



Humane Predator Control The case for acoustics

AA-01-044

by

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Summary

It is estimated that between 1 and 4 million farmed Scottish salmon die annually from marine mammals, principally common seals. The predation of farmed fish by sea mammals is not only financially damaging to the farmer but is unacceptable from an animal welfare viewpoint. Many sea mammals predate on fish but, in the case of the seal, far fewer than 1 in every 100 learn how to predate farmed fish. Seals predate farmed fish by first frightening them and it is argued that many predator attacks go unnoticed due to the lack of dead fish. Predator attacks, whether successful or not, leave the fish stressed and therefore more prone to disease.

All anti-predator measures currently employed have some environmental impact but Acoustic Deterrent Devices (ADDs) are alone in being humane, non-lethal and able to reverse any environmental impact by remaining silent.

The report reviews our current knowledge of the effects of underwater sound on sea mammals and how it can be used to control their behaviour (target animals) at aquaculture facilities.

It is obvious that any acoustic deterrent must eliminate the possibility of damaging the hearing of the target animal otherwise the device will quickly cease to be effective. Research results on captive sea mammals allow us to define the parameters that will achieve efficacious scaring without hearing loss. The report derives a Figure of Merit and compares several commercially available ADDs.

It is not surprising that a device designed to scare one sea mammal will also scare other sea mammals. The report reviews the literature on the subject and finds that only continuous noise-makers have been studied and of all these noise sources only one model of ADD – The Airmar dB II Plus. Even so several authors report that the non-target animals quickly moved back into the area once the sound had been switched off. The Airmar dB II Plus makes over 1,000 times the noise of the Ace Aquatec Silent Scrammer hence the report suggests that these field results found for the Airmar do not apply to Silent Scrammers which probably have no measurable aversion or disturbance ranges.

The report concludes that the use of ADDs at fish-farms is beneficial to the farmed fish and, unlike anti-predator netting and shooting, does not result in the destruction of wild-life. Careful design of the ADD can eliminate the possibility of hearing damage to all sea mammals and parsimonious use minimises the possibility of disturbing non-target species.

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1. Introduction

Many marine mammals eat fish as part of their natural diet and, since the introduction of fish farming, some individuals have added farmed fish to their menu. The main offender is the common seal in the Northern Hemisphere and the South American sea-lion in the Southern however all sea-lions and seals local to an aquaculture facility will attempt to prey on this captive food supply as will dolphins, mink and otters.

Economically the effects of sea mammal predation are high. Ross (1988) put the losses of the Scottish salmon industry at between £1.4 and 4.8 million pounds – between 1 and 5% of the (then) total revenue. The costs of sea mammal attacks is higher due to the stress that predator attacks induce in the fish which leads to poorer growth rates, lower immunity to disease and poorer quality fish (Nash *et al* (2000)).

Fish farmers, like all farmers, have a duty of welfare to their stock. The anti-predator measures used to control seals currently are: anti-predator netting, shooting of “rogue” seals, net tensioning and acoustic deterrents (ADDs).

Each of these measures has environmental consequences. Anti-predator netting drowns diving birds, seals and porpoises (Ross (1988)). Shooting of “rogue” seals is terminal for not only the animals involved in predation but for many others unfortunate to be in the vicinity. Net tensioning, widely practised in the industry, is good husbandry, does reduce predation losses but does not eliminate the stress on farmed fish (see next section). ADDs, when they are making noises, disturb other marine mammals in the vicinity (Olesiuk *et al.* (1995)).

Of all these measures the only one that is humane, non-lethal and capable of reversing its environmental impact is the acoustic deterrent (Olesiuk *et al* (1995) and Morton & Symonds (2001)).

2. Marine mammals and Farmed Fish

Farmed fish are constantly under threat from marine mammals which are adaptive enough to exploit this “new” food source.

2.1 Otters (and Mink)

In Scotland otters generally nibble a small hole just under the water-line, grab a single fish and depart. Whilst this has to be stressful to the farmed fish, otters seem to limit their hunting to individuals so it is likely that the remaining fish are not stressed for long. Mink show similar behaviour.

2.2 Dolphin

Dolphin attacks are rare in Scotland but are reported to occur more frequently in the Mediterranean. I have talked to two people that witnessed a Scottish attack. A small school of dolphins – frequent visitors to the farm – decided one day to attack the fish in the harvest pen. In unison the 5 or 6 dolphins dived under the pens and pushed the bottom of the nets upward, biting the fish as they went. Within seconds the surface of the water was “boiling” with fish trying to escape. The witnesses were powerless to stop the attack and the dolphins ignored all their efforts. After 15 minutes the dolphins departed. The farmers took 2,000 dead fish from the pens. In each case the head had been crushed as if it had been placed in a vice but were otherwise unmarked. The motivation behind this attack will remain a mystery but these animals are very powerful and, if they chose to attack farmed-fish on a regular basis, would become a serious problem predator.

2.3 Seal (and Sea-Lions)

I will concentrate this discussion on our knowledge of seal behaviour in the Northern Hemisphere (Scotland, Canada and USA) where the common seal is the major predator. The consequences of sea-lion attacks – ie what damage they do to the fish - (both North and South) are identical to the seal indicating a similar method of attack.

Direct observations of seal attacks are rare. Tillapaugh (1991) reports an account from a diver who witnessed a common seal attacking a pen. “*The seal circled the netpen until the fish were frightened*



enough to charge the opposite side of the pen. The seal then dove under the pen and attacked the fish pushing against the side of the netpen. **This procedure was repeated several times.”**

Seals rarely damage the growing net but grab a fish between their front paws, bite the abdomen of the fish and suck the guts through the mesh. The fish is then released to die sometime afterwards. In the wild a seal would need between 1 and 3 salmon to satisfy its daily appetite. Tillapaugh calculated the seal needs to kill 45 farmed fish per night to achieve satiation. In my experience (from farm records) a predating seal will kill nearer 70 farmed fish per night. Many of these dying animals linger for days and I find the sight of them distressing.

Fish respond to stress by losing their appetite, become easier to panic but slower to respond. Therefore it is not surprising that predating seals target only one or two pens on a farm and by continually stressing the fish the seal reduces its effort to get the same food-reward.

It would appear that this wasteful, unnatural behaviour is learned by very few individuals. In 1999 it was estimated that the Scottish grey seal population was 125,000 and the common seal population 29,000. Scotland produces some 40 million farmed salmon annually. Between 2 and 10% ♦ are lost to seals which represents between 1 and 4 million individuals. Using Tillapaugh’s figure of 45 fish per night we can calculate that this loss can be attributed to between 50 and 250 seals should they feed exclusively on farmed salmon. Predation is more pronounced in the Winter than in the Summer but even if we were to multiply the number of seals by five-fold **less than 1 in every 100 seals regularly predate on farmed salmon.**

2.4 The impact of predation stress on Farmed fish

Seals (and dolphins) will attack farmed fish in well-tensioned nets or when anti-predator nets are installed. The attack might (from the seal’s viewpoint) be unsuccessful but the fish will remain stressed for several days. An example of this was recorded by Ace Aquatec during the ANSS proving trial (AA-01-043).

The ANSS is unique in its ability to monitor the fish but remain totally silent (LISTEN mode). By chance the equipment was in this mode on the night of the 7th March 2002 when a seal attacked Pen 9. The attack spanned most of the night but was particularly ferocious between 03:23 and 06:21 on the morning of the 8th. This attack was unsuccessful and, probably because it was, was not repeated (Figure 4).

Whilst the attack was unsuccessful it had its consequences. Figure 5 shows the triggering activity against the Specific Food Ratio (SFR) for Pen 9. SFR is a measure of how well the fish are growing. The data has a variability from day to day so has had a 3 point smoothing average applied in an attempt to see the data trends. Until the 4th March the Trigger in Pen 9 had not sounded and the SFR had been on the increase. This situation reversed itself, the SFR started to fall and the proportion of Triggering events belonging to Pen 9 rose. The dramatic attack of the 7th March was successfully thwarted but the SFR did not reverse the downward trend for a further 5 days.

This sudden change in growth rate is common-place in the industry hence it is reasonable to conclude that attempted predation by seals, resulting in stressed fish, is more wide-spread than predicted by actual mortalities.

3. Types of ADD

There are several commercially available Acoustic Deterrent Devices on the market but they can all be categorised into one of three types: acoustic barriers, timed conditioners and triggered conditioners.

♦ Seals will predate on fish of most sizes so the fish predated would be worth approximately half the harvest value.



3.1 Acoustic Barriers

ADDs that fall into this category make noise sufficiently often so as to exclude all seals from the protected farm. The philosophy is that the animals are physically separated from the fish, have no opportunity to learn how to predate farmed fish and therefore will return to eating wild fish. The best and most numerous example of this type is the Airmar dB II Plus. In this report I will refer to acoustic barrier types as continuous noise-makers.

3.2 Timed Conditioners

Timed conditioners are ADDs that make sounds on an irregular basis. The philosophy is linked to negative reinforcement, that is, seals within range do not know when they will receive a loud irritating noise but quickly learn that they will shortly receive one. By associating the protected farm with the unpleasant noise they vacate the area. The best example of this type was the Ferranti-Thomson scammer. In this report I will refer to acoustic conditioners as discontinuous noise-makers.

3.3 Triggered conditioners

Triggered conditioners are those ADDs that make sounds in response to a predator. The only example of a Triggered ADD currently available is the Ace Aquatec Silent Scrammer. This scammer goes several stages beyond the definition of a Triggered ADD in that it sounds only in response to the behaviour of the predator. The philosophy is that a seal, which has panicked the fish, receives an audible conditioning signal followed shortly after by the loud irritating noise. The seal quickly associates its behaviour (frightening farmed-fish) with the conditioning signal. The system is a classic example of negative reinforcement as it conditions the animal's behaviour directly.

4. Hearing, Perception and Acoustics

4.1 The Decibel

Sound levels are nearly always quoted in decibels. The decibel is a tricky unit of measurement as it is both a relative quantity and is logarithmic. To explain: 40dB by itself is meaningless but 40dB(A) means 40 decibels above 20 micro-Pascals, which is meaningful. Likewise the difference between 40dB(A) and 46dB(A) sounds small but actually 46dB(A) is twice as loud as 40dB(A). If this was not enough there are several standards (see Table 1) which are quite different from each other.

Table 1			
Scale	Use	Units	Conversion into dB re 1 μ Pa
dB(A)	Air	dB re 20 micro-Pascals	add 26dB
dB re 1 μ Pa	Water	dB re 1 micro-Pascals	add 0dB
dB re 1 μ Bar	Water	dB re 1 micro-Bar	add 100dB
dB re 1 dyne/cm ²	Air	dB re 1 dyne/cm ²	add 80dB

It is also hard to grasp how sensitive our ears are. When we listen to a tone producing 1 acoustic milliwatt at our ear this is equivalent to a sound level of 105.5 dB(A). Should the tone be at 3.5kHz (our most sensitive spot) that tone will be 113.5 dB above our hearing threshold. We would have to reduce the volume by nearly a million times (0.02 micro-watts) before we cease to hear the sound.

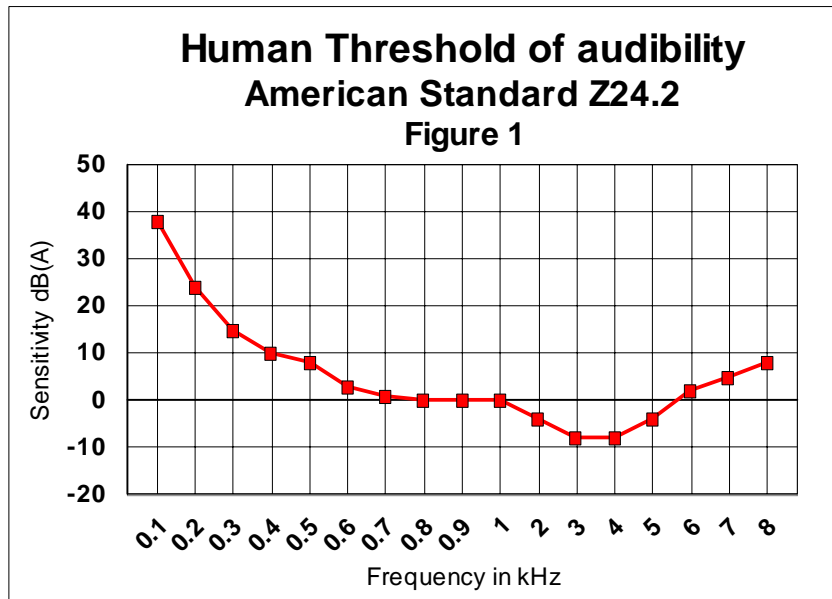
4.2 The ear

Whilst the outer ear can differ markedly, the structure of the inner ear is essentially the same for all mammals. Detection of sound takes place in the cochlea - a fluid-filled spiral shaped cavity that houses the Basilar membrane. Within this membrane are thousands of nerve endings. It is the selective vibration of these nerve-endings that excite the brain into recognising sound.

With age some of these nerves are over-stimulated and cease to function which is why many older people become hard of hearing. In mammals these nerves cannot regenerate so the loss is permanent. Audiologists term this PTS or Permanent Threshold Shift. PTS can be highly selective in frequency when an individual is exposed to the same sound too loudly and too frequently so that only certain nerve-ends are over-stressed and cease to function.

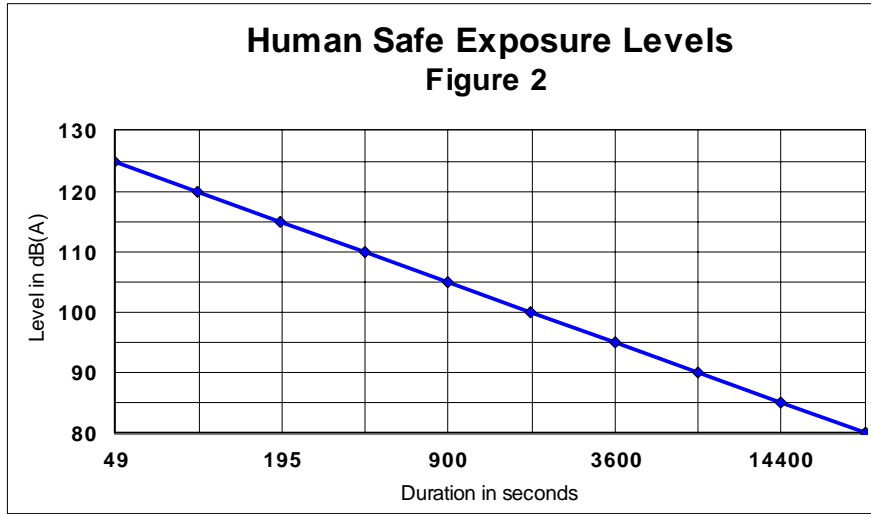
Audiologists tend not to design experiments that result in PTS but have extensively studied TTS. Temporary Threshold Shift (TTS) is a phenomenon of our daily lives. For example a person cutting the grass with a petrol-driven lawn-mower will probably develop TTS within a few minutes and, when finished, find that the world is a quieter place – temporarily. The nerve endings have been desensitised and temporarily you become slightly deaf. The onset of TTS is fairly accurately predicted and depends on the individual’s absolute hearing threshold, the loudness of the sound and its duration. What is less well predicted is the degree of deafness experienced and the recovery time. In our lawn-mower example sounds have to be twice as loud(ish) for half an hour(ish), but it could be 4 times and 10 minutes, depending on the individual.

The results of this work have been embodied in Health and Safety legislation which specifies the loudness of sound – 80dB(A) in USA, 90dB(A) in Europe - that an individual may be exposed to for 8 hours per day which will not result in TTS (and not result in PTS after 30 years). The exact application of this criterion depends upon the frequency content of the sound because the human ear – in common with all mammals – is more sensitive at some frequencies than at others, hence 80dB(A) applies at our most sensitive point – 3.5kHz – but can be exceeded at other frequencies (see Figure 1).

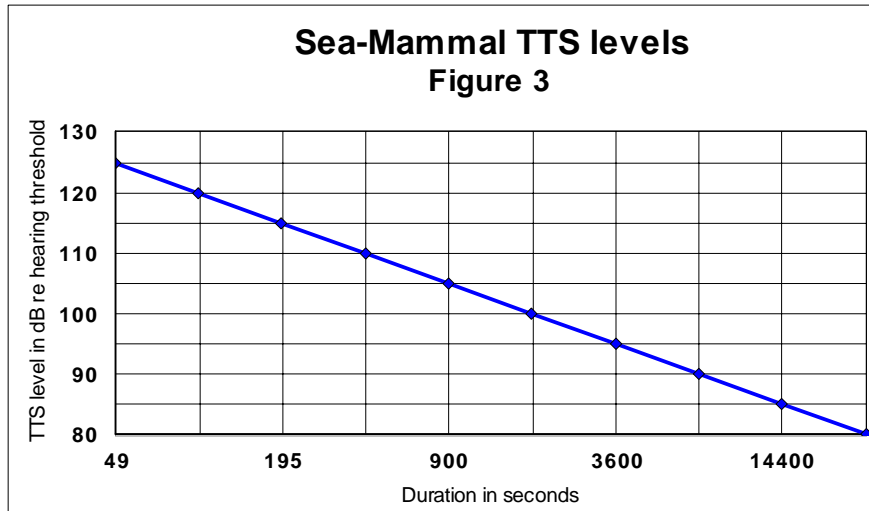


The 80dB(A) criterion can also be exceeded for short periods of time. It allows a 5dB increase in noise levels for half the standard time (see Figure 2).

TTS experiments have also been performed on several sea-mammals, (Au *et al.* (1999), bottlenose dolphin, Kastak *et al.* (1999), common seal, Northern elephant seal and Californian sea-lion and Schlundt *et al.* (2000), bottlenose dolphin and white whale) from which we can derive Figure 3.



At first glance you might think I have made an error in that the graph for humans and sea-mammals appear identical. However the y-axis for sea mammals is relative to their absolute hearing threshold whereas the human axis is dB(A). In reality the human graph is lower by 18dB which is to be expected since the occupational safe exposure curve for humans is set well below the level at which TTS will occur.



4.3 Perception of Sound

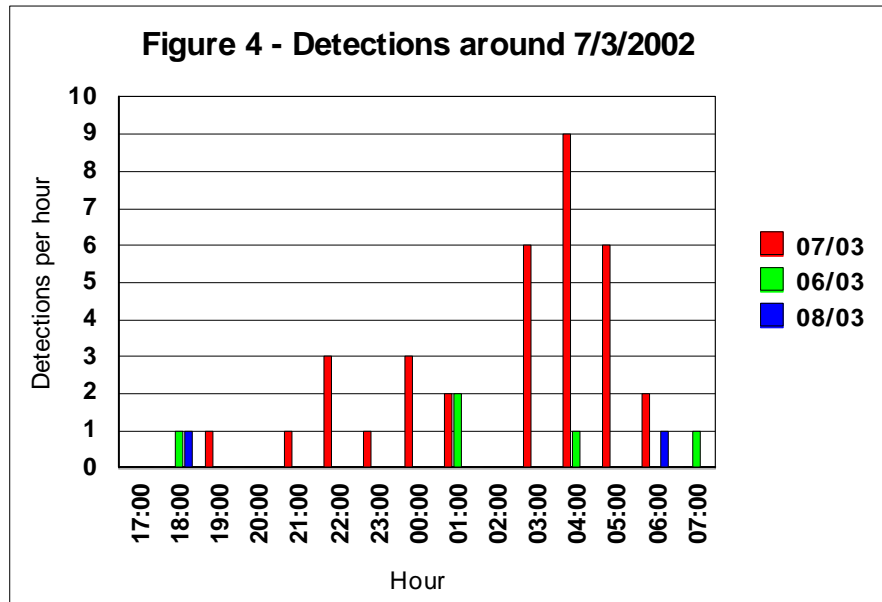
Beranek (1986) quotes sound levels for human volunteers in which they were asked to classify pure tones into one of three categories “Discomfort”, “Tickle” and “Painful”. This perceptual study found that “Discomfort” corresponded to a level 110dB(A) whereas “Painful” described sounds exceeding 140dB(A). This study also found that the volunteers that were tested daily raised their perceptual thresholds by 10dB.

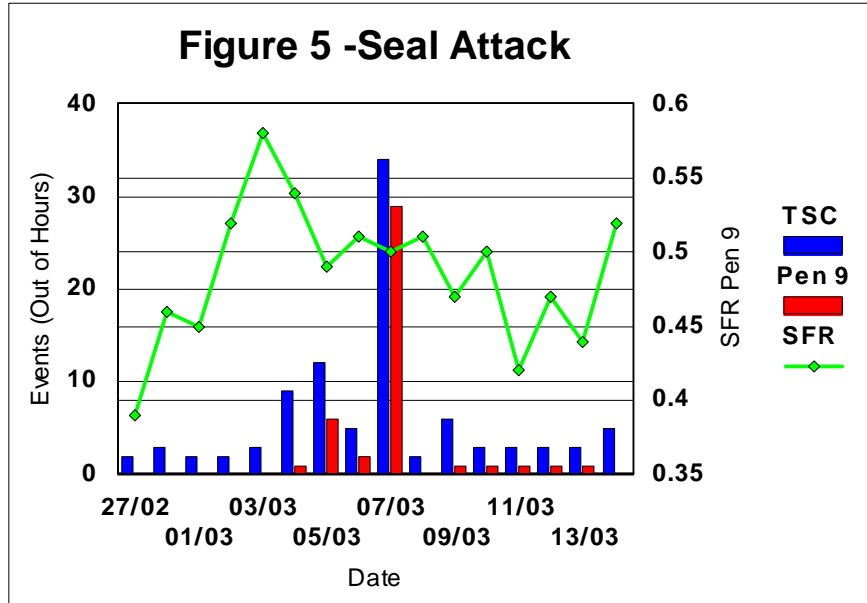
Evidence as to the perception of loud sounds in marine mammals is limited but in the Schuldt *et al.* (2000) the captive animals exhibited changes in their behaviour when exposed to 1 one second pure tone at sound levels exceeding 180dB re 1µPa.

Translating both of these figures to dB re absolute threshold humans describe “pain” above 148dB and dolphins express behavioural changes above 152dB. These figures correspond closely to each other demonstrating yet again the similarities in mammalian hearing.

Animals in the wild exposed to more complex sounds exhibit avoidance behaviour at much lower levels. The best studied has been the harbour porpoise which has good hearing sensitivity (48dB re 1µPa at 10kHz). Olesiuk *et al.* (1995) observed that harbour porpoises were excluded from a 10kHz continuous noise-maker (source level 194dB re 1µPa @ 1m) to a range of 400m whilst the machine was active. Johnson (in preparation), using the same source, found the exclusion zone to be 645m. Cox *et al.* (2001) showed that harbour porpoises, whilst initially avoiding a much weaker noise-maker (source level 130 to 150dB re 1µPa @ 1m) ignored it after a few days.

From the Olesiuk and Johnson results we can calculate that the harbour porpoise would not voluntarily enter a noise field when the signal level exceeds 140 dB re 1µPa but will tolerate sound levels in the region of 130 dB re 1µPa. From these studies we can conclude that wild marine mammals show aversive responses to ADDs 92 dB above their hearing threshold but will tolerate signals 82 dB above threshold.





5 Safe Design in ADDs

As previously stated an effective acoustic deterrent is one that produces an aversive reaction in the target animal without inducing hearing loss. To digress for a moment.

I understand (but have not tried it myself) that you can place a frog into cold water, heat the water slowly and the frog will not jump out of the pan but allow itself to be cooked. Take a frog and place it in warm water (which does not signify a threat) and the thing will jump out immediately.

Sound for mammals has the same effect as the slowly cooked frog (Witness the concerns of personal CD players on children). The on-set of TTS means the subject can – if he chooses – tolerate a higher level of sound which results in higher TTS which could eventually result in PTS. The question is how to avoid this situation? ADDs should mimic the pan of warm water not the slowly heated cold water i.e. seal harasses fish, scarer makes loud enough sound to produce aversive reaction in seal, seal departs to a range which will not induce TTS.

ADD’s produce aversive reactions at a level 92dB above the animal’s hearing threshold. For common seals this equates to a signal level of 156 dBre1µPa. Modern ADDs have source levels of 194 dBre1µPa @ 1m* which gives an effective range of 80m.

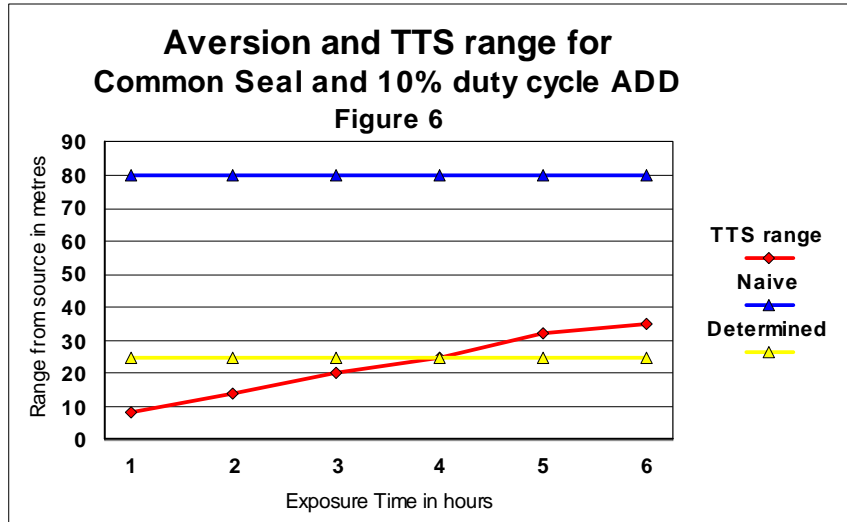
Ace Aquatec’s research (see AA-01-032) has measured that seals predate at fish farms for around 3 to 6 hours per night. Assuming that the noise source is a continuous noise-maker with a duty cycle of 10%* then we can plot the aversion range against the TTS range for various exposure times (Figure 6).

From Figure 6 we can conclude that this hypothetical ADD is safe for a naive common seal. However we should note from the Beranek study quoted in the last section that some subjects could alter their perceptual tolerance by 10dB when repeatedly exposed. As a consequence a “determined” seal might also be tolerant to this increase and therefore place himself at risk from this hypothetical machine after

* Source level is the loudness of the sound measured at a standard range. The signal level at other ranges can be calculated (to a first approximation) using the formula $SPL = SL - 20\log(r) - \alpha r$ where SPL is the signal level, SL is the source level, r is the range (in standard units) and α is the absorption coefficient in dB / standard unit.

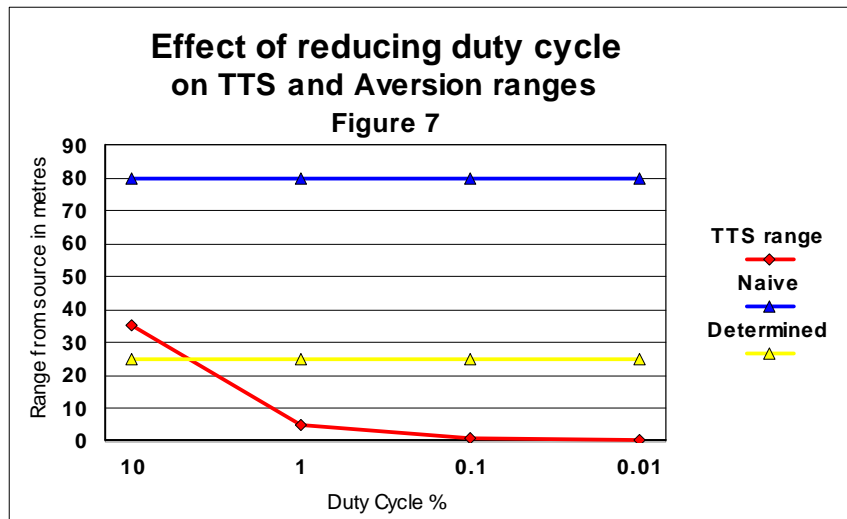
* For technical reasons ADDs produce pulse trains which are discontinuous. The duty cycle allows us to calculate the exposure time of the animal to the sound.

4 hours. There are two methods by which we can improve the zone of safety: increase the source level or reduce the duty cycle.



Seals become “determined” if they are, or have been able to gain food rewards from the protected site. This can happen when the ADD’s power output falls and the aversion range reduces. Ace Aquatec was able to establish this link at one trial site (see AA-01-032). By a similar argument increasing the source level pushes the seal further away and so his determination wanes.

Figure 7 shows the effect of reducing the duty cycle of the ADD for a 6 hour exposure. Once below a 5% duty cycle even “determined” seals are not at risk from this level of sound.





We can now define a Figure of Merit for various ADDs as follows:

$$\text{FOM} = (\text{Aversion Range} - \text{TTS Range}) / \text{TTS Range}$$

Model	Source Level in dB re 1µPa @ 1m	Duty cycle %	Aversion range in metres	TTS range for 6 hour exposure	FOM
Airmar dB II Plus	194	13	80	46	0.7
Terecos	185	10	28	14	1.0
Simrad “Fishguard”	191	3.1	57	10	4.7
Ferranti-Thomson Mk2	194	1.5	80	8	9.0
Ace Aquatec ANSS (SCRAM mode)	194	0.14	80	0.8	99.0

The ANSS has the best score due to its extremely low duty cycle. The reason why this machine is effective is that it is triggered into operation when the seal attacks the fish. If these were randomly timed transmissions (as is the case for the Ferranti-Thomson Mk2) the seal has plenty of time between transmissions to fish and so these machines were only partially effective.

6 Effects on non-target species

There is a wealth of literature available on the subject of the harmful effects of ADDs on non-target species much of which make exaggerated claims based on little or no information. Without going into details many papers, some by reputable scientists, leap on fragments of information and fabricate doomsday scenarios regarding habitat exclusion, population changes or even death! But none of this is proven and, where there is evidence, adverse effects are entirely reversed when the machine stops making a noise.

To say the debate borders on the hysterical is not exaggerated with the result that some scientists advising government prefer to advocate certain death of diving birds, seals and porpoises by promoting anti-predator nets in favour of possible disturbance to small cetacea by ADDs.

But what are the facts? Can we use our knowledge to construct more environmentally friendly ADDs?

- It is a fact that the hearing of seals is generally less sensitive than the toothed whales, hence the range of aversion will be greater for toothed whales.
- It is a fact that disturbance lasts only as long as the noise.
- It is a fact that the range of aversion is greater than the range at which TTS occurs.
- It is a fact that only one ADD – The Airmar dB II Plus – has been studied.

So can ADDs damage the hearing of marine mammals? The short answer is no, ADDs do not damage the hearing of marine mammals. For continuous noise-makers the animals have been shown to exclude themselves well before they reach the range where they might be at risk. For discontinuous noise-makers – where the animal might not be aware of the existence of the equipment the answer is still no, but we have to return to human data to prove this.

Kryter (1985) quotes the level of sound which will cause hearing damage as 155dB above threshold, Beranek (1986) quotes levels of 158 to 168dB and admits that the precise level of sound is not accurately known. Using Kryter’s lower level we can calculate the range at which damage might occur for various species with a sound source operating at 10kHz and 194 dB re 1µPa @ 1m.

Table 3 – Range of Hearing Damage			
Animal	Hearing sensitivity dB re 1µPa ♦	SPL required for hearing damage dB re 1µPa	Range from source in metres
Common seal	64	219	0
Beluga	61	216	0
Bottlenose dolphin	60	215	0
Harbour porpoise	48	203	0
Killer Whale	37	192	1.3

It is doubtful that even the killer-whale (the most sensitive marine mammal at this frequency) could sustain damage even if he were playing with the equipment as the animal's head is larger than the range of damage.

At what range are marine mammals excluded from ADDs? **Depends upon the source level, frequency and how often the ADD makes a noise.**

As explained previously the only information on this has been from continuous noise-makers. Harbour porpoises were excluded when the sound level reached 140dB re 1µPa. We can use this information to predict the range of exclusion against an Airmar dB II plus.

Table 4 – Exclusion ranges (Airmar)			
Animal	Hearing sensitivity dB re 1µPa ♦	SPL required for exclusion dB re 1µPa	Range from Airmar in metres
Common seal	64	156	80
Beluga	61	153	110
Bottlenose dolphin	60	152	130
Harbour porpoise	48	140	500
Killer Whale	37	129	1,600

This pattern will probably be repeated for other continuous noise makers but probably the Ace Aquatec ANSS will not have a range of exclusion. The only evidence that I can offer to support my statement is verbal reports from farm workers that seals remain in the vicinity of the farm when the ANSS is present. If seals are not excluded then it follows that other species are not excluded.

At what range are marine mammals displaced from ADDs? **Depends upon the source level, frequency and how often the ADD makes a noise.**

As before the only information on this has been from continuous noise-makers. Harbour porpoises were found to tolerate sound levels in the region of 130dB re 1µPa. We can use this information to predict the range of displacement against an Airmar dB II Plus.

Table 5 – Disturbance ranges (Airmar)			
Animal	Hearing sensitivity dB re 1µPa ♦	SPL required for exclusion dB re 1µPa	Range from Airmar in metres
Common seal	64	146	250
Beluga	61	143	350
Bottlenose dolphin	60	142	400
Harbour porpoise	48	130	1,450
Killer Whale	37	119	6,200

As before we would expect this pattern to be repeated for other continuous noise makers and again I will argue that the Ace Aquatec ANSS will not have a range of displacement.

♦ Figures taken from Richardson *et al.*(1995) at 10kHz

7 Reducing the Duty Cycle

Reducing the duty cycle (making sounds less often) is the key reason why I can be confident that the use of the Ace Aquatec Silent Scrammer (ANSS) will not result in habitat exclusion or displacement. As has been proven, when the machine is silent the animals return. Ace Aquatec has progressively reduced the scam rate (number of transmissions per hour) from 2 per hour with the Silent Scrammer, 0.5 per hour with the ANSS in SCRAM mode to **less than one transmission per day** in AUTO mode (see AA-01-043). Each transmission is the equivalent to a 10 second exposure so the well studied Airmar dB II Plus makes **more than 1,000 times the noise of an Ace Aquatec Silent Scrammer.**

8 Conclusions

Predation of farmed fish by marine mammals is an unnatural activity indulged in by a very few individuals. The major predator is the seal which wastes the majority of the food and leaves the farmed fish extremely stressed.

The ADD is the only anti-predator method currently used by fish-farmers which decreases the stress of predation on farmed fish and as such should be standard equipment. The ADD is also humane and, unlike some other measures, non-lethal, therefore it should become the environmentalist's method of choice.

The possibility of seals, active in predation, damaging their hearing is possible for some models but can be eliminated by good design. We can also be confident that other marine mammals will not be harmed by ADDs.

One type of continuous noise-maker has been demonstrated to exclude and displace marine mammals near their location. Whilst the exclusion range – within which the animal will not voluntarily stay – is fairly rigid, the much larger displacement range is voluntarily entered. The fact that the animals prefer to remain outside the displacement zone is through choice rather than necessity hence it is the exclusion, rather than the displacement range that should concern biologists.

Notwithstanding, the findings relating to continuous noise-makers. Silent Scrammers have never been studied in this manner. It is argued that Silent Scrammers eliminate the possibility of damaging predating seals, and, especially for the ANSS in AUTO mode, will not have a measurable zone of exclusion nor displacement since it makes sound so infrequently.



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