that there is some considerable variation in the width of the ‘bite’ mark left on the salmon from a single jaw. By deforming a large salmon and breaking its skin with the upper canines of a grey seal skull (41mm from canine tip to tip), we created wounds varying from 43mm to 55mm due to stretching of the fish flesh after puncture.

## 5.4 Discussion

This exploratory analysis obtained mixed results. The idea of collecting photographic evidence has proven to be generally useful, as it has allowed us to begin categorising damage types and, furthermore, to make inferences about the aetiology of the damage that we have seen. It is clear, for example, that wounds of categories 2 and 4 fish are inherently different and have almost certainly been caused by very different forms of attack. It seems likely that obtaining an understanding of the difference between these attack strategies is key to designing effective anti-predator measures. It is also hoped that the findings of this investigation will be informed by future results from video monitoring work described in Section 3. For instance, we have already seen examples of animals interacting with the side netting, and while no attacks were observed, this could be an occasion when the seal was attempting to suck fish through the side netting, resulting in category 2 injuries.

The techniques we have developed for taking measurements from morts may require further work before they can be used to make useful inferences about the number of animals involved in an attack, or the particular species involved. From our preliminary investigations into wound formation it seems that there is a naturally high degree of variability within the size of wounds created even by one individual seal. This suggests that fine scale measurements taken from seal inflicted injuries may not be reliable enough to compare with confidence against seal dentition measurements, especially given the overlap in distribution of the two species. Nevertheless, it still seems likely that these measurements can be used to infer some less specific information about the seal, such as the rough size of the seal involved. The measurements taken from morts during this study for example, with wounds of up to 58mm, were most likely caused by a large seal. There is no strong evidence from these measurements suggestive of more than one animal being involved in this particular attack, but neither can we rule this possibility out.

In terms of further collection of photographic evidence, the most efficient method would be to rely on contributions from industry but unfortunately these have not yet been forthcoming. We had hoped that by making measurement slates and waterproof cameras available to site workers it would be possible to make some progress in this direction. Without assistance and encouragement from management within the industry, fish farm workers have no practical and immediate reason to contribute to our investigation.

# 6. Industry data on seal damage

## 6.1 Introduction

The Scottish Aquaculture Code of Good Practice[11] requires farms to keep records of dead fish ("morts"):

> *3.2.7 At all stages, the number of dead fish must be recorded, along with, where possible, a record of the cause of death.*
>
> *5.2.9.4. Farmers should keep records of losses to predators and use of control systems.*

Furthermore:

> *5.3.5.1 Fish should be inspected daily and dead or moribund fish should be removed, minimising handling to avoid stress to the live fish within the enclosure.*
>
> *5.3.5.3 Records should be kept of each inspection, which include the number of dead fish removed and the likely cause of death, as determined by a competent person.*

These data, if properly collated, can provide a great deal of useful information on seal interactions with salmon at farm sites. One fish farm company supplied us with information on the number of fish recorded as having been taken by seals at each of

[11] http://www.thecodeofgoodpractice.co.uk/publish

its sites, for each month between January 2001 and September 2011, together with information on the biomass of fish present at the end of each of those months.

We have used these data to ask some simple questions about seal damage, including whether or not farms closer to seal haul out sites have more damage than those further away, whether there is any pattern to damage with respect to season or stage of the production cycle and, whether the length of time a farm has been operating influences the amount of damage it suffers.

### 6.2 Data treatment

The data were provided in excel spreadsheet table format but were reformatted for database analysis using MS Access. Data were tabulated by site name, date, no of fish killed by seals and biomass. We assumed that stocking began at a site whenever a month with zero biomass present was followed by a month with some biomass present. Production cycles typically run for about 23 months after which there is normally one or more months with no fish present. It was clear from the data that not all sites were in a continuous succession of production cycles and some sites were without fish for months or years at a time.

We matched company site names to the official site names and locations (latitude and longitude) as recorded by the Scottish Environmental Protections Agency (SEPA). Not all company names matched SEPA names exactly. On occasion the exact location of a site could not be determined due to differences in nomenclature and in particular where several 'sub-sites' were recorded in one data set for a single site in the other. Overall we were able to obtain accurate latitude and longitude data for 60 of 87 sites, and therefore only used data for 60 sites where we were looking at proximity to seal haul out sites, and where an accurate site location was needed.

Dead salmon (morts) are removed from cage pens regularly and cause of death attributed. The number of seal predated salmon was provided by site and by month. We used both the number of salmon killed by seals by month, and the presence or absence of any seal depredation in a specific month in subsequent analysis: for each site, any month when fish were present on site was regarded as a 'stocked month', and any of those months in which any seal depredation was reported was treated as a 'depredated month'. A measure of the *frequency of depredation* for each site was taken as the ratio of depredated months to stocked months. A measure of the average *intensity of depredation* was taken as the total number of seal-depredated salmon recorded at each site, divided by the number of 'stocked months', yielding an intensity metric of the 'average number of salmon taken by seals per month when fish were present'. These two metrics were used as our response variables.

Seal numbers were taken from aerial surveys conducted by the SMRU during the harbour seal moult (when most harbour seals are ashore) in August. During the time period in question (2001-2011), survey data were available for all years with the exception of 2011. Not all areas were covered every year (Table 5), but all areas have been covered at least three times during this decade.  Seal haul out sites are recorded with latitude and longitude, species present and number of individuals based on scrutiny of high definition aerial photographs.

We compared the location of each farm site with each seal haul out location and identified the closest haul out site (straight line distance in km) to each farm site over all surveys, as well as the average number of seals counted within 3km, 5km, 10km and 20km radii of each farm site over those years when surveys had been done. Distance calculations were done in Microsoft Access using custom written software in Microsoft VBA.

### Table 5: Summary of availability of seal count aerial survey data

| Seal Management Area | 2000 | 2001 | 2002 | 2003 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| East Coast | X | | X | | X | | X | | | |
| Moray Firth | X | | X | X | X | X | X | X | | |
| North Coast | | X | | | X | X | | X | | |
| Orkney | | X | | | X | X | X | X | X | X |
| Shetland | | X | | | | X | | | X | |
| West Scotland – North | | | | | X | | | X | | |
| West Scotland – Central | X | | | | X | | X | X | | |
| Western Isles | X | | X | X | | X | | X | | |
| West Scotland – South | X | | | | X | | X | | X | |
| South-West Scotland | | | | | X | | X | | X | |

### 6.3 Overview of levels of seal depredation

Overall the data covered 87 sites over a 129 month period.  Of the 11,223 site.month data points, fish were present (stocked) through 5,248 site.months, an average stocking rate of 47% of the study period.  Of these stocked months, 2,217 (42%) were reported to have suffered salmon depredation.

Of the 87 sites, 12 reported no losses to seals (14%), with between 3 and 73 (average=24) months of operation (i.e.  Stocked months) among these sites.  The greatest frequency of attack at one site was 55 depredated months out of 62 stocked months (89%), while the largest number of attacked months was 107 out of 123 stocked months (87%).  The average frequency of attack was 0.36 across all sites (36% of stocked months were reported with seal attacks).  Among sites with recorded seal depredation, fish were stocked an average of 66 months during the study period. Sites with no reported seal damage were therefore typically sites with fewer months of operation.

In terms of intensity, the number of fish removed during a seal depredated month ranged from 1 to over 70,000 (presumably associated with an escape incident or some other catastrophe). The average number of fish taken in any stocked month was 264 and during a seal depredation month was 625, but the numbers are highly over-dispersed (variance = $4x10^6$) with ten or fewer fish mortalities attributed to seals in 176 of the 2217 depredated months (8%), and 100 or fewer fish killed by seals in 824/2217 (37%) of depredated months.

This is not to trivialise the scale of the problem however as nearly 1.4 million salmon were reported killed by seals over the study period, which, assuming a value of £3.5 per kg[12] at the farm gate and assuming that all those killed had reached a harvest size of 5kg, would have been worth in excess of £25 million.

## 6.4 Seasonal damage levels

It is often reported that seal depredation of salmon farms is greatest in the winter. The data support this assertion to some extent, but the stage of the production cycle seems to be more important. Below we have plotted the frequency and intensity of seal damage by calendar month (Figure 30 and Figure 31) and by month of the 23 month production cycle (Figure 32 and Figure 33). For the latter data we have excluded 364 production months (7.5%) during cycles where we were unsure of the start of the production cycle.

[12] http://www.undercurrentnews.com/2012/09/10/scottish-salmon-production-boom/#.UPaBRGfDWSc

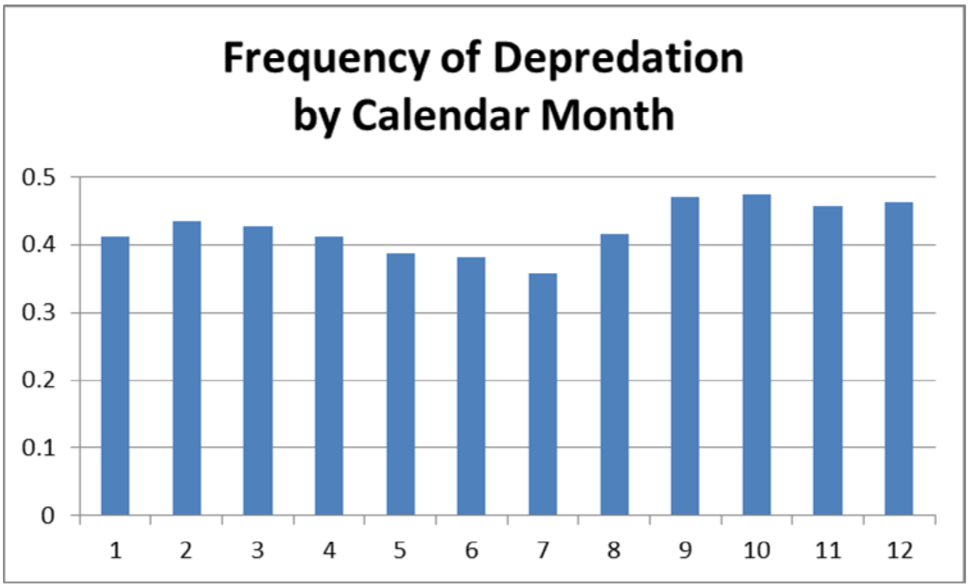



Figure 30: Frequency of depredation - proportion of stocked months with reported depredation, by calendar month

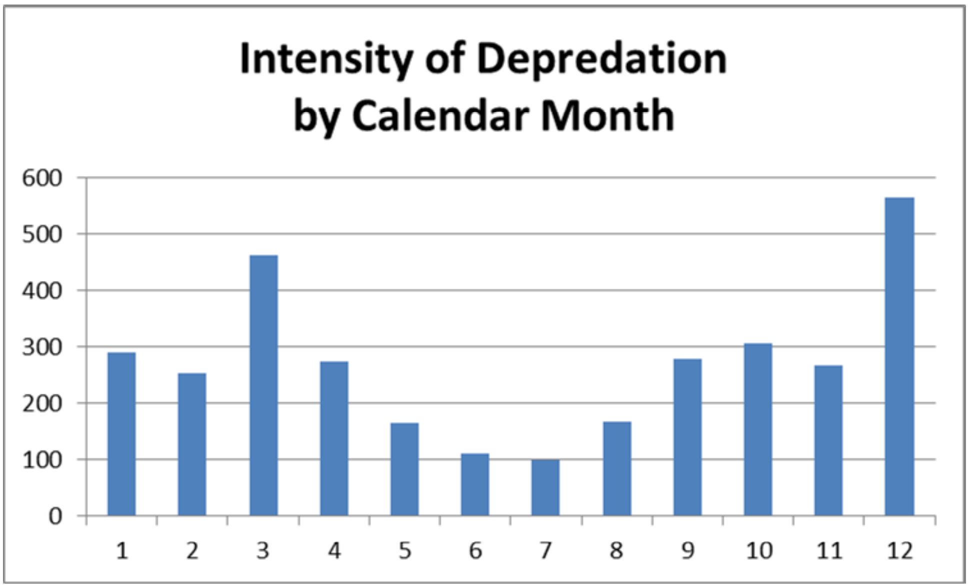



Figure 31: Intensity of depredation – mean number of fish per month, by calendar month

There is little evidence of any change in the frequency of attacks by calendar month suggesting a seal depredation event is as likely in any one month as another. There is some suggestion that fewer fish are actually removed per event or per month during the summer, with peak number of fish removed in December, and highs throughout autumn and winter.

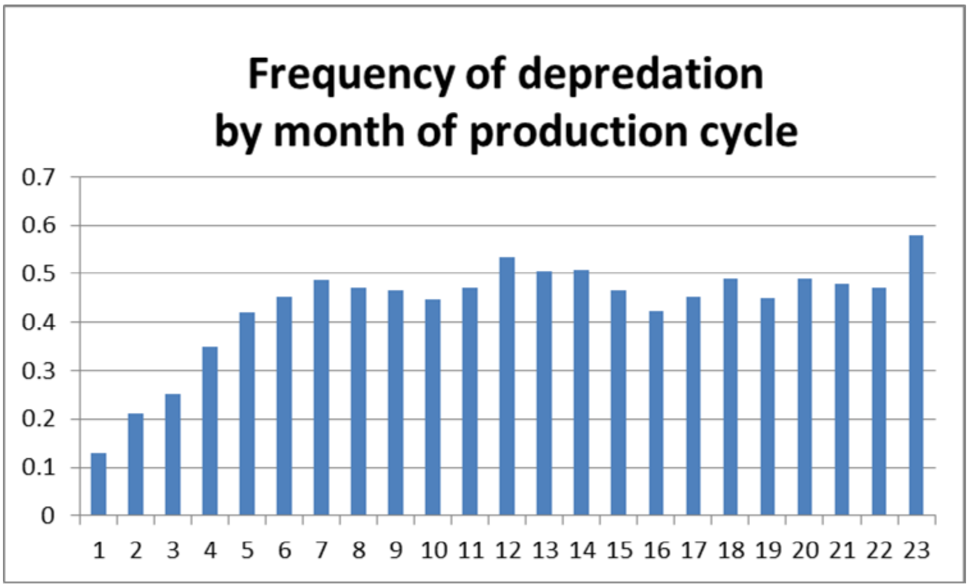



**Figure 32: Frequency of depredation events by month of production cycle**

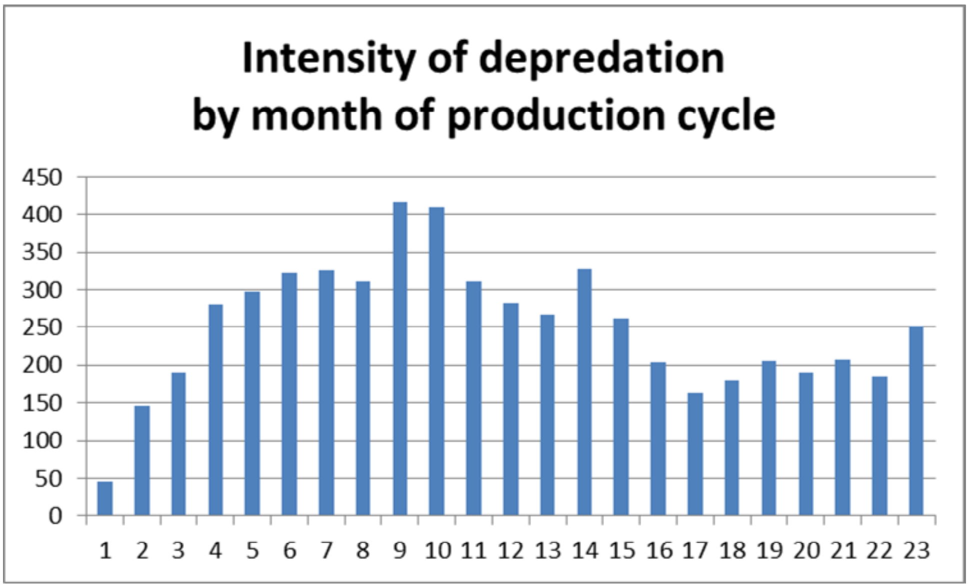



**Figure 33: Intensity of depredation by month of production cycle**

There is a somewhat clear pattern in depredation with respect to the growing or production cycle. The frequency of attacks is low initially, but increases steadily for the first 7 months of the cycle, and thereafter reaches a plateau of around 45% (depredation occurring in 45% of months: see Figure 32). In terms of intensity of attack however, while a similar increase in rate is observed over the first 6 or 7 months, the greatest number of fish per month are lost around months 9 and 10 (Figure 33), which is usually when fish are transferred from smolt type netting (typically 15mm mesh) to grower pens with a larger mesh size (typically 25mm). Thereafter, intensity of depredation falls away, suggesting fish may become more difficult to catch.

These data suggest that depredation rates are influenced by the production stage of the cycle and possibly by calendar month too (the two are related as 60% of fish stocking occurs during Jan-April). The peak intensity of seal depredation occurs in December, immediately after the grey seal breeding season, when adult animals have been fasting. In terms of the production cycle, lowest depredation rates occur during the first few months of the cycle and peak in intensity at the stage when fish are transferred to larger mesh cages. It may be that larger meshes make salmon more visible, or perhaps easy to grab. This suggests an area for further research.

### 6.5 Duration of production

Among the sites for which we have data and for the period we have been examining, some sites were active for only a very short length of time (minimum of 3 months) while others were active for much of the study period (maximum 126 months). We investigated whether or not the duration of activity at a site might be related to levels of seal depredation (Figure 34).

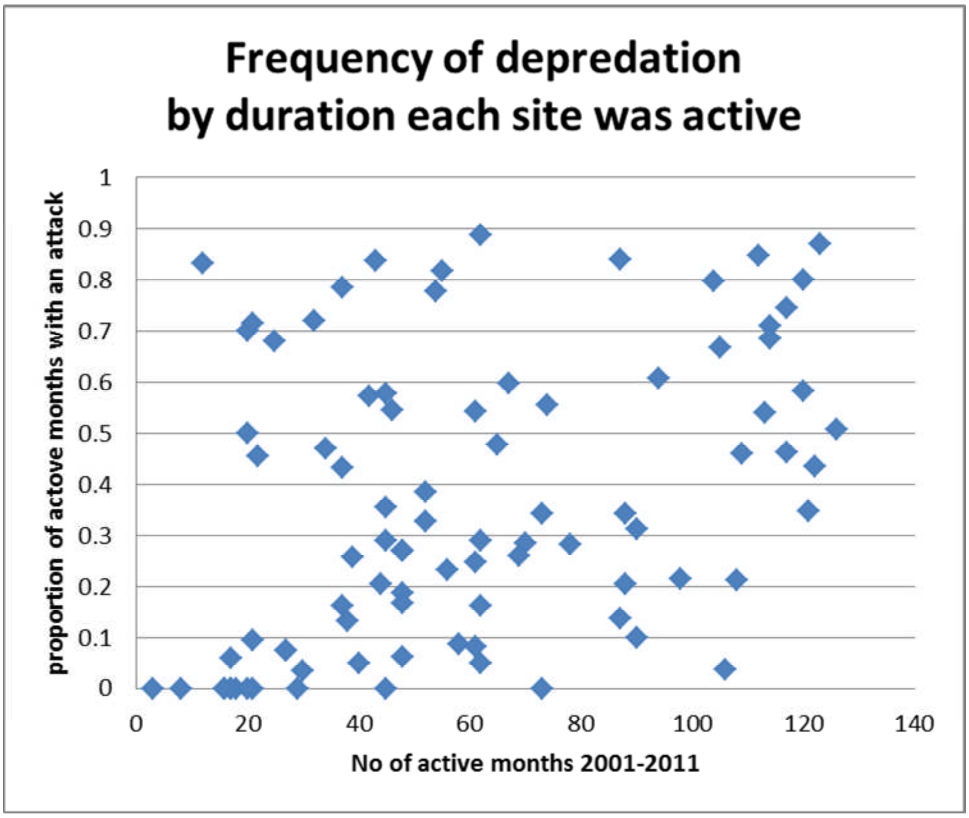



Figure 34: Site activity levels not related to frequency of attack

The data do not suggest that there is any relationship between damage levels and the length of time a site has been operational, although most of the sites with zero damage have been in operation for less than the average lengths of time. Nevertheless there are plenty of sites with relatively high levels of depredation that have been in operations for relatively few months, and vice versa.

### 6.6 Site location and seal proximity

We compared both frequency and intensity of depredation at each of 60 sites for which we had reliable geographical co-ordinates with the distance to the nearest haul out location for each of the two seal species.  Given the ubiquitous nature of seals in Scottish coastal waters, it is not surprising that most farm sites were within 3km of the nearest seal haul out site. Indeed only one site was further than 6km from a harbour seal haul out site, and the average distance to a harbour seal haul out site was 1.7km. Grey seal haul outs are less numerous in the sheltered coastal waters of the west coast, but the furthest haul out site from any fish farm was just 11.3km, and the average distance to a grey seal haul out site was 4km.

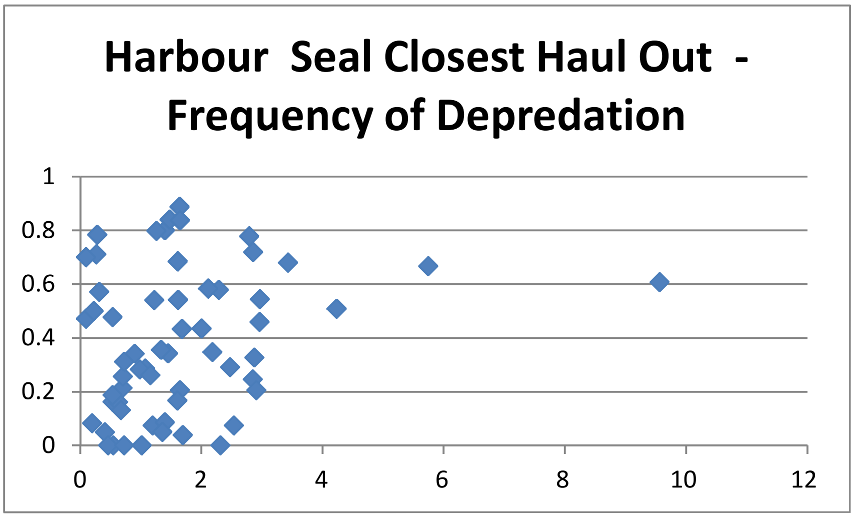



Figure 35: Harbour seal closest haul out site (km) vs frequency of depredation by farm site

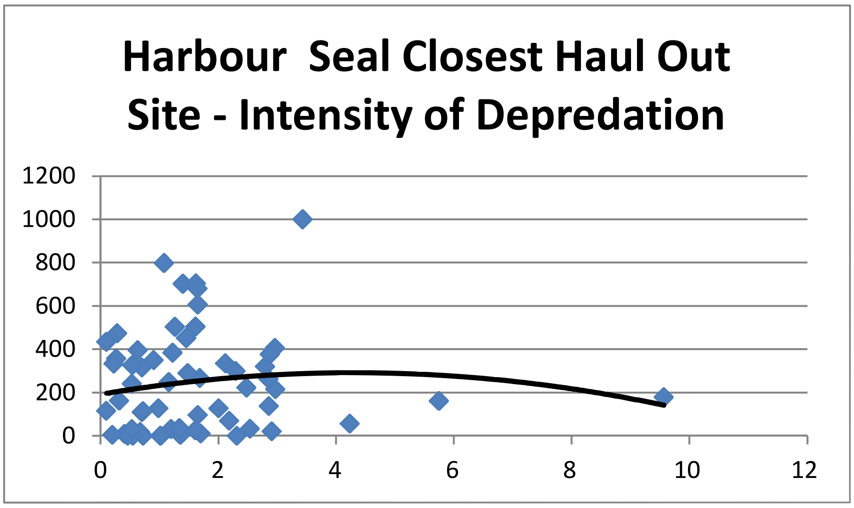



Figure 36: Harbour seal closest haul out site (km) vs intensity of depredation by farm site

It is clear from Figure 35 and Figure 36 that the proximity of the nearest harbour seal haul out site has no effect on the frequency or the intensity of seal depredation. Several sites within a few hundred metres of harbour seal haul out sites still have relatively low levels of depredation.

The situation with grey seals is quite different.

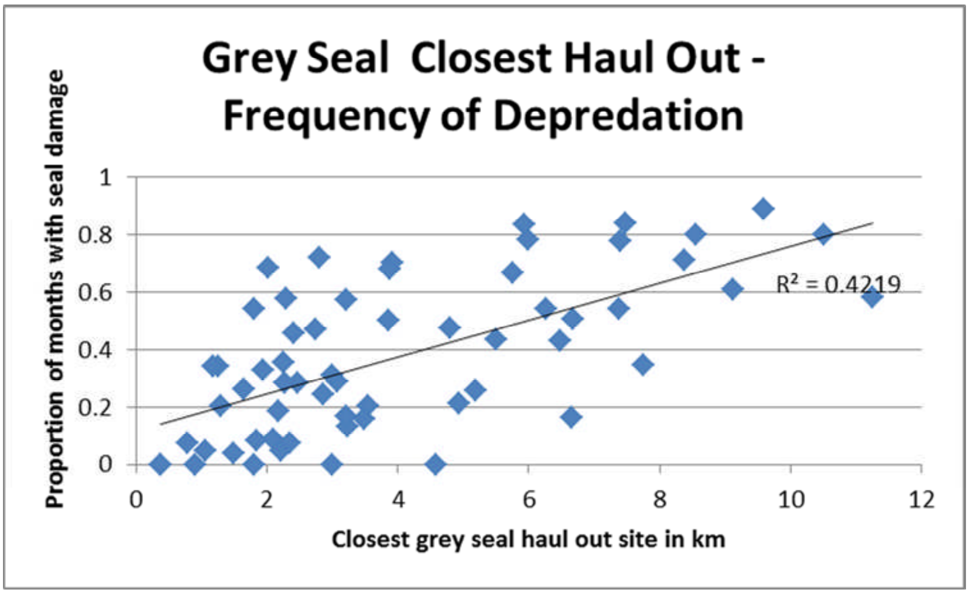



Figure 37: Proximity of grey seal haul out site to fish farm - frequency of depredation

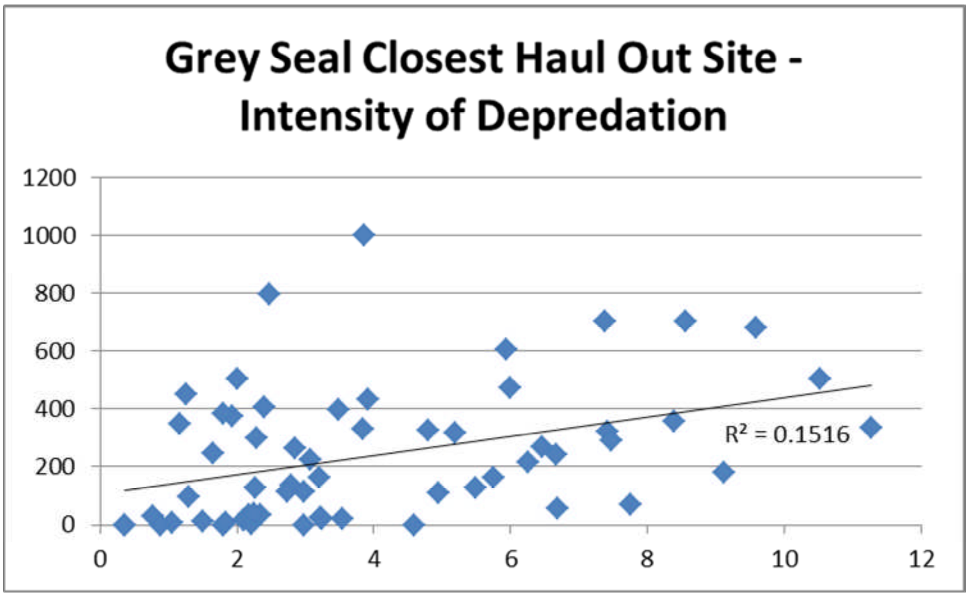



Figure 38: Proximity of grey seal haul out site to fish farms: intensity of depredation

For grey seal haul out sites there is a clear *positive* relationship between frequency of depredation months and distance to the nearest haul out site (Figure 37: $r^2$ 0.42;

F=40.97 and p <0.00001). Likewise, there is also a less clear but still significant relationship between intensity of damage and distance to closest grey seal haul out (Figure 38: $r^2$ = 0.34; F=10.36 and p=0.002).

This is a counter-intuitive result that cannot be explained with the data currently available. It implies that the closer the farm site is to a grey seal haul out the less damage is likely. In order to check whether this might have been an artefact of the data we made some further comparisons. Firstly we compared grey seal haul out proximity to frequency of depredation after having removed any depredation month where less than 100 fish had been killed by seals. This was to focus on depredation that was most intense and ignore what might be 'casual' events. This excluded about a third of all events, but even so the same relationship can be seen (Figure 39: $R^2$ =0.34; F=29.53, p=0.0001).

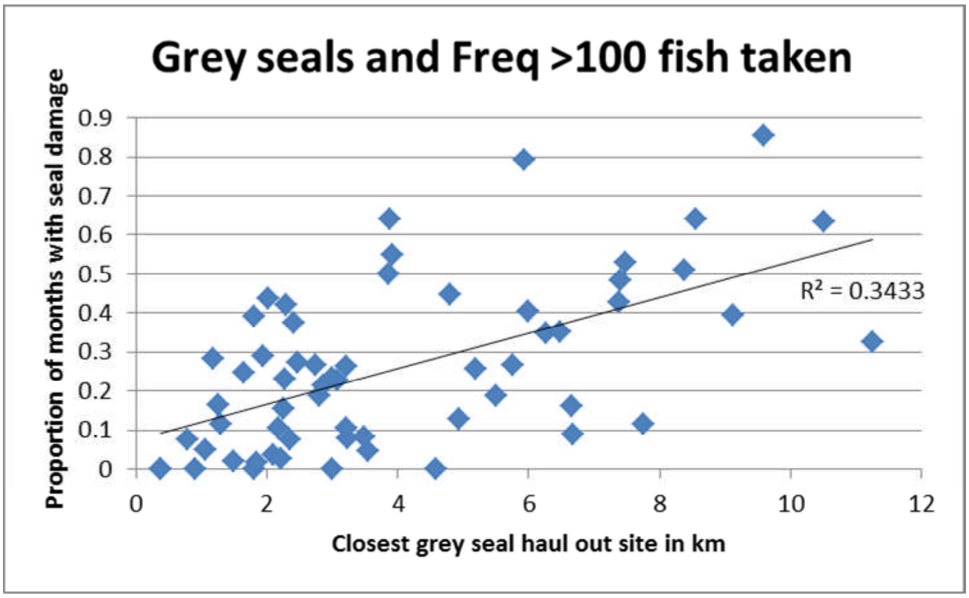



Figure 39: Relationship between frequency of more serious depredation events and distance to grye seal haul out site

Rather than relying on the closest seal haul out site as an indicator of seal proximity alone, we also investigated depredation rates in relation to a measure of seal density in the region surrounding each farm site. We did this by comparing depredation levels at a farm by farm level with the mean number of seals counted within 20km, 10km, 5km and 3km of each site.

For none of the harbour seal density metrics was there any discernible relationship with either frequency or intensity of seal depredation on caged salmon. Two examples of the 8 scatter plots for harbour seals are shown below as examples (Figure 40 and Figure 41).

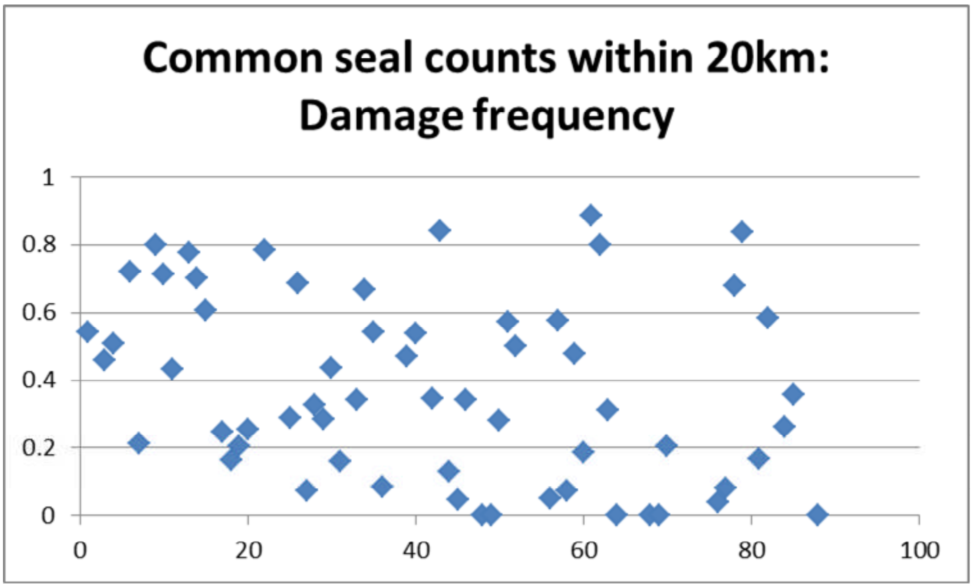



**Figure 40: Frequency of depredation in relation to average numbers of seals counted within 20km all surveys**

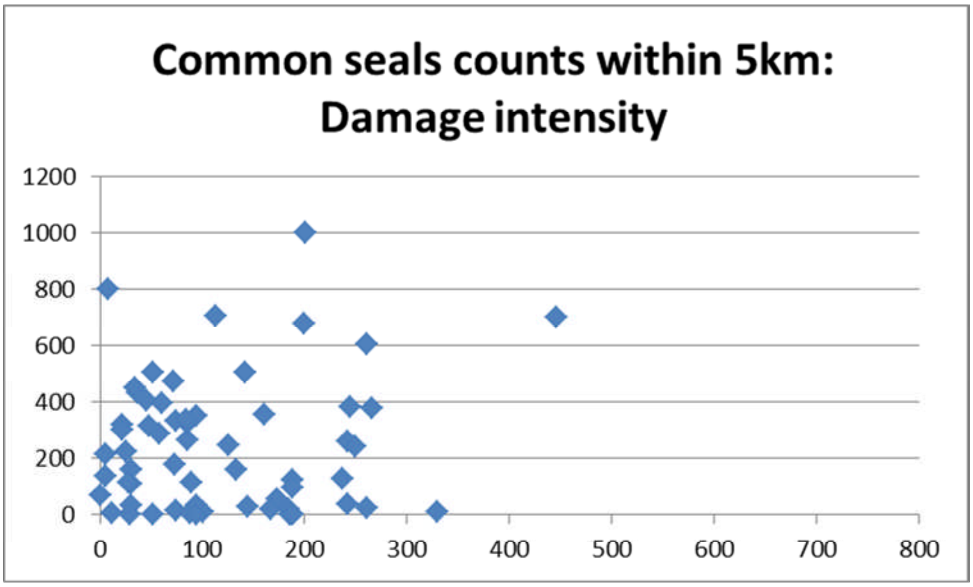



**Figure 41: Intensity of depredation in relation to average numbers of seals counted within 5km -all surveys**

For grey seals, the situation is again different and counter-intuitive and there is again a clear *negative* relationship between frequency of depredation and counts of grey seals within 20km. This relationship cannot be seen clearly at smaller spatial scales (10km, 5km or 3km), nor are there significant relationships with damage intensity and grey seal counts at any spatial scale.

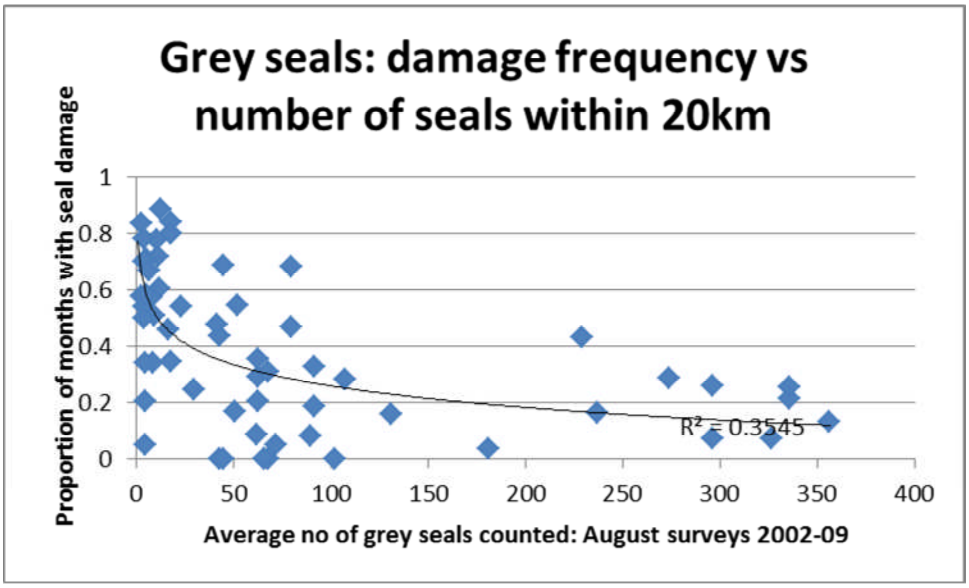



Figure 42: Frequency of depredation declines with increasing numbers of grey seals within 20km

Nevertheless Figure 42 and Figure 37 suggest that closer and greater densities of grey seals are associated with lower levels of depredation.

It is hard to interpret these findings without further data. One obvious explanation may be that when farms are close to grey seal haul out sites, or in areas with lots of grey seals, site managers are more assiduous in ensuring mitigation measures are properly maintained. This would suggest that a degree of damage limitation would be possible by more careful husbandry at other sites; but it is at this point merely speculation. Other more intriguing possibilities relate to grey seal behaviour, and might include 'stranger danger' where a disproportionate amount of the depredation is due to seals that are not locally based but are ranging more widely.

It should be noted that all of these results depend on aerial counts in August when depredation is low. It is likely that seal densities and local haul out locations may be somewhat different at different times of year.

Our final spatial analysis of seal depredation at farm sites is simply a map. We have plotted out the locations (or approximate locations) of all 87 sites for which we have data, and have colour coded them according to frequency of seal depredation. Those with more red circles are those with higher depredation frequencies (max 88% of all months of operation), while orange sites have intermediate frequencies of depredation and those progressively more green have lessening frequencies down to zero (Figure 43).

This figure suggests that there are some clear regional differences in depredation rates that have not been picked up in the above numerical analyses. Depredation rates are generally low in the Outer Hebrides for example, and there are several other areas where higher depredation frequencies seem to be clustered, notably the north coast of Skye, Loch Sunart and Loch Linnhe. As yet we have no explanation as to why these regional differences may be. It is again feasible that these are due to husbandry practices, but this is not possible to explore without either more detailed site specific data or site interviews.

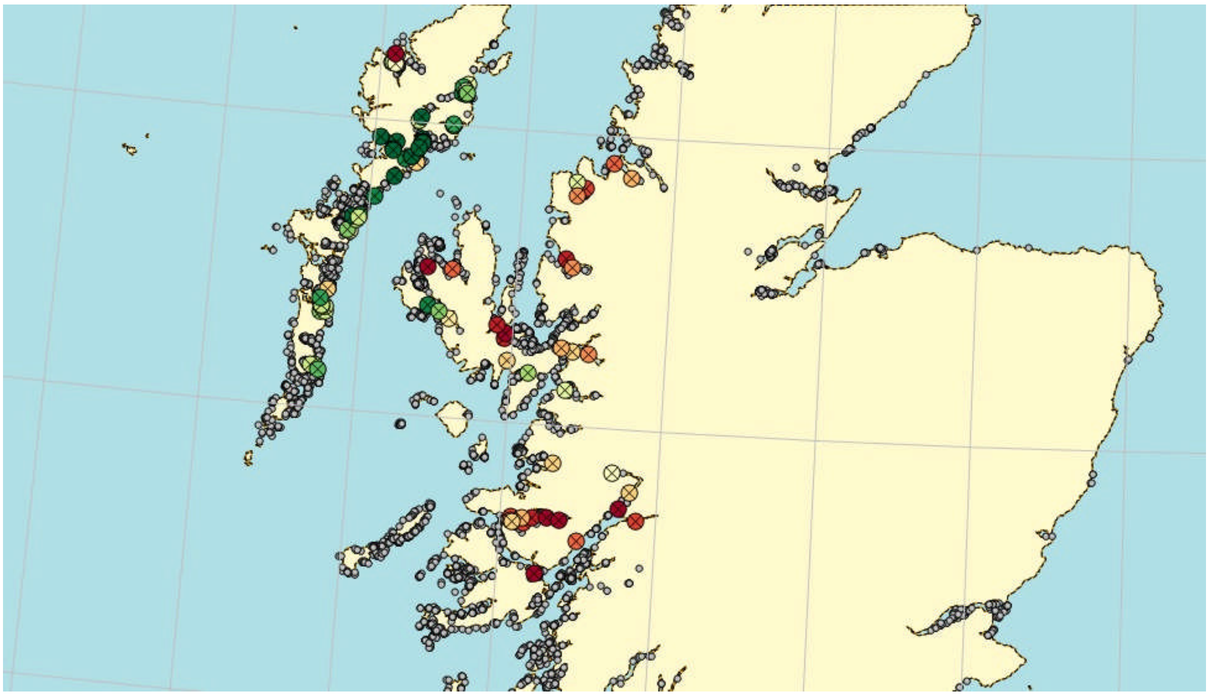


**Figure 43: Map of fish farm sites considered in this analysis, colour coded by frequency of seal depredation months. Grey circles indicate harbour seal haul out sites**

To conclude this section we emphasise that the analysis of existing data can reveal much about the process, and while we have so far been able to explain all of the results of these analyses, they provide scope for more detailed study and raise the possibility of further investigations into, for example, the effects of different husbandry techniques on seal depredation levels, and the behaviour and origins of individual seals around farm sites.

## 7. Acoustic Deterrent Devices – impacts on porpoises

### 7.1 Introduction

It is well known that Acoustic Deterrent Devices (ADDs) can have a significant impact on cetacean distribution, and several studies have shown that harbour porpoises in particular seem to avoid areas where ADDs are in use. Studies by Olesiuk *et al* (2002), Johnston (2002) and Northridge *et al* (2010) have shown greatly reduced porpoise detections within several kilometres of active ADDs. However, all of these studies have used the same type of ADD made by a single manufacturer (Airmar). We are aware that several other devices are in use in Scotland, made by at least three other manufacturers, namely Ace Aquatec, Lofitech and Terecos. A previous study suggested that about half the sites surveyed during the study were using Terecos devices (Northridge *et al* 2010) but no studies to date have examined how cetaceans react to Ace Aquatec, Lofitech or Terecos ADDs.

Under EU and domestic legislation, the deliberate or reckless disturbance of cetaceans (and other European Protected Species) in Scotland is prohibited. At present Scottish Natural Heritage (SNH), as the statutory nature conservation body, is consulted on fish farm site licence applications in Scotland. SNH policy towards the use of ADDs used at new sites is currently based on whether or not the site is considered important for cetaceans. However, it is still unclear whether or not the use of ADDs more widely might be construed as the deliberate or reckless disturbance of cetaceans, and the uncertainty seems unlikely to be clarified until the current interpretation is challenged in court. This means that it is conceivable that the existing permitted use of ADDs in Scotland could be challenged, perhaps leading to more widespread restrictions on their use. Furthermore, under recently agreed Global Standards for Salmon Aquaculture, initiated by the WWF and agreed by over 500 international stakeholders, ADDs are intended to be phased out in salmon aquaculture within three years of the publication of the Salmon Aquaculture Dialogue[13] (SAD) by those companies that sign up to the Standards. The SAD proscription of ADDs appears to be based on the assumption that all such deterrents are inimical to cetacean conservation. An exception to this may be granted where new technologies can be shown to present less risk to non-target populations.

We established a relatively simple method of measuring the impact of ADDs through the use of passive acoustic monitoring devices (known as PODs – porpoise click loggers) which can be deployed from temporary moorings around a farm site and left for several weeks or longer to detect characteristic high frequency echolocation clicks of porpoises. It is believed that porpoises make echolocation clicks much of the time, and do so in order to locate their food. Any decline in echolocation activity can be taken to imply a decline in porpoise activity. By positioning PODs around a farm site where an ADD is deployed, and then switching the device on and off at known intervals, the impact on porpoise echolocation clicks, and by inference on their distribution, can be inferred. We have adopted this method in previous studies of Airmar devices (Northridge *et al*., 2010) and have repeated the experiment on a site at Loch Hourn where a Terecos device was deployed.

## 7.2 Methods

Nine C-PODs (Chelonia Ltd) were deployed in and around Loch Hourn on 26th June 2011 and retrieved on 5th September 2011. Figure 43 shows the locations of the deployments and also the location of the Marine Harvest fish farm in the Loch. The site manager agreed to turn the device on and off on a weekly basis. We made

[13] *Final Salmon Aquaculture Dialogue Standards for the Aquaculture Stewardship Council, June 13, 2012*

acoustic recording of the device at various distances on the first day of deployment while the device was on. The device was turned off on 27th June and we subsequently made telephone calls on a weekly basis to check the ADD status. No serious seal interactions had been experienced at the site in the period immediately preceding the trial, so the site manager was content to switch the ADD on and off, but we understood that the trial would be abandoned should the need arise to turn the device back on continuously if seal attacks became a serious issue.

The C-PODs were set on temporary moorings under contract by a local lobster trap vessel, and were retrieved by the same vessel and transported back to St Andrews for download and analysis.

We have compared porpoise click detections between treatments (ADD ON and ADD OFF) as click positive minutes per day and click positive hours per day. The number of clicks per day or per replicate is a less reliable way of quantifying differences between treatments because clicks are highly auto-correlated. Click positive minutes and click positive hours are both aggregate measures which reduce the risk of auto-correlation. Click bursts are typically some seconds in duration, but can contain a few or many thousand individual clicks. When click positive minutes are used, some resolution is lost in the sense that the number of clicks or click trains per minute is ignored, so that differences in click intensity between treatments are damped down: a minute is deemed either to have contained a click train or it has not. Autocorrelation is reduced, but may not be eliminated if click trains run over from one minute to the next. Click positive hours lose even more resolution but are even less likely to be auto-correlated.

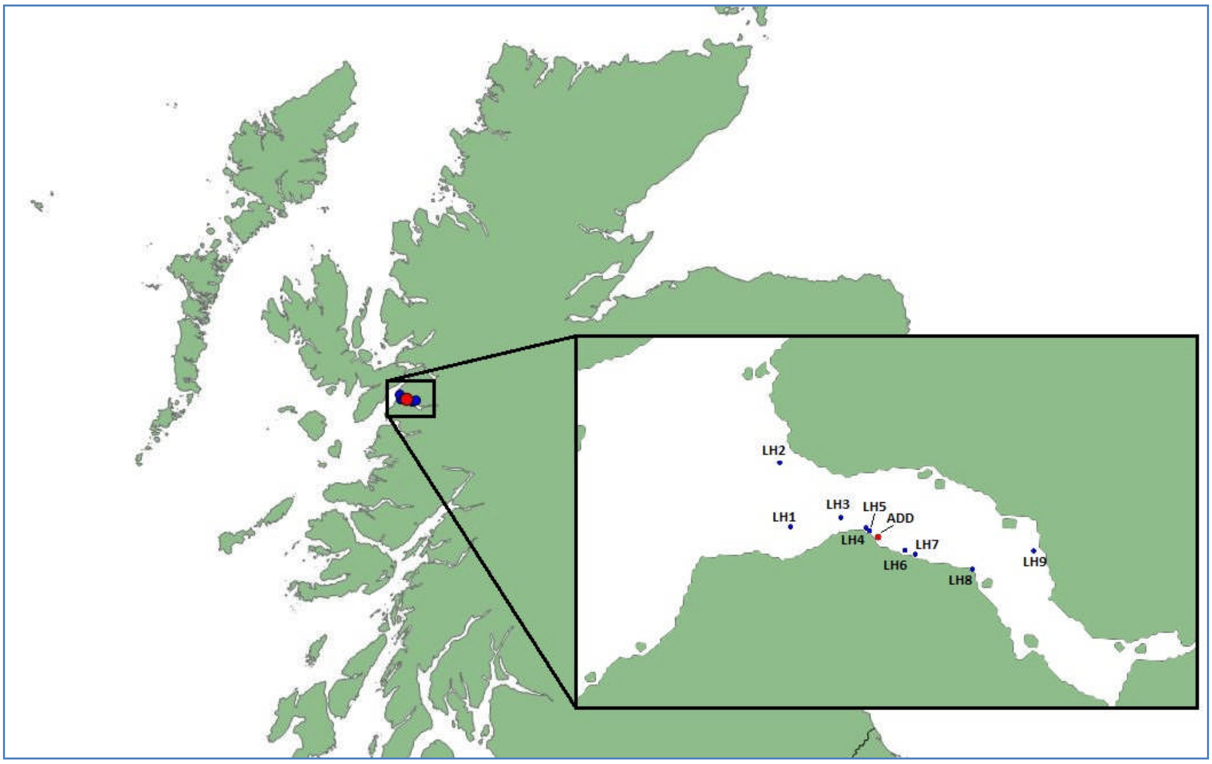



**Figure 44: Map of study site, Loch Hourn, C-POD and ADD locations**

Comparisons between treatments were made on a site by site basis, avoiding making any assumptions about the comparability of C-PODs. We first divided the data into ADD-ON days (n=31) and ADD-OFF days (n=34) and compared mean detection positive hours per day between the treatment and control days at each site. We expressed the difference between the two observed means as the proportional change in the number of click positive hours during ON periods compared with OFF periods. We used a bootstrap resampling procedure to determine the probability of the observed results. By resampling from all 65 days with recordings, we determined the probability that the observed differences in mean detection rates may have occurred by chance. As we are interested in the possibility that ADDs made lead to a reduction in porpoise activity, we adopted a one-tailed assessment by asking how often we might expect even fewer detection positive hours per day to have been recorded.

## 7.3 Results

The nine C-PODs were deployed and they collected data on click detections for 65 days; on 34 days the ADDs were off (7,7,11,7 and 2 day periods) and on 31 days when the ADDs were on (7,7,10,7 day periods). Initial graphical plots of click positive minutes per day and click positive hours per day did not reveal any obvious difference in click occurrence. This is in contrast to previous similar experiments with Airmar ADDs where the status of the ADD can clearly be seen reflected in the number of click positive minutes per day (Northridge *et al* 2010).

The average numbers of click positive hours per day ranged from 2.9-3.4 at the north side of the entrance to Loch Hourn (LH2), to a maximum of more than 21 hours per day on the southern edge of Loch Hourn (LH7). Detection positive hours were slightly lower at 6 sites and slightly higher at 3 sites when the ADD was on. The bootstrap resampling procedure allowed us to estimate the probability that the observed detection positive hours (DPH) values would have occurred by chance, and also provided us with a basis for generating 95% confidence limits on the expected distribution of DPH values at each site. Table 6: Summary results from C-POD experiment in Loch Hourn) shows the results at each of the nine sites, and the associated probability levels. Changes in the detection rates for the two treatments ranged from a 5% increase to a 10% decrease in activity (DPH). Only at one site - LH5, which was also the closest site to the ADD, was there any significant difference in the number of DPH per day when the ADD was ON. Even there the difference was only significant at the 10% level.

**Table 6: Summary results from C-POD experiment in Loch Hourn**

| Mooring location | Distance to ADD (m) | Detection Positive Hours per Day | | Observed Proportional Difference | P value for observed difference (1 tailed) |
|---|---|---|---|---|---|
| | | ADD ON | ADD OFF | | |
| LH1 | 2560 | 18.1 | 17.3 | 0.050 | 0.85 |
| LH2 | 3569 | 2.9 | 3.4 | -0.125 | 0.14 |
| LH3 | 1215 | 13.5 | 13.4 | 0.012 | 0.56 |
| LH4 | 438 | 13.3 | 14.4 | -0.074 | 0.14 |
| LH5 | 301 | 13.5 | 15.0 | -0.099 | 0.08* |
| LH6 | 855 | 15.2 | 15.9 | -0.043 | 0.21 |
| LH7 | 1169 | 20.8 | 21.1 | -0.015 | 0.30 |
| LH8 | 2865 | 17.5 | 16.9 | 0.034 | 0.76 |
| LH9 | 4502 | 16.0 | 16.3 | -0.016 | 0.37 |

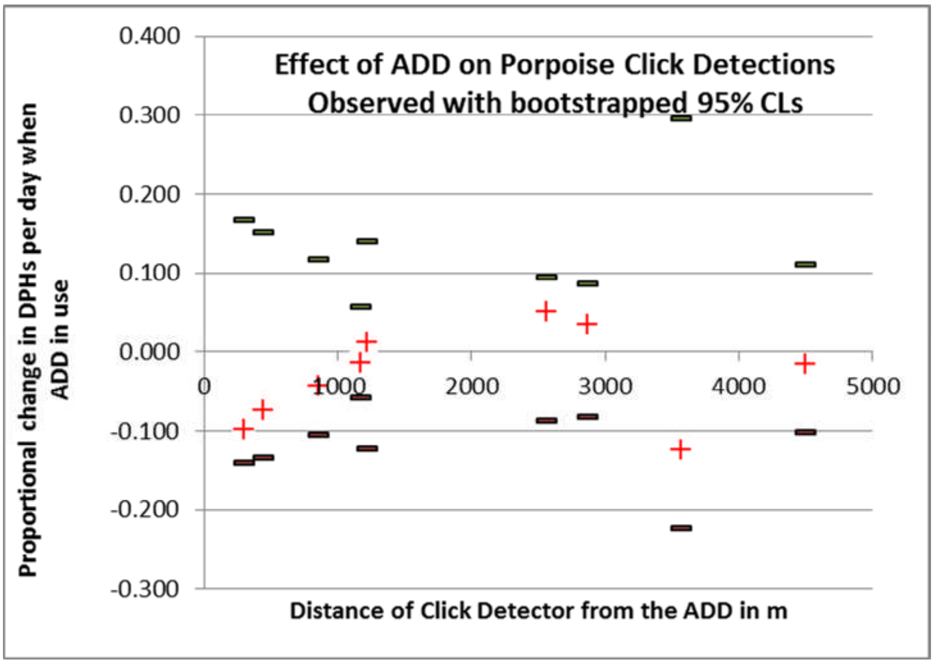



**Figure 45: Differences in porpoise activity between periods of ADD activity and inactivity with distance from the sound source**

Although there was little evidence of any reduction in porpoise activity associated with the Terecos ADD being ON, it is noteworthy that the sites where porpoise activity was reduced during ADD-ON periods were generally those closest to the device.

Indeed, as can be seen in Figure 45: Differences in porpoise activity between periods of ADD activity and inactivity with distance from the sound source) there is also a trend in the observed differences, with a reduction in DPH by 9.9% at 300m, then 7.4% at 438m, 4.3% at 855 and then 1.4% at 1169m.

## 7.4 Discussion

These data suggest a weak or minimal response by porpoises to the sounds generated by the Terecos device, but a response that nevertheless is proportional to distance from the device, out to around 1.2km from the site. It may or may not be significant that the other three sites closest to the ADD (LH1, LH3, LH8) but beyond 1.2km all had slightly elevated click detection rates when the device was on. Though far from conclusive, this suggests the possibility of displacement of animals slightly further away from the device when it was on.

It is also worth noting that the mean number of click positive hours per day inside Loch Hourn ranged from 13 to 21 – indicating a high frequency of occurrence of porpoises, whereas at site LH2, outside the Loch and 3.5 km from the ADD, detection levels were much lower (3.4 click positive hours per day when the device was off), so a small change in the number of click-trains picked up here represents a proportionally large difference.

This is to our knowledge the first time the reactions of porpoises have been studied in relation to any ADD other than an Airmar, and the results are strikingly different. We are reluctant to conclude that Terecos devices have no significant effect on porpoise distribution or activity based on this single set of results. Further tests at this or other sites using Terecos ADDs would help to ascertain the extent to which these results can be generalised.

Although we measured the received levels of the signal produced by the Terecos ADD at several sites around the Loch with the aim of producing a sounds field map, our calibrated hydrophone proved to be mal-functional when we came to analyse the data, and we have not had the opportunity to make new recordings, though clearly this could help to explain the reaction of porpoises in Loch Hourn to the active device.

# 8. Acoustic Deterrent Devices – field measurement of source levels

## 8.1 Introduction

Acoustic Deterrent Devices (ADDs) are one of the primary tools used in Scottish salmon aquaculture to minimise seal damage. Northridge *et al* (2010) found that among 81 sites that were the subject of interview questionnaires, 40 used ADDs (49%). As noted in Section 4, few sites use predator nets, and after net tensioning and mort removals, ADDs are probably the main method used to limit seal depredation. Given this, it is perhaps surprising in the light of the reported damage levels described in Section 6 (86% of sites report some level of seal depredation and 42% of months of fish production suffering losses with an average loss of 264 fish per month of operation) that more than half of sampled sites did not use ADDs. A large proportion of sites must therefore rely on alternative anti-predator strategies.

The effectiveness of these devices has long been questioned and despite two published studies of the effectiveness of ADDs in deterring seals from a wild salmon netting station and from the lower reaches of a salmon river (Fjalling *et al*. 2006; Graham *et al*. 2009), no study has demonstrated the effectiveness or otherwise of ADDs used at salmon/fish farms. Indeed there is controversy over the use of such devices in relation to cetaceans (described in Section 7). The only published data that we are aware of, are provided by TEP (2010b) in a report on containment to the SARF, where it is reported that among 28 fish escape incidents that had been caused by predators, 9 occurred at sites using ADDs, 12 at sites not using ADDs while the availability of ADDs at the remaining 7 sites was unknown. The authors noted, however, that “since ADD may be switched off, it should be noted that this ...

Does not confirm that ADD was actually in use at the time of the incident. It is anyway clear that ADDs do not work all the time. Northridge *et al* (2010) reported on the basis of site interview that: “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”. Likewise TEP (2010) reported that “many consultees commented that ADD appeared effective to start with and then seal became used to them”.

Northridge *et al.* (2010) also reported that ADDs are not always switched on or deployed when available. At 16 of 40 sites ADDs were used continuously, while at 12 sites they were only switched on when the fish reached a certain size, at 4 sites they were used only when seals showed an apparent interest in the cages. At 21 of these sites ADDs were used when seal damage began to be a problem. None of this makes it easy to make a simple comparison between sites using ADDs and those not using them.

A further concern is that even when ADDs are actually deployed and switched on, it is not always certain that they are functioning as intended. One of the problems here is that there are no industry standards to determine the proper functioning of an ADD transducer, and all models produce their own idiosyncratic acoustic signals. As much of the sound energy being produced is at or above the limits of human hearing, specialist equipment is needed to ensure that the acoustic output is as intended. Furthermore, there is very limited information on the acoustic signals that each model produces.

During the course of the project we measured the source levels of several ADDs. Some of these measurements were opportunistic in order to better quantify the acoustic signature of specific models, but in one case measurements were made specifically to check whether any transducers at a particular site might have been malfunctioning. In this case, we consulted the manager of a farm site that had been experiencing severe levels of seal depredation, and were informed that the site had been using an Airmar ADD throughout the period of seal depredation, but that when the system was replaced with a new one, the problem had ceased. This suggested some malfunction of the original system, which appeared (or sounded) to the site manager to be working normally. The original system had been moved to a nearby site that had previously been without an ADD and we therefore made field measurements of the source levels of each of the 8 transducers of this system.

## 8.2 Testing a System that had not been effective in deterring seals.

Measurements were made at two sister sites each consisting of 8 square steel cages surrounded by a substantial walkway. Each site hosted 8 transducers, and 2 Airmar control units, such that each controlled 4 transducers. We hauled each transducer to within 1 meter of the surface of the water using its deployment rope, and then lowered a Reson TC4032 hydrophone linked via a pre-amp to a Lenovo laptop computer, to the same depth at a distance of 5m along the walkway. We recorded each transducer for at least one minute to capture several transmissions.

We selected at least 4 clear transmissions of the closest ADD from each recording using acoustic analysis software (Raven: Cornell Lab of Ornithology) and calculated various parameters including average power. Source levels were back calculated from 5m range.

In general our predicted source levels were somewhat lower than those reported by Lepper *et al*. (2004), though this may be due to different methodologies. We have focused on the frequency spectra and relative differences in source levels among the 16 measured transducers.

Transducers 1-4 were transmitting with a peak frequency of about 7kHz, while transducer 5 was totally non-functional. All of these transducers belonged to the system associated with the seal depredation incidents. Transducers 1-4 were all driven from the same control unit. All of the units in the second system (transducers 9-16) as well as numbers 6-8 on the first system, where transmitting with a peak frequency of close to 10 kHz (9750Hz) as has previously been reported for this model. With regard to amplitude, in general all of the ‘10kHz’ transducers had a higher output than the ‘7kHz’ units, with some overlap (Figure 46).

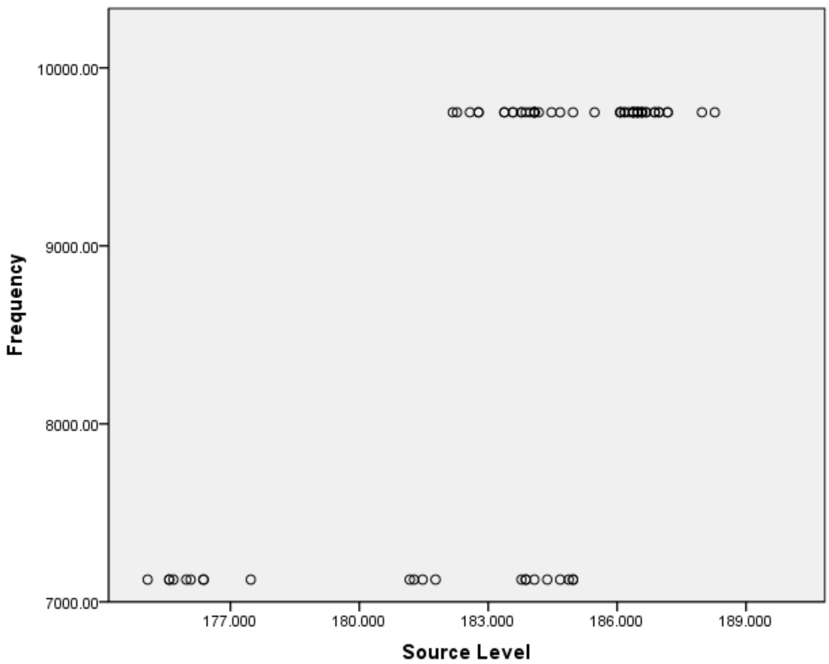



**Figure 46: Measurements of individual pulses from 15 transducers: source level against dominant frequency**

The mean output of the 7kHz transducers, at 180.4dB, was 5dB lower than the 10kHz transducers 185.4 dB. This is a substantial difference in power, and would equate to a 1.8 times difference in the effective range for a device for which acoustic power was the effective metric.

Overall, there was quite a high variability in source levels between transducers with mean values ranging from 176 to 187 dB (11 dB) equating to a 3.5 times difference in effective range (Figure 47 and Figure 48).

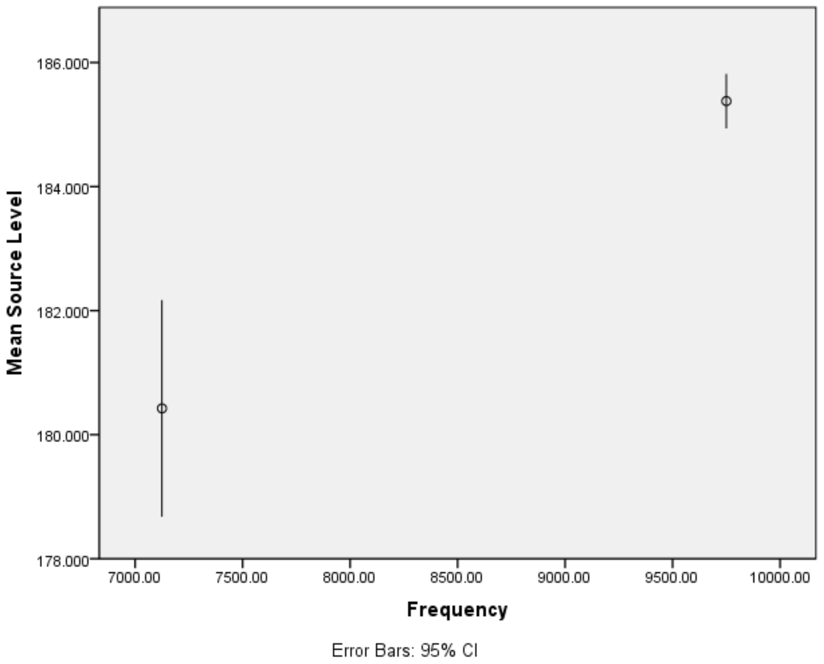



**Figure 47: Mean transducer output against frequency**

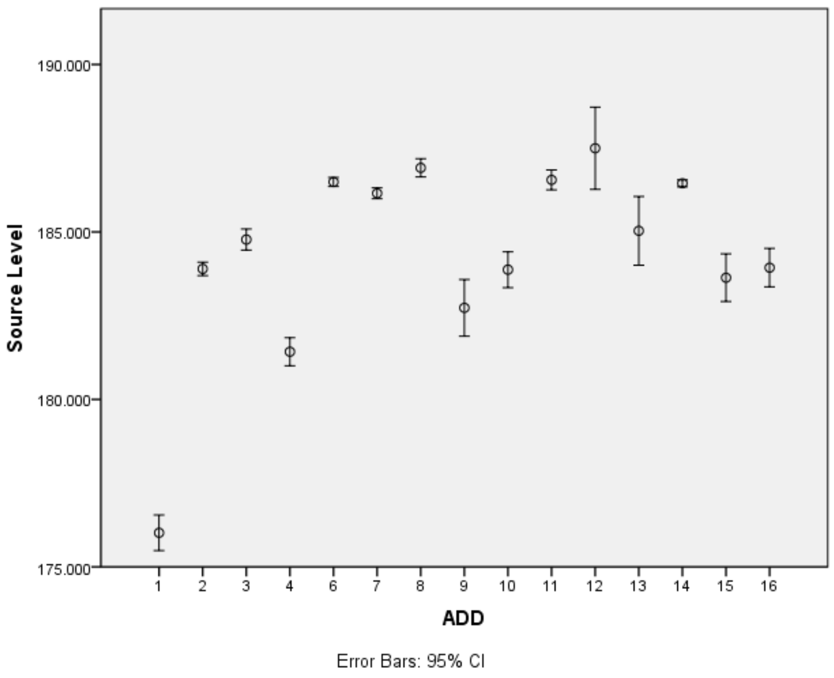



**Figure 48: Mean and standard deviation of source levels for 15 different transducers (no 5 was mute)**

The source levels that we recorded seemed lower than previously reported, but this should be considered a preliminary finding and may have been due to the sensitivity of the hydrophone that we used having drifted since a previous calibration. More important are the evident relative differences in the output characteristics of the 16 units we measured. Specifically, one group of transducers was transmitting at a frequency quite different from that specified, and these generally had lower power output than the others. These transducers were also associated with a series of serious seal attacks.

If farms are to rely on ADDs for predator management it is important that their sound output characteristics (and perhaps even sound fields) are measured after deployment and regularly thereafter. To this end a simple acoustic level measuring instrument has been developed using off the shelf components, and a prototype being tested at one farm site to monitor relative output levels over time, and check for any gradual (or sudden) changes in power output from each of the transducers.

## 8.3 Field measurements of four other Commercial Acoustic Deterrents

### 8.3.1 Methods

Recordings of four commercially available acoustic deterrents were made during two separate field trips. On both occasions recordings were made from the platform of an active fish-farm: firstly, on the 8th of November 2012 at the Marine Harvest Salmon farm on Loch Leven, West Scotland and secondly, on the 21st of November 2012 at a site owned by another operator in Loch Carron. The former consists of around twelve square nets with wide steel walkways, and the latter around sixteen large circular nets (approx. 100m in circumference). Both are situated in at least 25m of water, and are approximately 300m from the shore. The use of fish-farms as platforms for recording was convenient because they provide a fixed and stable platform above deep water with obstructions beyond the depth of the walkway (<1m). On the downside they can be quite noisy places and we occasionally needed to wait for work boats to pass by before continuing a recording.

Our objective here was to examine the acoustic characteristics of a variety of ADDs and compare our findings with those of Lepper *et al*. (2004) who described an Airmar dB Plus II, an Ace Aquatec Silent Scrammer and a Terecos DSMS-4.

Recordings were made using a calibrated B&K 8103 hydrophone, through a B&K 2635 charge amplifier, a national instruments digitiser with 1 MHz sample rate and an IBM Thinkpad laptop using the open source software 'PAMGuard'. The full sample rate of the digitiser was used in order to detect the upper extent of high frequency harmonics, which to our knowledge have not been described elsewhere.

Measurements were taken using audio software ‘Raven Pro 1.4’ after applying bandstop filters in ‘Adobe Audition’. A high-pass filter at 500Hz was used to remove low frequency noise from all recordings, and low-pass filters were set above the highest frequency component of the device in order to remove excess high frequency and electrical noise bands. Sound pressure levels quoted here are intended to be taken as relative values only, as until the equipment has been fully calibrated it is impossible to compare quantitatively with other studies.

A Terecos DSMS-4 was available to test on the first occasion, with two transducers operating from one control unit. The two transducers were situated approximately 50m apart and could not be activated independently. However, the signals from the different transducers can be discerned in post-processing by examining the relative amplitudes – the nearer one being significantly greater.

Figure 50: Terecos Transducer No 1 before defouling

Figure 49: Terecos Transducer No1 after defouling

Observations during recording confirm that the two transducers seemed to be ‘out of phase’ at least for a part of the recordings. The housings of these transducers were found to be very heavily fouled with colonial ascidians and bivalve molluscs (Figure 50) so we took the opportunity to test for a difference in sound output level due to the growth by cleaning the transducer (Figure 49).

Measurements were taken from three different on periods for each device, each transducer and in the case of the Terecos, each fouling condition (fouled and unfouled). This allowed average sound pressure levels to be calculated, and the level of variability to be examined.

### 8.3.2 Results

The first Terecos transducer (fouled) had an average Peak Sound Pressure Level (SPL) measurement of 177 dB (all dB measurements quoted here are reference to 1uPa at 1m – as is standard for underwater noise), however this varied from 173 dB to 179dB across the three emissions examined.  After defouling this transducer seemed to emit a more consistent, and slightly louder noise level, averaging 178 dB, range 178 to 179 dB.  The second transducer was equally fouled, and for logistic reasons could not be cleaned.  SPL for this transducer was in line with the defouled transducer, averaging 179 dB, range 178 – 180 dB.  Spectral characteristics for this were very similar to those described by Lepper *et al.* (2004), with a complex series of tones of varying frequency but peak energy at around 7.5 kHz (though sometimes ranging up to 15 kHz).  These pulses apparently consist of two distinct signal types (Figure 52) combined to produce bursts of one to two seconds.  Harmonic frequencies can be seen above the ambient noise level up to c. 65 kHz.

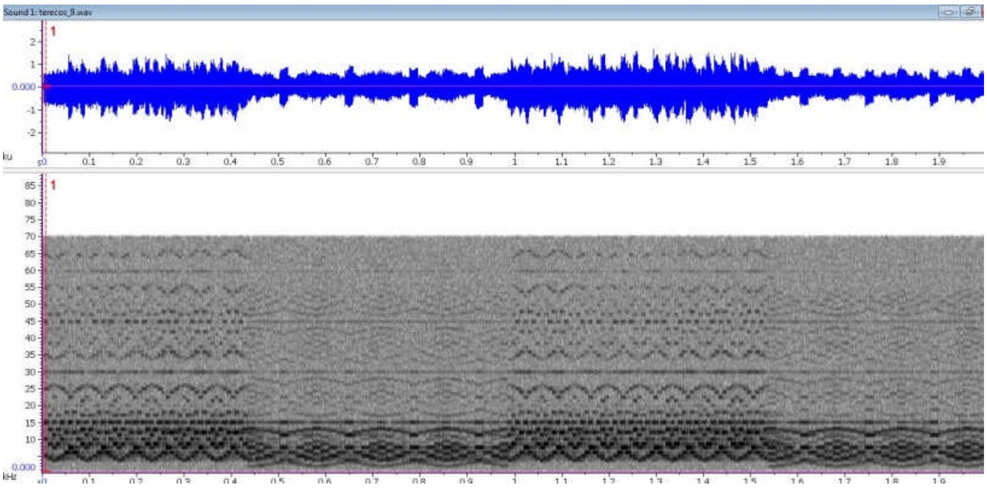


**Figure 51: Terecos Transducer no 2 spectrogram**

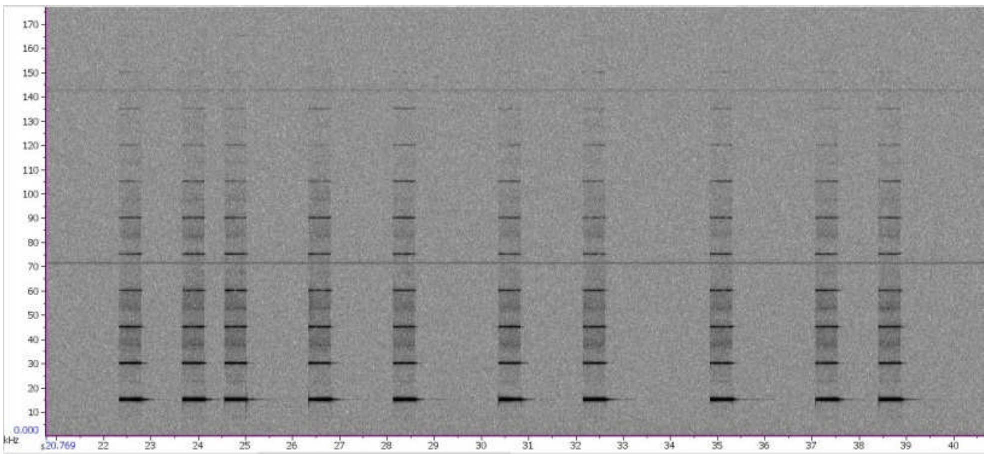


**Figure 52: Lofitech output spectrogram over c. 20 s**

We also had the use of a Lofitech Seal Scarer, which we were told had been modified to output an especially short duration sound pulse (as used by Fjalling *et al*.

2006). This had an average peak SPL of 189 dB with peak energy at 15 kHz and visible harmonics up to 150 kHz (Figure 53). The device outputs 500 ms bursts at apparently random intervals, but averaging around 10 per minute.

A 24V Ferranti-Thompson/Ace-Aquatec device on loan from Ecologic UK was also tested, which had an average peak SPL of 187 dB (range 186 – 187 dB). This device also seems to emit a complex array of short tones (around 5 ms) between 7 and 50 kHz (peak at 25 kHz), with harmonics up to 100 kHz (Figure 54). These tones are emitted in bursts of around 24 seconds in length.

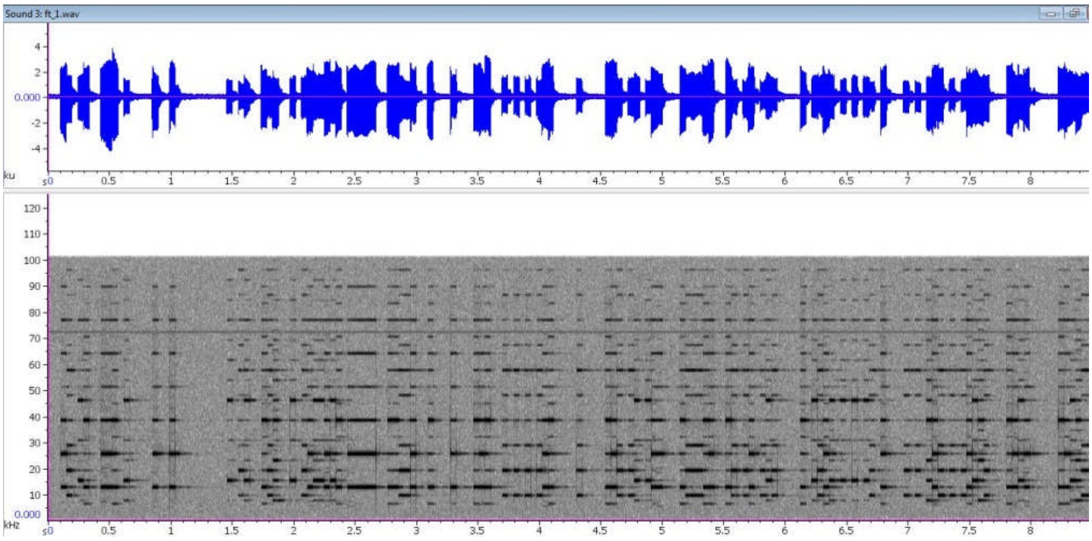


**Figure 53: 24V Ace-Aquatec spectrogram**

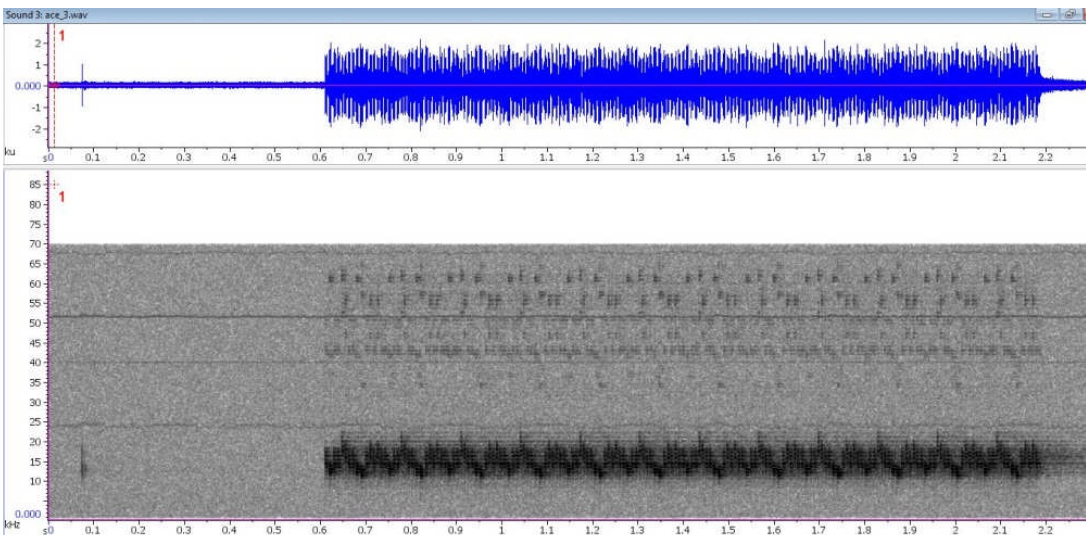


**Figure 54: Ace-Aquatec US3 spectrogram**

On the second date we made recordings of an Ace-Aquatec US3 and found a consistent source level of 185 dB. Interestingly, the signal type for this device was quite different from the other Ace-Aquatec device. This newer model still has tonal noises of around 5 ms, but these are concentrated in the 12 – 22 kHz noise band with a little noise at higher frequencies (though not harmonic) up to 65 kHz. Bursts of these tones last for 1.6 s, but there is also a very short, low energy signal in the same frequency range which precedes each burst by around 0.5 s (Figure 54).

**Table 7: Summary of ADD acoustic properties as measured**

| Device | Peak frequency (kHz) | Average Peak SPL (dB) | Range (dB) |
|---|---|---|---|
| | | | |
| *Terecos DSMS-4* | 7.5 | 178 | 173 – 180 |
| *Ace-Aquatec 24v* | 25 | 187 | 186 – 187 |
| *Lofitech Seal Scarer* | 15 | 189 | 188 – 189 |
| *Ace-Aquatec US3* | 12 | 185 | 185 – 186 |

## 8.4 Discussion

The fact that four of the 16 Airmar transducers tested were producing a very different signal from the remaining devices highlights the fact that it is very difficult for farm site managers to know what the acoustic properties are of the devices they are using. Changes due to malfunction or gradual deterioration are very difficult to detect without adequate equipment.

Testing of other devices also suggests that variability in the noise level outputs are in fact commonplace. This makes it difficult to judge or predict the potential effect on either seals or cetaceans.

The fouling on the Terecos transducers seems to have little effect on the relative output levels. The second transducer did seem to have a slightly higher output power level than the first, despite being heavily fouled. This is interesting as biogenic fouling has been put forward as one of the possible reasons for occasional inefficacy of a device. The regular maintenance of transducers is an extra source of expense to a fish-farm company, but here we can see little evidence that it is likely to have an effect on the efficacy of the device (though this would warrant further investigation before any recommendations about transducer cleaning frequency could be made).

All of the devices tested here had high frequency (ultrasonic) components to the sound signal, which are more likely to affect cetaceans, but only the Lofitech device could be seen to exceed ambient noise levels above 100 kHz. One particular harmonic band from the Lofitech sits at approximately 120 kHz, in the same frequency band as the echolocation clicks of the harbour porpoise raising the potential for masking of echolocation/communication behaviour. The Lofitech was also the loudest device with an average source level of 189 dB.

The difference between the two Ace-Aquatec signals is interesting from a biological perspective, as the more recently marketed device has a very similar source level, but the energy is much more concentrated into the most sensitive area of Pinniped hearing. The short, low-energy noise which precedes the main signal is also interesting as it could be there to act as a conditioning stimulus – though the 0.5 s gap does not allow much time for a seal to react. We have seen no evidence from the manufacturer that this is the intention, but would be interested to hear if that were the case.

We suggest that more widespread testing of the acoustic output of these and other types of device should be undertaken, because it is clear that there is considerable variability in the acoustic signals that are being used at different sites.

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