Report on the use of acoustic deterrent devices (ADDs) in salmon farming to control predation by seals and their wider effects on wildlife

Scottish Animal Welfare Commission

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APPENDICES

1. Introduction

The Scottish Animal Welfare Commission (SAWC) was established by the Scottish Animal Welfare Commission Regulations 2020, made under section 36 of the Animal Health and Welfare (Scotland) Act 2006. The function of providing advice on the protection of wildlife under section 23 of the Wildlife and Countryside Act 1981 has been assigned by Ministerial declaration.

Further information on the Commission, including reports and minutes of previous meetings, is published when available on the SAWC web page.

SAWC's terms of reference are to focus on the welfare of wild and companion animals in Scotland while also providing scientific and ethical advice to the Scottish Government. The Commission will only consider areas that are within the normal current remit of the UK Animal Welfare Committee and the UK Zoo Expert Committee where these relate to the overall responsibility to consider the welfare needs of sentient animals in all areas of Scottish Government policy or at the specific request of the Scottish Ministers. The Commission will not consider matters that are reserved to the UK Government, including the welfare of animals used in scientific procedures.

The Commission provides written reports and opinions to Scottish Ministers giving practical recommendations based on scientific evidence and ethical considerations on the welfare of sentient animals in Scotland, and the impact of policy on welfare.

2. Scope

This report considers the validity of use of acoustic deterrent devices (ADDs) as a means of deterring seal attacks on, and harassment of, finfish in sea pens. ADDs are reported to have adverse effects on the welfare of seals and non-target species such as cetaceans. This topic is within the scope of the remit of SAWC, as aquaculture is not in the current remit of AWC (Animal Welfare Committee) and the issue involves the welfare of wild animals. Aquaculture is of particular importance to the Scottish economy and therefore the Scottish Government and its policies.

3. Background and definition of area of analysis

Context: The Scottish finfish industry

The majority of the finfish reared in Scotland are Atlantic salmon (*Salmo salar*), with 192,129 tonnes produced in 2020. Rainbow trout (*Oncorhynchus mykiss*) are also reared, but in smaller quantities (7,576 tonnes), with very small quantities of other species produced (43 tonnes)[1]. Because of the predominance of salmon and salmon farms, this report primarily considers salmon, but refers to other farmed fish where appropriate. Farmed salmon is the UK's biggest food export, employing 2,500 people in Scotland, generating up to £614 million per year in export sales[2]) and plays a major role in the Scottish economy. As well as the economic value of the industry to Scotland, the salmon industry is important in socioeconomic terms as it is a major employer in remote coastal areas and islands.

In 2021, there were approximately 230 salmon production sites in Scotland, located primarily around the west coast, Highlands and Northern Isles of Scotland[1]. Salmon farming has two major phases. The freshwater phase involves rearing fish in tanks on land from eggs through to fry, then in tanks or pens for the parr and pre-smolt phases. The second phase of the production cycle occurs in sea pens. Systems vary between companies, but on average the salmon production cycle lasts around 2.5 years, with the freshwater phase lasting one year and the seawater phase about 1.5 years.

Description of the issue: seals, cetaceans and farmed fish

Seal interactions with salmon

The use of open-water marine sites for sea pens means that the fish farms are often located in the home ranges of wild species of marine mammals. For example, grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) are commonly found in these areas[3]. These marine carnivores are attracted to the sea farm sites because of the presence of the fish. Predation by seals on farmed fish in sea pens has been stated to result in the death or injury of significant numbers of fish. A study surveying fish farmers reported that 1.4 million salmon were lost to seals over a 10-year period[4]. Anecdotal evidence and the previously mentioned study suggest that seals manipulate the nets to get close to the fish and then bite them through the netting of the sea pen. As well as attacking through the netting, seals occasionally enter sea pens through holes in the nets or over the top of the handrails. The process of removing seals is difficult and can be distressing for the seals and the fish. As well as direct predation, the presence of seals near sea pens, moving through the area or actively monitoring the pens, is thought to be stressful for the fish[5]. If a chronic stress response occurs, it may result in a reduction in immune function, making the fish more vulnerable to disease and parasites.

Seal control and deterrent measures

Because of these detrimental effects on fish welfare and the economics of fish farming, finfish farmers have used several different approaches to try to deter seals from approaching and attacking the sea pens and thereby prevent the negative effects on fish. In the past, lethal control (shooting under licence from the Scottish Government) was used to kill seals that persistently caused damage to fish or caused fish health and welfare issues (so-called ‘rogue’ seals). However, changes to the Marine (Scotland) Act 2010, which came into force in February 2021, removed two provisions for which Scottish Ministers could grant licences to fish farmers to take or kill seals. The purpose of these provisions was to prevent serious damage to fisheries and fish farms and to protect the health and welfare of farmed fish. This means that Scottish Government can no longer issue licences for these purposes. However, data suggest that the use of lethal control for seals was already declining. In 2020, 329 licences were granted, and 104 seals shot, which is a reduction from 2011, when 1339 licences were granted, and 359 seals were shot[6].

Thus, farmers have adopted other methods to deter seals. Farmers more commonly use measures, such as the regular removal of dead fish from the bottom of the pens (‘mort removal’), or the use of ‘extra strength’ netting or secondary layers of netting around the pens[7]. This denser netting or additional netting layers may adversely affect water quality, affecting fish health and welfare. However, this effect can be mitigated by regular cleaning of the netting. Scottish Government provides advice on non-lethal deterrents[8].

Another method of seal deterrent that has attracted controversy is the use of acoustic deterrent devices (ADDs). ADDs are devices that transmit loud (170-200 db), mid-frequency sound from the farm site into the surrounding sea water. The intention is that seals will find the frequency and volume of the sound aversive and be deterred from approaching the sea pens, thereby reducing both attacks and seal presence. Several types of ADD with different characteristics have been developed over time, and they can be deployed in different ways. Therefore, the term “ADD” is a generic term for a group of devices that vary in their specification and use, and consequently may vary in their likely effectiveness or potential for harmful effects. A Scottish Parliamentary Report in 2021 stated that a total of 146 sites (of the 220+ finfish sites in Scotland) used ADDs in 2019[3]. This suggests that approximately 66% of the total number of finfish farm sites in Scotland deployed a device in this period.

It is also important to note that ADDs are also used in other contexts (such as to exclude cetaceans and seals from marine construction sites, e.g., off-shore wind farms) and a number of studies have assessed the effects of these devices on the welfare of these species[9]. As these devices are not used in aquaculture, they will not be considered here, except where the information provided is relevant.

Potential for harmful effects of ADDs on seals and other non-target species

Clearly, the sound transmission from ADDs is designed to be aversive to seals, to attempt to deter them from approaching sea pens and attacking fish or causing stress by their presence. However, transmitting sound into the marine environment at high volumes, with the intention of being aversive to seals, has the potential for adverse effects on other marine species (see below). Several cetacean species are found in these marine areas, including harbour porpoises (*Phocoena phocoena*), bottle-nosed dolphins (*Tursiops truncatus*), minke whales (*Balaenoptera acutorostrata*) and killer whales (*Orcinus orca)*. The numbers of individual animals affected by acoustic deterrents is difficult to determine, but the most common cetacean species found on the west coast of Scotland is the harbour porpoise, with smaller numbers of the other cetacean species present there[10].

The main welfare concerns for seals and cetaceans with respect to ADD use are temporary or permanent loss of hearing, and avoidance of potential habitat areas where ADDs are deployed, which may affect foraging and reproduction[3,11]. Although there has not been a great deal of work done in Scottish waters, researchers believe that the existing evidence suggests that there is a credible risk that ADDs can cause hearing loss with cumulative exposure and affect the habitat use of seals and cetaceans in Scotland[11,12]. The extent of these impacts on the welfare of cetaceans and seals is a major issue related to the use of ADDs by the finfish industry and forms a major part of SAWC's consideration on the validity of ADD use.

Legislation regarding disturbance of European Protected Species
All cetaceans are European Protected Species (EPS) under the The Conservation (Natural Habitats, &c.) Regulations 1994 (legislation.gov.uk). Under these regulations it is an offence to deliberately or recklessly capture, injure, kill, or harass a wild animal that is an EPS without a licence. Of particular relevance to the issue explored in this report, it is an offence to deliberately or recklessly disturb any dolphin, porpoise or whale (cetacean). The term 'disturbance' is not defined in legislation and so may potentially include stimuli that cause any change in behaviour indicating a negative experience. Marine turtles, Eurasian otters (*Lutra lutra*) and Atlantic sturgeon (*Acipenser* spp.), are also protected species and could potentially be affected by ADDs, as could other marine species without conservation protection, but no research has been carried out to assess the potential impacts on these species. The Scottish Government provides more information in relation to this provision and on farmers' responsibilities[8,13].

However, given current scientific advice, it is likely that an EPS licence will be required for all currently available ADDs unless the fish farm operator can demonstrate that the device(s) operating at their site will not cause disturbance to cetaceans[14].

The evidence outlined above suggests that the use of an ADD in an area containing cetaceans may potentially cause disturbance, and therefore, fish farms must demonstrate that no alternative solution exists and apply for a licence. However, aquaculture companies also have a legal duty to ensure the welfare of farmed fish under the Animal Health and Welfare (Scotland) Act 2006. Thus, there are legal drivers both for and against the use of ADDs to deter seals, resulting in a difficult legislative background to the issue.

4. SAWC evidence gathering and analysis

As outlined above, the situation is complex. There are three groups of animals involved: seals, cetaceans and fish. The welfare of the seals and cetaceans could potentially be adversely affected by ADD use, while the welfare of the fish may be adversely affected if ADDs cannot be deployed. In addition, since there is a conflicting legislative background, SAWC considers it timely to investigate the welfare implications of the use of ADDs for seals and cetaceans, and conversely the implications for the welfare of salmon and other farmed fish in the absence of ADD use. However, to justify the use of ADDs, there must be evidence that seals present a threat to the welfare issue of the salmon, both in terms of predation (causing mortality and injury), or in terms of stress causing an increase in disease and reduction in growth rates. There must also be evidence that ADDs are effective at protecting farmed fish from seals, to justify their use by the sector

Therefore the key questions are:
What are the welfare impacts of seals on farmed fish?
What are the welfare impacts of ADDs on cetaceans?
What are the welfare impacts of ADDs on seals?
Is the use of ADDs effective in deterring seals?
Are there effective and viable alternatives to ADDs?
Does the balance of harms and benefits support the use of ADDs in Scottish aquaculture?

To address these issues, a review of the published literature was carried out, which included scientific papers and governmental reports. This review showed that there were some studies available on the hearing ranges of seals and cetaceans and on their response to ADD-like sound transmission. However, only a small number of these studies are set in the Scottish context and in aquaculture[3,4,15]. There are studies that simulate the transmission of sound in marine environments and use the resulting maps to predict possible effects on cetacean ranging behaviour[16].

However, ADD use and design is continually changing, which may mean that the older literature does not represent the current situation. In particular, there is very little published research on whether the fish may suffer from stress due to the close proximity of seals to sea pens (by passing or ‘patrolling’ seals), which could lead to negative effects on fish welfare, leading to increased susceptibility to disease or impaired growth and development, and ultimately to economic losses.

SAWC used a number of approaches to update and augment this information. A survey of Scottish finfish industry groups and relevant NGOs was carried out in September/October 2021 to attempt to gather this information directly. The survey asked for evidence or informed opinion on the effects of direct seal attacks on sea pens, the effects of seal presence on fish behaviour and feeding, disease rates and the perceived efficacy of ADDs or alternatives in deterring seals. Three producer organisations, three NGOs, the APHA and a researcher responded to the survey and provided informative responses (see Appendix III for a list of respondents).

However, there were still unanswered questions about current ADD design and efficacy, and potential effects on wildlife, so a series of interviews with experts was held to address these topics and a visit was made to a salmon farm.

Scientific and other quantitative evidence can be used to establish where welfare impacts or ‘harms’ exist, and also the severity of these harms and the number of animals affected. However, this type of analysis cannot easily be used to compare the relative impact of the different harms on the different species involved in this issue or weigh up the more intangible impacts on an animal’s freedom to perform natural behaviours. To do this, three types of ethical analysis were used.

Firstly, an ethical matrix comprising four principles (welfare, flourishing, freedom and fairness), was used to assess the impacts on the different species and a qualitative approach was taken to reconcile the relative welfare impacts on the species involved. Ethical matrices are increasingly used to deal with complex and sometimes conflicting situations in food production[17], conservation and animal welfare[18]. They can be beneficial in facilitating decision-making, where there are different value dimensions and competing interests for different stakeholders (in this case the different animal populations involved). In the present situation the matrix acted as a means to identify the main benefits and harms for each of the species involved, and the possible trade-offs between the welfare of different species.

Whilst the ethical matrix is designed to identify potential harms and benefits, it does not consider the severity, duration or frequency of these harms, nor does it consider the number of individual animals affected. The European Food Safety Authority (EFSA) uses these principles to determine the magnitude of impacts on animal welfare across a range of situations[19]. This approach was also applied to the current issue on ADD use.

Finally, the seven principles for ethical wildlife management[20] were also considered. These principles were developed by an international team as a means of applying ethical and evidence-based approaches to human-wildlife conflicts. Consideration of the principles facilitates an assessment of all human interactions and interests in the issue. Ultimately, because humans have placed the fish farms into the environment of the seals and cetaceans, it is important to consider what implications this may have, and what remedial actions might be taken by farmers and society.

5. Outcomes of evidence gathering

What effect do seals have on farmed finfish?

Direct losses

There is evidence from Scotland and other countries that direct attacks by seals can cause significant mortality in farmed fish. In 2013, Northridge and colleagues reported that 1.4 million fish were lost to seals over a 10-year period in Scottish salmon farms[4]. In response to the SAWC survey, data were presented from salmon producers organisations (Scottish Salmon Producers Organisation (SSPO) – now Salmon Scotland) that showed that up to 500,000 fish could be lost per year, with 80-92% of Scottish farms affected. Images were presented in the reports from the producer organisations (SSPO, Scottish Sea Farms) that showed injuries indicative of bite wounds, which in some cases caused the loss of substantial portions of the bodies of the fish. It was suggested that seals preferentially target the heart and liver.

Effects of seal presence on stress and subsequent disease in fish

In terms of the effect of seal presence, it was suggested that this could cause reductions in feeding, reduced growth or compromise the immune system leading to secondary disease. However, data directly linking seal presence with disease events or reductions in growth were not presented in the survey responses. It was explained that while feed consumption, growth and mortality are extensively recorded, seal presence could not be systematically monitored. Seals may also be present in the vicinity of the farm for an extended period of time rather than in a single defined 'event'. Additionally, fluctuations in growth and disease occurrence can also occur due to other factors. This means that while fluctuations in feeding and growth occur regularly and can be quantified, it is difficult to link any particular disease event or perturbation in growth or feeding to the presence of seals at particular times.

However, the opinion was strongly expressed that seal presence does cause stress to the fish, and that this has adverse effects on their health and welfare. The SSPO stated that it was universally accepted among fish farmers that seal attacks (the SSPO categorised both 'direct attacks' and 'presence' as 'attacks') cause reductions in feeding and growth. It was noted that these effects were more marked in sea pens with more seal presence/attack, which provides indirect evidence of a link. Further indirect evidence comes from observation of the video camera footage that is used to monitor feeding. It was stated that changes in fish behaviour are seen in the presence of seals and/or seal attacks. However, it should be noted that the fish do not always have sufficient space to 'escape', i.e., by moving far away from the predator, particularly when being crowded for handling, or when kept at high stocking densities in sea pens (although this is not recommended practice).

The SSPO Prescribing Vets Group presented a separate response. The members of this group are experienced fish veterinarians, who mostly work with the salmon producer companies. Their submission stated that based on their professional expertise and experience, seal attacks and presence have significant negative impacts on salmon growth, health and the incidence of disease, and that seal presence causes changes in fish behaviour. Additionally, they stated that they have witnessed instances of disease outbreak where they considered that a seal attack was the primary or an underpinning factor.

Evidence from other species

As there is no research that directly shows that salmon and trout are stressed by the presence of seals, and that stress may be responsible for down-stream effects on health and functioning, we have taken into consideration the literature relating to other species, in order to understand more generally the nature of the response of prey species to predators and to determine whether fishes are capable of showing a similar response.

The effects of the presence of predators on their prey is well known to be stressful and profound, as it is fundamentally related to survival. In addition to lethal encounters with predators, animals that are preyed upon also show changes in foraging response and increased energetic expenditure from mounting a 'fight' or ‘flight’ response. This is typically expressed through activation of physiological pathways, leading to increased metabolism and other changes that promote effective escape (such as increased oxygenation of tissues), and behavioural responses. Stress, even for a relatively short period of time, if severe, can lead to marked behavioural and physiological changes. For example, feeding responses were reduced for six days in two fish species towed in a net for 15 minutes and for one species (walleye pollock, *Gadus chalcogrammus*), the fish did not recover and the treatment resulted in 100% mortality[21]. As a significant predator of salmon, seals are undoubtedly a stressor for salmon, but the extent and impact of this on fish welfare, health and behaviour needs to be assessed, if at all possible.

There is no published study which assesses the impact or extent of a stress response by salmon to the presence of seals. However, recently published papers indicate that fishes of other species show an acute physiological stress response in the presence of a predator. In a study of the response to practices, such as handling and slaughter in European whitefish (*Coregonus lavaretus*), fish were implanted with cardiac monitors[22]. During the experiment, an unintended event occurred where the holding cage of the group of test whitefish was held close to a cage of rainbow trout (*Oncorhynchus mykiss)*, a natural predator of the whitefish. There was a sustained rise in heart rate that lasted at least 12 hours. The authors stated that such a response is suggestive of a major allostatic load on the fish that would have had a negative impact on other physiological processes.

In studies performed with qingbo (the Chinese barbed carp, *Spinibarbus sinensis*) and zebrafish (*Danio rerio*), the fish showed behavioural responses, increases in physiological stress responses (cortisol release), and increased metabolic rates in the presence of predator species[23,24,25]). However, these papers only considered the short-term response of the fishes and not a longer-term impact of the presence of a predator on behaviour and health.

There are studies of responses of prey species to the presence of predators in mammalian species that are of relevance here. Studies of predator-prey relationships on stress responses and longer-term consequences are sparse, but some intriguing studies relevant to the current issue are available, involving terrestrial and aquatic animals, including impacts of predation on seals themselves. Cape fur seals (*Arctocephalus pusillus pusillus*), which are preyed upon by great white sharks (*Carcharodon carcharias)*, have been shown to have higher chronic physiological stress responses (faecal glucocorticoid metabolites), when living in areas of high shark predation, when compared with fur seals in areas of lower predation[26]. Wild ungulate species are also vulnerable to predation, as are domestic ungulates (sheep (*Ovis aries*)), cattle (*Bos taurus*), pigs (*Sus domesticus*)) and poultry species. In the presence of high predator density, wild sheep species escape to areas of their range that are perceived to be safer (something generally not available to domestic animals and farmed salmon which are confined) and then remain immobile until the threat has passed. With greater predation pressure animals maintain longer periods of reduced activity[27]. Greater flight distances, increased vigilance and reduced time spent in maintenance behaviours (such as feeding) are also seen in several wild ungulate species when the predation risk increases. Prolonged avoidance of pastures, where predator attacks have occurred, are also reported in domestic ungulates where they have the opportunity to express these responses[28]. Chronic or prolonged stress, such as that experienced when animals are frequently exposed to predator attack or in areas of high predator population density, can cause reduced growth rates, impair reproductive function, reduce immune responses and increase disease susceptibility[29]. In cattle farming in Australia, for example, predation by wild dogs (dingoes (*Canis familiaris*)) is thought to cause stress-related impacts, including reduced weight gain and poor reproduction (lactation and delayed oestrus[30]) even in the absence of direct attacks on individuals.

Section summary

There are reports that document incidents in which seals have attacked and killed large numbers of farmed salmon. Anecdotal evidence from producers agree that seals may cause high level of mortality. However, there are no data currently available to show that the close presence of seals causes chronic stress leading to increased susceptibility to disease, or other negative aspects of health and welfare. However, it is likely that the fish show a similar stress response to seals as a prey mammal would to the close proximity of a predator. There is also increasing evidence that fishes respond in this way, although farmed animals, including fishes, are often physically prevented from showing avoidance or distancing responses from predators, which may intensify the stress response.

Evidence for effects of ADDs on cetaceans and seals

The main welfare concerns for cetaceans and seals with respect to ADD use are temporary or permanent loss of hearing, interference with the ability of cetaceans to hunt and navigate using their own sonar, and avoidance of habitats where ADDs are deployed, which may affect foraging and reproduction. These aspects will be discussed below.

Cetacean hearing thresholds compared with ADD output

Hearing is central to vital behaviours in cetaceans, such as communication, prey location, predator detection and navigation[31]. The characteristics of hearing that are important with respect to ADD disturbance are the range and sensitivity of hearing. Cetaceans are classified into low-, mid- and high-frequency hearing groups based on their hearing ranges[32]. Minke whales (*Balaenoptera acutorostrata*) are considered to be in the low-frequency class, killer whales (*Orcinus orca*) in the mid-frequency class and bottlenose dolphins (*Tursiops truncatus*) and harbour porpoises (*Phocoena phocena*) in the high frequency class[33]. Hearing thresholds of the relevant cetaceans and seals are shown in Table 1. For reference, reports state that the transmission frequency of ADDs range between 5 to 27 kHz[11] or 2-40 kHz[12] and at a source level (intensity of sound) of between 170-200 dB re 1 µPa. However, since this study was published, most ADD manufacturers have reduced the frequency transmitted by their devices. It is thought that the output of most devices is now below 10kHz, but manufacturers do not typically publish this information.

Table 1. Hearing ranges for marine mammal species commonly found in Scottish waters

Species	Maximum sensitivity (kHz)	Range of best hearing (kHz)	Reference
Harbour seal (*Phoca vitulina*)	1	0.5-40	34
Harbour porpoise (*Phocoena phocoena*)	125	13-~140	35
Bottle-nosed dolphin (*Tursiops truncatus*)	40-100	5-140	36
Killer whale (*Orcinus orca*)	15-20	5-81	37
Minke whale (*Balaenoptera acutorostrata*)	0.4-15		38

The data from the table above shows that the hearing ranges of seals and cetaceans largely overlap, so that there is no frequency that can be used by ADDs to target seals that is outwith that of all species of cetaceans found near Scotland.

Assessing the effects of ADD transmission on cetacean hearing, behaviour and welfare

There are a few studies that have directly measured the hearing range of cetaceans and the parts of the hearing range at which hearing damage occurs[32,33]. The data from these audiometry studies have been used, together with sound pressure level and exposure times created by ADD outputs, in calculations that suggest that hearing damage may occur following exposures ranging from two minutes to several hours, depending on the specifications of the ADD deployed[11].

A range of impacts on cetaceans has also been observed from *in-situ* studies, with individuals' reactions ranging from no reaction to ADD sounds to faster swimming away from ADDs. For example, studies using ADDs designed to exclude cetaceans from construction sites have shown that porpoises and baleen whales (such as the minke whale) avoid areas in which they are deployed[9,39].

There have been a number of studies that suggest that ADDs may cause animals to leave areas of habitat. Studies from Canada have recorded animals retreating from ADD transmissions and lower numbers of cetaceans in areas where ADDs were deployed[40,41,42]. A study in Scotland found that harbour porpoises tend to avoid areas where ADDs are active, but not exclusively, as animals were detected feeding within 200m of an ADD site[43]. In order to understand the potential geographical spread of the ADD sound, one study[16] created a map depicting areas of sea off the western coast of Scotland and around the Northern Isles that were likely to receive levels of ADD sound that could affect cetaceans. The resulting map showed almost total geographical coverage of some areas, but given the different duty cycles or schedules of use, this does not mean that the transmission was constant.

However, there are some methodological issues with these studies. In studies that observe the response of wild or captive animals to ADD deployment, only small numbers of animals are typically used. The studies are often of a short duration, which is not appropriate for understanding the effects of long-term use of ADDs in commercial finfish farming.

However, local environmental conditions, such as water depth, sediment type, slope of the seabed, and the complexity and topography of the seabed and coastline, can affect the propagation loss of ADD outputs and hence their effectiveness against seals or their adverse effects on cetaceans[12,43]. These environmental conditions are difficult to account for in modelling studies. Critically, many of these studies were based on older models of the ADDs, which were often used for prolonged periods of transmission, and used a wider range of frequencies and a longer duty cycle (duration of transmission) than current models of ADDs. These studies also mostly used a particular brand of ADD which was not widely used in Scotland.

Additionally, if ADDs were causing the permanent exclusion of cetaceans from their home ranges, it would be expected that reductions in the numbers of cetaceans living in the areas where fish farms are located would be observed. An assessment which considered information on the abundance and distribution of the major species (produced by large-scale surveys carried out in European waters), suggests that cetacean numbers are stable in the North Sea and on the European continental shelf areas, but data are not available for the west coast where large numbers of fish farms are located[45].

Effect of ADD transmissions on seal welfare

ADDs are considered to work by either causing auditory pain in the seal, such that the animal avoids the area where pain is experienced (known as conditioned place avoidance), or by creating aversive but non-painful acoustic stimuli that alter the behaviour of the animal to avoid exposure (known as a startle response). Newer types of ADD evoke a startle response. Seals may suffer acute and chronic exposure to the sounds from ADDs, which may have negative effects on their welfare. With a wide hearing range of 0.5-40 kHz[34], it is unclear how temporary or permanent impairment, or even loss of hearing may affect seals, but impacts may include reduced dynamic range (sound intensity), frequency discrimination and passive listening space. These effects in turn could impact detection of predators and prey, and communication with other seals, such as competition between males for females, and vocalising in the breeding season to attract mates[44], as well as increased energetic costs caused by moving greater distances[46]. Even temporary impairment of hearing could have slight cumulative effects that become permanent injuries. It could be argued that permanent loss of hearing caused by ADDs could result in more seal depredation from sea pens as the seals will become "immune" to the deterrent effects of the ADDs and may become more dependent on an assured supply of food. In some studies, use of ADDs has resulted in increased losses to seals through a "dinner bell" effect of the ADDs, which attracts the seals when switched on[11].

It has been estimated that over short time periods, permanent damage to hearing may occur in harbour seals at a distance of only 7m from ADDs, but permanent damage may also occur at distances up to 60m when the exposure occurs over longer periods of months and years[11]. Exposure times that cause hearing impairment vary between different brands of ADD, ranging from 3 minutes to 57 hours and 51 minutes[11].

Studies in the wild suggest variable responses of the seals to ADD deployment, with some seals avoiding sites with ADDs, sometimes for only a short period, and others where ADDs do not appear to have much impact on seal behaviour. Harbour seals may stop foraging and move away when they are within 1 km of ADDs, which are being used at levels of 134.6 dB re 1 μPa (RMS)[46]. Seals have also been reported lifting their heads out of the water or even hauling or leaping out of the water when close to ADDs to avoid the sound, potentially reducing foraging time[46,47].

Another study was carried out in which seven harbour seals were tagged to examine their potential exposure to ADDs and potential for auditory impairment, if they were present. All seals were potentially exposed to ADDs at 51 of 56 sites, where mean ambient noise levels were exceeded. Temporary auditory impairment was expected in one of the seven seals (14.3%) across 1.7% of waters per 24 hours, which over time could impact significantly on the local seal population[44]. Another study used FaunaGuard Seal modules, which operate at 0.2-200 kHz for 3-10 seconds (142 dB re 1 μPa) and found that there was no permanent hearing impairment, if the seals were more than 100-200 metres away[48].

In humans, persistent low-level noise exposure may increase stress hormone levels, blood pressure and heart rate, leading to hypertension, arrhythmia, dyslipidemia, increased blood viscosity and blood glucose, and the activation of blood clotting factors, consequently increasing the risk of cerebrocardiovascular diseases such as stroke, ischaemic heart disease, acute myocardial infarction, heart failure, and arterial hypertension[49]. Therefore, chronic noise from ADDs may have similar effects on the health of seals in close proximity to finfish farms. As well as the direct effects of ADDs on seal behaviour, stress responses (such as a startle response), and possible hearing damage, effective use of ADDs may also exclude seals from feeding, resting and breeding habitats. Depending on the availability of suitable alternative habitats, this may affect hunger and feeding motivation (with a potential impact on increasing attacks on farmed fish), social interactions, reproductive success, and disease resistance as outcomes of chronic stress.

Although ADDs are normally aversive to harbour seals, captive seals habituated quickly when exposed to sounds at 146 dB, when they were fed, which suggests that seals are willing to overcome discomfort, if they are hungry, so that motivation may be an important factor in the effectiveness of ADDs[15]. However, hearing impairment would not be expected at this source level[33]. Habituation times vary greatly between studies from a few days to up to several years[11].

Section summary

Although the evidence comes from a number of different sources and methodologies, it indicates that the sound transmitted from ADDs has the potential to cause hearing damage in cetaceans when exposed to the sound over a period of time. Exclusion from home ranges and feeding areas is more difficult to determine given the paucity of data. There is also evidence for the potential for hearing to be damaged in seals, and other impacts on seal welfare. The change in use of ADDs over time, and the variety of different brands with different specifications in current use also means that it is difficult to determine what the current situation is, compared to these published studies.

How effective are ADDs? Are there any viable alternatives?
There are varying reports on the effectiveness of ADDs. Some observational studies in fisheries have shown that ADDs are effective in deterring seals from salmon netting sites (i.e. not aquaculture sites[47,50]) over a long period of time, while others have found that seals eventually return to the site. Experimental studies using live seals in a test pool have shown that the seals habituate to the sound or are able to overcome it when food was offered[15]. A survey of managers of marine salmon sites in Scotland and found that only 23% of them thought that the ADDs were very effective, but 50% thought that they were moderately effective[51]. However, it was noted that their use had increased markedly in the preceding decades. In another survey of Scottish fish farmers, there was little consensus found among fish farmers about the efficacy of ADDs, but most thought that they are effective at least some of the time[43]. A major study in Scotland[5] analysed the number of months in which seal predation was recorded as a function of whether the ADD was turned on or not, and also compared predation at sites where ADD use was not permitted with sites where it could be used. The results were equivocal. Overall, reports of seal predation were higher on farms using ADDs, but this likely reflects the fact that farms with seal predation issues are more likely to use ADDs. However, the small number of farms that were not permitted to use ADDs had higher predation rates than farms allowed to use ADDs, suggesting some efficacy of the devices. Responses to the SAWC survey from industry stated that ADDs formed 'part of a wider predator management strategy' and that ADDs' effectiveness depended on a number of factors such as farm location and seal predation pressure.

Other main means of deterring seals are frequent removal of mortalities from the bottom of nets, seal blinds and double-netting, maintaining good net tension and the use of extra-strength, high-density netting[7]. This netting requires higher levels of maintenance to prevent algal growth reducing water flow, but appears to have had some success in some locations. Research into electrifying the netting of the cages or the use of electrified or repellent-tasting baited 'dummy' fish are other alternatives[7]. The use of higher handrails or 'top-nets' (over the exposed water at the top of the net) were also suggested. The use of larger pen sizes, or lower stocking densities that allow the fish more room to escape or retreat were also suggested. However, many of these measures will deter seal attacks, but not necessarily seal presence.

Section summary
Uncertainty about the effectiveness of ADDs, coupled with apparent reluctance to give up their use, suggests that they may work in some cases for some of the time. Demand for their use suggests that seal predation is a constant problem for fish farmers, but also that there are not any sufficiently effective alternative solutions currently available

Developments in seal deterrent methods
When ADDs were first installed to deter seals, they tended to be turned on continuously, but more modern devices have the ability to be used only when seal presence occurs or is suspected[7]. The use of technological solutions to detect seals in the vicinity of the nets to trigger ADD transmission has been recommended[7] and is being used by at least one ADD producer, and others may follow this route. There is potential for ADDs to be able to detect only those seals that are planning to attack

(such as swimming directly towards a sea pen) and these ADDs may also be able to detect the presence or absence of cetaceans before deployment. Similarly, if the technology could distinguish between cetaceans and seals, this would allow further targeting of ADD deployment and avoid unnecessary impacts on cetaceans. However, further development and testing of the technology are required.

Further developments of a range of non-lethal control options are essential, to avoid a continuing "arms race" between seals and fish farmers in the development and use of non-excluding technologies. To resolve the issue of seals entering the pens over the sides of the pen, alternative designs could be developed. Sea pens with higher side walls that prevent seal ingress have been designed and used in areas of Tasmania, for example. Although this design requires a much bigger pen diameter than currently used in Scotland, and may pose operational difficulties, it may provide a viable solution to this problem.

More research is needed into the viability of alternatives, such as methods that startle seals. Using ADDs that elicited the startle reflex in grey seals led to a sensitisation (i.e., enhancement) of avoidance responses and resulted in avoidance of food locations near the source of the startling sounds[52]. Where ADD startle devices have been used for seals, the numbers of salmon predated by seals fell by 91%, while the numbers of harbour seals fell by 91% up to 250m away and there was no habituation. However, the studies were short term, and carried out over periods of 19 months and two months respectively[53,54].

Section summary
There are a number of promising developments that could reduce the use of or replace traditional 'constant transmission' types of ADDs. These include devices that evoke a startle response or technology that detects seal presence and/or the presence of cetaceans.

6. Ethical Analysis and Critical Issues

Three ethical frameworks were used to assess different aspects of this problem and are discussed below.

Ethical matrix
Ethical matrices are used to assess multiple principles across multiple actors and are particularly used to deal with complex and sometimes conflicting situations in food production. The matrix that was used set out the positive and negative outcomes of the use of ADDs in general with respect to the principles of 'welfare', 'flourishing', 'freedom' and 'fairness' for the species involved (farmed fishes, seals, harbour porpoises, killer whales and minke whales). This approach allows a greater consideration of the more intangible elements of an animal's quality of life that cannot easily be understood from the scientific data. A summary is shown in Table 2.

Table 2. Summary of potential positive outcomes (+) and negative outcomes (-) for each species in the scenario where ADDs are used effectively.

Species/aspect	Welfare	Flourishing		Freedom	Fairness
Farmed Fish	Lower risk of mortality, injury +	Fewer other control measure +			Duty of care exercised +
Seals	Hearing loss; temporary and permanent -	Disrupts feeding on farmed fish -	Prevents entry to sea pens and need for removal +		Displacement from habitat Duty of care not met -
Harbour porpoise	Hearing loss; temporary and permanent -	Disrupts echolocation and feeding -			Displacement from habitat Duty of care not met -
Bottle-nosed dolphin	Hearing loss; temporary and permanent -	Disrupts echolocation and feeding -			Displacement from habitat Duty of care not met -
Killer whale	Hearing loss: temporary and permanent -	Disrupts echolocation and feeding -			Displacement from habitat Duty of care not met -
Minke whale	Hearing loss: temporary and permanent -	Disrupts feeding -		Disrupts navigation and migration -	Displacement from habitat Duty of care not met -

This approach suggests that there are potential negative impacts on seals and at least four species of cetacean across 2-3 dimensions, while the fish receive positive impacts in three dimensions. At first sight this suggests that there is a greater potential impact on the cetaceans as a group than on the other species.

Consideration of magnitude and severity

However, while this ethical matrix approach allows us a better appreciation of the different dimensions where ADD deployment has positive and negative effects, it does not capture the severity and duration of harms, nor the number of animals affected. Animal welfare pertains to the experience of the individual animal. It is SAWC's opinion that the welfare needs of all sentient animals should be considered. Fishes are considered sentient animals. The numbers of fish affected by seal attacks is far greater than the number of seals and cetaceans affected. Mortality is an outcome for the fishes attacked by seals, and cetaceans forced out of their home ranges by ADD deployment, but mortality rates are far higher in the fish. The severity of other injuries is also arguably higher in the fish, as we are comparing bites to the body of the fish compared with hearing loss in seals and cetaceans, although both types of injury may be fatal or contribute to poor viability. Stress may affect all species. If we applied a 'weighting' system, which accounted for numbers of animals involved and the severity of the negative welfare effects, it would appear that the positive impacts of ADD use are greater for the fish than the negative impacts for the seals or cetaceans.

Application of the Seven Principles for Ethical Wildlife Management to seal control

There is a third ethical element to consider in this context, and that is the role of humans. The farmed fish have been placed into the habitat of the wild seals and cetaceans by fish farmers, who are providing food for the wider human population, and this placement has caused the conflict between the welfare interests of the wild animals and the farmed animals.

The international consensus principles for ethical wildlife control[20] were developed as a means of applying ethical and evidence-based approaches to human-wildlife conflicts, and these principles may be helpful in this context. These ethical principles apply to the control of seals around fish farms, where there is a clear conflict between human management of fish populations, fish welfare, and seal welfare. The first principle and second principles suggest modifying human practices and justification for control are the initial approaches to resolving conflict. In the context of fish farming, and particularly the impact on fish welfare of seal attacks and presence, some method of minimising the impacts of seal predation on fish welfare is justified. However, we suggest also that research and technological developments to improve barrier methods to deter seals and reduce the impact of deterrent methods used (such as ADDs) should also be investigated and would be encouraged under the application of the Seven Principles. The third principle addresses the need for clear and achievable outcome-based objectives. This implies that the need for using ADDs must be based on evidence for a negative impact of seal behaviour on fish welfare, and that monitoring of the efficacy and outcomes of the use of ADDs on predation are implemented to justify continued use. The fourth principle of animal welfare has been partly addressed above, but continued research into the welfare impacts of use of ADDs, and methods to minimise these are still required. The remaining principles require consideration of the social acceptability of the use of ADDs (for example in the communities, which might be impacted by their use), requirements for systematic planning to avoid the continued need for the use of ADDs and to minimise conflict with seals in the future and focusing management attention on the specific situation on each site rather than employing a blanket approach to seal management.

Section summary

The greatest impact on welfare lies with the fish, given that seal attacks can result in serious injury and death. Large numbers of fish are also affected. However, given that it is humans that place the fish into the natural habitat of wild seals and cetaceans, it is incumbent on humans to place significant effort into finding viable options to safeguard the welfare of these wild animals, whilst still protecting the welfare of the fish.

7. Conclusions and Recommendations

1. The use of ADDs may be justifiable in some situations when there is no satisfactory alternative, as their use appears to be effective in some situations and contexts. However, SAWC recommends the application of the international consensus principles of wildlife control in the management of seals to ensure that this is continually evaluated in each situation.

2. When it has been identified that ADD use is justifiable, the selective or targeted use of these devices is strongly recommended. It would appear that ADDs are initially aversive to naïve seals, but that they may overcome the unpleasant nature of the sound if they have learnt that food (fish) is available. Therefore, use should be reserved for critical periods or as part of a suite of controls that can be used at different times.

3. SAWC recommends that any appropriate measures that can be made to reduce the possibility of harm to cetaceans is implemented as far as possible. Devices that are deployed only when seal attack or presence occurs, during periods such as fish crowding, when seals are likely to attack, are recommended. ADDs should also only be deployed when cetaceans are at a safe distance away. Available technologies should be reviewed at least every five years to determine whether ADD use can be phased out.

4. Alternative strategies to deter seals should also be used wherever possible. These include strategies that the industry is currently using or developing, such as extra-strength netting, double-netting and removal of mortalities. Altering sea-pen design to prevent seals entering pens should also be considered. As above, a review of state-of-the-art technologies should be made at least every five years to determine whether viable alternatives to ADDs are available and ADD use can be phased out.

5. Further research is required. Alternatives to the use of ADDs that do not impact on the welfare of protected species should be explored, as well as the use of technologies that protect fish, deter seals, but do not harm cetaceans.

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Appendix I – Questionnaire sent to stakeholders

We would like to understand the experiences of stakeholders in the use of these devices, and to gather any information, data or opinions from stakeholders that are relevant to the welfare impacts on fish and seals. The group seeks information on the following topics. We would like to gather opinions and experiences of all stakeholders and would also be very interested in data or video footage of the responses of salmonids to seal attacks or presence.

1. Firstly, please state which organisation/company you are representing and your role in that organisation, or whether you are replying independently

In your experience, please provide any information you may have on:

2. The extent of fish predation by seals:
   a. estimates of numbers of attacks, number of fish predated and economic losses. Information on any other impacts of seal presence would be very useful

3. The impact of seal attack or presence on farmed salmonids in terms of the physical aspects of fish welfare:
   a. Types of injuries and mortality and numbers of fish affected
   b. Effects on growth rates and disease?
   c. Do you have any data available to support this?

4. The impact of seal attack or presence on farmed salmonids in terms of behavioural responses:
   a. Are there observable responses from the fish to seal presence or seal attack such as changes in feeding or changes in swimming patterns or schooling?
   b. How close do seals need to be to elicit these responses?
   c. How long do these responses persist if the seals move away?
   d. Are any data or video footage available that illustrates this?

5. What is your opinion on the efficacy of currently used acoustic deterrent devices in deterring seals?
   a. Are they effective in preventing seal approach or attack?
   b. In what circumstances are they or are they not effective?
   c. Are some devices more effective than others?

6. What alternative practices or deterrents are effective?
   a. If you farm salmonids, what other alternative practices or devices (e.g. seal blinds, tension nets) have you tried and how effective are they?
   b. What other methods do you think may be effective (whether you have tried these or not)?

7. Are there other impacts in terms of sustainability of the business or in terms of social acceptability of approaches to deal with seal presence?

8. Please also provide any other comments you would like to make on this issue

Appendix II – Membership of the Scottish Animal Welfare Commission

The Scottish Animal Welfare Commission Members are:

- Professor Cathy Dwyer from Scotland's Rural College and the University of Edinburgh (Chair)
- Dr Harvey Carruthers, veterinary surgeon
- Mike Radford, lawyer specialising in Animal Welfare
- Paula Boyden, Veterinary Director at Dogs Trust
- Professor Marie Haskell, Professor in Animal Welfare Science at Scotland's Rural College
- Dr James Yeates, Chief Executive Officer of the World Federation for Animals
- Libby Anderson, Animal Welfare Policy Advisor
- Dr Simon Girling, Head of Veterinary Services, Royal Zoological Society of Scotland
- Mike Flynn, Chief Superintendent at the Scottish SPCA
- Dr Pete Goddard, veterinary surgeon
- Dr Andrew Kitchener, Principal Curator of Vertebrates at the National Museum of Scotland
- Dr Ellie Wigham, Lecturer in Veterinary Public Health, University of Glasgow

Full biographies can be found here.

The following were co-opted onto the SAWC Aquaculture Sub-committee and SAWC is very grateful for their expertise and guidance:

Professor Jimmy Turnbull, Institute of Aquaculture, University of Stirling
Lorna King, Marine Scotland
Vivienne McKinnon, APHA

Appendix III – Acknowledgements

Dr David Grummett of the University of Edinburgh and AWC, kindly lent his expertise in developing the ethical matrix.

The following organisations provided written submissions to the Commission.

ACE Aquatec
APHA (Animal and Plant Health Agency)
BTA (British Trout Association)
OneKind
CIWF (Compassion in World Farming)
SSF (Scottish Sea Farms
SSPO (Scottish Salmon Producers Organisation): (now known as Salmon Scotland)
University of St Andrews
Whale and Dolphin Conservation

Scottish Government
Riaghaltas na h-Alba

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