Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad

By email: ■■■■■■■■■■■■■■■■

Our Ref: SIR150721/A2655569   12 July 2018

Dear ■■■■■■■■

Information Request – SNH support for GenusWave 'Targeted Acoustic Startle Technology'

Thank you for your information request, which we received on 22 May. We have considered your request under the Environmental Information (Scotland) Regulations 2004 ('the EIRs').

You asked us for information on SNH support for GenusWave 'Targeted Acoustic Startle Technology''. I have listed each part of your request below, along with our responses.

1. Please provide information relating to GenusWave's 'Targeted Acoustic Startle Technology'.

    We have carried out a detailed search of the information we hold, and we have identified a number of documents which fall within the scope of your request. Copies of the documents are attached along with this letter.

    We have marked out (redacted) some personal data in the documents. Releasing this personal data into the public domain in response to an access to information request would breach the Data Protection Act 2018. We are therefore withholding the information under EIRs Regulation 11(2) (Personal data).

    We have also withheld some information because it is commercially confidential. Disclosing the information into the public domain in response to an access to information request would be likely to cause substantial harm to a legitimate economic interest. We are therefore withholding the information under EIRs Regulation 10(5)(e) (Confidentiality of commercial or industrial information).

    We have concluded that, in this case, it is not in the public interest for SNH to release information that would harm a legitimate economic interest.

2. Please provide any emails and correspondence with GenusWave and any other parties in relation to GenusWave.

    Please see attached documents.

3. Please include information relating to any field studies.

    Please see attached documents.

Scottish Natural Heritage, Battleby, Redgorton, Perth, PH1 3EW
Tel 01738 444177 Fax 01738 458611 www.nature.scot

4. Please include any assessments and information relating to harm and impacts on cetaceans.

   We do not hold any information relating to harm and impacts on cetaceans linked to the GenusWave technology. I therefore need to advise that this means that EIRs Regulation 10(4)(a)(Information not held) applies to this part of your request.

5. Please include information relating to any determinations by SNH and consents to use SalmonSafe systems in 'SNH Protected Waters'.

   We do not hold any information that meets the terms of this part of your request, and EIRs Regulation 10(4)(a)(Information not held) therefore applies.

6. If GenusWave is guilty of a making false representation regarding SNH support, please provide details.

   We can confirm that the statement referring to SNH was inaccurate and misleading and have asked that it be removed from the GenusWave website. The statement was posted in error while the site was in development and has now been deleted.

7. Please also include any information relating to [GenusWave's WhaleSafe](#).

   We do not hold any information that meets the terms of this part of your request, and EIRs Regulation 10(4)(a)(Information not held) therefore applies.

How We Handled Your Request

We believe you have asked for environmental information as defined in the Environmental Information (Scotland) Regulations 2004 ('the EIRs'), so we are dealing with your request under those regulations. To be able to use the EIRs, we must apply an exemption under section 39(2) of the Freedom of Information (Scotland) Act 2002 ('FOISA'). The Scottish Information Commissioner's guidance recommends that public authorities apply this exemption to environmental information and handle requests under the EIRs.

If you would like to find out more about the access to information legislation there is a guidance booklet available on the Scottish Information Commissioner's website:

http://www.itspublicknowledge.info/nmsruntime/saveasdialog.aspx?lID=5487&sID=5024.

Review and Appeal

I hope this information meets your requirements but if you are dissatisfied with how we have responded to your information request, please write to us within 40 working days explaining your concerns. You can contact us at Battleby, Redgorton, Perth, PH1 3EW or email us at foi@snh.gov.uk. We will carry out a review of our response and contact you with our findings within 20 working days.

If you are not satisfied following this, you can make an appeal to the Scottish Information Commissioner. The Scottish Information Commissioner can be contacted at:

Scottish Information Commissioner
Kinburn Castle
Doubledykes Road
St Andrews
Fife
KY16 9DS

Online appeal service: www.itspublicknowledge.info/Appeal

Website: http://www.itspublicknowledge.info/

Telephone: 01334 464610

Yours sincerely

Rhoda Davidson

Rhoda Davidson
Information Officer
FOI@snh.gov.uk

A2655569

Licensing Section
Scottish Natural Heritage
Great Glen House
Leachkin Road
Inverness
IV3 8NW
01463 725000
LICENSING@snh.gov.uk

Other animals – Scientific and Surveying (this includes research, education, monitoring, tagging, & taking)

Licence application form

Wildlife and Countryside Act 1981 (as amended) or The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended), as required by species

Please send the completed and signed form by **post** to the above address

SNH will hold your contact details on our Customer Database. All licence application forms, licences issued and correspondence relating to licensing decisions will be stored in our electronic filing system. We will use this information to undertake licensing functions. To do this we may have to discuss applications with relevant third parties.

We manage personal information in accordance with the Data Protection Act 1998. The Act gives individuals the right to know what data we hold on them, how we use it and to which third parties it is disclosed.

Section A - Applicant details

Please give the complete details of the person who will hold the licence.

Title	■ *please select one*		
Surname	■■■		
First name	■■■■		
Address	*House name or number*	Scottish Oceans Institute	
	Street	East Sands	
	District	University of St Andrews	
	City or Town	St Andrews	
	County	Fife	
	Post Code	KY16 8LB	
	Country	UK	
Date of birth *(dd/mm/yyyy)*	■■■■■		
Home telephone number	■■■■■		
Work telephone number	■■■■		
Mobile number			
E-mail address	■@st-and.ac.uk		
Organisation & position *(if applicable)*	University of St Andrews, ■■■■■		

Section B – Species and activities

Please indicate the species you wish to disturb and details about the location of your work.

Species *(incl. scientific name, if known)*	Coastal marine mammals in Scotland, primarily Phocoena, Tursiops, Phoca, Halichoerus
Proposed licence start date:	01/03/2014 **End date:** 31/12/2015
Location of work *council area or specific area*	see attached information
Grid reference *6 or 8 digit (e.g. NN 123456)*	see attached information
Brief description of proposal	see attached information
Brief explanation of why works need to be undertaken	see attached information
Details of how the work will be undertaken *(including equipment, methodologies, etc.)*	see attached inforamtion

If a licence is sought to **ring, mark,** or **tag** a wild animal, please provide details below.

Do you intend to ring, mark or tag any animals?	☐ Ring	☐ Mark	☐ Tag	☐ No to All
Specify the type of rings or marks that will be used and where they will be obtained				
Provide details of your experience in ringing or marking in this way				

If a licence is sought to **kill** or **take** wild animals, please provide details below.

Do you intend to kill or take any specimens?	☐ Kill	☐ Take	☐ No to both
How will the specimens be taken / killed?			
How and where will the specimens be kept?			
If applicable, how and where will the specimens be released?			

Any further information

Is there any further information you would like to provide in support of your application?	**see attached information**

Section C Additional persons

If there are any additional persons to be included in this licence, please include their details below, in full. Indicate if they are to be included as an **Agent** or **Assistant.** An Agent may work independently of the licence holder; the licence holder is responsible for ensuring that Agents have the appropriate training and experience. Assistants must work under the personal supervision of the licence holder. If more than one Agent or Assistant is to be included, please use the extra tables at the end of this application and print off pages accordingly.

Status		Agent
Title		███
Surname		█████
First Name		██████
Address	*House name or number*	Scottish Oceans Institute
	Street	East Sands
	District	University of St Andrews
	City or Town	St Andrews
	County	Fife
	Post Code	KY16 8LB
	Country	UK
Date of birth *(dd/mm/yyyy)*		██████████
Telephone number		████████
Mobile number		
E-mail address		████@st-and.ac.uk
Organisation & position *(if applicable)*		University of St Andrews, ███████████████
Are there any restrictions you require to be placed on the activities of this person? *(e.g. action, species, location)*		no

Section D – Previous experience

Please give details of your relevant experience in carrying out this type of work.

Details of relevant skills / experience	██████████████████████████ ████████████████████████████ ████████████████████████████ ████████████████████████████ ████████████████████████ ████████████████████████████ ████████████████████████ ██████████████████ I have used the system we describe here in Scottish waters, showing that it deters seals over a limited range and that it does not affect harbour porpoises. These projects were conducted at different fish farm sites in Scotland under SNH licence.
Worked under someone else's licence	No ☐ Agent ☐ Assistant
Licence number	
Details of this licence	

Have you held any wildlife licences previously? Please tick the most relevant box for 'YES'.

Have you held an SNH licence, to do this type of work, in the last 5 years?	☒
Have you held an SNH licence, to do this type of work, *more* than 5 years ago?	☒
Have you held a licence, to do this type of work, in England, Wales or Northern Ireland?	☐
Have you never held a licence to do this type of work before?	☐

If you have held a licence previously, please give details below.

Licence number	6495, 8111, 10778, 13645	**Country**:	Scotland
Brief detail of most recent / relevant licence held	The most relevant licence was 8111.		

Section E – Referees
If you have *not held* an SNH licence for similar type of work in the last five years, please give the names and contact details of two referees. These should be **familiar with your experience carrying out this type of work** and are able to advise on your suitability to receive this licence.

Title	SELECT		
Surname			
First name			
Address	*House name or number*		
	Street		
	District		
	City or Town		
	County		
	Post Code		
	Country		
Telephone number			
E-mail address			
Organisation & position (*if applicable*)			
Licence number (*if held*)			

Title	SELECT		
Surname			
First name			
Address	*House name or number*		
	Street		
	District		
	City or Town		
	County		
	Post Code		
	Country		
Telephone number			
E-mail address			
Organisation & position (*if applicable*)			
Licence number (*if held*)			

If you have **not held** an SNH licence for similar type of work in the last five years, please give the names and contact details of two referees. These should be **familiar with your experience carrying out this type of work** and are able to advise on

Checklist of Attachments

Details of project or works proposed	☒

Declaration

Applicants should note that it is an offence under Section 17 of the Wildlife and Countryside Act 1981 and under Regulation 46 of the Conservation (Natural Habitats &c) Regulations 1994 to knowingly or recklessly provide false information in order to obtain a licence.

- *I understand that failure to comply with any conditions included on any licence granted in respect of this application may constitute an offence.*

- *I declare that the particulars given in this application and any accompanying documents are true and accurate to the best of my knowledge and belief, and I apply for a licence in accordance with these particulars.*

- *If a licence is granted, I agree to send to SNH a written report of the licensed activities within one month of the expiry of the licence.*

DATE: 11/02/2014	SIGNATURE:

This application must be printed and signed by the applicant and a hard copy must be posted into the Licensing Team at GGH. Digital signatures are not accepted at this time.

Where appropriate we may use your information within SNH for other purposes for example: sending you our magazine, inviting you to an event or asking for your feedback.

Do you wish to receive our quarterly magazine?   ☒ *Yes*

Do you wish to receive other appropriate mailings from us?   ☒ *Yes*

Section C - Additional Persons continued, *as needed only*

Please only use these pages if you have several agents or assistants to add. If you have more than a further three, please use these tables and print off accordingly.

Status	SELECT		
Title	SELECT		
Surname			
First name			
Address	*House name or number*		
	Street		
	District		
	City or Town		
	County		
	Post Code		
	Country		
Date of birth *(dd/mm/yyyy)*			
Telephone number			
Mobile number			
E-mail Address			
Organisation & position *(if applicable)*			
Are there any restrictions you require to be placed on the activities of this person? *(e.g. action, species, locations)*			

Status	SELECT		
Title	SELECT		
Surname			
First name			
Address	*House name or number*		
	Street		
	District		
	City or Town		
	County		

	Post Code	
	Country	
Date of birth (dd/mm/yyyy)		
Telephone number		
Mobile number		
E-mail Address		
Organisation & position (if applicable)		
Are there any restrictions you require to be placed on the activities of this person? (e.g. action, species, locations)		

Status	SELECT	
Title	SELECT	
Surname		
First name		
Address	House name or number	
	Street	
	District	
	City or Town	
	County	
	Post Code	
	Country	
Date of birth (dd/mm/yyyy)		
Telephone number		
Mobile number		
E-mail Address		
Organisation & position (if applicable)		
Are there any restrictions you require to be placed on the activities of this person? (e.g. action, species, locations)		

A field study to test efficiency of a new acoustic deterrent device designed to mitigate adverse impacts on odontocetes

1 General description of the project and previous work

Current acoustic deterrent devices (ADDs) used on fish farms to avoid seal damage show highly varying success (Götz & Janik, 2013). ADDs have also been highlighted as a serious conservation concern since they inflict large-scale habitat exclusion in porpoises and other *delphinids* (Johnston et al. 2002). Furthermore, high duty cycle devices (e.g. Airmar) which operate multi-transducer arrays may in some cases cause hearing damage in target and non-target species (see Götz & Janik, 2013 for a review). In two separate projects funded by the Scottish Government we investigated potential solutions which could contribute to an increase in efficiency and target-specificity of acoustic predator control methods (Janik & Götz 2008, 2013). In a series of response trials we generally found that seals habituate quickly to most deterring sounds including commercial seal scarers (Götz & Janik, 2010). There was, however, one notable exception. Seals which were repeatedly exposed to sounds that elicited an oligo-synaptic reflex arc in brainstem (acoustic startle) showed the opposite trend. These animals generally sensitized i.e. they increasingly developed flight responses and place avoidance of the area around a simulated food source (Götz & Janik, 2011). The method of using startling pulses is also advantageous because the reflex will only be elicited if the received level crosses the startle threshold. Hence, any deterrence effect can be limited to a confined area around the site of interest. Furthermore, the use of infrequent, isolated pulses instead of almost continuous emissions reduces noise pollution and therefore mitigates concerns related to hearing damage. The startle reflex method was consecutively tested around a stocked salmon farm where it led to a strong reduction in the number of seals within 250m of the loudspeaker over a 2month period (Janik & Götz 2008). In a final series of fish farm experiments a prototype device which operated at a duty cycle of less 1% succeeded in protecting a salmon on the Scottish west coast over a one year period (Janik & Götz 2013).

Habitat exclusion in odontocetes caused by current ADDs can potentially be explained by differences in species hearing sensitivity and the fact that odontocetes typically lack food motivation to approach farm sites (Götz & Janik, 2013). All currently available seal scarers operate in a frequency band where odontocete

hearing is much more sensitive than hearing in seals. Hence, these devices will cause higher perceived loudness in non-target species than in target species (Götz & Janik, 2013, see fig 1). Therefore, when optimising target-specificity it would be desirable to move to a frequency band between 700Hz and 2 kHz where seals are more sensitive than odontocetes (see fig 1). The startle threshold roughly follows the hearing threshold (see fig 1 for audiograms). Hence, it is possible to design a sound which exceeds the startle threshold in seals but not in odontocetes. These theoretical considerations have been confirmed by empirical data from at least two different study sites. In a first study in the Northern Sound of Mull (SNH license 8111) porpoise distribution was not effected by playback of startling sounds (source level 180 dB re µPa) centred at 1 kHz (Janik & Götz 2008). In fact, porpoise were regularly seen between the fish farm cages In a 2nd study on the west coast of Scotland a basic prototype device (with 3 transducers operating ~179 dB re µPa) was installed on a fish farm for a one year period and marine mammals were monitored at regular intervals (Janik & Götz, 2013). There was no difference in porpoise distribution as the result of sound exposure. Interestingly, seals were seen within <50-100m of the farm but the farm did not suffer predation during most of the experimental period. This shows that effects on odontocetes can be mitigated and seals will only be affected in a small area around the fish farm.

The deterrent technology developed and tested in these studies is currently in the process of being commercialised through Genuswave ltd. An industrial prototype is in development and will be ready for testing in March 2014. The aim of the proposed

Fig 1. Audiograms of odontocetes, pinnipeds and fish typically found around fish farms (reproduced from Götz & Janik, 2013). The graphs depict the threshold of hearing with low numbers reflecting high auditory sensitivity.

study is to run a full-scale commercial trial on an operating fish farm. The experiment will involve monitoring of predation levels before, during and after deployment of the deterrent device. The trial should be conducted in an area where license restrictions previously prevented the industry from using deterrents. This is important because a real evaluation of the technology requires a farm site that has previously not operated a seal scarer. This is important as seals predating on farms around which operate high-duty cycle ADDs (e.g. Airmar) may have hearing damage.

2 Experimental procedures

The experiment involves deployment a full-scale commercial deterrent device (based on the startle technology) on a fish farm ███████████████████████. The maximum deployment time would be the length of a production cycle (~18 month). We are interested in potentially running experiments on two different sites:

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███

███

███████████████████████████████ Initially, three units will be deployed but ultimately the number of units will be determined by the number of stocked cages on the farm site. The acoustic features of startle pulses will be the same as in the previous experiments (Janik & Götz, 2008, 2013). The individual units will emit isolated, band-limited noise pulses (0.2 long) at a source level of ~178 to 182 dB re µPa (rms). This source level is therefore ~10-15 dB lower than in an Airmar device (see Götz & Janik, 2013). █████████████████████████

███

█████████████████ This represents a reduction in emission time by at least one order of magnitude (factor 10) compared to current commercially available devices (Götz & Janik, 2013). ██████████████████████████

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█████████████████ (see Götz & Janik, 2011). This would then make it possible to further reduce the time during which the startle pulse needs to be played as it should be possible to cause an avoidance response by █████████████████████

███████████████████████████████ Since our studies showed no effect on odontocetes

we do not expect any responses in animal distribution around the fish farm. Nevertheless, the commercial trial will involve a basic marine mammal monitoring scheme. This will be implemented in form of a questionnaire survey asking farm staff to opportunistically report sightings (see appendix I). Our previous data shows that presence of porpoise can be reliably estimated from such questionnaire surveys (Janik & Götz 2013).

References

Götz, T., and V. M. Janik. 2010. Aversiveness of sound in phocid seals: psycho-physiological factors, learning processes and motivation. Journal of Experimental Biology 213:1536-1548.

Götz, T. and Janik, V. M. (2011). Repeated elicitation of the acoustic startle reflex leads to sensitisation in subsequent avoidance behaviour and induces fear conditioning. BMC Neuroscience 12:30.

Götz, T. and Janik, V. M. (2013). Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. Marine Ecology Progress Series 492:285-302.

Janik, V. M., and Götz, T. (2008). An investigation of target-specificity and effectiveness of seal deterring sounds. Report to Marine Scotland

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REVIEW

Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions

Thomas Götz*, Vincent M. Janik

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ABSTRACT: Acoustic deterrent devices (ADDs) to prevent pinniped predation on fish farms and fisheries are widely used, but show highly varying success. Recently, ADDs have also been highlighted as a conservation concern due to their adverse impact on toothed whales. We review the available literature on the efficiency of commercial ADDs, evaluate the unintended impact on behaviour, communication and hearing of marine life, and suggest solutions based on psycho-physiological predictions. The main problems associated with ADDs are a lack of long-term efficiency, introduction of substantial noise pollution to the marine environment and long-term effects on target and non-target species. Odontocetes have more sensitive hearing than pinnipeds at the frequencies where most ADDs operate, which may explain the reported large-scale habitat exclusion of odontocetes when ADDs are used. Furthermore, long-term exposure to ADDs may damage the hearing of marine mammals. Fish and invertebrates have less sensitive hearing than marine mammals and fewer efforts have been made to quantify the effects of noise on these taxa. Solutions can be found by decreasing sound exposure, exploiting neuronal reflex arcs associated with flight behaviour and making use of differences in species' hearing abilities to increase target specificity. To minimise adverse effects, environmental impact assessments should be carried out before deploying ADDs and only effective and target-specific devices should be used.

KEY WORDS: Acoustic deterrent device · ADD · Noise pollution · Predation · Seal · Hearing damage · Aquaculture · Fisheries · Temporary threshold shift · Permanent threshold shift

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INTRODUCTION

Worldwide farming of marine and diadromous finfish species has experienced tremendous growth, with a 10-fold increase over the past 3 decades (Food and Agriculture Organization 2005). The resulting increase in potential food resources for other species in the marine environment could be expected to induce interactions with predatory species. Foraging models predict that air-breathing predators such as marine mammals will exploit food resources depending on

their profitability and potential costs, with dive depths playing a major role (Thompson & Fedak 2001). Without any predator-control methods, the costs, for example, for a seal of attacking a fish farm are low while the profitability is high. It is therefore not surprising that such interactions occur. Nevertheless, predation losses on fish farms in both North America and Europe have often been reported to be caused by only a few 'rogue' individuals (Scottish Salmon Growers Association 1990, Morris 1996). On some occasions, salmon growers reported that predation by harbour seals *Phoca*

vitulina stopped after the specific individuals believed to be causing the problem were removed (Morris 1996). Similarly, reports from British Columbia showed that just a few male California sea lions *Zalophus californianus* reduced the annual steelhead trout *Oncorhynchus mykiss* run through the Ballard locks from 2500 to ~200 in less than a decade (Fraker & Mate 1999).

Predatory behaviour by seals around fish farms can cause a variety of economic as well as market-related risks for the owner (Nash et al. 2000), which has led to the development of several predator-control methods. These methods fall into one of the following categories: net modifications or additions of barrier nets, acoustic devices to deter seals, population control through lethal or non-lethal removals of seals, and aversive conditioning (Hawkins 1985, Würsig & Gailey 2002, Quick et al. 2004). The most problematic of these is predator population control by lethal removal. These methods can be ecologically hazardous, particularly if the number of removed animals is underestimated (Ross 1988), are ethically controversial and their effectiveness is questionable (Pemberton & Shaughnessy 1993), as newly arriving individuals can quickly replace removed animals (Ross 1988, Morris 1996). Furthermore, culling of higher-order predators can affect predation rates by other predators. Pinnipeds forage on predatory fish species around the net pen that could potentially feed on aquaculturally important species (Fraker & Mate 1999).

Of all predator-control measures, acoustic deterrent devices (ADDs) have often been considered the most benign way of dealing with the problem. There are 2 basic assumptions of how acoustic deterrence may work. The first solution presents acoustic stimuli at a source level that exeeds the auditory pain threshold, with the idea being that animals would avoid such stimuli, and the second relies on the acoustic stimulus itself being aversive without causing pain. Over the past 2 decades, a variety of acoustic devices have been designed to reduce or stop predation by pinnipeds on finfish farms (Table 1). Low-power devices operating at source levels below 185 dB re 1 µPa have commonly been labelled as ADDs, while those operating at higher source levels are considered to be acoustic harassment devices (AHDs) (Reeves et al. 2001). However, suggesting an effect based on source level is problematic when reaction thresholds are poorly understood and vary depending on animal motivation (Götz & Janik 2010). We will therefore refer to all devices as ADDs in this review, as deterrence is the ultimate goal when using them. Our review summa-rizes the current methodology in acoustic seal deterrence, investigates the problematic biological effects and their potential ecological consequences, and evaluates the potential of acoustics to control predation in general.

HOW EFFECTIVE IS ACOUSTIC DETERRENCE?

One of the first attempts to deter seals by the use of sound was carried out in the late 1970s with captive harbour seals and wild grey seals *Halichoerus grypus* around netted salmon (Anderson & Hawkins 1978). The results were not promising: pure tones of unspecified source level had no effect and killer whale *Orcinus orca* calls and other recorded sounds (e.g. noise) seemed to be effective for a few successive trials, but aversive responses waned quickly.

Experiments with more powerful devices operating at high source levels were carried out by Mate & Harvey (1987) and Mate et al. (1987). They used frequency-modulated pulses (8 to 20 kHz) of variable length at peak-to-peak (p-p) source levels of ~187 dB re 1 µPa to deter harbour seals from salmon hatcheries for 4 successive years (1 to 32 ms long pulses at random intervals with an average of 2 per second). The paradigm applied was to deter seals by broadcasting sounds within the most sensitive frequency range of a seal. Reactions included seals turning away from the sound source and sometimes leaping out of the water before retreating quickly. In the 3 following years, the predation rate was substantially lower and only one individual seal was responsible for most of the damage. However, although the device seemed to prevent recruitment of new animals, in the fourth year the predation rate returned to its original level. Geiger & Jeffries (1987) investigated the effect of an ADD on harbour seal predation on salmon fisheries using a device similar to that used by Mate & Harvey (1987). While the ADD reduced predation in some fisheries, there were 2 sites where predation rates were higher when the ADD was switched on. In one fishery, predation increased over a 3 wk period until it reached a much higher level than during control periods, which may indicate that the originally aversive sound had become a conditioned reinforcer, resulting in a 'dinner bell effect' (see also Jefferson & Curry 1996).

The time until devices become ineffective varies between studies and study sites. Harvey & Mate (1987) tried to establish an acoustic barrier after driving harbour seals from a haul-out in a bay where they forage on migrating salmon. Within the following week about one-third of the animals returned, which

Table 1. Acoustic characteristics of currently used acoustic deterrent devices. If multiple sources were used, the letters in superscript indicate the citation the information was taken from. All dB values are based on a reference value of 1 µPa

Manufacturer	Model	Source level (re 1 µPa)	Frequency structure	Temporal pattern	Emission duty cycle: % time an emission is produced	Ultrasonic components	Commercially available (2011)
Ferranti-Thomson	Ferranti-Thomson MK2 Seal Scrammer	194 dB at 27 kHz[a] (peak)	Pulses centred at 5 different frequencies arranged in 5 pre-set sequences which are chosen randomly[b]	20 ms pulses repeated every 40 ms in trains of 20 s duration[b]	3% max. 5.5 scrams per hour[b]	At least up to 40 kHz[a]	No, but most likely still used
	Ferranti-Thomson MK2 4X	200 dB at 25 kHz (no information)[b]	Similar to Ferranti-Thomson MK2	Similar to Ferranti-Thomson MK2	3% max. 5.5 scrams per hour[b]		No, probably only rarely used[b]
Ace-Aquatec	Ace-Aquatec 'Silent Scrammer'[c]	193 dB at 10 kHz (rms)[c]	Pulses centred at 28 different frequencies (pattern of jumping frequencies) arranged in 64 sequences, which are randomly chosen[c]	3.3 to 14 ms long segments, pulse interval: 33.2 to 48.5 ms in 5 s long trains[c]	Activity dependent 50% short term for 5 s period[c], manufacturers' user manual states between 6× and 72× 5 s long emissions per hour[c]	More than 165 dB at 30 kHz and 145 dB at 70 kHz[c]	Yes
Airmar	Airmar dB Plus	192 dB at 10.3 kHz (rms)[c] 198 dB (rms)[d] Side-bands at 20.5, 31.0 and 41.0 kHz	More or less sinusoidal: 10.3 kHz (2nd harmonic 43 dB weaker)[c]	1.4 ms long segments at 40 ms intervals in 2.25 s long trains; 4 transducers produce these trains in an alternating pattern[c]	50%[c] Almost continuous during typical operation with >1 transducer[e]	145 dB up to 103 kHz[c]	Yes
Terecos Ltd	Terecos type DSMS-4	178 dB at 4.9 kHz[c] (rms) (manufacturer claims 90 to 100 dB)	Complex randomized sequences: tonal blocks (with harmonics) forming up and down sweeps (fundamental from 1.8 to 3.0 kHz), sequences of continuous and time-variant multi-component blocks (2.4 to 6.0 kHz)[c]	Depending on operation mode: 8 ms segments in sequences of 8 or 16 ms segments in sequences of 5; variation possible due to randomisation software[c] trains from 200 ms to 8 s long[e], some segments follow with no pulse interval	Difficult to quantify and user selectable[c,e] 20×20 s emissions per hour: 0.11%[e]	Less than 143 dB above 27 kHz[c]	Yes (company also offers rental scheme)
Lofitech (older models by Simrad)	Lofitech 'universal or seal scarer'	191 dB (unspecified)[e] 182 dB (rms) at 14.9 kHz[f] 189 dB (unspecified)[g]	15 kHz (narrow-band)[e] 14.9 kHz[f]	~500 ms long pulses emitted in variable length blocks containing a randomised number of pulses minimum pulse interval within blocks ~0.5 s consecutive blocks separated by 20 to 60 s intervals[f] 550 ms pulse duration[h]	20 to 25%[e] ~10%[f] 12%[h]	Multiple harmonics, 2nd harmonic at −15 to −40 dB[f] or −10 dB[h]	Yes

Sources: [a]Yurk & Trites (2000); [b]Manufacturer's description cited in Gordon & Northridge (2002); [c]Lepper et al. (2004); [d]Manufacturer's 'owners manual' (confirmed by present authors' measurements); [e]Reeves et al. (2001); [f]Present authors' measurements; [g]Manufacturer's specification; [h]Brandt et al. (2013)

may have been partly caused by intermittent failure of the deterrence device. In contrast, Rivinus (1987) reported that only in the third year after the introduction of a similar ADD did 1 or 2 harbour seals return to predate on a fish ladder. Kastelein et al. (2006a) successfully deterred captive harbour seals over a 2 mo period using 250 ms long pulses of 8 to 45 kHz tones with harmonics. However, in this study there was no food associated with the location of the ADD.

Working on otariidae (eared seals), Akamatsu et al. (1996) investigated the reactions of captive Steller sea lions *Eumetopias jubatus* to sound while the animals were swimming in a pool or feeding on salmon attached to a net. They tested an iron drum (0.5 to 2 kHz, 210 dB re 1 µPa) and different playback sounds at a maximum source level (rms) of 165 dB re 1 µPa. They found that killer whale calls yielded little effect, frequency-modulated sweeps (1 to 4 kHz, 1 s duration, 1 s inter-stimulus interval) repelled juveniles and pure tones (8 kHz, 5 s duration, 5 s inter-stimulus interval) were successful in repelling all animals except adult males. Only the iron drum was able to deter adult males in the feeding trial, which might have been due to the high source levels of its sounds.

Only a few experiments have been carried out using commercially available ADDs under realistic settings. As Table 1 shows, the acoustic characteristics of devices that were sold commercially over the past years differ by manufacturer and model, which makes generalisations difficult. While some devices produce trains of brief pulses (Airmar, Ace-Aquatec), others produce longer, separated pulses (Lofitech) or emissions of more continuous noise (Terecos) (Table 1). Yurk & Trites (2000) tested ADDs produced by Airmar and Ferranti-Thompson in an attempt to keep harbour seals from feeding on out-migrating salmon under a bridge. The Airmar dB Plus II deterrent device yielded a decrease of predation rate in 7 successive trials, but further trials were not carried out. The Ferranti-Thompson device was only tested once, yielding a decrease in the number of seals compared with the control trial on the following day, but seal numbers were still high compared with earlier control trials. Jacobs & Terhune (2002) tested an Airmar dB Plus ADD (consisting of an array of 4 transducers, p-p source level 172 re 1 µPa) after chasing harbour seals from a haul-out into the water. They found no differences between control and sound exposure sessions in surface positions taken by the animals. In another experiment, the authors could not find any effect of an acoustic barrier consisting of Airmar ADDs on harbour seals approaching a haul-out site. Similarly, ADDs used to protect salmon runs (Na-

tional Marine Fisheries Service 1995) and fish farms (Norberg 1998) had little effect on otariids, although in some cases recruitment of new individuals was successfully prevented (National Marine Fisheries Service 1995). Installation of an Airmar dB Plus II deterrent device did not seem to result in a dramatic drop of predation levels inflicted by southern sea lions *Otaria flavescens* on a salmon farm in Chile (Vilata et al. 2010). However, a comparison of predation levels at the test site with the test site during the previous year and a control site on the same production cycle showed that the device caused a significant reduction in losses (Vilata et al. 2010). As the authors state, deployment was limited to a 3 mo period and long-term habituation was not evaluated. In an internal company report, Ace-Hopkins (2002a) presented a number of trials with his Ace-Aquatec device at different salmon farms in Scotland where potential predators are grey and harbour seals. He reported a reduction of fish damage at 2 farms while no effect was found at a third farm. Unlike other ADDs that produce sounds at random or regular intervals, the Ace-Aquatec device uses a triggering system that senses salmon movements in response to predator presence (Ace-Hopkins 2002b). Fjälling et al. (2006) used a Lofitech seal scarer that emitted at a source level of 179 dB re 1 µPa to protect salmon traps from grey seal predation in the Baltic Sea (an unmodified version of the device operates at a duty cycle of about 9 to 10%; the authors partly used a modified version with a duty cycle of 4.5% by reducing the pulse length to 250 ms). The use of this seal scarer resulted in both higher catch rates and lower fish damage during the test periods over 3 consecutive years. However, the effect waned towards the end of the season in each year. Similarly, Graham et al. (2009) found that a Lofitech ADD that was deployed in 2 rivers in Scotland for a 5 mo period reduced the number of seals upstream of the device by 50%. However, overall numbers of seals in the river system were unaffected.

These experiments showed substantial variation in behavioural responses across studies and study sites. This is probably the result of a variety of poorly understood factors influencing animal responses to sound in the wild. In a recent study, Götz & Janik (2010) demonstrated that the behavioural avoidance responses to sound in phocid seals were influenced by food motivation, learning processes, sound type and sensation levels (the level by which a sound exceeds the hearing threshold). The study also tested sounds of 4 commercially available ADDs (Terescos, Ace-Aquatec, Lofitech and Airmar dB plus). Study subjects habituated rapidly to all sound types when

played at a received level of 146 dB 1 µPa (rms) and food was presented next to the sound projector. Most ADD manufacturers claim a deterrence effect at this received level (e.g. Lofitech). Thus, these results generally question whether current ADDs can be efficient. However, the same study also demonstrated that without food presentation, ADD sounds of 3 out of 4 manufacturers yielded a deterrence effect down to received levels of 135 dB re 1µPa.

Indirect information on the effectiveness of current ADDs has been obtained by analysing the results of a questionnaire survey in Scotland where a variety of devices were in use (Quick et al. 2004). Only 23% of the fish farmers reported ADDs to be very effective, 50% reported moderate, 15% poor and 7% little efficiency. As in other areas (e.g. Mate et al. 1987) some of the farmers believed them to even attract seals. Perceived performance of currently available commercial deterrent systems (evaluated through interviews) was even worse in Chile where predation is inflicted by southern sea lions (Sepulveda & Oliva 2005). Acoustic deterrent systems were considered ineffective at 12 out of 16 sites, while only 4 sites claimed high or moderate efficiency.

The reasons for differences in reported efficiency may be diverse, and include the exact ADD deployment method and schedule, the animals' foraging motivation, differences between populations and species in reactions to human actions and differences in sound propagation characteristics of the habitat. The potential reasons for the loss of effectiveness observed in most studies over time are also varied. These are the induction of hearing damage due to ADD sound exposure (Reeves et al. 1996), habituation to sounds (Groves & Thompson, 1970), learning that sounds indicate the location of a fish farm (the 'dinner bell effect') and learning how to avoid the sound by swimming with the head above the surface.

ECOLOGICAL IMPACTS ON TARGET AND NON-TARGET SPECIES

Acoustic devices could cause negative impacts on animals in 4 different ways. They could cause damage to the ear due to high sound pressure, mask sounds used for communication, orientation or prey detection, lead to avoidance and an exclusion of animals from parts of their habitat, and/or induce detrimental physiological changes, such as increased stress hormone levels.

To affect the behaviour of an animal a sound must be audible. A high-power ADD (e.g. Ferranti-

Thompson 4) can be audible to the harbour porpoise *Phocoena phocoena* for up to 10 km under low ambient noise (Taylor et al. 1997). Similarly, a harbour seal could potentially hear a device with a source level of 175 dB re 1 µPa at distances of 1.4 to 2.9 km in quiet conditions (Terhune et al. 2002). The effects on fish and other marine life with less sensitive hearing may be more localized, but could still be detrimental. We will now review the potential effects of ADD sounds on marine life.

Impacts on target species should be considered a concern for ecologists, managers and the industry alike. If ADDs cause permanent hearing damage, this would create a problem not only from a conservation point of view, but also from a commercial perspective as efficiency of the devices would be reduced. It is also important to note that hearing damage first affects the outer hair cells in the cochlea, which leads to only a small rise of the hearing threshold. However, even at this level, hearing damage causes a diminution of the dynamic range and a loss of the frequency discrimination ability (see Moore (1997) for a review on psychophysical effects of hearing damage). As pinnipeds are likely to rely on passive acoustics for prey detection (Schusterman et al. 2000) and mating (van Parijs et al. 2000), sensory effects caused by even weak hearing loss would probably reduce the ability to classify sounds. This could make these animals more dependent on predictable food sources such as farmed fish and affect their reproductive success.

Hearing damage

General considerations

There is controversy over the effects of ADDs on cetacean and pinniped hearing. Although manufacturers reject the possibility of hearing damage caused by their ADDs (Ace-Hopkins 2002b), researchers say that this concern can neither be proven nor dismissed at present (Gordon & Northridge 2002). If an animal is exposed to stimuli that are above a certain level, hearing damage can occur as a temporary but fully recoverable shift of the hearing threshold (temporary threshold shift, TTS). If an animal is exposed to sound pressure levels (SPLs) beyond the TTS level or for longer durations, recovery may not be possible and the threshold shift becomes permanent (permanent threshold shift, PTS). The risk of hearing damage is considered to be a function of SPL and exposure time (Eldred et al. 1955). For instance, a sound with a short

duration can be safely presented at a higher source level than a longer one. It has been suggested that stimuli of equal acoustic energy carry the risk of causing similar damage ('equal energy hypothesis'; Eldred et al. 1955). Therefore, sound exposure level (SEL) was suggested as a measure for defining safe exposure levels: $SEL = SPL + 10\log_{10}(t)$, where t is the exposure time in seconds, and SPL is the root mean square sound pressure level (Southall et al. 2007, see Madsen 2005 for equation). However, the equal energy hypothesis has recently been challenged by studies showing that disproportionally higher SELs are required to cause a TTS when exposure times are short (Mooney et al. 2009a,b, Finneran et al. 2010a; see also Supplement 1 at www.int-res.com/articles/suppl/m492p285_supp.pdf). The onset of a TTS in odontocetes occurs at a SEL between 193 and 214 dB re 1 µPa^2 s (Finneran et al. 2000, 2002, 2005, 2010a,b, Schlundt et al. 2000, Nachtigall et al. 2004, Mooney et al. 2009a,b) while pinnipeds developed a TTS at levels of about 183 dB re 1 µPa^2 s (Kastak et al. 2005). In a harbour porpoise exposed to short transient noise pulses, a TTS was found at a lower level of 164 dB re 1 µPa^2 s (Lucke et al. 2009).

Marine mammal noise exposure criteria that can be used to predict the potential for hearing damage caused by ADDs have been developed based on available information on TTSs and permanent hearing damage in a range of taxa (Southall et al. 2007). The Southall et al. (2007) review is impressive in scope and provides highly valuable information, but we believe that there is room for improvement when using the criteria proposed in it. The main problem is that frequency weighting functions (M-weighting) suggested by Southall et al. (2007) cannot be considered conservative. This has mostly to do with the fact that animals in TTS studies used to derive exposure criteria were not always tested within their most sensitive range of hearing or in some cases tested individuals that had elevated hearing thresholds (see Supplement 1). We therefore suggest an alternative, more conservative approach that references SELs to the test subject's hearing threshold (sound exposure sensation level, SEL$_{sens}$). This has previously been suggested by Kastak et al. (2005) and should be considered as a complementary rather than alternative approach. It acknowledges the fact that in spite of recent advances there is still considerable

uncertainty when predicting permanent hearing damage in marine mammals. Supplement 1 explains the derivation of the unit of SEL$_{sens}$. Supplement 2 at www.int-res.com/articles/suppl/m492p285_supp.pdf provides the calculations of the impact zones for each species group. We predicted zones within which temporary and permanent hearing damage might occur for several exposure scenarios, taking differences in the devices' SPL and pulse emission pattern into account (Tables 2 & 3). This was achieved by choosing 2 cumulative SELs (203 dB re 1 µPa^2 s and 221.6 dB re 1 µPa^2 s) and then calculating corresponding impact zones within which an animal would have to reside for a specified amount of time to suffer the respective effect. Therefore, each impact zone (Table 2) has a corresponding exposure time required to cause the effect (Table 3). Impact zones (Table 2) are provided using the impact criteria provided by Southall et al. (2007), data by Lucke et al. (2009), as well as our new criteria based on SEL$_{sens}$. In addition, long-term exposure scenarios that model accumulation of hearing damage over months or years were reviewed (see Supplement 2).

The exposure times needed to cause a TTS or PTS within the respective impact zones differ remarkably between different devices (Tables 2 & 3), which is the result of differences in pulse emission patterns, pulse length and source level. Comparably shorter expo-

Table 2. Zones of temporary and permanent threshold shift for a short- and longer-term exposure scenario based on cumulative sound exposure levels (SELs). A cumulative SEL of 203 dB re 1 µPa^2 s is equivalent to continuous exposure for 10 s at 193 dB re 1 µPa, while 221.6 dB re 1 µPa^2 s is equivalent to continuous exposure for 720 s (10 min) at 193 dB re 1 µPa. The impact zone refers to the range within which the cumulative SEL will exceed the respective criterion for temporary or permanent hearing damage. These zones have to be interpreted in conjunction with the exposure times given for the respective devices in Table 3

Species	Temporary threshold shift	Permanent threshold shift	
	caused by a cumulative SEL of:		
	203 dB re 1 µPa^2 s	203 dB re 1 µPa^2 s	221.6 dB re 1 µPa^2 s
Common seal	10 m[a]	7 m[a]	60 m[a]
Porpoise	89 m[c]	9 m[c]	76 m[c]
	345 m[b]	35 m[b]	295 m[b]
Delphinids			
Tursiops spp.	2.5 m[a]	2 m[a]	15 m[a]
	175 m[b]	18 m[b]	150 m[b]
Orcinus sp.	748 m[b]	79 m[b]	642 m[b]

[a]Southall et al. (2007); [b]SEL$_{sens}$ presented in this paper (see Supplements 1 & 2); [c]Lucke et al. (2009)

Table 3. Exposure times required to reach the cumulative sound exposure level needed to cause the impact zones given in Table 2. In some devices multiple scenarios are given to take typical deployment strategies and differing information on duty cycles into account. The duty cycle (dc) in the first column refers to the time during which an emission (e.g. pulse train) is produced. In devices which are typically used with multiple transducers the resulting emission duty cycle is stated. The calculation of the cumulative sound exposure was based on the effective duty cycle (rather on the emission duty cycle) to take pulse length and pulse interval pulse trains into account (see Supplements 1 & 2)

Acoustic deterrent device	Time needed to reach an SEL of:	
	203 dB re 1 μPa^2 s	221.6 dB re 1 μPa^2 s
Airmar (@ 192 dB re 1 μPa)		
50% dc	11 min 49 s	14 h 29 min
200% dc (4 transducers)	3 min	3h 37 min
Airmar (@ 198 dB re 1 μPa)		
50% dc	3 min 1 s	3 h 38min
200% dc (4 transducers)	45 s	55 min
Ace-Aquatec		
10% dc[a]	7 min 52 s	9 h 30 min
30% (3 transducers)[a]	2 min 37 s	3 h 10 min
Lofitech		
12% dc	17 min 29 s	21 h 7 min
25% dc	8 min 24 s	10 h 8 min
Terecos		
11% dc	47 min 55 s	57 h 51 min
33% (3 transducers)	15 min 58 s	19 h 17 min

[a]This duty cycle and the impact can be significantly reduced if used with the Ace-Aquatec trigger device

sure times are needed to cause an adverse effect on hearing in devices that operate at high source levels or at high duty cycles due to the deployment of multi-transducer arrays (e.g. Airmar). For example, a 4 transducer Airmar array will reach the lower cumulative SEL used in our calculations (203 dB re 1 μPa^2 s) within 2 min 17 s or 45 s (depending on the source level), while a single Terecos device will have to run for almost 48 min to reach the same SEL.

TTS and PTS: short-term exposure scenario (SEL 203 dB re 1 μPa^2 s)

Using the duty cycles given in Table 1, an exposure for 45 s to 48 min (depending on the model) is predicted to cause a TTS in harbour seals when animals are less than 10 m from the sound source. In the same short-term exposure scenario, delphinids would be affected at up to 3 m distance and harbour porpoise *Phocoena phocoena* potentially at up to 89 m. Our

alternative approach using SEL_{sens} would however predict somewhat larger TTS zones for odontocetes ranging from 175 m (bottlenose dolphin) to 748 m (killer whale).

Following criteria suggested by Southall et al. (2007), a PTS in common seals *Phoca vitulina* would be caused by exposure of the same duration if the animal was within 7 m of the device. The noise criteria by Southall et al. (2007) suggest that delphinids will only be affected when remaining within a couple of metres from the device. According to data by Lucke et al. (2009), porpoises would suffer permanent damage when staying within a zone of 9 m around a transducer. Our more conservative approach based on SEL_{sens} yields larger PTS zones of up to 18 m (bottlenose dolphin), 35 m (harbour porpoise) and 79 m (killer whale) for odontocetes.

PTS: longer-term exposure scenario (SEL 203 dB re 1 μPa^2 s)

The longer-term exposure scenario (Tables 2 & 3) based on a cumulative SEL of 221.6 dB re 1 μPa^2 s requires animals to be exposed to ADDs for between 55 min (Airmar array at high source levels) and ~58 h (single Terecos). Southall et al. (2007) predict that such exposure will only cause PTS in odontocetes if animals remain within 15 m of one of the transducers. Data collected by Lucke et al. (2009) suggests that porpoises would suffer permanent damage within a zone of 76 m. Our approach based on SEL_{sens} yields much larger impact zones of 295 m for porpoises, 150 m for bottlenose dolphin and 642 m for killer whales. Pinnipeds would suffer PTS at distances of up to 60 m from a transducer.

PTS: exposure over months or years

Predictions of exposure to low received levels over several months or years are associated with significant uncertainties and based on potentially problematic extrapolations (see Supplement 2). We would expect permanent hearing damage for pinnipeds within a zone of about 60 m from a device while odontocetes may be affected up to 40 m or more than 1 km from the farm depending on the assumptions made (see also Supplement 2).

Fish and invertebrates

Impact zones for fish and other marine wildlife are much smaller or non-existent (see Supplement 2). Few data are available for these other taxa, but these suggest that fish and invertebrates are unlikely to be affected by current ADDs. The exception may be fish species with good hearing, however, even these may only be affected within a few metres of the device (see Supplement 2).

Conclusions

Effects of current ADDs on fish and invertebrates without specialized hearing are unlikely. However, current acoustic deterrence methods, particularly multi-transducer arrays operating at high source levels, may carry some risk of damaging hearing of pinnipeds and delphinids if animals stay in the vicinity of a fish farm for an extended time. Depending on the assumptions made, the acoustic characteristics of the device and the species hearing sensitivity, distances within which ADDs can cause permanent or temporary hearing damage range from negligible (several metres) to relevant (several hundred metres). However, we believe that as all calculations are based on relatively little data (mostly only one or a few animals were measured) the most precautionary approach should be considered. The extent of the risk will primarily depend on whether marine mammals are likely to stay in the vicinity of a fish farm (less than a few hundred metres) for long enough (e.g. over 1 h) to be exposed to sufficient noise doses. This scenario may not be too unlikely, as aquaculture sites often attract shoals of wild fish, which in turn attract marine mammals. Marine mammals have been shown to ignore sound exposure when attracted to a simulated, potentially profitable foraging spot (Götz & Janik 2010). Therefore, this risk should be taken into account, particularly in areas with a high density of fish farms using ADDs. If hearing damage is inflicted then this would most likely reduce fitness of the individuals involved and, if large parts of the population were affected, hearing loss could lead to effects on a population level.

Masking

In masking, the detection of one sound (signal) is influenced by a second sound (masker). There are many levels to masking, including energetic mask-

ing, informational masking and effects of noise on attention and stress that affect information transmission (Clark et al. 2009). ADDs may have such an effect on marine mammal communication networks (Janik 2005) by decreasing detection distances of communication signals. Fletcher (1940) found that masking effects in mammals depend on the bandwidth of the masker (centred at the frequency of the signal) until it reaches a so-called critical bandwidth. Therefore, noise only masks a signal efficiently if it covers the frequency range of the signal of interest (but see Martin & Pickett (1970) for a discussion of upward masking). Marine mammal communication and echolocation signals overlap strongly with those produced by current ADDs. Hence, there is significant potential for masking, particularly for devices that emit broadband noise (e.g. Ace-Aquatec, Terecos). The zone of masking can potentially extend up to the zone of audibility. However, cetacean and pinniped sensory physiology also provides ways to alleviate masking effects. Critical bandwidths in marine mammals are generally below 10% of the signal's centre frequency (Richardson et al. 1995). Additionally, masking effects are attenuated if the masker and signal come from different directions. Terhune (1974) found that the harbour seal's minimal audible angle distinction for clicks is 4.5°. Bottlenose dolphins *Tursiops truncatus* can distinguish sound sources that are presented at angles of less than 3° apart (Renaud & Popper 1975). Furthermore, bottlenose dolphin hearing sensitivity is direction-dependent (Au & Moore 1984), which increases the capability of detecting signals in noise if noise source and target sound are spatially separated. Another way in which animals adapt to increased noise is by changing calling patterns. Beluga whales, for example, change their calling behaviour significantly by either producing less calls when close to a noise source or by increasing redundancy in calling when noise increases moderately (Lesage et al. 1999). Some of these changes are adaptations to natural noise, such as a decrease in calling rates when noise is high due to calling conspecifics (Quick & Janik 2008).

The masking potential of ADDs has not been investigated directly, but the effects of vessel noise on communication space have been modelled for baleen whales (Clark et al. 2009) and delphinids (Erbe 2002, Jensen et al. 2009). These suggest that broadband noise can result in a significant reduction of active communication space. The fact that some ADDs produce broadband noise within a similar frequency range as small vessels but at much higher source levels certainly highlights the masking potential, partic-

ularly in areas with dense fish farming. Further studies, incorporating direct sound field measurements from such areas, are needed to further assess this problem.

Most communication signals in fish are fundamentally lower than the frequency band in which most ADDs operate (see Zelick et al. 1999). However, hearing abilities (e.g. localization and frequency discrimination) in the majority of fish species are less sophisticated than in mammals (Fay & Popper 1999), which might make them more prone to masking effects. Elevated detection thresholds as a result of masking have been shown in hearing generalists as well as specialists (Wysocki & Ladich 2005, Vasconcelos et al. 2007). Fish species also seem to differ in their susceptibility to masking (Ramcharitar & Popper 2004). A neuro-physiological study on goldfish (a hearing specialist) showed that responses of nerve fibres to tones between 400 and 800 Hz can be suppressed by maskers of a broad range of frequencies essentially covering most of the hearing range (Fay 1991). These studies show that masking of communication signals in fish is a possibility and could also be caused by noise that does not overlap with the communication signals. However, only few ADDs produce signals that are audible to fish with the exception of species that are hearing specialists. Therefore, the overall potential of current ADDs to mask fish sounds is probably rather low. Most invertebrates and sea turtles are unable to detect sounds in the frequency range of ADDs and are therefore unlikely to be affected (see Supplement 2).

Habitat exclusion

Behavioural reactions of marine mammals to noise have been documented for a variety of noise sources (Richardson et al. 1995). Avoidance responses to ADDs leading to an exclusion from the habitat have been well studied in harbour porpoises and killer whales. Olesiuk et al. (2002) carried out a study in the Broughton Archipelago (British Columbia) investigating effects of the Airmar ADD on harbour porpoise distribution in the respective observation area. When the ADD was switched on the number of animals detected dropped significantly to 1.9% and 3.8% of values in control sessions, depending on the sector scanned. Porpoises were completely excluded from an area of 400 m radius around the ADD and the number of sightings was still below 10% of the expected value at ranges between 2500 and 3500 m from the device. Johnston (2002) carried out an addi-

tional experiment using a theodolite tracking method and found that porpoises did not approach an emitting ADD closer than 645 m (received level at this distance would be 128 dB re 1 µPa). The average closest approaches were 991 m (in contrast to 363 m during control) and significantly fewer porpoises could be seen within a range of 1500 m. In addition, porpoises moved out of the area after the ADD was switched on. In a more recent study, a Lofitech seal scarer was found to cause a reduction in harbour porpoise density down to 1% within an area of 1 km around the device (Brandt et al. 2013). Here, porpoises showed avoidance responses within 1.9 km of the device where received levels exceeded 122 dB re 1 µPa. Morton & Symonds (2002) reported a considerable decrease in killer whale sightings in Johnstone Strait, Canada after ADDs (most likely different brands) had been introduced on fish farms and a recovery of sighting rates after fish farmers stopped using them. This change did not correlate with changes in local food availability. Interestingly, no differences in sightings of seals were observed. This study covers a period of 15 yr and therefore indicates that killer whales, in contrast to seals, did not habituate to ADDs. Morton (2000) found that Pacific white-sided dolphins *Lagenorhynchus obliquidens* abundance decreased after ADDs were introduced in the area.

Less information is available on behavioural disturbance of fish by noise similar to that used in ADDs, but these effects might be limited to species with sophisticated hearing. Kraus et al. (1997) found that catch rates in gillnets with pingers were lower, but a causal relationship to the sound could not be proven. Experiments with salmon smolts showed that a 10 Hz signal caused avoidance responses at particle accelerations of 0.01 m s^{-2} (3 m distance). In contrast, a 150 Hz signal did not cause avoidance reactions even when animals were right next to the sound source where particle acceleration was 4 m s^{-2}, which is about 114 dB above the hearing threshold (Knudsen et al. 1994). Wardle et al. (2001) used video observations and tagging methods to monitor behaviour of cold water reef fish (including pollack *Pollachius pollachius*) during airgun emissions; however, in contrast to the sounds produced by ADDs, airgun pulses fall in the most sensitive frequency range of fish. All fish showed C-starts (a reflex initiated by quick motor neurons) in response to every sound emission at p-p SPLs higher than 195 dB re 1 µPa, but directional avoidance responses only occurred when fish could also see the explosion. No behavioural or physiological responses were found in cod *Gadus morhua* exposed to ultrasonic clicks at 50 kHz (Schack et al.

2008). Kastelein et al. (2007) tested behavioural responses of a variety of North Sea fish species to several commercially available pingers used to reduce bycatch of cetaceans in gillnets. The authors concluded that, in particular, pingers with signals higher than 10 kHz are less likely to affect fish species. In a second experiment, Kastelein et al. (2008) showed that none of the tested North Sea fish species exhibited a C-start startle reflex to pure tones at frequencies higher than 5 kHz, even at the highest source level tested (170 to 180 dB re 1 µPa depending on frequency). The highest frequencies that elicited a C-start response in any of the fish was 4 kHz in Atlantic herring *Clupea harengus*, with an average 50% response threshold of 170 dB re 1 µPa. Although all this points towards habitat exclusion in fish being less likely, some fish developed ultrasound detection capabilities, presumably to avoid echolocating predators (Mann et al. 1997, Wilson et al. 2011). In shad *Alosa alosa*, ultrasonic single pulses presented at levels of 192 dB re 1 µPa (p-p) did not cause a C-start or directional avoidance response, but trains of such pulses at repetition rates from 20 to 250 clicks s^{-1} did (Wilson et al. 2011). Similarly, alewives *Alosa pseudoharengus* respond to broadband pulses at frequencies between 117 and 130 kHz, with an avoidance response if predation is likely. Some ADDs produce such pulse trains so that habitat exclusion is a possibility in the vicinity of farms. While overall habitat exclusion may appear less likely for fish, empirical data is lacking for many species and behavioural reactions to noise in fish are still poorly understood.

PROBLEMS AND POTENTIAL SOLUTIONS

The problem of impact on cetaceans: frequency bands

A major difference in the hearing systems of pinnipeds and odontocetes is that the latter are much more sensitive to frequencies above 5 kHz (Fig. 1). In humans, contours of perceived equal loudness roughly follow the hearing threshold in the most sensitive frequency range, but contours flatten towards the edge of the hearing range (Fletcher & Munson 1933). Thus, sounds that have the same sensation level (i.e. they exceed the auditory threshold by a similar amount) are perceived as roughly equal in loudness even though this relationship breaks down at the edge of the auditory range. The importance of sensation levels is supported by a behavioural study on terrestrial mammals that demonstrated that aver-

sion thresholds run roughly parallel to the hearing threshold (Campbell 1957). Most importantly, there is now direct empirical evidence for equal loudness contours roughly following the auditory threshold in a bottlenose dolphin that was trained to perform a 2-alternative forced choice task in which it had to report a tone as louder or weaker than a comparison tone (Finneran & Schlundt 2011). Fig. 1 shows the hearing thresholds for a representative spectrum of marine wildlife. Odontocete hearing is generally 15 to 30 dB more sensitive than pinniped hearing in the frequency band from 4 to 40 kHz. This means that perceived loudness of sounds within the frequency band where ADDs operate is likely to be much higher for odontocetes than for pinnipeds. For example, at 10 kHz (the frequency used by the Airmar dB Plus II device) the hearing thresholds of most odontocetes are 15 to 20 dB lower than those of pinnipeds. This may in part explain why ADDs seem to have more pronounced effects on the behaviour of toothed whales than on that of pinnipeds. Therefore, although current ADDs operate at frequencies close to the most sensitive hearing of pinnipeds (20 to 30 kHz) these frequencies cannot be generally recommended, as hearing in odontocetes is even more sensitive in this band. Many cetaceans have their most sensitive hearing in the ultrasonic range between 30 and 50 kHz (Fig. 1). If impact on odontocetes is to be mitigated an ADD should not produce energy above 5 kHz.

It appears that a frequency band between 1 and 2 kHz for ADDs would be ideal for mitigating impact on odontocetes when targeting pinnipeds. Compared with the frequency band used at present in seal scarers, this would lower sensation levels in odontocetes by about 40 dB (Fig. 1), which could lead to a significant reduction in deterrence ranges for odontocetes. One concern might be that low-frequency sound can propagate over longer ranges, which could cause more noise pollution. Absorption coefficients are in the order of 0.06 dB km^{-1} at 1 kHz, compared with 0.7 dB km^{-1} at 10 kHz, the peak frequency of the Airmar device (Fisher & Simmons 1977). The difference in transmission loss between a 1 kHz and 10 kHz signal at 5 km distance would therefore only be ~3 dB. A more serious concern than sound propagation is that lower-frequency signals would be more audible to fish and baleen whales and may therefore affect these species. Tests on baleen whales and hearing specialist fish would be required before low frequency ADDs were to be deployed in baleen whale habitat. However, we think that an impact on fish would be less likely. The audiograms of fish species with no specific adaptations generally show a rapid
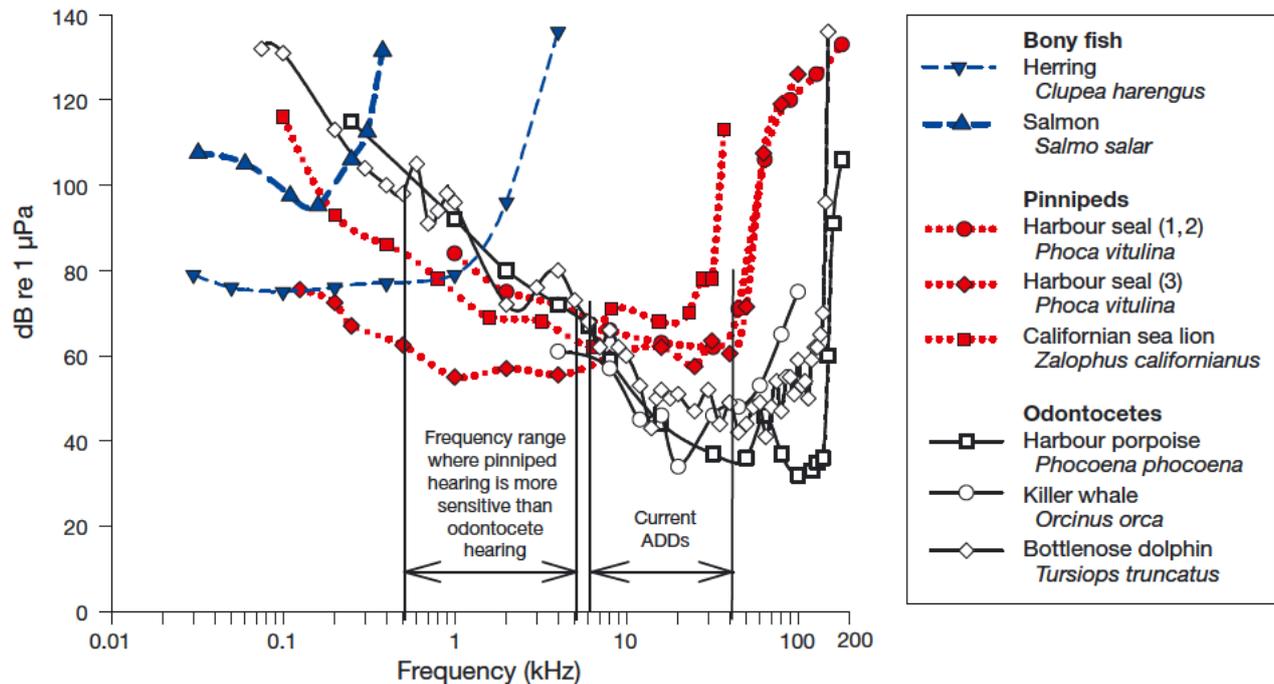
Fig. 1. Hearing thresholds for selected fish (blue dashed lines), pinnipeds (red dotted lines) and cetacean species (black solid lines). Note that most current acoustic deterrent devices (ADDs) operate in a frequency range where cetacean hearing is more sensitive than pinniped hearing. Harbour seal (1): Kastak & Schusterman (1998; lower frequencies); harbour seal (2): Terhune (1988; higher frequencies); harbour seal (3): Kastelein et al. (2009); Californian sea lion: Reichmuth & Southall (2012, subject 'Rio'); harbour porpoise: Kastelein et al. (2002); killer whale: Szymanski et al. (1999); bottlenose dolphin: Johnson (1967); herring: Enger (1967); salmon: Hawkins & Johnstone (1978)

decline in sensitivity at frequencies above 500 to 1000 Hz, making them less vulnerable to the suggested frequency range. Kastelein et al. (2007) showed that 6 out of 8 North Sea fish species did not exhibit startle responses (C-starts) at frequencies above 800 Hz, even at the maximum tested SPL of 180 dB re 1 μPa. However, there are some fish species with a broad hearing range. For example, American shad *Alosa sappidissima* are sensitive up to 180 kHz (Mann et al. 1997). However, their absolute hearing sensitivity at frequencies between 1 and 2 kHz is rather low (~130 dB re 1 μPa), which makes them 40 to 50 dB less sensitive than most odontocetes at these frequencies. This still leaves hearing specialists with lower auditory thresholds (e.g. clupeids) as a concern. Although most hearing specialists among fish are pelagic animals and therefore less likely to occur around coastal fish farms, some use coastal spawning grounds. However, even hearing specialists such as herring are not more sensitive than odontocetes in the range of 1 to 2 kHz (see Fig. 1). In conclusion, behavioural studies suggest that signals between 1 and 2 kHz would not result in dramatic effects in most fish species, but may have some influence on hearing specialists close to the device.

The problem of loudness perception: source levels

The general paradigm applied in current ADDs is that a high source level sound is expected to cause physical discomfort or even pain and therefore results in the animal leaving an area. There are several problems involved when operating at the upper end of the dynamic range of an animal. In humans, the relationship between the magnitude of sensation (Ψ) and the magnitude of the physical parameter (φ) of a stimulus can be approximately modelled by Stevens' law (Stevens 1956):

$$\Psi = k(\varphi - \varphi_0)^m$$

with k being a constant, φ_0 being the lowest perceivable physical stimulus (threshold) and m being a modality-specific coefficient determining the essential shape of the function. In the human auditory system $m = 0.6$; however, other sensory modalities have been found to have exponents higher than 1.0, e.g. $m = 3.6$ for pain caused by electric shocks (Fig. 2; Stevens 1961). Therefore, in the auditory system, a given increase of the level of a high sound pressure stimulus leads only to a small increase of the per-
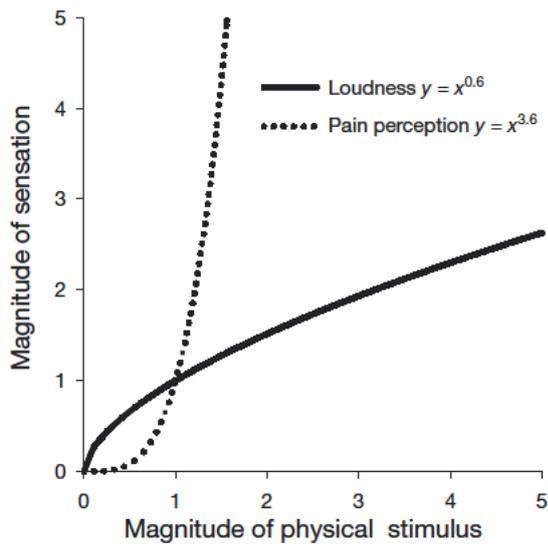
Fig. 2. Qualitative representation of Stevens' law (arbitrary units)

increase of sound pressure in the upper range of the curve in Fig. 2 can be expected to disproportionately increase the risk of damaging the ear without yielding a much stronger aversive effect. In humans, the perceived loudness of a sound is generally measured using the sone scale. On the sone scale a doubling directly reflects a doubling of perceived loudness. One sone means that a sound has a perceived loudness equal to that of a 40 dB re 20 µPa tone at 1 kHz in air for humans. The perceived loudness in sone (L) can be calculated by the equation $L = 0.01(p - p_o)^{-0.6}$ where p is the sound pressure in µPa and p_o is the effective hearing threshold (Scharf 1978). Fig. 3 applies Stevens' law to the harbour seal hearing threshold and shows different sound sources on a SPL versus perception scale. This is purely done for illustrative purposes and should not be interpreted as a claim that these human psychophysical parameters are directly applicable to marine mammals. On this scale, background noise in sea state 2 would lie between 2 and 3 sone. The lowest level of observed avoidance for harbour seals described by Kastelein et al. (2006b) would lie at about 6 sone (Fig. 3). Fig. 3 also shows that most seal scarers operate at the upper edge of the dynamic range of the animals (800 sone).

ceived loudness, while the same increase of a low sound pressure stimulus would lead to a stronger increase in perceived loudness (Fig. 2). In this context 'increase' does not refer to a ratio but means adding a defined sound pressure value. Thus, an
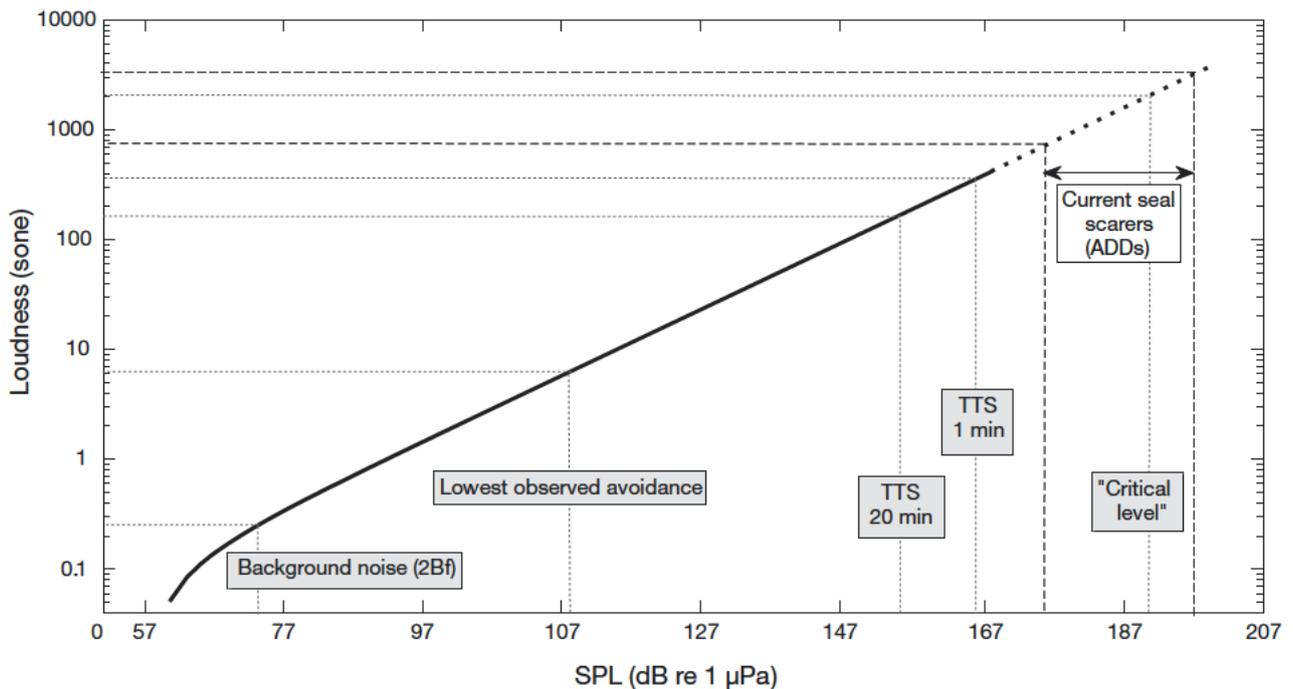
Fig. 3. Theoretical loudness scale for the harbour seal. The y axis shows the perceived loudness in sones; a doubling of the loudness in sones reflects a doubling in perceived loudness. The x axis represents the sound pressure level (SPL) with 57 dB re 1 µPa as the hearing threshold at 2.5 kHz (Kastak et al. 2005). TTS means that the source level causes a temporary threshold shift if the animal is exposed for the mentioned amount of time (based on sound exposure levels measured by Kastak et al. 2005). Values for current seal scarers are source levels at 1 m distance. The lowest observed avoidance threshold is taken from Kastelein et al. (2006b) and critical levels are based on the data reviewed in our discussion on hearing damage, 2Bf: Beaufort sea state 2

Some ADDs produce pulse trains with very short pulse durations of less than 2 ms, while others produce pulse trains with pulses of several hundred ms or continuous noise. While the perceived loudness and possibly also the risk of hearing damage is lower in a device emitting short pulses, short inter-pulse intervals can counter this effect.

In humans, pain thresholds are 130 to 140 dB above the auditory threshold (Spreng 1975), which is close to SPLs at which an impulsive noise causes hearing damage (135 dB above auditory threshold; Danielson et al. 1991). Thus, current seal scarers are either not likely to cause 'pain' or if they do they are also likely to cause hearing damage. Apart from immediate damage, long-term exposure to moderate levels can also lead to permanent damage. This can easily occur without pain. For example, students working in entertainment venues have been shown to have PTSs up to a maximum of 30 dB (Sadhra et al. 2002). Therefore, no attempt should be made to increase the source level used at present or, indeed, use devices that emit sound continuously at source levels that fall at the upper end of the dynamic range close to the suspected pain threshold. Several studies on terrestrial mammals showed that the risk of damage from exposures to brief impulses is substantially increased if a stimulus exceeds the auditory threshold by 130 to 135 dB (Danielson et al. 1991, Levine et al. 1998). This so called 'critical level' should ideally never be exceeded (Fig. 3).

Our examples here were based on human sound perception, as little data is available for marine mammals. While such direct comparisons need to be looked at critically, they can be useful to visualise basic principles in mammalian hearing and therefore develop a more accurate framework that can be used to address the problems related to ADDs. We clearly need to expand our studies on marine mammal hearing to include effects such as loudness perception. We suggest that the actual source level of an ADD should be based on models that take likely exposure time and received level combinations into account to ensure both efficiency and minimal impact on the auditory system of target and non-target species.

The aversiveness of sound stimuli

In the light of the previous consideration, it would be beneficial to exploit factors other than loudness for deterring pinnipeds. Zwicker & Fastl (1990) developed a model to describe what makes sound pleasant or unpleasant for humans. The relevant psy-

chophysical parameters in the model are sharpness, roughness, tonality and loudness. In humans, roughness of a stimulus can be maximised by applying a 70 Hz frequency modulation to a carrier signal. The perceived pleasantness of a sound is likely to be based on the general functioning of the mammalian auditory system (Plomp & Levelt 1965), but it may be worthwhile testing whether animals judge sounds in the same way as humans. Götz & Janik (2010) tested sounds based on the psychophysical model of unpleasantness by Zwicker & Fastl (1990) with free-ranging seals around a haul-out site and found that the supposedly more aversive sound types elicited stronger and longer-lasting avoidance responses compared with control sounds and ADD sounds. However, this effect was not found with captive animals in a situation where animals were highly motivated to approach a food source.

How to prevent habituation?

Experimental playbacks with harbour seals in a pool resulted in an exclusion of the animals from a zone with received levels higher than 108 re 1 µPa without habituation in 7 consecutive playback sessions per sound type used (Kastelein et al. 2006b). The fact that seals predating on fish farms appear to tolerate much higher exposure levels shows that food motivation must have a major influence on deterrence. Indeed, harbour and grey seals have been shown to habituate rapidly to sounds in a context that simulates strong food motivation (Götz & Janik 2010). In addition, the observation that odontocetes do not seem to habituate to ADDs in areas where they do not forage on farmed fish (Morton & Symonds 2002) indicates that food motivation is important with respect to habituation.

Several manufacturers state that using highly variable sound types prevents habituation. However, empirical data for animals in a feeding context demonstrate that habituation occurs quickly even if stimulus types are varied (Götz & Janik 2010). It is likely that trying to prevent habituation will not be possible unless a stimulus has strong aversive properties (see Skinner 1969 and Pryor 1987 for marine mammals). It may be possible to apply classical conditioning paradigms in the following way: an unconditioned stimulus, e.g. a fish treated with an emetic substance that causes sickness, is associated with a conditioned stimulus, e.g. an artificial acoustic signal with no biological meaning. After several pairings the conditioned stimulus is able to cause the condi-

tioned responses, which consists of the same behavioural pattern as the unconditioned response. Unfortunately, reinforcement methods are limited in an underwater environment and the only known way is to use emetics (e.g. ivory soap, LiCl). Emetics have been shown to be temporarily successful against California sea lions (Kuljis 1984, Costa 1986), but some animals learnt to avoid treated fish and continued to feed on the natural salmon run (National Marine Fisheries Service 1996). Pairing of food aversion learning with non-gustatory modalities (e.g. sound) does not seem to work very effectively (Nachman & Ashe 1977).

An alternative may be found by studying learning processes in relation to repeated stimulus elicitation. The dual process theory of habituation predicts that reactions to repeated presentations of a stimulus are always influenced by a decreasing (sensitisation) and increasing (habituation) component (Groves & Thompson 1970). These processes have been studied extensively in simple reflexes, such as the acoustic startle response (Koch & Schnitzler 1997). The startle response constitutes a pattern that involves flexor muscle contraction and is mediated by a simple oligo-synaptic reflex arc in the brainstem (Koch & Schnitzler 1997). Pilz & Schnitzler (1996) showed that latencies of the responses shorten with repeated exposures (sensitisation), while the magnitude of flexor muscle contraction slowly declines (habituation). For an application in an ADD, one can try to exploit the sensitising components of the physiological process. In this context, the startle reflex itself is an interesting candidate as it has been argued that its function is to facilitate flight responses (Pilz & Schnitzler 1996). The startle reflex is only elicited by isolated sound pulses that have rise times shorter than 15 to 20 ms and minimum amplitudes of at least 80 dB above the auditory threshold (Koch & Schnitzler 1997). Behavioural follow-up responses associated with the reflex have only recently been investigated in grey seals *Halichoerus grypus*. The majority of seals that were exposed to startling stimuli sensitised so that animals were increasingly likely to exhibit rapid flight responses, left the exposure pool and displayed clear signs of fear conditioning (Götz & Janik 2011). Once sensitized, seals also avoided a known food dispenser and showed place avoidance even in control periods. In contrast, animals exposed to stimuli of similar SPL but with longer rise times habituated. These data indicate that the startle reflex plays an important role in mediating flight responses and that it can replace habituation with sensitisation.

Acoustic deterrent devices used in other applications

Pinniped ADDs have been suggested for use in applications such as exclusion of animals from areas of potential harm, i.e. marine construction sites employing pile-driving or tidal turbines. In these applications, the large deterrence ranges caused by ADDs in odontocetes are considered advantageous as they may ensure that animals will move out of the area within which they could suffer hearing damage (Brandt et al. 2013). Our suggestions for improving ADDs do generally also apply to these applications, but there are some differences. For example, exposure may be short-term and therefore habituation may be less of a problem (Brandt et al. 2013). However, pile-driving operation in areas of foraging habitat could be an exception as habituation occurs quickly when food motivation is high (Götz & Janik, 2010). Given the potential effects of ADDs on marine mammal hearing, it may be a better solution to develop novel devices that are designed for purpose than to use currently available ADDs.

CONCLUSIONS

Efficiency of ADDs differed considerably between studies and study sites, which appears to be the result of differences in environmental conditions, populations, species, deployment or study design. Overall, efficiency seemed to range from poor to moderate with only a few examples where ADDs have been reported to be very effective, mainly when used in small and defined areas. Habituation to ADDs occurred within varying time frames, ranging from days to years, but it seemed to be a substantial problem in almost all studies. In contrast, odontocete species have been shown to be excluded from their habitat and long-term studies did not find any obvious habituation of these effects. This is most likely because odontocetes have more sensitive hearing in the devices' frequency range and apparently little motivation to feed on farmed fish in the studied areas. Therefore, to minimise effects of ADDs on odontocetes, one should shift to a lower frequency band than used at present, where the hearing sensitivity is higher in seals than in odontocetes. However, potential impacts on baleen whales and hearing specialist fish should be investigated if these occur in the vicinity of the fish farm. In no case should ADD signals contain much energy above 5 kHz if odontocetes use habitats around the fish farm. In addition, meth-

ods to reduce the duty cycle of ADDs should be found. Particularly, the effects of triggering methods or the presentation of isolated sound pulses exploiting autonomous reflexes related to flight behaviour, such as the startle reflex, should be more thoroughly tested. Signals should be short and duty cycles as low as possible to avoid hearing damage. The maximum SPL should be chosen based on available data for the onset of TTSs, assuming realistic exposure scenarios.

Most current, commercially available ADDs have some potential to damage the hearing of marine mammals, particularly if an animal stays in the vicinity of a fish farm for hours. In areas with a high density of fish farms, acoustic trauma may accumulate, similar to exposure of human workers to industrial noise. Therefore, only sound exposure protocols that use sound pressure level and exposure time combinations that are unlikely to cause hearing damage in pinnipeds and cetaceans should be used. Methods to prevent habituation, such as fear conditioning or the startle reflex, should be investigated in tests around fish farms. Furthermore, as food motivation appears to be a major factor, any newly established fish farm should try to prevent predation from the beginning. Most importantly, efficiency and target specificity of any device should be tested by independent studies before devices are deployed in fisheries or on fish farms.

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Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions

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Supplement 1: Sound exposure sensation levels (SEL$_{sens}$)

As a conservative approach, Southall et al. (2007) suggested an M weighting function to correct for frequency dependency of hearing damage. Their argument is that the weighting function is flat over large parts of the hearing range. However, this is only correct if the subjects used to derive temporary threshold shift (TTS) or permanent threshold shift (PTS) criteria had been tested within their most sensitive hearing range. However, most of the animals used to derive these criteria were tested at mid-frequencies (e.g. Finneran et al. 2005) where their hearing is less sensitive than at higher frequencies. Therefore, the use of the M weighting is not fully adequate as it does not correct for the fact that the test signals used to derive the noise exposure criteria may have been less harmful because they did not fall in the frequency range where odontocete hearing is most sensitive (see also Fig. 1 in main text). In addition, some test subjects had slightly compromised hearing. For example, one animal (Ben) had a hearing threshold of about 90 dB re 1 μPa at 3 kHz under quiet conditions (Finneran et al. 2005) while Johnson (1967) reported a threshold of 76 dB re 1 μPa at the same frequency for a bottlenose dolphin The same animals showed clear signs of permanent hearing damage in the frequency band between 10 and 40 kHz. More importantly, bottlenose dolphin hearing thresholds are much lower at higher frequencies compared to the test frequencies used in many TTS studies i.e. the lowest threshold measured in the ultrasonic range is 43 dB re 1 μPa (Johnson 1967). Thus, it is possible that a bottlenose dolphin that is exposed to signals at higher frequencies develops TTS at lower exposure levels than suggested by Southall et al. (2007). This has also been suggested in a recent study that demonstrated onset of TTS at 20 dB less when exposed to 20 kHz compared to 3 kHz (Finneran & Schlundt 2010). Finally, one needs to consider that other *odontocete* species appear to have somewhat lower hearing thresholds at the test frequencies (e.g. killer whales; see Fig. 1) than bottlenose dolphins and might therefore develop TTS at lower sound exposure levels. In spite of the fact that this data is only based on a few test subjects we believe that in the absence of additional data a more detailed categorization than the 'mid frequency odontocetes' proposed by Southall et al. (2007) should be considered.

We suggest that exposure criteria should be referenced to the hearing sensitivity of the test subject instead, using sensation levels as a measure. Apart from the previously mentioned arguments this is also supported by the fact that in humans low-frequency noise (300–600 Hz) causes much lower levels of TTS compared to noise that falls in a frequency band between 2400–4800 Hz where hearing is more sensitive (Ward et al. 1959). The importance of sensation levels has been highlighted by studies on fish, birds, terrestrial mammals and humans which found a clear correlation between the amount of TTS and the sound pressure level difference between the baseline hearing threshold and the exposure level (Ward et al. 1959, Smith et al. 2004b). In marine mammals, Mooney et al. (2009a) reported a negative correlation between the sensation level that causes onset of TTS and exposure time indicating that TTS onset depends at least in part on sensation levels.

We suggest to use SEL$_{sens}$ (sound exposure sensation levels) as a noise exposure criterion with units of dB re (hearing theshold of test subject in μPa)^2 s. Kastak et al. (2005) used a similar unit for comparative purposes and found that sensation levels could explain differences in the onset TTS levels across 3 different species and test subjects with slightly different hearing abilities. Applying SEL$_{sens}$ levels would be beneficial for several reasons: a) to compensate for potential differences in hearing sensitivity between test subjects (in TTS studies) and the average of a population, b) to compensate for differences in the audiograms of different species which are currently classed in the same category (Southall et al. 2007) and c) to allow for the fact that not all test subjects in TTS studies were tested at the frequencies of their most sensitive hearing.

SEL$_{sens}$ levels are a combination of 2 different concepts, the sound exposure level and the sensation level. Sound exposure levels (SEL) can be calculated by the following simplified equation (see Madsen 2005)

$$SEL = SPL_{rms} + 10\log_{10}(t)$$

where SPL$_{rms}$ is the root mean square (rms) sound pressure level of the signal the animal is exposed to and t is the exposure time of the signal. The sound pressure level is defined as

$$SPL = 20 \cdot \log(p/p_0)$$

where p is the sound pressure of the signal and p_0 is the reference sound pressure underwater of 1 μPa.

For the SEL$_{sens}$ level we suggest to replace the reference sound pressure level p_0 with the pressure p_h which is the pressure at the hearing threshold for the frequency of the sound and to use the received level p_{exp} at the receiver so that SEL$_{sens}$ is

$$SEL_{sens} = [20 \cdot \log(p_{exp}/p_h)] + 10\log(t)$$

Given the logarithmic nature of the dB scale the values obtained from this calculation are numerically identical to simply subtracting the hearing threshold (in SPL) from the sound exposure level that marks onset of TTS. We did not consider the duration of the test signals used to measure auditory thresholds in these calculations since there is no evidence that hearing thresholds (in contrast to TTS) depend crucially on the duration of test signal as long as the test signal exceeded the integration time of the auditory system (Au 1993). SEL$_{sens}$ can be used to arrive at (a) a noise exposure criterion that marks onset of TTS for untested species by assuming TTS occur at similar sensation levels in different species, (b) a noise exposure criterion for a signal that falls in an untested frequency range where the hearing threshold is known and (c) a noise exposure criterion for animals of the same species with lower hearing thresholds than the test subjects in which TTS was measured. This can be done by inserting the hearing threshold of the respective species into the 'sensation level-sound exposure levels' equation which is numerically identical to simply adding the new hearing threshold to the SEL$_{sens}$ criterion.

Finally, we also included a review of predictions that are based on extrapolation from humans (Taylor et al. 1997). While we are aware that researchers generally tend to call for caution when extrapolating information from human data (e.g. Southall et al. 2007) we believe that they should be mentioned for 3 reasons. First, there is a complete lack of data on how hearing damage develops in marine mammals as a result of exposure to noise for several months or years at moderate received levels. Second, in spite of the fact that some marine mammals have specific adaptations to aquatic hearing there is currently little evidence that the basic functioning of the cochlea is fundamentally different from terrestrial mammals. A closer look at the TTS data does in fact reveal that *odontocetes* do not seem to have a much larger dynamic range than humans. For example, Finneran et al. (2005) proposed that 1 s exposure to 195 dB re 1 μPa would cause onset of TTS. This value is only 110 dB above the hearing threshold of the test subject (approx. 85 dB re 1 μPa) and would therefore fall in the same order of magnitude as in humans. Third, we believe that comparisons to terrestrial mammals are helpful to understand the general problems raised in this review (see 'The problem of loudness perception' section). This can help to sharpen research questions and direct future research more towards answering conservation-related questions based on general biological concepts rather than specific ideas prominent within marine mammal biology.

Supplement 2: Calculation of the zones for hearing damage

General considerations

In the following sections we try to answer the question whether acoustic deterrent devices (ADDs) are likely to cause hearing damage in marine mammals using current physiological data. Such an attempt inevitably requires a variety of different assumptions to be made. In order to predict impact zones, sound propagation needs to be modelled, which can be difficult in shallow water habitats. Shapiro et al. (2009) measured sound propagation in a range of ADDs and showed that that there can be considerable variation in received levels (up to 15 dB) at locations separated by less than a metre. Shapiro et al. (2009) conclude that this challenges the concept of concentric impact zones and animals might not be able to show a directional avoidance response. However, one also needs to consider that there is empirical evidence for both directed avoidance behaviour (Johnson 2002) and directed approach responses (Mate & Harvey 1987) in marine mammals living in shallow water habitats. Also, Shapiro et al. (2009) found that on average received levels dropped with increasing distance and received levels tended to be lower than predicted by spherical spreading. We therefore believe that in the absence of sufficient data using a simple spherical spreading model will provide a reasonably conservative approach.

As previously mentioned the 'equal energy hypothesis' has recently been challenged by a study that showed that disproportionally higher SELs are required to cause TTS when exposure times are short (Mooney et al. 2009a,b). Similarly, Finneran et al. (2010a) showed that while TTS can be predicted by using sound exposure levels for short exposure time a better fit to the empirical data can be achieved by applying a more complicated model that treats exposure time and sound pressure level as independent variables. In spite of these recent advances in our understanding of TTS we feel that data on TTS models is still scarce and we therefore based the following analysis on simple SELs as initially suggested by Southall et al. (2007).

Another aspect which needs to be taken into account is that commercial ADDs differ remarkably in their pulse emission patterns, pulse lengths, duty cycles and source levels. Furthermore, some companies have produced various models which differ in their emission patterns or offer user-selectable duty cycles. To take these differences into account we calculated impact zones for the effects caused by 2 different cumulative sound exposure levels: 203 dB re 1 µPa^2 s and 221.6 dB re 1 µPa^2 s. These 2 SEL reflect continuous exposure to a level of 193 re 1 µPa (SL of the Ace-Aquatec & ~Airmar) for 10 s and 12 min respectively. The actual exposure times needed to reach these cumulative SELs when exposed to ADDs are much larger because of quiet periods between emissions and the short duration of pulses within a pulse train (emission). Therefore, we calculated, for each device the 'effective duty cycle' i.e. the time during which a sound is actually produced taking intervals between pulses and emissions as well as pulse lengths into account. This 'effective duty cycle' is different from the 'emission duty cycle' mentioned in Table 1 which refers to the time during which a pulse train or emission is produced. The effective duty cycle was then used to calculate how long each device will have to operate at its given source level to reach this cumulative SEL. This exposure time was calculated as

$$\text{Time [s]} = \frac{10^{\left[\frac{\text{SEL}-\text{SL}}{10}\right]}}{\text{dc}}$$

where SEL is the sound exposure level, SL the source level of the device and dc the effective duty cycle as a fraction of 1 (=100%).

The following average numbers (derived from the information provided in Table 1) were used in this calculation:

	Source level (dB re 1 μ Pa) rms	Average pulse length (ms)	Average pulse interval within emission	Emission duty cycle (% time emission)	Effective duty cycle: (% time sound)
Ace-Aquatec	193	8.65 ms	40.85 ms	10% 30% (3 transd.)	2.11%, 10.58%
Airmar	192 & 198	1.4 ms	40 ms	50% 200% (4 transd.)	1.75% 7%
Lofitech	182	500 ms	NA (no trains)	12%, 25%	12%, 25%
Terecos	178	4100 ms	NA (continuous)	11%	11%

Marine mammals: temporary threshold shifts (SEL 203 dB re 1 μPa^2 s)

Mooney et al. (2009b) showed that a bottlenose dolphin exposed to series of 500 ms long double pulses (sonar pings) only developed TTS at sound exposure levels (SEL) of 214 dB re 1 μPa^2 s. Finneran et al. (2005) reported levels of around 195 dB re 1 μPa^2 s to be sufficient to cause TTS when the animals were exposed to pulses of 1–8 s duration. Currently available seal scarers produce either pulse trains or continuous emissions of an overall length from 0.5–20 s (see Table 1). Using Finneran et al. (2005) TTS criterion of 195 dB re 1 μPa^2 s and assuming exposure to noise from an ADD reflecting a cumulative SEL of 203 dB re 1 μPa^2 s the difference between the sound exposure level causing onset of TTS and the sound exposure level of the ADD would be 8 dB. Assuming spherical spreading, TTS in bottlenose dolphins would be caused at about 2.5 m distance from a device. However, data on harbour porpoises suggested that SELs as low as 164 dB re 1 μPa^2 s can cause TTS (Lucke et al. 2009). The signals tested by Lucke et al. (2009) were short transients with broad spectra with most energy below the most sensitive hearing range of the harbour porpoise. Assuming spherical spreading, absorption losses of about 0.7 dB per km for a 10 kHz signal (Fisher & Simmons, 1977, 12°C water temperature) and ADD noise reflecting a cumulative SEL of 203 dB re 1 μPa^2 s, TTS would be caused in porpoise closer than around 89 m to the transducer.

As we argue in Supplement 1 there is a possibility that TTS maybe caused at lower SELs at frequencies where hearing is more sensitive (see Supplement 1 for justification of the calculations). We therefore provide alternative impact zones based on an approach that takes the hearing sensitivity of the test subject from which TTS data was derived and the hearing threshold of the target species within the respective frequency band into account ('sound exposure sensation levels (SEL$_{sens}$), see Supplement 1 for justification of the calculations). This approach seems justified given that TTS is caused by lower sound pressure levels in a frequency range where dolphin hearing is more sensitive (Finneran & Schlundt 2010). Studies on odontocetes generally found SELs between 193 and 214 dB re 1 μPa^2 s to cause mild to moderate but fully recoverable TTS (Finneran et al. 2000, Schlundt et al. 2000, Finneran et al. 2002, Nachtigall et al. 2004, Finneran et al. 2005, Mooney et al. 2009 a,b, Finneran et al. 2010a,b). Finneran et al. (2005) suggested an onset-TTS criterion of 195 re 1 μPa^2 s while the test subjects hearing threshold was between 80 dB re 1 μPa (rms) and 90 dB re 1 μPa (rms) at the exposure frequency under quiet conditions (see Fig. 3 in Finneran et al. 2005). Mooney et al. (2009a) found an onset of TTS at an SEL of 198 dB re 1 μPa^2 s for exposures in the range of 2min. Their subjects' hearing threshold was about 95 dB re 1 μPa (rms) at the test frequencies. Summarising these data we find that SEL$_{sens}$ levels between 100–130 dB re re (hearing threshold in μPa)^2 s are likely to result in onset of TTS. We therefore used an average value of 115 dB re (hearing threshold in μPa)^2 s for the following calculations. The sound exposure levels re 1 μPa^2 s that cause onset of TTS can then be calculated by adding the most sensitive hearing threshold in dB re 1 μPa within the relevant frequency range (10–35 kHz). These hearing thresholds were 37 dB re 1 μPa (rms) for the harbour porpoise (Kastelein et al. 2002), 43 dB re 1 μPa (rms) for the bottlenose dolphins (Johnson 1967), and 30 dB re 1 μPa (rms) for killer whales (Hall & Johnson 1971). The respective onset-TTS sound exposure levels would then be 152 dB re 1 μPa^2 s for the harbour porpoise, 158 dB re 1 μPa^2 s for the bottlenose dolphin, and 145 dB re 1 μPa^2 s for the killer whale. Assuming spherical spreading and absorption loss of 0.7 dB per km (Fisher & Simmons, 1977, for a 10 kHz signal), exposure to a 10 s continuous ADD signal of 10 kHz at 193 dB re 1 μPa (rms) (SEL =

203 dB re 1 μPa^2 s) would therefore result in TTS zones of 345 m for the harbour porpoises, 175 m for the bottlenose dolphins and over 748 m for killer whales.

The lowest SEL causing TTS in a pinniped was found to be 183 dB re 1 μPa^2 s for the harbour seal (Kastak et al. 2005). Assuming spherical spreading in the vicinity of the device temporary threshold shifts in a harbour seal would occur up to a distance of 10 m from the seal scarer. In the harbour seal, SEL has been measured directly at 1–4 kHz (Kastak et al. 2005). Since this was in the most sensitive hearing range of the species (see Kastelein et al. 2009) and since the harbour seal audiogram is flat over a large frequency range (Kastelein et al. 2009) referencing the directly measured sound exposure level to the auditory threshold in the frequency range where ADDs operate would not change the results. Therefore, no SEL_{sens} calculations were carried for the pinnipeds.

Marine mammals: permanent threshold shift (PTS)

The noise exposure criteria published by Southall et al. (2007) would suggest permanent injury in most *odontocetes* at SELs of 198 dB re 1 μPa^2 s for multiple pulses and 215 dB re 1 μPa^2 s for continuous noise. As most seal scarers emit pulse trains (e.g. Airmar; see Table 1) we used the criterion for multiple pulses for our calculations. When calculating impact zones based on the same assumptions mentioned in the previous section this would mean that a cumulative sound exposure levels of 203 dB re 1 μPa^2 s would only cause hearing damage in *odontocetes* if an animal is closer than 2m to the sound source. Exposure to a cumulative sound exposure level of 221.6 dB re 1 μPa^2 s would result in an impact zone for *odontocetes* of up to 15 m.

Lucke et al. (2009) found that onset of TTS in harbour porpoises may occur at sound exposure levels of 164 dB re 1 μPa^2 s. Data on humans showed that threshold shifts of about 40 dB are correlated with an increase of the exposure level by approximately 20 dB (Ward et al. 1958). Therefore, one might attempt to derive at a noise exposure criterion for PTS by adding 20 dB to the onset TTS criterion (see Southall et al. 2007). Based on the assumption that permanent hearing damage may occur at levels 20 dB higher than those that cause onset of TTS permanent hearing would occur at SELs of 184 dB re 1 μPa^2 s. Assuming spherical spreading and previously mentioned absorption losses (0.7 dB/km), exposure to a cumulative SEL of 203 re 1 μPa^2 s would be only sufficient to damage hearing at distances of up to 9 m. However, exposure to ADD noise reflecting a cumulative SEL of 221.6 dB re 1 μPa^2 s would result in a damage zone of 76 m.

Alternatively, one might try to calculate damage zones using the SEL_{sens} approach (Supplement 1). If we add the 20 dB increase in SPL needed to cause 40 dB TTS to the SEL_{sens} that causes onset TTS in bottlenose dolphins (115 dB re (hearing threshold in $\mu Pa)^2$ s), then permanent threshold shifts would occur at 135 dB re (hearing threshold in $\mu Pa)^2$ s. The auditory thresholds of the respective species are 37 dB re 1 μPa for the harbour porpoise (Kastelein et al. 2002), 43 dB re 1 μPa for the bottlenose dolphins (Johnson 1967), and 30 dB re 1 μPa for killer whales (Hall & Johnson 1971). Inserting these thresholds we arrive at SEL damage criteria of 165 dB re 1 μPa^2 s for killer whales, 172 dB re 1 μPa^2 s for harbour porpoises, and 178 dB re 1 μPa^2 s for bottlenose dolphins. Assuming spherical spreading and absorption of 0.7 dB per km (10 kHz signal) a cumulative sound exposure level of 203 dB re 1 μPa^2 s would cause PTS at distances up to 18 m, 35 m and 79 m for the bottlenose dolphin, harbour porpoise and killer whale respectively. The scenario based on the higher SEL of 221.6 dB re 1 μPa^2 s would result in larger impact zones of 150 m (bottlenose dolphin), 295 m (harbour porpoise) and 642 m (killer whale)

Using the Southall et al. (2007) criterion for pinnipeds (multiple pulses: 186 re 1 μPa^2 s), the cumulative SEL of 203 dB re 1 μPa^2 s would cause a damage zone of 7 m (assuming spherical spreading) while the higher SEL (221.6 dB re 1 μPa^2 s) would result in a larger impact zone of 60 m.

Marine mammals: extrapolations from human data and long-term exposure scenarios

There is no data available on hearing damage in marine mammals as a result of exposure for several months or years at moderate to low source levels. Therefore, predictions have been based on human damage criteria. Gordon & Northridge (2002) used Kryter's (1994) damage threshold of 115 dB above the hearing threshold. They yielded PTS ranges between 79 m and 562 m for a high power device (200 dB re 1 μPa @ 1 m) and values between 40 and 281 m for a 194 dB re 1 μPa ADD depending on the species' hearing threshold. In humans, noise levels at industrial workplaces should not exceed 85 dB above the hearing threshold (NIOSH 1998). Taylor et al. (1997) applied an even more conservative threshold of 80 dB above the hearing to marine mammals in the context of ADDs. The zone where this value is exceeded would be over a kilometre for most ADDs. In areas with dense fish farming, animals could potentially be exposed to such levels for an extensive amount of time. However, it should be noted that there is no empirical basis for such extrapolation to marine mammals and hence the results should be interpreted with caution.

ADD effects on other marine life

The literature provides less data on the effects of underwater noise on hearing in fish than it does in mammals (Popper & Hasting 2009). Assessing hearing damage in fish is complicated by the fact that auditory sensitivity and hearing ranges vary dramatically across species. While some species evolved specific adaptations which result in more sensitive hearing over a broader frequency range other species have much more restricted hearing abilities (Popper & Hasting 2009). Temporary threshold shift and hair cell damage have only been demonstrated in a limited number of species (Popper & Hasting 2009). Hair cell damage has been found in cod exposed to a 400 Hz signal sound pressure levels of 180 dB re 1 µPa for several hours (Enger 1981). Similarly, hair cell damage was found in oscars *Astronotus ocellatus* that were exposed to 300 Hz sine wave sounds of the same source levels (Hastings et al. 1996) and snappers that were repeatedly exposed to airgun emissions (received levels up to 180 dB re 1 µPa, peak frequencies between 20–100 Hz) used for seismic surveys (McCauley et al. 2003). The signals used in these studies had most energy concentrated in a frequency range where the tested fish species were most sensitive. In contrast, very few ADDs emit any significant amount of energy at frequencies below 2–3 kHz making it unlikely that ADDs could cause similar effects. For instance, the signal component with the lowest frequency emitted by an Ace-Aquatec ADD has a frequency of 6 kHz and a source level of only 178 dB re 1 µPa (Lepper et al. 2004). This is well below the received levels found to cause hair cell damage in all previously mentioned studies.

Temporary threshold shift has been most thoroughly documented in freshwater *cyprinids* which possess excellent hearing abilities. Goldfish developed weak temporary threshold shift after just 10 min of sound exposure to white noise at received levels of 170 dB re 1 µPa (Smith et al. 2004a). Fathead minnows (*Pimephales promelas*) exposed to band-limited noise (0.3 and 2 kHz) for 1 hour exhibited TTS at even lower received levels of only 142 dB re 1 µPa (Scholik & Yan 2001). While these levels were rather low, both studies used broadband noise with significant energy within the main hearing range of the species which is below the typical frequency range of ADDs. Smith et al. (2004b) showed that the sound pressure level difference (sensation levels) between the baseline hearing threshold and levels that cause onset of TTS are a good predictor for the amount of TTS caused. Their data can be used for a rough estimate of the risk that ADDs may pose: sensation level of at about 68 dB would be required to cause significant TTS in the order of 15 dB. The auditory sensitivity of herring at a frequency of about 4 kHz is 136 dB re 1 µPa (Enger 1967) while a 4 kHz segment of a Terecos ADD has a source level of 166 dB re 1 µPa (Lepper et al. 2004). The maximum sensation level caused by the Terecos device would therefore only be 30 dB and hence no such TTS is likely to be caused. In addition the experiment by Smith et al. (2004b) involved noise exposure for 24 h while ADDs usually only produce short bursts of pulses at low frequencies which are then followed by a pause or emissions at even higher frequencies. Similarly, sensation levels would be low in fish with ultrasonic hearing (e.g. shad *Alosa sappidissima,* Mann et al. 1997): the absolute sensitivity of shad at a frequency of 40 kHz is 141 dB re 1 µPa (Mann et al. 1997) while an Ace-Aquatec ADD produces a source level of about 165 dB at 30 kHz (Lepper et al. 2004). Hence, even in the most conservative scenario, assuming maximum overlap between the most sensitive hearing range of shad and the spectrum produced by an Ace-Aquatec ADD, the sensation level would only be 24 dB. The only scenario in which a sensation level caused by ADDs would be somewhat higher is if a marine fish species existed with an absolute hearing sensitivity similar to that of a freshwater cyprinid (i.e. goldfish, minnow). The auditory threshold of goldfish is about 116 dB at 2.5 kHz (Fay 1969) and hence sensation levels caused by a 4 kHz segment of a Terecos ADD would be in the order of 50 dB. Farmed fish species like salmon are unlikely to be affected by ADDs since they are insensitive to frequencies above 1 kHz (see Fig. 1). This has also been confirmed by empirical studies which found no evidence for behavioural responses or any influence on egg fertility at frequencies above 800 Hz (Mate et al. 1987)

Thus, while marine fish species with high-frequency hearing abilities (e.g. *clupeids*) are generally more likely to be affected by ADDs, sensation levels and absolute sound pressure levels inflicted by ADDs are probably insufficient to cause hair cell damage. Similarly, sensation levels in species with ultrasonic hearing would probably be insufficient to cause damage but no empirical TTS data is available for these species. Finally, it is also important to note that in contrast to mammals hair cells in fish can re-grow after acoustic trauma and depending on the exposure scenario damage caused might in some cases only be temporary (Corwin 1981, Popper & Hoxter 1984, Lombarte et al. 1993). However, this does not mean that hearing damage is never of any concern in fish since temporary threshold shifts may have a fitness consequence.

The effect of noise on hearing in reptiles and invertebrates is poorly understood but will depend on the ability of these animals to detect sound. Sea turtles seem to be primarily sensitive to low-frequency sound below 1 kHz (Bartol et al. 1999). Invertebrate detection of vibration stimuli is primarily low-frequency and mostly limited to the particle motion component of the signals. The lateral line of some cephalopods is

sensitive to water movement stimuli up to 100 Hz (Budelmann & Bleckmann 1988). Early studies showed that the statocysts of cephalopods are sensitive to about 100Hz (Packard et al. 1990) while more recent studies revealed sensitivity to the particle motion component of sound up to 500 Hz (Mooney et al. 2010). The fact that auditory sensitivity at high frequencies is low or non-existent is also supported by a study that showed cephalopods exhibiting no avoidance responses to simulated high intensity ultrasonic odontocete clicks (Wilson et al. 2007). This suggests that the effects of noise on some of these species may be similar to that on fish with no specialised hearing and hence ADDs are unlikely to affect these animals.

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Final Report to the Scottish Government

An investigation of target-specificity and effectiveness of seal deterring sounds

███████████████████

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Contents

Abstract

Current acoustic deterrent devices (ADDs) to prevent seal predation on fish farms appear to have limited effects on seals but exclude dolphins and porpoises from their habitat. This study had the objective to design novel sounds that would efficiently deter seals but have no effect on other wildlife. We tested a variety of novel artificial sounds and also natural seal sounds. We designed the artificial sounds to make them less audible to dolphins and porpoises and more aversive to seals using data on their hearing thresholds and the reactions of mammals to sound playbacks. While sounds of other seals only attracted the animals, seals could be deterred by commercial ADD sounds and our novel artificial sounds on first exposure but habituated within minutes to commercial ADD sounds and most of our novel sounds. However, most seals sensitized to a newly designed startle stimulus so that avoidance reactions grew stronger over time leading to the avoidance of a known feeding station. This stimulus was also used to successfully deter seals from a fish farm for 2 months. Field tests also showed that the startle sound had no effect on porpoise and minke whale distribution. The sound is not audible to salmon but might be to fish with more sensitive hearing. However, studies on startle responses in herring suggest that they would only affect such species within 100m of the ADD. We recommend replacing all ADDs in current use with devices using this new stimulus in connection with a stimulus trigger that elicits a sound when a seal approaches.

Executive Summary

Acoustic deterrence devices (ADDs) are used on many fish farms to decrease the risk of seals taking fish from the farm and destroying nets in the process. Studies on the effectiveness of these devices have produced mixed results with no clear indication that they remain effective over longer periods of time. More recent studies have shown that ADDs also have detrimental effects on other wildlife (Morton 2000, Johnston 2002, Morton & Symmonds 2002, Olesiuk *et al.* 2002). For example, dolphins and porpoises have been shown to avoid areas where ADDs are being used, but return if ADDs are switched off. Since most farms use ADDs and require them to work continuously, there is concern that whales, dolphins and porpoises are being excluded from important habitats which in turn may affect their survival.

The objective of this study was to design a more effective ADD that deters seals from fish farms but has no effect on other wildlife. We tested natural seal sounds but also newly designed artificial sounds and compared them with sounds used in commercial ADDs produced by Airmar, Ace-Aquatec, Lofitech and Terecos. Tests were conducted on harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) in captivity and in the wild. We used an underwater speaker system to play sounds tested in this study.

While most seal sounds had no effect, some of them caused seals to approach, and they are therefore not suitable to deter seals from fish farms. In the second step we designed novel, low pitched, artificial sounds that were more audible to seals than to dolphins and porpoises based on their hearing thresholds and that were expected to be aversive based on the scientific literature on unpleasantness of sounds in humans. While seals avoided our novel sounds and commercial ADD sounds on the first exposure, they habituated to these sounds within minutes and quickly returned to the known feeding station next to the underwater speaker. In the wild, commercial ADD sounds and our novel sounds managed to decrease the number of seals within 40 to 60 m of the speaker near a haul-out site. However, there was no food motivation for these animals, so that there was no food cost when avoiding the area by either hauling out or swimming away from the speaker. Furthermore, sounds were only tested up to 10 times with often days or weeks between exposures. Therefore, it is likely that we exposed different seals in each playback session. Thus, we cannot assess how quickly seals would habituate to these sounds in the wild. The results from the captive study suggest that habituation would occur quickly under food motivation.

In a third step we tested a novel startle-eliciting sound pulse which had a completely different effect on seal behaviour. This very brief sound had a short rise time with all its energy below 2.5 kHz. The sound pulse was designed to elicit a startle response in seals but not in odontocetes by making use of differences in the hearing sensitivity of both groups of animals. To elicit a startle reflex and cause an avoidance response the startle stimulus had to cause a hearing sensation that was at least 80-85 dB above the hearing threshold of a seal. For the typical phocid seal this meant it had to be received at levels of above 160 dB re 1 µPa. This is well below the threshold where sound exposure to a single pulse would cause temporary hearing damage (190 dB re 1 µPa). In the captive tests five animals sensitized to the startle sound so that the avoidance response grew stronger over time and the seals were effectively deterred from their feeding station. These seals showed immediate flight responses, rapidly left the pool and stayed on land for long periods of time. They also showed great reluctance to approach the feeding

station. Animals that did not sensitize (n=3) still showed stronger aversion to this sound than to all other sounds that we tested. A subsequent test confirmed that these animals appeared to have poorer hearing. Therefore, the tested sound level would not have been loud enough to elicit a startle response. The startle sound was also the most effective one in deterring seals around haul-out sites in the wild.

In a final test we investigated the effect of this startle sound on seals and harbour porpoises on a fish farm on the West coast of Scotland. The startle stimulus managed to deter seals from the farm for the duration of the field experiment (2 months) and did not affect the distribution of harbour porpoises in the area. Minke whales were seen more often when startle stimuli were played than in quiet control periods However, this was based on a total of 8 sightings and needs further study. Based on the literature, salmon cannot hear this startle sound and fish with more sensitive hearing should only be affected within 100 m of the speaker. However, this should be tested experimentally.

We conclude that all current ADDs should be replaced with devices using our novel startle stimulus since it is more effective than current ADD sounds, decreases overall noise pollution and does not have significant detrimental effects on the distribution of other wildlife.

Introduction

Worldwide farming of marine and diadromous finfish species has experienced tremendous growth rates showing a tenth fold increase over the last three decades (FAO 2005). This increase in food resources presented in a marine environment led inevitably to interactions with predatory species. The costs of attacking a fish-farm for a predator are low while the profitability is high. It is therefore not surprising that these interactions occur.

Seal predatory behaviour around fish farms can cause a variety of economical risks for the owner (Nash, Iwamoto & Mahnken 2000) which led to the development of a range of anti-predator control methods. These methods fall in one of the following categories (Würsig & Gailey 2002; Quick et al. 2004):

- net modifications e.g. tensioning nets or adding a second net to avoid capture of farmed fish from outside the enclosure,
- acoustic deterrent devices (ADDs) to scare seals,
- lethal or non-lethal removals,
- population control,
- aversive conditioning.

However, all of these methods have their problems. For example, some types of predator nets can cause tangling of predators and non-predatory species. Lethal removals as well as population control may have an impact at the population level (Ross 1988), are ethically questionable and not effective in some areas (Pemberton & Shaughnessy 1993). Culling of higher order predators can also have negative impacts on predation rates by other predators. Pinnipeds forage on predatory fish species around the net pen which, in turn, potentially feed on aquaculturally important species (Fraker & Mate 1999). Finally, food aversion conditioning requires that individuals learn to associate treated fish with sickness which may be hard to achieve when predator numbers are high (Würsig & Gailey 2002).

Acoustic deterrent devices have often been considered a benign way of dealing with the predation problem. However, its main problems appear to be habituation and the effects it has on other marine wildlife (Johnston 2002). A variety of ADDs were designed over the last two decades to reduce or stop predation of pinnipeds on finfish farms (Table 1). Early trials on harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) were relatively unsuccessful with habituation setting in quickly (Anderson & Hawkins 1978). Experiments using higher source levels by Mate *et al.* (1987) used frequency-modulated pulses (8-20 kHz) of variable length at peak-to-peak source levels of 187 dB re 1μPa to deter harbour seals from salmon hatcheries. As a result the predation rate dropped substantially for the next 3 years, but returned to its original level in the fourth year. In the fourth year, the device also seemed to attract seals. A similar "dinner bell" effect was reported by Geiger & Jeffries (1987). The time to habituation varies widely in different field studies ranging from a few days (Harvey & Mate 1987) to 3 years (Rivinus 1987). Kastelein et al. (2006) deterred captive harbour seals successfully for 2 months using 250 ms long pulses of 8-45 kHz tones with harmonics. However, there was no food motivation associated with the location of the ADD. Akamatsu *et al.* (1996) tested an iron drum (0.5-2 kHz, 210 dB re 1μPa) and different playback sounds at a maximum source level of 165 dB re 1 μPa rms on captive Steller sea lions. Killer

whale (*Orcinus orca*) calls had no effect, frequency–modulated sweeps (1-4 kHz, 1 s duration, 1s inter-stimulus interval) repelled juveniles and pure tones (8 kHz, 5 s duration, 5s inter-stimulus interval) repelled most animals. Only the iron-drum was able to deter males in feeding trials, most likely due to the high source level of the sound. Acoustic deterrent devices used to protect salmon runs (National Marine Fisheries Service 1995) and fish farms (Norberg 1998) had little effect on otariids although in some cases recruitment of new individuals was successfully prevented (National Marine Fisheries Service 1995).

Yurk & Trites (2000) tested commercially available Airmar and Ferranti-Thompson Mk3 ADDs (Tab 1) on harbour seals feeding on out-migrating salmon. The Airmar device yielded a decrease in predation rate in all 7 successive trials. The Ferranti-Thompson was only tested once, yielding a decrease in the number of seals in comparison to a control trial on the following day. Jacobs & Terhune (2002) tested an Airmar dB Plus II by monitoring surfacing positions of harbour seals near haul-out sites as well as in a river where they tried to establish an acoustic barrier (p-p source level was 172 re 1µPa). No effect was found. Fjälling, Wahlberg & Westerberg (2006) documented successful deterrence of grey seals from salmon traps over three years without habituation using a modified Lofitech AS fishguard. In a questionnaire survey on Scottish fish farms only 23% of farmers reported ADDs to be very effective, 50% reported moderate, 15 % poor and 7% no efficiency (Quick, Middlemas & Armstrong 2004). Just like in other areas (Mate *et al.* 1987) some of the farmers believed them to attract seals.

Any animal that can perceive ADD sounds can potentially be affected by them. A high-power ADD like the Ferranti-Thompson 4x can be audible to a harbour porpoise (*Phocoena phocoena*) for up to 10 km (Taylor, Johnston & Verboom 1997). The zone of potential audibility for a harbour seal for a 175 dB re 1µPa device (e.g. Ferranti-Thompson 4X Special) lies between 1.4 km and 2.9 km (Terhune, Hoover & Jacobs 2002). While some authors have argued that there is a possibility that certain ADDs could damage the hearing system of cetaceans (Gordon and Northridge, 2002; Taylor et al., 1997), experimental evidence for adverse impacts of ADDs on cetaceans exists only on the level of behavioural avoidance responses and habitat exclusion. Olesiuk *et al.* (2002) studied effects of the Airmar ADD on harbour porpoise abundance in British Columbia. When the ADD was switched on the number of animals detected dropped to 1.9% and 3.8 % of values in control sessions depending on the sector scanned. Porpoises were completely excluded from an area of 400m radius around the ADD and the number of sightings was still below 10 % of expected values at ranges of 2500 to 3500m from the device. Johnston (2002) reported that harbour porpoises did not approach an emitting ADD closer than 645 m (received level at this distance: 128 dB re 1µPa). The average closest approaches were 991 m (in contrast to 363 m during control periods) and significantly less porpoises were seen within a range of 1500m. Morton & Symmonds (2002) reported a dramatic decrease in killer whale sightings in the Johnston Strait/Canada for 15 years after ADDs (most likely different brands) had been introduced. The killer whales returned after fish farmers stopped using ADDs. This change did not correlate with changes in local food availability. Interestingly, no differences in sightings of seals were observed. Morton (2000) found that Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) abundance also decreased after the ADD introduction.

Table 1: Acoustic characteristics of currently used acoustic deterrent devices (ADDs).

Manufacturer	Ferranti-Thomson	Ace-Aquatec	Airmar Technology Corporation	Terecos Ldt	Lofitech
Model	Ferranti-Thomson MK2, Mk3 & 4X Seal scrammer	Ace-Aquatec "Silent Scrammer"	Airmar dB Plus II	Terecos type DSMS-4	Lofitech "universal scarer" or "seal scarer"
Source level (re 1 µ Pa)	195dB @ 27 kHz[1] (peak) for MK2 model 200dB @ 25 kHz (n/a) for MK2 4X model	193 dB @ 10 kHz (rms)	192 dB @ 10.3 KHz (rms)	178 dB @4.9 kHz[1] (rms)	191 dB @15 kHz (n/a)
Frequency structure	pulses centred at 5 different frequencies arranged in 5 pre-set sequences (pattern of jumping frequencies) which are chosen randomly[2]	pulses centred at 28 different frequencies (pattern of jumping frequencies) arranged in 64 sequences which are randomly chosen	more or less sinusoidal: 10.3 kHz (2nd harmonic 43 dB weaker)	complex (randomized sequences of different components): tonal blocks (with harmonics) forming up and down sweeps (fundamental from 1.8 kHz-3 kHz), randomised sequences of continuous and time variant multi-component blocks (2.4 kHz-6kHz), continuous tonal blocks forming up and down sweeps combined with continuous multi-component blocks [1]	15 kHz (tonal, narrow-band)
Temporal pattern	20 ms pulses repeated every 40 ms in trains of 20s duration[2]	3.3-14 ms long segments in 20 s long trains	1.4 ms long segments at 20 ms intervals in 2.25m long trains; 4 transducers produce these trains in an alternating pattern	depending on operation mode: 8ms segments in sequences of eight or 16ms segments in sequences of 5; variation possible due to randomisation software[1]; trains from 200ms to 8 s long[2]	500ms pulses in 6s trains long trains
Duty cycle	3 %[2] max.5.5 scrams per hour	activity-dependant (50% if trigger is released, but max 18 times per hour)	40-50 %	ca. 50 % [2]	20-25 %
Energy in the ultrasonic range	Yes, at least up to 40 kHz[1]	more than 165dB at 30 kHz;145 dB at 70 kHz	145 dB up to 103 kHz	less than 143 dB above 27 kHz[1]	occasionally one harmonic depending on battery status
Reference	Yurk & Trites (2000)[1] manufacturer's description cited in Gordon & Northridge (2002)[2]	Lepper et al. (2004)	Lepper et al. (2004)	Lepper et al. (2004)[1] Reeves, Read & Nortabartolo di Sciara.(2001)[2]	Reeves, Read & Nortabartolo di Sciara (2001)

ADD impacts on seals seem to be of little concern since they are designed to deter seals. However, there is a possibility that ADDs could cause hearing damage in target and non-target species (Gordon & Northridge 2002). While impact on all species can potentially be of concern from a conservation point of view, hearing damage in seals would reduce the efficiency of the ADD. Furthermore, since seals rely on passive listening to detect prey (Schusterman *et al.* 2000), this could make them more dependent on predictable food sources like farmed fish. Hearing damage can occur as temporary or permanent rise of the hearing threshold. Ideally both, temporary (TTS) and permanent (PTS) threshold shifts, should be avoided since repeated TTS can potentially lead to PTS. Using data from Kastak et al. (2005), assuming spherical sound spreading and predictions based on the hypothesis that sound stimuli of equal acoustic energy have a similar effect, a 10 s sound burst of an 194 dB re 1µPa device would cause a temporary threshold shift in a harbour seal at distances of up to 12 m. Temporary threshold shifts in cetaceans have been shown to occur at sound exposure levels of 195 re1µPa^2·s dB (Finneran et al. 2005). However, these values might be too high since some of the tested subjects had higher thresholds than previously tested animals and animals were not tested within their most sensitive hearing range. Depending on the assumptions made, impact zones could range from a few meters up to several hundreds of meters for a 10 s exposure to a 194 dB re 1µPa device. Interestingly, TTS in response to impulse low-frequency impact noise has been shown to occur at sound exposure levels as low as 164 dB re1µPa^2·s in harbour porpoises (Lucke et al. 2007). This would point towards an impact zone of around 100m in response to a single 10s exposure. For permanent hearing damage, results also depend on the assumptions made. However, some authors have convincingly pointed out that longer-term exposure to just 1.5 min per day could result in permanent hearing damage (Gordon & Northridge, 2002). This shows that the use of high source level seal scarers is highly questionable.

Project Objectives

Given the problems that ADDs create combined with the uncertainty over their effectiveness, we conducted a study to find an effective and target-specific, acoustic method to decrease predation on fish farms.

The objective of this study was to investigate more effective and target-specific acoustic scaring techniques that concentrate on keeping harbour seals and grey seals away from salmon aggregations but do not affect other marine mammals.

We addressed this by asking the following questions:

- How do seals react to acoustic stimuli that were (a) designed to be target specific by using a lower frequency band and (b) aversive based on the literature on unpleasantness of sounds in humans? How do their reactions compare to those elicited by existing ADDs?

- Can seal sounds be used to exclude seals from areas of interest?

- Do seals have an acoustic startle response and, if so, can this be used to deter seals?

- How does the most effective method identified in this study affect cetaceans and seals in a field trial on a fish farm?

The following report will address these questions in turn in separate sections.

Methodology and Results

Section 1: Aversiveness of artificial sounds: Problems with existing ADD sounds and the development of novel, more target-specific sounds

Many different types of sounds exist and little is known on how seals and cetaceans react to them. If we want to increase target specificity of ADDs and decrease effects on currently affected, non-target species like odontocetes, we need to consider several aspects of the sound used. In an artificial sound that has no biological meaning to an animal, perceived loudness is of crucial importance. Perceived loudness does not only depend on the physical amplitude of a sound stimulus but also on several factors that are related to how the mammalian ear processes sound. Most importantly, the ears of seals and cetaceans (as most other mammals) are not equally sensitive over a range of different frequencies. The sound pressure level that is just audible to a species under quiet conditions (called the hearing threshold) varies with frequency (refer to Fig. 1). We know from humans that the contours of perceived equal loudness are roughly parallel to the hearing threshold within the most sensitive hearing range, but are compressed at the high and low frequency ends of the hearing range (Fletcher and Munson, 1933; Robinson and Dadson, 1956). A rough approximation is to assume that sound pressure levels that exceed the hearing threshold by a similar amount in dB will cause a similar perceived loudness. These so called sensation levels are expressed as sound pressure level in dB above the hearing threshold and can be expected to cause a similar loudness sensation. When comparing the hearing thresholds of cetaceans and seals (Fig. 1), it becomes obvious that the range of most sensitive hearing in cetaceans coincides with the frequency range where most current acoustic deterrent devices operate. In this frequency band hearing thresholds of cetaceans are 20-30 dB lower than thresholds in seals, meaning that current ADDs sound a lot louder to an odontocete than they do to a seal. One opportunity to mitigate impacts on high-frequency hearing specialists (e.g. odontocetes) would therefore be to decrease perceived loudness of the sound. In a narrow band between 500 Hz and 2 kHz, seal hearing is better than that of odontocetes. Sensation levels and therefore perceived loudness of sound could be reduced by approximately 40-50 dB if this frequency band would be chosen. We therefore developed novel sounds using this frequency band (new sounds in experiment 1 and 2 and startle pulses in experiments 5 to 8). While most fish including salmon will not be able to hear sounds in this frequency band, fish that are hearing specialists like herring and other clupeid fish could hear them and may therefore be impacted (see general discussion). Apart from frequency and sound pressure level, the bandwidth of a sound also affects perceived loudness. Broadband sounds cause a higher perceived loudness than pure-tones.

Current acoustic deterrent devices use very high source levels at high duty cycles of up to 50% which are assumed to cause pain if seals approach too closely. The duty cycle gives the percentage of time in which a sound is played. A duty cycle of 50% means

that the sound is playing for 30 seconds in every minute. In humans the pain threshold lies at around 120 dB above the hearing threshold, while discomfort or distress occurs at lower sensation levels ranging from 70-80 dB (Spreng, 1975). The pain threshold is therefore quite close to sensation levels where single exposure can damage the ears (i.e. 130 dB) (Danielson et al., 1991). We believe that the sound pressure level of an ADD sound should therefore exceed the discomfort threshold but still be below the pain threshold. This is also supported by the fact that the mammalian human ear processes sound intensity as an exponential function (Stevens 1956). This means that a given increase of the physical parameter (sound pressure level) is perceived as a much stronger increase of the perceived loudness at the lower end of the dynamic range of the ear than at the upper end. Any further increase of the source level at high intensities would therefore only slightly increase the perceived loudness but put the ear of an animal at a much higher risk. Another problem is that the likelihood of causing hearing damage depends on the sound pressure level as well as on the exposure time. Long term exposure to high duty cycle sounds can therefore cause hearing damage without any pain at all (Sadhra et al. 2002). Finally, very high source levels would lead to more noise pollution since a louder sound will travel further. Sounds with sensation levels close to 130 dB should only be presented for a very short time with long breaks between exposure and sound pressure levels should generally be as low as possible. This also means that it would be highly desirable to increase aversiveness by means other than mere sound pressure level.

Zwicker & Fastl (1990) developed a model to describe what makes sound pleasant or unpleasant for humans. The relevant psychophysical parameters are sharpness, roughness, tonality and loudness. It is likely that perceived pleasantness of a sound is based on general peripheral auditory processing in mammals and therefore may provide a way to deter seals with moderately loud sounds. We used Zwicker and Fastl's model to design novel sounds for seals and compared them to control sounds and those used in commercially available ADDs. In the first experiment sounds were presented at sound pressure level of 146 dB re 1 µPa which can be expected to exceed the discomfort or distress threshold. We tested the reactions of captive seals when hearing these sounds around a known food source.
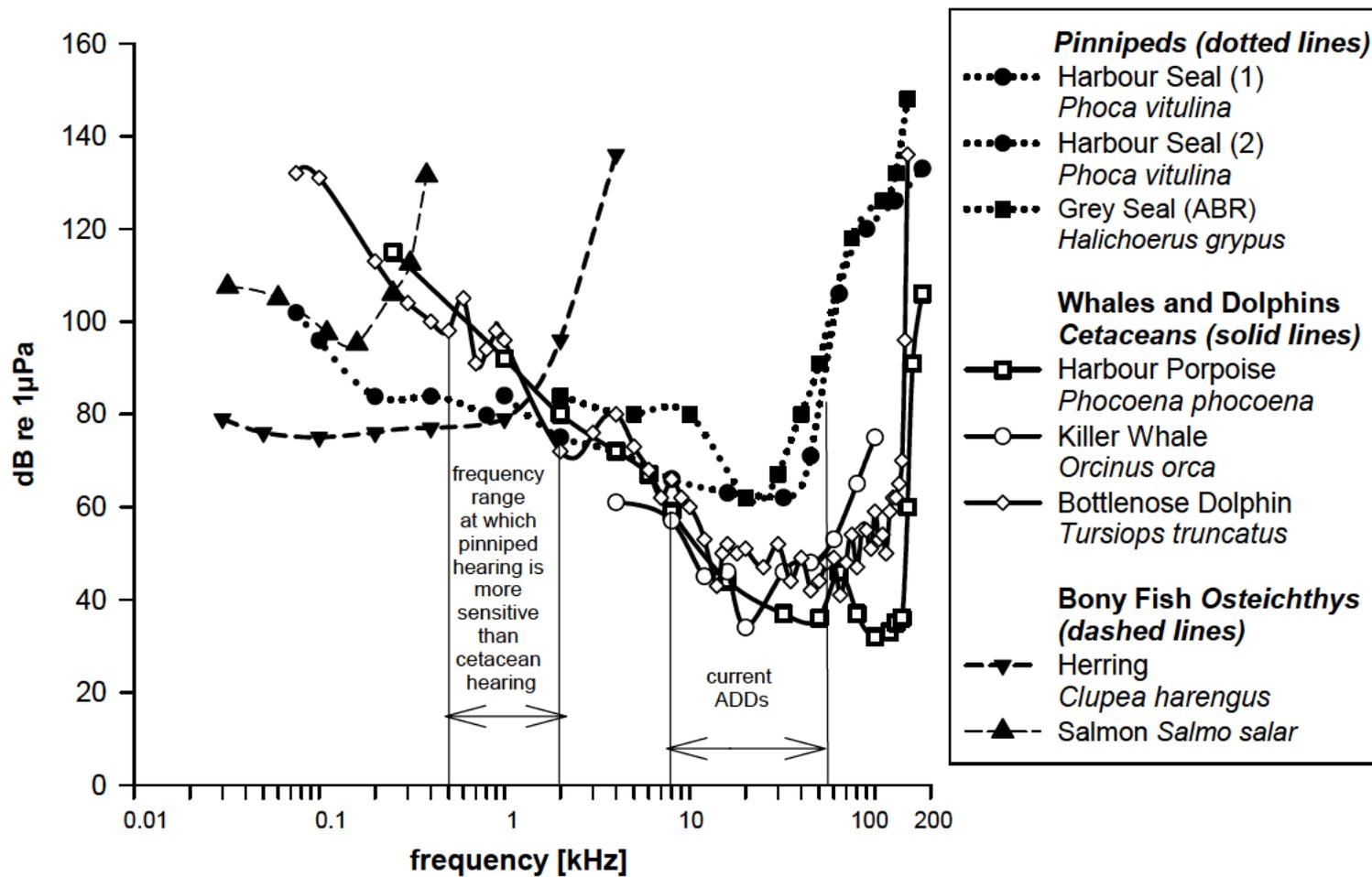
Fig. 1: Hearing thresholds for selected fish, pinniped and odontocete species. Note that most current ADDs operate in a frequency range at which cetacean hearing is more sensitive than pinniped hearing. Harbour seal (1): Terhune (1988); harbour seal (2): Kastak & Schusterman (1998); grey seal: Ridgway & Joyce (1975), harbour porpoise: Kastelein *et al.* (2002), killer whale: Szymanski *et al.* (1999), bottlenose dolphin: Johnson (1967); herring: Enger (1967), salmon: Hawkins & Johnstone (1978).
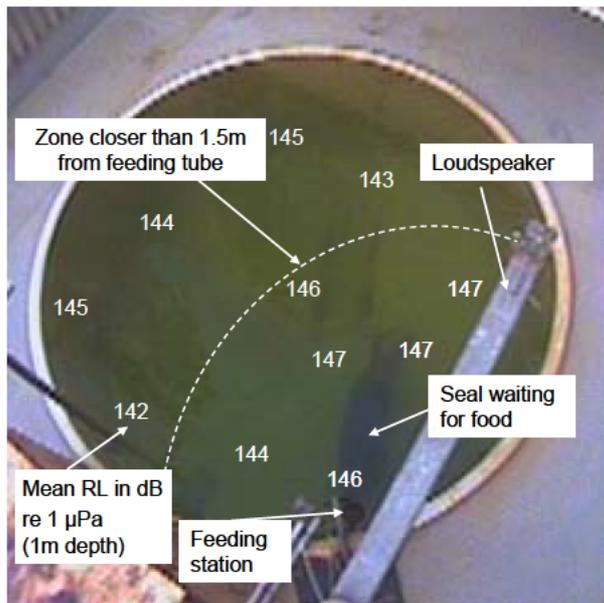
Fig. 2: Experimental setup and sound field in playback pool (depth 1.5 m, diameter 3 m) for experiment 1.

Experiment 1: Artificial sounds and captive seals

Methods

Six grey seals and two harbour seals were tested in the experimental facility of the Sea Mammal Research Unit at the University of St Andrews. Four out of the six grey seals were sexually mature adult females and two were juveniles (one male, one female). The juveniles ranged in age from approximately 6-11 months at the time of the experiments. The two harbour seals were adult males. One of the male harbour seals had been flipper tagged in 1999 indicating that it was at least 8-10 old. All seals were wild-captured. The harbour seals were in the facility for two weeks and one month respectively before being used in the experiment while the tested grey seals were in the facility for a time ranging from 3-8 months prior to the experiments. Experiments were carried out in a circular, sea-water filled pool (Fig. 2).

Sound were played through a calibrated Lubell 9162 loudspeaker (Lubell Labs Inc, Columbus, Ohio) that was placed 1 m from an underwater feeding station hanging freely from a crane approximately 20 cm from the wall of the pool (Fig. 2). The loudspeaker was powered by a Phonic MAR 2 power amplifier and playback sounds were played from a Panasonic CD player. Using data from the speaker calibration, all sound types were equalized to ensure an identical source level for all stimuli in the whole frequency band. The loudspeaker was then placed in the pool (Fig. 2) and received levels of all playback stimuli were measured at 11 different positions in the pool. Transducer calibration and sound field measurements were conducted using a calibrated Bruehl & Kjaer 8103 hydrophone and a Bruehl & Kjaer 2635 charge amplifier with the signal digitized onto a Toshiba laptop computer. Sound pressure levels used in a deterrent should be sufficiently loud to cause sensation levels that are associated with discomfort to the animal but should not cause any impact on the hearing system itself. Spreng (1975) showed that electro-physiologically measured discomfort or distress thresholds in humans require sound pressure level of about 70-80 dB. With a

hearing threshold of 72 dB re 1 μPa at 1 kHz for seals, received levels of at least 140 dB re 1 μPa would be needed to cause distress or discomfort. We therefore set our system to create average received levels of 146 dB re 1 μPa (rms) at the typical position of the seal's head in our pool.

The following sound stimuli were compared:

1) *Controls*
   a) No sound
   b) White noise
   c) Tone of 500 Hz

2) *Novel sounds*
   a) Square 500/530 FM:
      Two 70-Hz frequency modulated square-wave tone with a carrier frequency of 500 and 527 Hz. Both tones were presented at the same time. Modulation depth was 50 % of the carrier frequency.
   b) Square 500/507 FM:
      This is the same sound as a) but with carrier frequencies of 500 and 507 Hz.
   c) Square 500:
      A 70-Hz frequency modulated square-wave tone with a carrier frequency of 500 Hz. Modulation depth was 50 % of the carrier frequency.
   d) Sweeps FM
      This was a complex sound consisting of frequency modulated square wave up and down-sweeps. The frequency modulation applied to the square waves ranged from 0 (no modulation) to 100 Hz with modulation depth between 30 and 60% of the carrier frequency. Modulation patterns were presented in a pseudo-randomized order. The sweep range covered a frequency band from 400 Hz up to 3.5 kHz and sweeps duration ranged from 1 to 4 s.
   e) Square variable
      This sound consisted of short (100ms to 300ms) constant-frequency square wave pulses. The carrier frequency of each individual pulse ranged from 400 Hz to 1.5 kHz. Some of the square wave pulses were frequency-modulated similar to the sound type "Square FM".

3) *ADD sounds*
   a) Ace-Aquatec[1], b) Terecos, c) Airmar, d) Lofitech

The peak frequencies of all five novel sounds broadcasted through the loudspeaker was between 750 Hz and 800 Hz. The levels of these sounds was down by 20 dB below 550 and 600 Hz and above 2.5-3.5 kHz.

We carried out six playback sessions. In each session each of the sounds was played for one minute. Within this one minute playback period a sound was played four times for six seconds separated by 12 second silent breaks. Playbacks of different sound types were separated by at least 5 minutes within each session. The sequence in which

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[1] Note that the older Ferranti-Thompson device used a similar sound as the Ace-Aquatec, but is no longer available on the market.

different sound types were played was pseudo-randomized across sessions. We started each experiment by lowering a fish in a metal cup through a tube (feeding station) that had an opening at approximately 1.2m depth. As the edge of the cup became visible the animal positioned its head in front of the feeding station. If the animals' tip of the nose was within 40cm distance of the cup the playback started. The cup was then lowered completely 2 seconds after the playback onset so that the seal could access the fish. The animals had previous experience with the feeding station as a source of food. Three playback sessions were carried out with food presentation. Then, one session was conducted without food reward. The fifth playback session was again a food trial while the last one was another no food trial. The aim of this was to test how different motivational states influence behaviour (known but empty food source versus profitable food source).

Playbacks were monitored using an HTI hydrophone, an underwater camera and an in-air video camera mounted on a 4m long pole to give an overview of the whole pool area. Video tracks from both cameras were linked to a multiplexer and together with the audio track from the hydrophone recorded on either a Sony DV video walkman (GVD 1000E) or on a Sony MVX 350i video camera. The response variables measured are given in Table 2.

Table 2: Response variables analysed during the 1 minute sound exposure time.

Time the animal spent underwater within 1.5 m distance from the feeding tube (position of the head as reference point)
Dive time during playback defined as head being completely submerged
Time hauled out defined as the head and shoulders of the seals being completely on dry land
Index of aversiveness defined as a cumulative index of occurrence of different aversive behaviours. Depending on whether all or none of the following behaviours occurred the index ranged from 0 (not aversive) to 4 (highly aversive):   - Fish catch prevented: fish remains in cup for the whole minute   - Seal suddenly turns away from speaker: a change in the orientation of the line between shoulder blades and the tip of the nose by at least 100 from the original orientation (nose pointing towards feeding station).   - Escape response: seal increases distance from speaker at speeds of more than 3m/s. This behaviour was counted if the animal crossed the pool diagonally swimming away from the feeding station in less than 1 s.   - Haul-out behaviour for at least 30s after flight response

Results

The results for the first playback session are shown in Fig. 3a. The seals reacted to all sounds in a similar way in that they did not leave the pool, but showed a maximum index of aversiveness of 3. A Kruskal-Wallis test (KW = 9.38, p = 0.025) across all conditions in session one shows that there was a significant difference in the index of aversiveness between conditions. However, this significance disappeared in all

subsequent sessions, showing that habituation set in very quickly (Fig 3b). The habituation process was completed within the first playback session as is shown by the continuous decrease of the index of aversiveness from playback 1 to 11 in Fig. 4. While the first stimuli within the first playback session caused an aversive response, later stimuli elicited a lower or no response even though the exact sound type played was different (Fig. 4). The time spent close to the feeding station and dive time was also lower than in the control with no sound (Fig. 5). However, these response variables did not habituate in the same way as the more extreme avoidance behaviour captured by the index of aversiveness.

A general linear model looking at the time spent within 1.5 m of the feeding station and the dive times in the first three food sessions was highly significant. For the time spent close to the feeder, most of the variance was explained by the identity of the seal, followed by whether or not and which sound was played (treatment). For dive times, the largest proportion of the variance was also explained by the individual difference followed by the playback session number, and then the actual sound type played. Furthermore, these more subtle reactions did not change with the sequence number in the playback, i.e. there was no habituation in these reactions over the first 4 food trials. Interestingly, the interaction between the individual and the treatment was significant in the models, meaning that different individuals showed different types of reactions. Furthermore, animals tended to reduce dive times in later playback sessions, indicating either that they learn to take the food more quickly or avoid sound exposure generally by keeping their heads above the surface as much as possible.

We also applied comparison models to look at the difference between the last food trials and the following no food trials (Fig. 5). For the comparison of session 3 and 4 these models were not significant. However, they were significant for the comparison between session 5 and 6 for both variables (time close to feeder and dive time). In these models, there was again a significant influence of individual variation, but not of the sound types played. Seals dived for longer and stayed close to the feeding station for longer in session 6 in which no food was presented.

a)
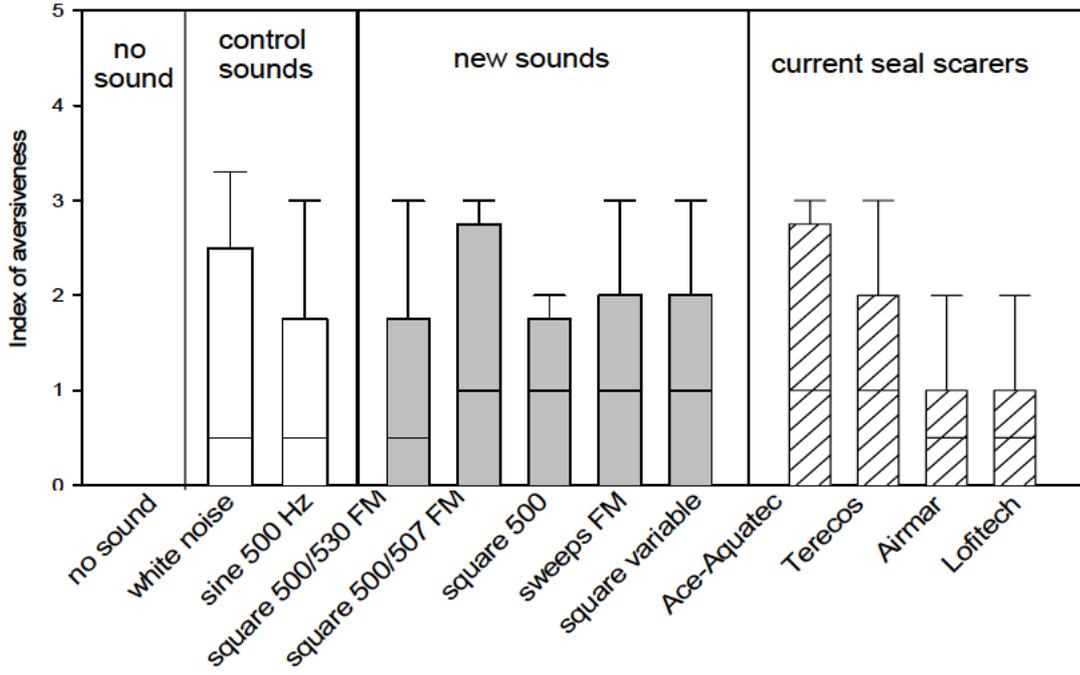
b)
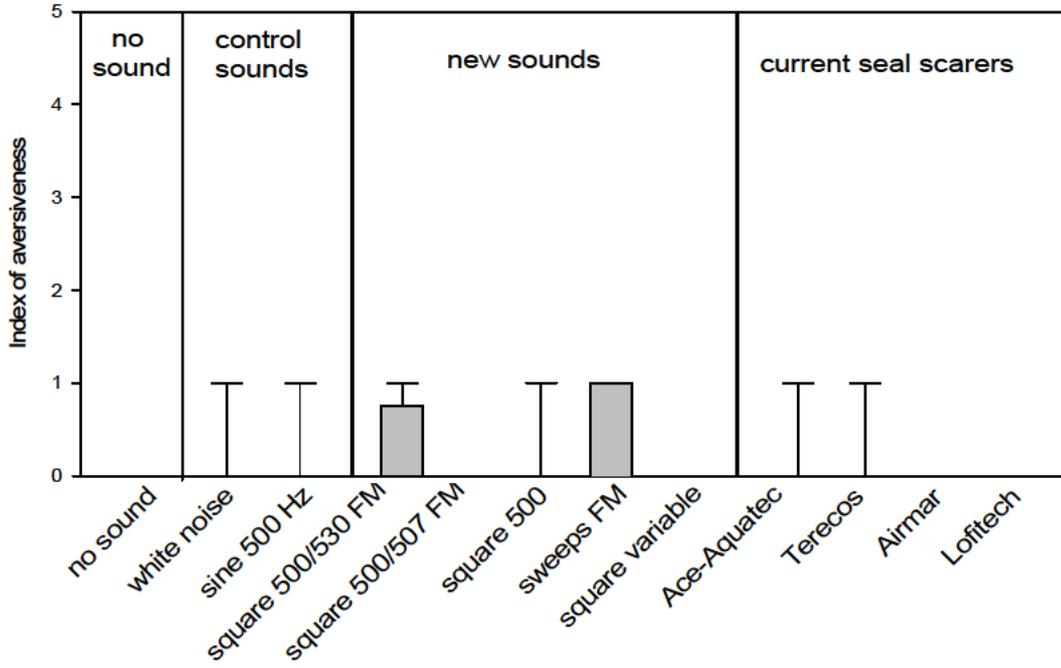
Fig. 3: Reactions to no sound, control sounds, novel sounds and seal scarer sounds in a) the first session and b) the second session in captivity with food motvation. The data are median, interquartile ranges and 90% margins for all seals. Note the strong habituation in the second session.
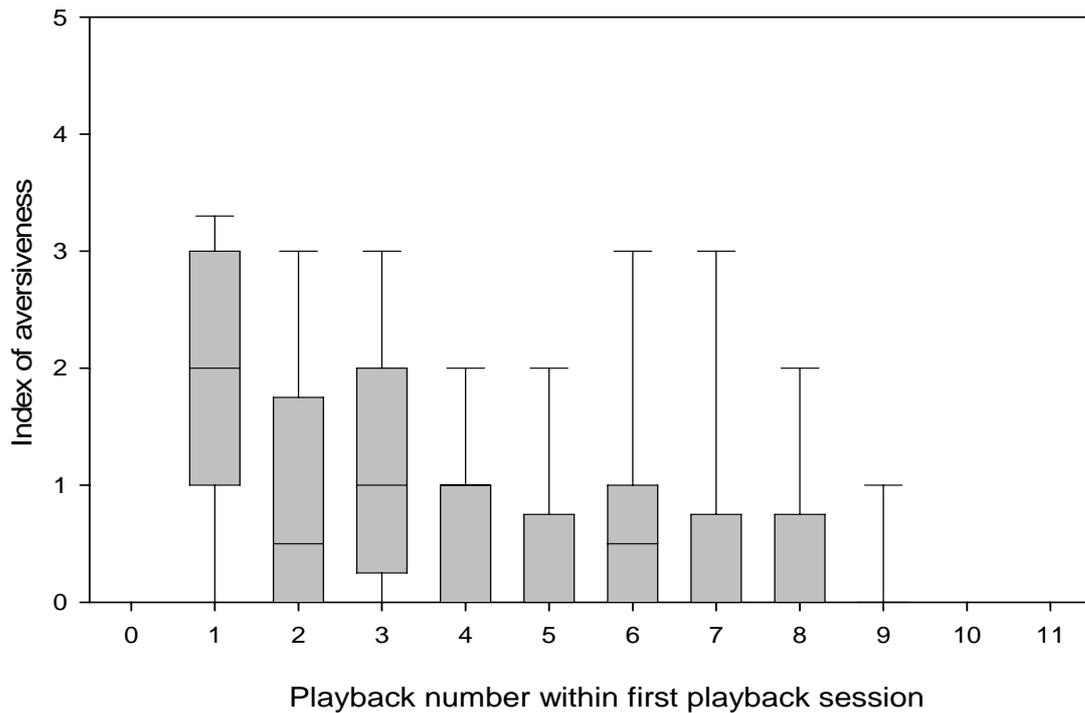
Fig. 4: Habituation of responses within the first session. Data are median, interquartile ranges and 90% margins for all seals. Since each seal had a different sequence in which sounds were presented, data are listed by playback position in the first session.

Conclusions

This first experiment gives us a good impression on how seals react to non-startling artificial sounds when near a known food source. It appears that while they show an avoidance response initially, they habituate very quickly. This means that these sounds are not able to keep seals from a known food source. The fact that seals habituated within the first playback session when we presented 11 different stimuli also shows that variable stimulus design does not seem to be effective in preventing habituation. Our novel stimuli caused the same type of aversiveness as stimuli used in commercially available ADDs. The way we designed these stimuli predicts that they would not have the same detrimental effects on odontocetes that have been described for commercial ADDs. However, since none of the sounds are effective in deterring seals under these conditions, they should not be used to deter seals that are foraging on a food source.

a)

b)
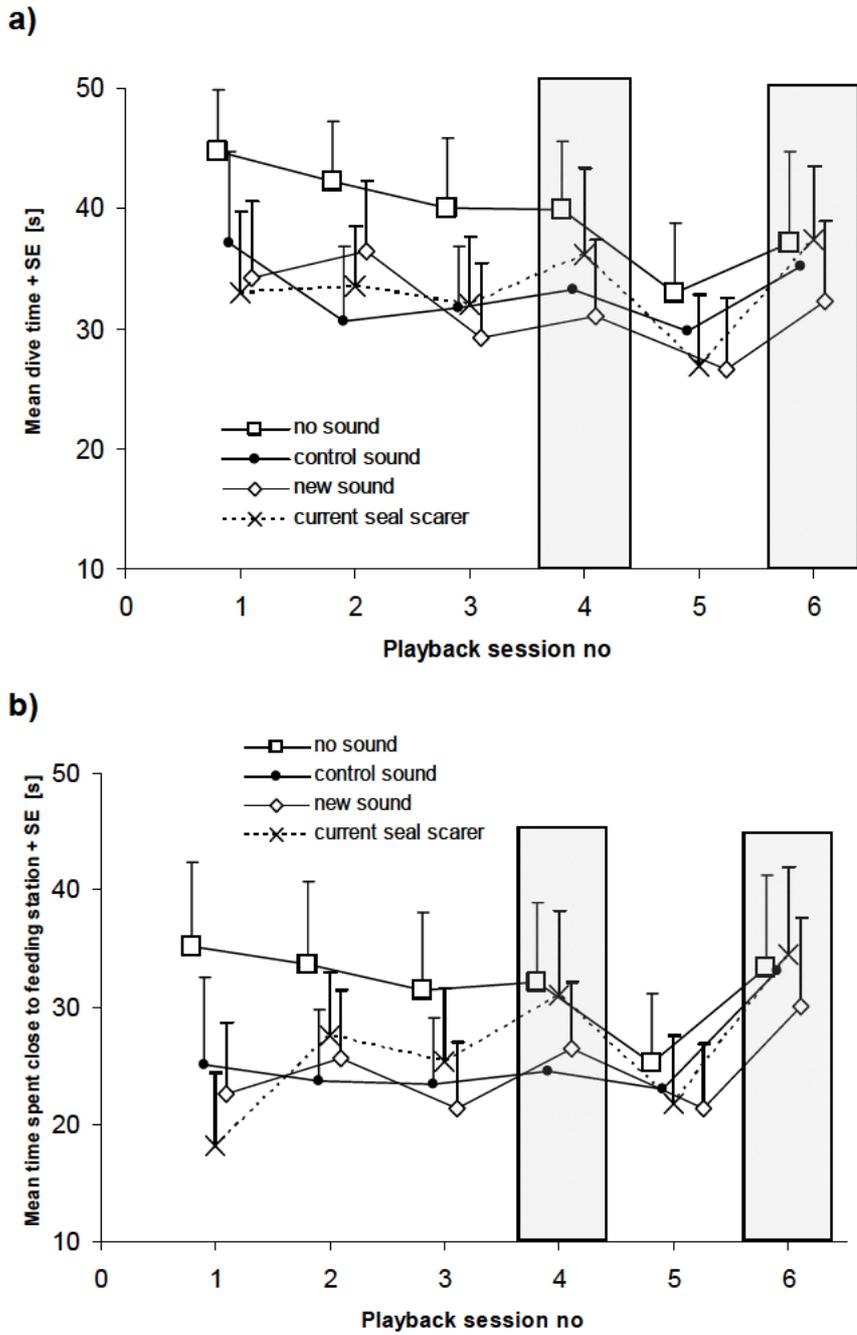
Fig. 5: Mean plus standard error (a) dive time and (b) time spent close to the feeding station in response to playbacks. Sessions with grey bars had no food presented to the animal. The increase in both parameters from the 5th session (with food) to the 6th session (no food) was significant for all sounds and the no sound control.

Experiment 2: Artificial sounds and wild seals

Methods

We tested the same stimuli as in experiment 1 in the wild near a haul-out site for grey seals in Tentsmuir Forest, Fife. The haulout site was approached from sea with a RIB and this boat was anchored 80-250 m from shore depending on the reaction of the seals to our approach. The playback source was deployed at a depth of approximately 1.5m at the stern of the boat. The playback equipment was the same as in the captive experiment. Observations were carried out starting 5 min prior to playback (pre), 5 min during the playback (sound) and for 5 min following the playback (post). Sounds were played at a source level of 172 dB re 1 µPa (rms) for 10 s followed by 10 s of silence for a 5 min period. A 15 min recovery period separated the 15 min observation blocks. During the experiment, surface positions of seals were measured continuously relative to the playback boat, using a laser range finder and a handheld compass. Seals surfacing at a distance of more than 100m from the source were not included in the observations and analysis. We conducted 18 playback sessions on separate days in 2006 and 2007. Each 5 min playback trial consisted of just one sound type as described in the captive experiment. However, we only played the two novel sounds that still elicited a noticeable effect in the second playback session in captivity. These were "Sweeps FM" and "Square 500/530 FM". Not all sounds were played in each playback session and the sequence in which sound types were used in each session was pseudo-randomized. Each sound was used in 10 trials on different days over the course of a year. Sounds of current commercially available ADDs were only used 6 times. The data were analysed comparing the number of animals seen in distance bins of 20 m between pre, sound and post observation periods. Finally, received levels along two depth profiles (parallel to shore and from boat to shore) were measured to determine the received levels at which avoidance occurred.

Results

Most sounds had at least a mild deterrence effect over the first 60 m (Fig. 6) although there were clear differences in effectiveness between sound types (Kruskal Wallis test, $p < 0.05$). All of the novel sounds and most of the ADD sounds had a clear deterrence effect.

The no sound control shows that there was a deterrence effect caused by the presence of the boat within the first 20 m (Fig. 7). The effect that the boat presence had was a smaller sample size of seals for the close distance bins, so that we could not test the results for the closest bin. All signals had a significant deterrence effect at some of the distance bins (Fig. 8) except for the Terecos ADD sounds. Control sound and ADD sounds were efficient in reducing the number of seals up to a distance of 40-60 m. The novel sound "Sweeps FM" had a deterrence range of 60m and was therefore as efficient as the commercial ADD sounds in deterring seals. The novel sound "Square 500/530" had a deterrence effect up to 80m and was therefore more efficient than any of the other tested sounds. Compared to the control sound "Sine Wave 500 Hz", the deterrence range of the "Square 500/530" was twice as large. Sound field measurements that we conducted in our playback area indicated that seals avoided sounds of the most effective types at a received level of 135 to 140 dB re 1 µPa. There was also no indication of habituation within or between days.
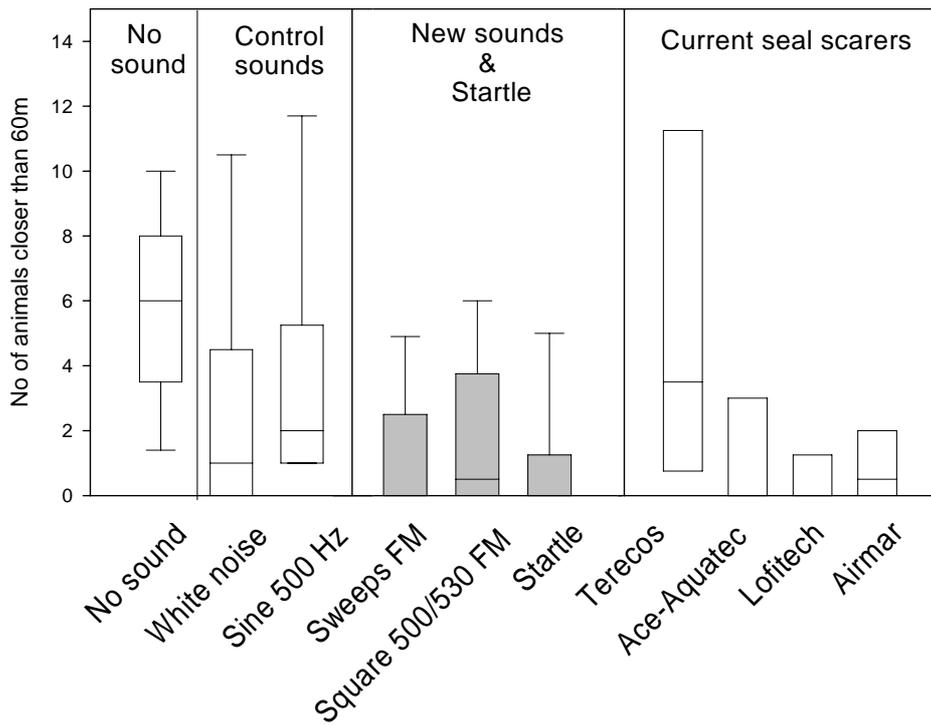
Fig. 6: Deterrence effects of the eight different sound types and the no sound control in an area of up to 60 m from the sound source. The data show median, interquartile ranges and 90% margins.
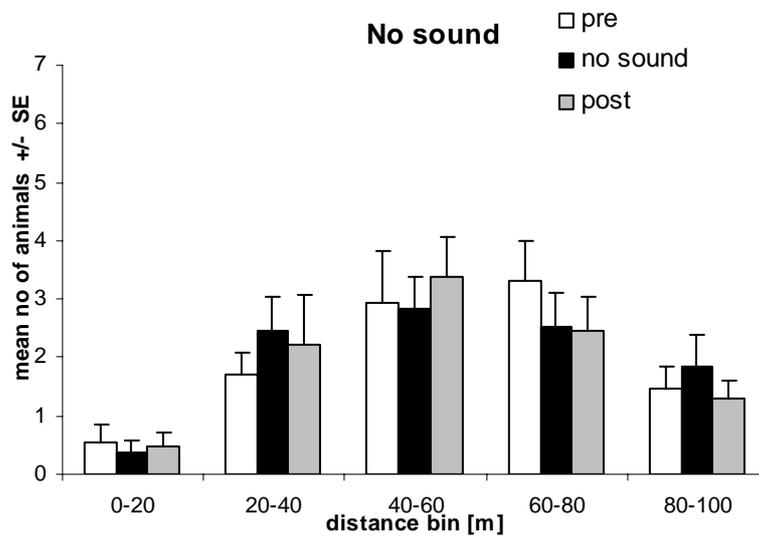

Fig. 7: Number of seals surfacing in different distance bins from the speaker (and nearby boat) in the wild in control trials when no sound was played.
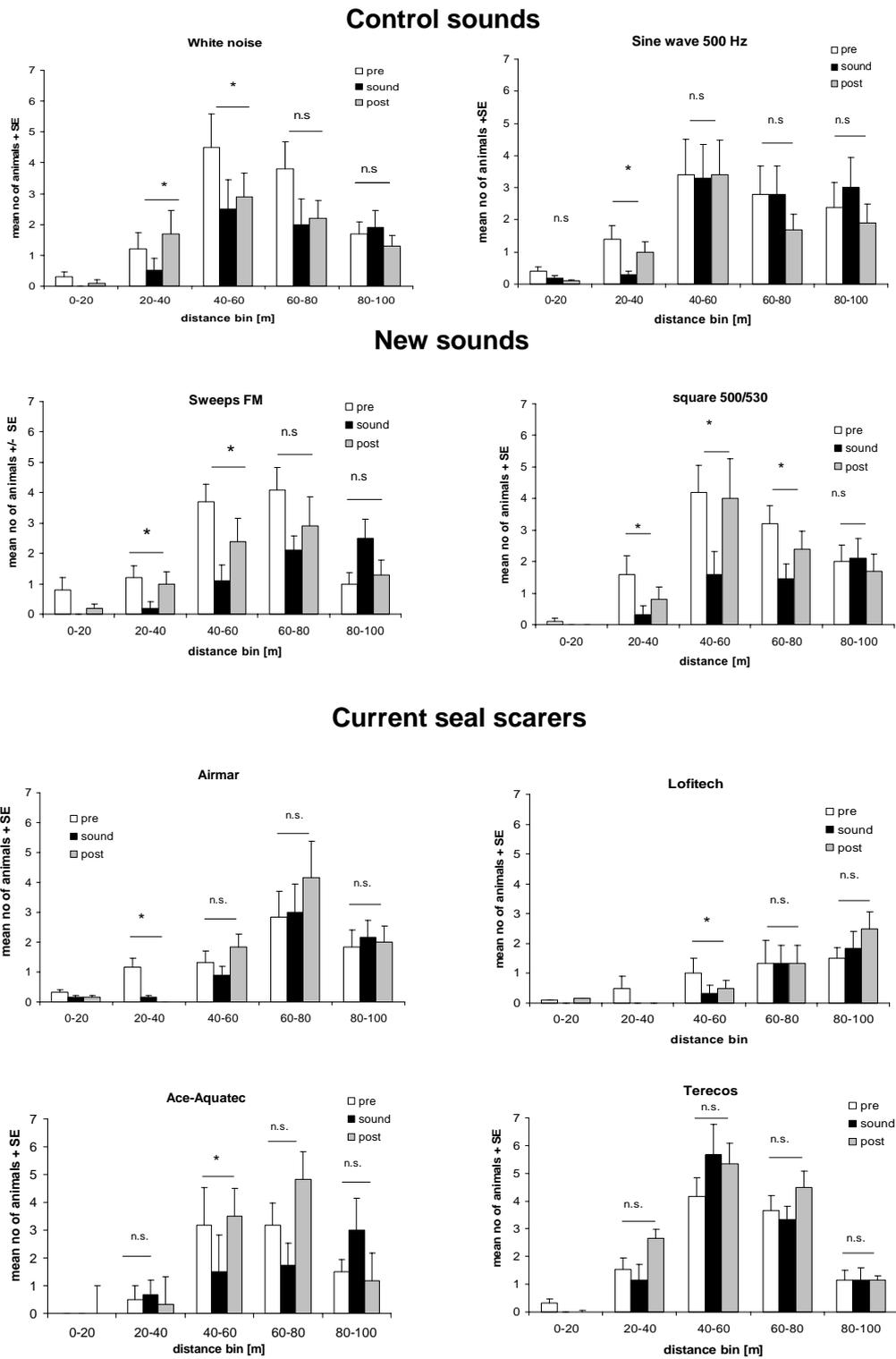
Control sounds

White noise

Sine wave 500 Hz

New sounds

Sweeps FM

square 500/530

Current seal scarers

Airmar

Lofitech

Ace-Aquatec

Terecos

Fig 8: Number of seals surfacing in different distance bins from the speaker (and nearby boat) in the wild when different types of sounds were played.

22

Conclusions

This experiment showed that our novel as well as most of the ADD sounds, can be used to keep seals from entering an area within which sensation levels are higher than 70 dB (in our case SPL were 135-140 dB re 1 μPa). Interestingly, the corresponding sensation levels are in line with data for human discomfort thresholds. This supports our hypothesis that a sound that exceeds the discomfort threshold seems to be sufficient to cause a deterrence effect and that there is no need to use sound levels close to the pain threshold. Deterrence ranges for control and novel sounds ranged from 40-80m. The difference between the sine wave control sound of 500 Hz and the "Square 500/530" sound could in part be explained by the hearing threshold of phocid seals. Seal hearing is less sensitive at 500 Hz than it is at 530 Hz. However, given that white noise caused only a deterrence range of 60m in spite of having a higher sensation level than the "Square 500/530", other factors must be important too. The "Square 500/530" may be more aversive due to its features (e.g. roughness) that we implemented from the literature on unpleasantness of sounds in humans. The "Square 500/530" would be the recommended sound for high duty cycle seal scarers although we do not recommend to use high duty cycles (see above).

It is important to note that these seals were not foraging in the area and that the lack of habituation even within sessions is most likely due to seal movements. Our experimental sessions lasted up to 2.5 hours. Seals may not stay in the area for long and only use it to access the haul-out site. Furthermore, as shown in experiment 1, seals avoided our playback sounds when they heard them for the first time and would have moved away from the area. Thus, it is likely that successive playback trials were conducted on different seals. Therefore, we would not find habituation because individual seals were only exposed to one or a few playbacks.

Section 2: Seal responses to natural sounds: seals listening to seals

While killer whale sounds have been shown to be aversive to seals (Deecke et al. 2002), they equally affect other cetaceans (review in Janik 2005). To avoid effects on non-target species, predator sounds should therefore be avoided. They also bear the risk that animals habituate to predator sounds and become more vulnerable to real predation.
One very target specific way to deter seals would be to use sounds that are of biological relevance to only one species, and the only sounds which have the potential to be used in this way are sounds of conspecifics. We therefore conducted playback experiments on grey seals with grey seal sounds to investigate whether any sound types used by the animals themselves could be used to deter or attract seals to a playback site.

Experiment 3: Natural sounds and captive harbour seals

Methods

We tested three male harbour seals in captivity using harbour seal roar sounds that appear to be territorial and/or mate attraction calls (e.g. Hayes et al. 2004). As a control we used a 'no noise' condition and a playback of white noise. Seals were also tested on a synthetic roar that was lowered in frequency and increased in duration to simulate a

larger male. The playback setup was the same as in Experiment 1, except that the first animal was tested in a larger pool, since it was difficult to move this individual. In each trial the seal heard two versions of the same call type with a silent period of 30 sec between the renditions. We observed responses for one minute from the start of the first sound playback. The response variables we measured were vocalizations, approaches to the speaker, and dive times.

Results

The first seal only reacted to its own roar sounds by closely approaching the speaker (p< 0.05, Kruskal Wallis test, n = 5 for each call) but the response decreased over subsequent playback trials. No other types of responses were observed. The second seal did not show any statistically significant response to any of the natural or synthetic roars but showed a moderate avoidance response to the white noise. The sound had first been played to this seal through a loudspeaker that reproduced them with poor quality which may have had an influence on behaviour in the following sessions. The third seal responded to the natural and synthetic roars by closely approaching the loudspeaker in the first two playbacks but not in the following three. It did not respond to the other sounds and did not show any other reactions.

Conclusions

Two of the three harbour seals were initially attracted to roar sounds, but the response habituated quickly. There was no deterrence effect even though these calls appear to be used by territorial males in song displays in the wild. As a result attraction of seals to another location would not be a viable method of keeping them from predating fish farms, since the animals need to forage and would only be attracted for short periods of time.

Experiment 4: Natural sounds and grey seals

Methods

Experiments in captivity were carried out in a pool of 2.5 m depth and 40 by 6 m surface area. Eleven grey seals were tested. Ten were females (5 adults, 5 juveniles) and one was a juvenile male. The playback stimuli are described in table 3.

Calls were digitized from analogue tapes and at least 10 examples of each call type were extracted. The recordings were taken by McCulloch (1999) at seal haul-outs in Fife on the Isle of May during the breeding season and at the Tentsmuir haul-out site outside the breeding season. In case of the growls only 6 suitable calls could be extracted from the recordings. All playback stimuli were normalised using the following procedure: The -20 dB start and end point around the peak frequency of the loudest section or element of the call was defined. Then this section of all calls was normalised to the same average rms-level.

One playback session consisted of a 'no sound' control and 8 sound stimuli. All playback stimuli were presented in pseudo-randomised order which was different for each animal. Four playback sessions were carried out with each individual over the course of at least 2 days. Playback sessions were separated by at least 3 hours. Each

version of a call type was only presented once to an individual to prevent pseudo-replication.

The experimental setup consisted of an underwater feeding station (same as in experiment 1) placed at the side of the pool at 1.2 m depth, and the sound source, a J11 projector. The J11 projector was deployed from a movable crane at a depth of approximately 1.5m. The experimental pool was covered with wire plates so that the seal could only surface in four areas. Surfacing was thus possible next to the feeding

Table 3: Playback stimuli used in experiment 4.

Control sounds	white noise
	sine wave of 500 Hz
	harbour seal roars
Grey seal calls (classification in brackets from McCulloch 1999):	Moans (type 7): Calls with a harmonic structure and occasional frequency modulation; fundamental frequency ranges from 100-700 Hz; audible impression very similar to calls frequently heard in air when seals are hauled out
	Rupe (type 5): Multiple element call with peak frequencies between 100 and 300 Hz; consists of two elements that are repeated up to 20 times; 1st element can be interpreted as a pulse or sharp downsweep while the 2nd element is tonal, longer and typically decreasing in frequency.
	Rup or "guttural rup" (type 1): Call is similar to rupe but tonal component/element is missing.
	Growl (type 9): noisy call; if harmonic structure present then it is associated with non-linear phenomena
	Type 10: very low-frequency call with a harmonic structure; fundamental frequency ranging from 20-150 Hz
Fish sounds	Selection of herring gas bubble release sounds and haddock spawning calls

station, next to the speaker and in two other locations further away from the speaker. All seals had spent several weeks in the pool before experiments were started and were used to restricted surfacing areas. Behaviour was monitored with two underwater cameras, one placed 1.5 m away from the feeding station and one positioned to provide a good view of the sound source. Additionally an aerial camera was mounted on a 4m long pole in order to provide an overview of the whole pool area showing all four potential surfacing spots. All cameras were linked to a multiplexer and recorded as described in experiment 1.

The seal was attracted to the underwater feeding station by lowering the edge of the cup prior to the playback. Once the seal approached, the cup was lowered completely and the fish was taken by the seal. If the seal stayed close within view of the underwater camera a playback was started 30s after the seal took the fish. Behaviour was monitored over 3 min following the start of the playback.

Since behavioural responses consisted of animals coming closer to the loudspeaker an approach score was defined:

1   Turned towards speaker but no approach
2   Swam towards playback source but did not appear on the underwater camera monitoring the sound source
3   Approached and surfaced close to the playback source but did not appear on underwater camera monitoring the sound source
4   Appeared on the underwater camera monitoring the sound source (animal was closer than 1.5m)
5   Came close as in 4 but also touched the speaker with its muzzle

Other response variables measured were: the delay time until the animal showed a clear approach, the time the animal spent close to the underwater speaker (visible on the first underwater camera) and the time the animal spent close to the feeding station (visible on the second underwater camera).

The rms source level of the loudest section of the call selected by the -20 dB start and end points around the peak frequency was 135-137 dB re 1µPa. The peak to peak source level ranged from 145 to 155 dB re 1µPa depending on the sound type. Pulsed components in rups and rupes had higher p-p levels than the more tonal moans.

Tests on wild grey seals were also performed following the same experimental methods as in experiment 2.

Results

The captive grey seals were attracted by three types of grey seal calls, which were moans, rupe and rups (Fig. 9). All of these were found to be more attractive than harbour seal sounds, which were the control in this experiment (Friedman test, Bonferoni adjusted $p < 0.05$). Furthermore, attractiveness of moans and rupes appeared to be stronger since they also led to longer times that were spent close to the speaker (repeated measures ANOVA, $p < 0.05$). While there was a significant decrease in the time the animal spent close to the feeding station (ANOVA, $p < 0.05$) during playback of moans, this difference was relatively small.
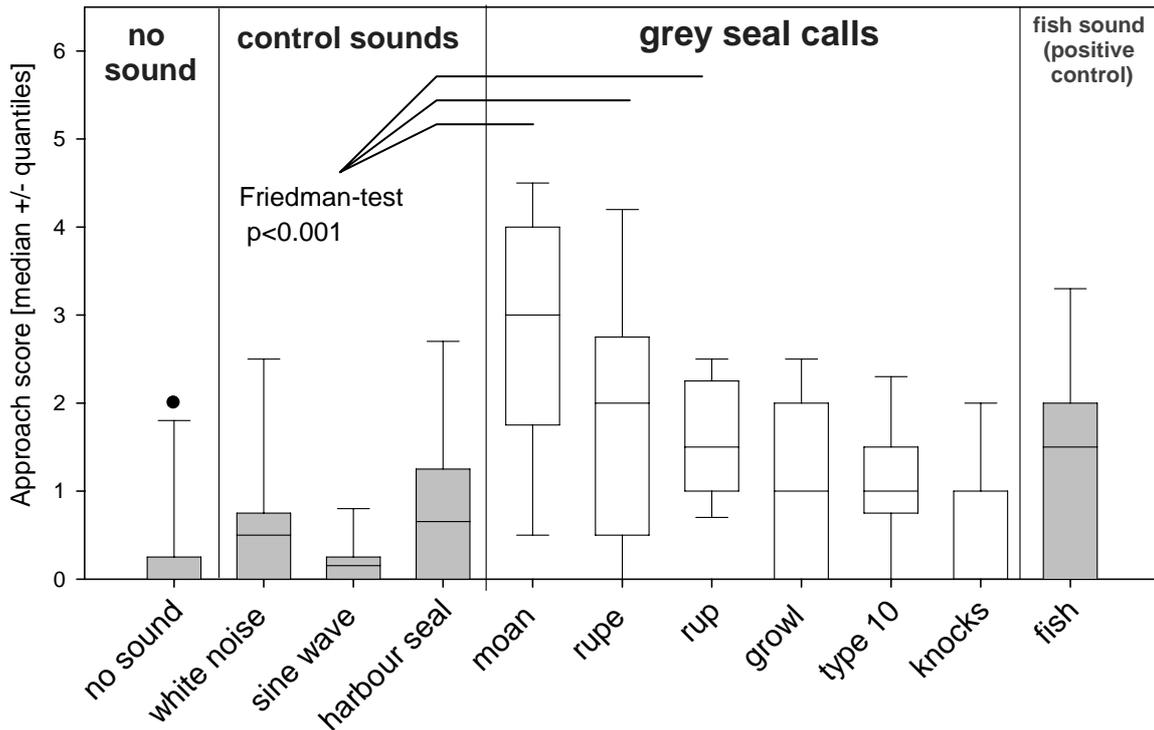
Fig. 9: Reactions to no sound, control sounds, grey seal sounds and fish sounds in captivity with food motivation at a location away from the speaker. The data are median, interquartile ranges and 90% margins for all seals. Moans, rupes and rups were more attractive than harbour seal sounds.

In the wild, moans also clearly attracted grey seals (ANOVA, $p < 0.05$) into the distance bin closer than 20m from the boat while rupe and rups attracted them to distances closer than 40m.

Conclusions

None of the tested grey seal or fish sounds had a deterrence effect. While some grey seal sounds attracted animals away from a food source in captivity, it is unlikely that this attraction would last for long enough to be useful as a seal attraction away from a food source in the wild. Animals have to forage and will set their priorities according to their motivation. These sounds are therefore not suitable for use in ADDs.

Section 3: Testing the startle response in seals

In terrestrial mammals, the acoustic startle response (ASR) is an obligatory reflex elicited by short sound stimuli that exceed the hearing threshold by at least 80-90 dB (Pilz et al. 1987). The ASR involves the interruption of ongoing behaviour patterns and the initiation of protective motor-patterns e.g. an involuntary flexor contraction as indicated by sudden neck twitching (Landis & Hunt 1939) and has been interpreted as a preparation or pre-cursor of a flight response. Despite the fact that the reflex can be modulated by a variety of pathways, the response elicitation itself is very simple and mediated by only a few neurons (Koch & Schnitzler, 1997). Most importantly, the likelihood of eliciting the response depends only on a few simple factors like rise-time,

27

bandwidth, intensity and duration (Blumenthal et *al.*, 2005). The likelihood for eliciting the response can be maximised by using broadband, short-rise time stimuli that are longer than 6 ms but not continuous.

Therefore, if present in marine mammals, exploiting the ASR would be a promising approach to develop a successful, target-specific deterrent. This can be done by designing stimuli that fall in a frequency band where the hearing sensitivity of the target-species is lower than that of other animals. Such a stimulus would exceed the startle threshold in one species but not in another at a given distance from the sound source. Furthermore, the startle response can best be elicited by short, single sound pulses, and therefore it holds potential to reduce anthropogenic noise pollution and mitigate potential impact on the hearing system of any species (compared to high duty cycles currently used by ADDs). The startle pulses tested in this experiment were also designed to fall in a low frequency band to minimize impacts on odontocetes.

Experiment 5: Reactions to startle sounds in captivity

Methods

Seven grey seals and one harbour seal were tested in this experiment. Three of the grey seals were adult females while four were juveniles. Three of the juveniles were females and one was a male. The harbour seal was an adult male. The age of the juvenile grey seals ranged from approximately 7 -11 months at the start of the experiment.

Tests were conducted in the same pool and with the same setup as experiment 1. The playback stimulus was a 200 ms long noise pulse with a rise time of 5 ms. The peak frequency of the signal projected through the loudspeaker was 950 Hz. The -20 dB bandwidth spanned approximately two to three octaves with the average -20 dB power points being at 450 Hz and 1.9 kHz. The sound pulse was synthesized as a white noise pulse and then shaped through filtering processes (Butterworth filter). The startle pulse was always paired with a substantially weaker pre-sound to test whether it would be possible to condition a seal to respond to a weaker sound in the same way as to the unconditioned startling stimulus. The pre-sound was a 3-Hz-frequency modulated 1.2s long sine wave pure tone. The sweeps caused by the frequency modulation covered a frequency range from 700Hz to 1.3 kHz. The end of pre-sound ended 2s before presentation of the startle pulse.

Received levels were measured at 0.8 and 1.2 m depth and for four positions close to the tube also at 0.4 m depth (animals spent most of the time deeper than 1m). The received level at the typical position of the animal's head in front of the feeding station was between 170 dB and 171 dB re 1μPa. Measured received levels in the pool only ranged from 170 to 173 dB re 1μPa (rms) (Fig. 10). The received level of the pre sound was between 125 dB and 130 dB re 1μPa.

The experimental protocol, responses measured and the monitoring equipment (video & hydrophone) were the same as in experiment 1. However, behaviour was monitored over 3 minutes instead of just one minute. The occurrence of clearly visible neck twitches or whole body muscle contraction was also monitored (as a sign of startle) as a response variable.
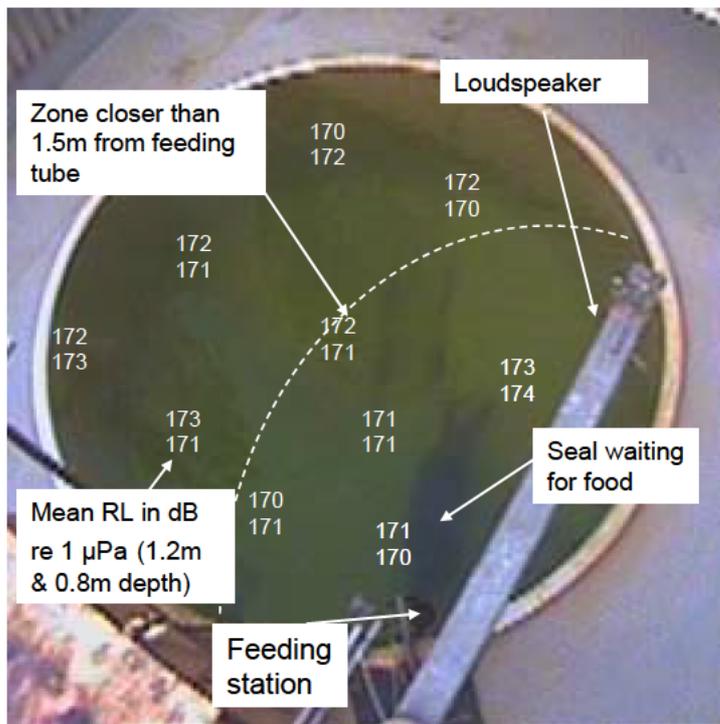
Fig. 10: Experimental setup and sound field in playback pool (depth 1.5 m, diameter 3 m) for experiment 5.

A playback session consisted of the following 3 or 4 three-minute observation periods/treatments that were each separated by a silent period of at least 5 min.

- no sound control
- startle pulse preceded by pre-sound
- startle sound preceded by pre-sound
- after third playback session: pre-sound alone

The startle pulse with the pre-sound was presented once when the animal positioned itself in front of the feeding station. If the animal stayed closer than 40cm for at least 30s after the first presentation, a second startle pulse was presented. Also, if the animal left the feeding station but returned later in the experiment a second startle pulse would be presented. Since no more than two presentations were given within the 3 min observation period, the maximum duty cycle for the startle pulses was 0.002 %.

The data from the two 3 min observation periods with the startle pulse were averaged and compared to the no sound control and the pre sound only treatment. A total of 10 playback sessions were conducted over the course of at least 3 days for each animal. Each playback session was separated by at least a 20 min break and after two playback sessions a recovery time of at least 3 hours was given before a new playback session started. Data were analysed separately for animals that showed a clear neck twitch (signs of a startle) in the first two playbacks and those who did not show any clear muscle contraction.

Results

The behaviour of the eight seals (7 grey and one harbour seal) in this experiment fell into two broad categories. Five of the seals showed a clear indication of a startle

response (e.g. neck twitch) while three animals did not show any signs of a startle response. In the 5 individuals that showed the startle reflex, avoidance responses (measured by the index of aversiveness) increased dramatically over time. The increase in the index of aversiveness from playback session 1 to 10 was highly significant (Spearman rank correlation; p=0.002; r^2=0.70) and can therefore be considered as evidence for sensitisation. By the end of the experiment, all five animals showed an immediate flight response and left the water after hearing the startle sound. In addition foraging behaviour was interrupted in response to sound exposure and animals grew reluctant to approach the feeding station in later playback sessions.   In contrast, responses of the three animals that did not show any signs of a startle reflex habituated (Spearman rank correlation, p=0.006, r^2=0.63).

Interestingly, in the animals that startled the pre-sound alone was able to elicit a similar response in the last trials. Figure 11 shows how the reactions here compare to those of experiment 1. There was a highly significant difference between the responses to the startle sound for the group that sensitised compared to the artificial sounds used in experiment 1 (Mann-Whitney U-test, p<0.0001). Even in the animals that habituated, the startle pulse still had a slightly higher effectiveness than the sounds used in experiment 1 (Mann-Whitney U-test, p=0.021).
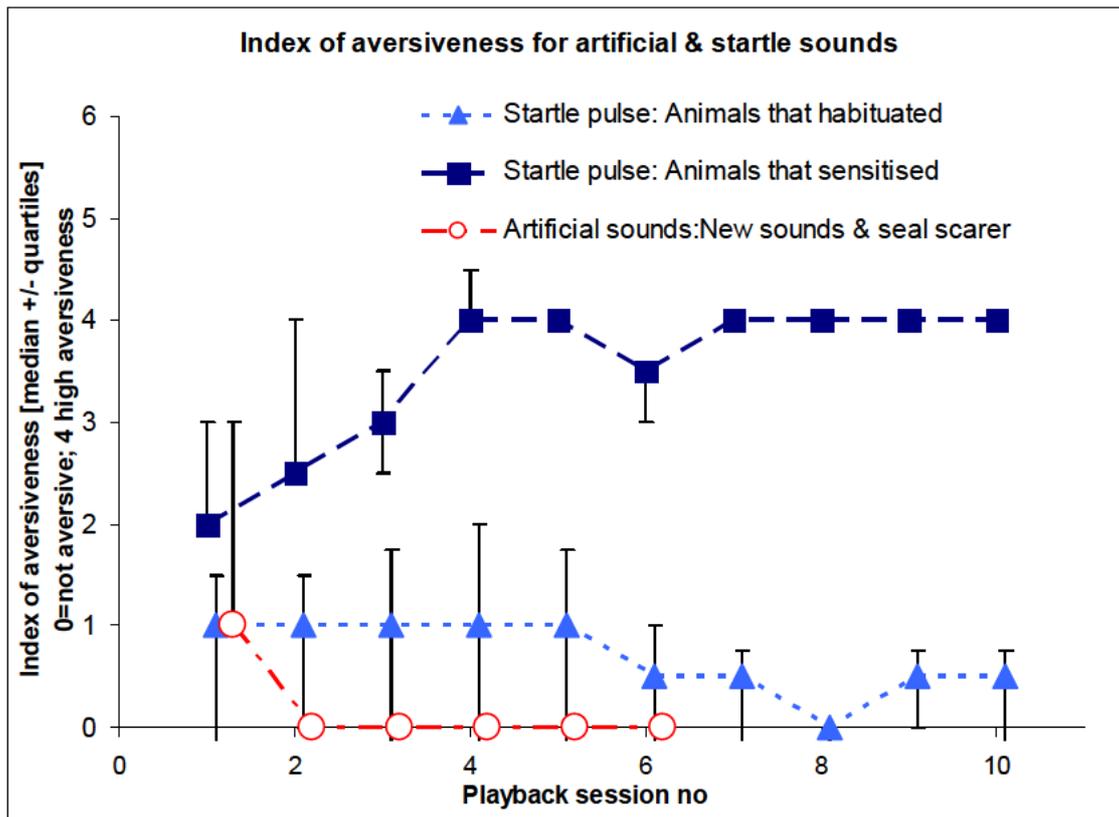
Fig. 11: Comparison of responses to startle sounds and sounds tested in experiment 1. Seals showed two different responses, habituation and sensitization. The startle stimulus was the most successful deterrence sound tested independent of whether seals habituated or sensitized.
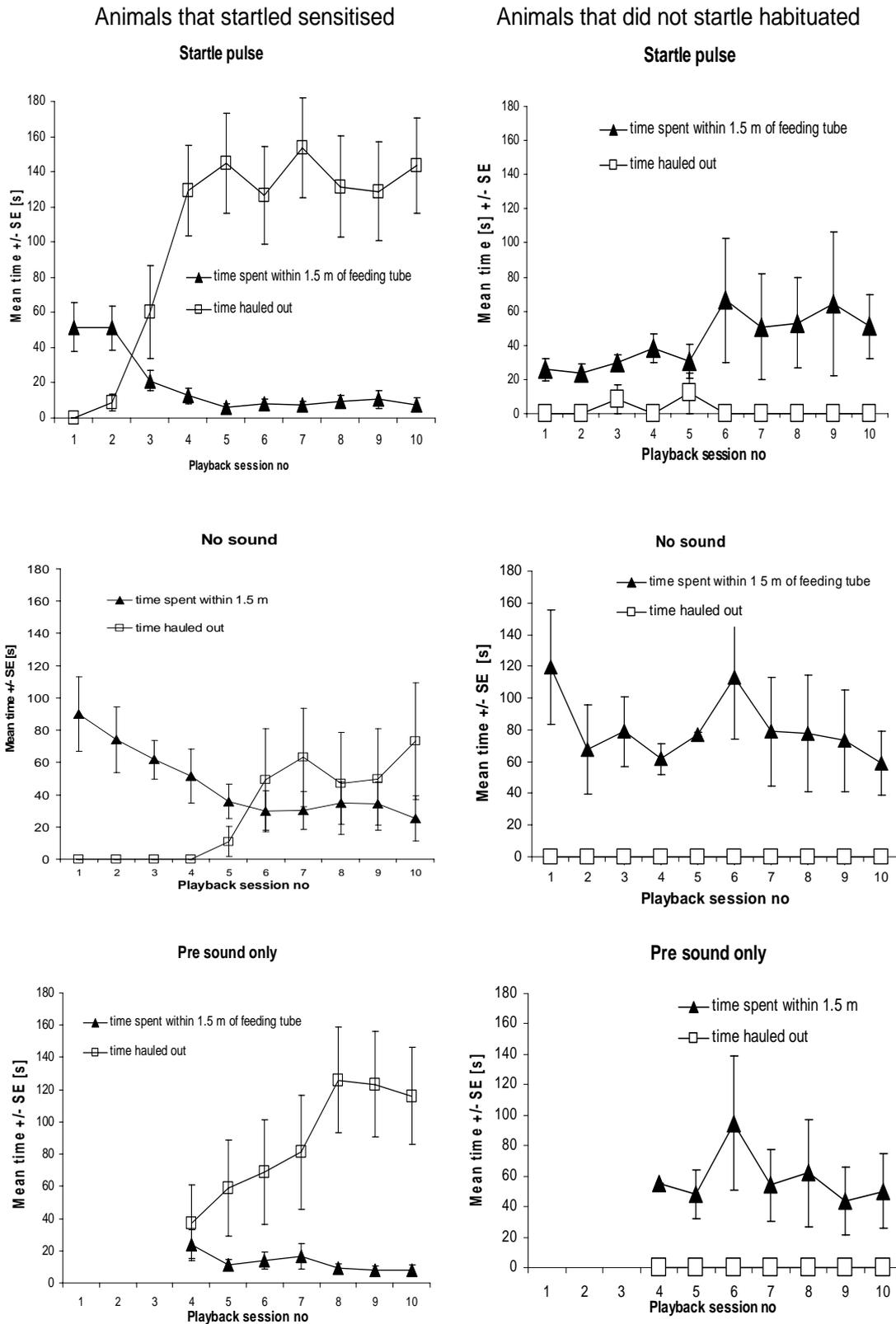
Fig. 12: Reactions of grey seals to startle sounds, no sound controls and pre-sounds alone. The left column gives results for animals that sensitized, the right column shows results for animals that habituated.

To test the effects on the time the animal spent close to the feeding station, we used the same models to test the results as in experiment 1. A general linear model (GLM) conducted for the animals that sensitized to the stimulus explained 60 % of the variance in the data set, with the factor with the strongest influence being treatment (i.e. startle pulse, no sound or the pre sound only). The second factor explaining variance was the number of the playback session (between 1 and 10), implying that the behaviour of each animal changed over the course of the experiment. From the evidence in Fig 12 it can be concluded that this is an indication for sensitisation to the sound. While there was some individual variation in the general behaviour of the seals, the interaction of the individual and the treatment was not significant indicating that there was no significant individual difference in the responses to the treatment. As shown in figure 12 these animals spent almost no time close to the feeding station by the end of the experiment in the startle treatment as well as when the pre-sound was presented alone. They also minimised the time close to the feeding station during the no sound control showing that previous experience led to a strong aversion against the foraging spot even without any sound being presented.

The GLM for dive time for the animals that sensitised yielded similar results (55% explained variance) with the treatment being by far the most important factor followed by the playback session. Individual differences and the interaction of treatment and individual were less important in terms of effect size but were still significant. The pre-sound was able to cause the animals to haul out and stay on land in a similar way as the startle treatment in the last three playback sessions. The seals also started leaving the pool after the 6th playback session in the no sound session. This shows that the seals developed a general reluctance to enter the pool where they have heard the startle pulses.

The GLM for the animals that habituated explained only 32% of the variance with individual variation being the strongest factor, followed by treatment. The interaction between individual and treatment was also significant, similar to what we found in experiment 1.

Conclusions

The startle sound that we developed showed great potential for use in future ADDs. While the initial reaction was comparable to that found in response to our other novel sounds and the commercial ADD sounds, five out of the eight animals tested sensitised to the sound, with responses being strongest in the last three playback sessions. Furthermore, animals that sensitised, spent most time hauled out on land and were extremely reluctant to approach the feeding station by the end of the experiments. This result is striking given that 3 of the 5 animals that sensitised to the startle pulses had previously been tested in experiment 1 where they had habituated to all sound playbacks (recovery time was less than 12-15h between experiments). It is also important to note that exposure to the startle pulse led to a general reluctance to approach the food source by the end of the experiments even during no sound control sessions indicating that place conditioning occurred (i.e. association of the food source with a negative experience).

While habituation has often been observed in marine mammals (e.g. Anderson & Hawkins 1978, Mate et al. 1987, Norberg 1998), this is the first example of extreme sensitisation to anthropogenic noise for any marine mammal species in a context where

food motivation is involved. The data also showed that it is possible to use classical conditioning to elicit flight responses by pairing a non-aversive stimulus (pre-sound) with an unconditioned stimulus (startle sound). This could be applied to greatly reduce noise pollution around fish farms because the loud, unconditioned stimulus (the startle pulse) would not have to be presented in every playback.

Our results also show that some seals did not sensitize to the sounds but did appear to habituate. Given that our startle stimulus relies on eliciting a sensation level of more than 80 dB, it is possible that the animals that habituated never experienced a sensation level of that magnitude. This is possible if they had experienced prior damage to their hearing system so that their hearing thresholds were higher than those reported in the literature for seals. To test this hypothesis further we used the same animals to determine a startle threshold for each individual.

Experiment 6: Startle thresholds in grey seals

Methods

Playback and monitoring equipment were as in experiment 1. Threshold measurements were carried out after experiment 1 was finished. The main problem was that due to the strong aversiveness of the stimuli in the previous experiment it proved very difficult to attract animals to the feeding station. In the case of animals that had sensitised in the previous experiment, a break of at least 24 h and substantial food rewards were required to make the animal approach the feeding tube again (and in some cases the animal would still only approach for a short time). After an animal got accustomed again to wait in front of the feeding station, experiments were carried out. The edge of the cup was lowered as a cue for the seal to position itself in front of the feeding station. If the animal was closer than 40 cm either lying on the bottom of the pool or drifting motionless in front of the feeding station the experiment was started. This involved presentations of 200 ms long, 5 ms rise-time, pure tone pulses ranging in intensity from 140-180 dB re 1µPa. The highest intensity stimulus was only presented twice in the two sessions furthest apart.

Since subtle responses like neck twitches could only be analysed appropriately by watching the videos from the underwater camera on a big screen, no classical staircase design could be applied which would have required us to decrease or increase stimulus intensity depending on the observed response. Therefore, all nine intensity steps were presented in a pseudo-randomised order. Four playback blocks were carried out, each containing all nine intensities in a different order. There was at least a 1 min break between the presentations of each intensity within a block and a 1h break between the end of one block and the start of the next one. No more than 2 blocks were presented on one day. The silent period after presentation of 2 consecutive blocks (separated by 1h) was at least 12 hours. The startle threshold was defined as the 75% response threshold meaning that an animal had to exhibit a neck twitch or a whole body startle in at least 3 out the 4 blocks for a given intensity. Behaviour was coded as "neck twitch" or "whole body startle" if there was a clear shift ("jump" or "curving") of the whole body in the video frame.

Results

Startle thresholds were found at 155 to 165 dB re 1 µPa for all animals that sensitized in the previous experiment (Table 4). Taking the hearing threshold of a typical phocid seal into account, this threshold is 80-85 dB above the hearing threshold. However, we could not find a startle threshold for the animals that habituated to the sound. They showed no apparent response even to the loudest stimulus tested which had a received level of 180 dB re 1µPa.

Table 4: Startle thresholds for animals used in experiment 5.

Test order/ species Harbour seal (HS) Grey seal (GS)	Age (when tested) adults unknown	Startle threshold (dB re 1 µPa)	Lowest RL to which startle occurred (dB re 1µPa)	Behaviour in experiment 5
1 HS male	adult	>180	-	habituated
2.GS female	7 month	160	155	sensitised
3.GS female	adult	>180	-	habituated
4.GS female	adult	160	155	sensitised
5.GS male	11-12month	165	160	sensitised
6.GS female	7 month	160	155	sensitised
7.GS female	7-8 month	165	160	sensitised
8.GS female	adult	>180	-	habituated

Conclusions

Startle responses occurred at sensation levels above 80-85 dB in animals that showed a startle reflex in our experiment, which is what would have been predicted from the startle literature in other mammals (Pilz et al. 1987). As seen in table 4, animals that habituated to the startle stimulus in experiment 6, never showed a startle response even with higher source levels used here. This suggests that they had higher hearing thresholds. This conclusion is supported by data on terrestrial mammals showing that animals that develop hearing loss have higher startle thresholds (Ouagazzal et al. 2006). This can either be a result of exposure to loud sound in the wild or simply age-related hearing loss. A threshold shift of 20dB is not uncommon in middle aged humans and has also been shown for marine mammals (Finneran et *al.* 2005). In the interest of animal welfare we could not increase the source levels further in this experiment. Unfortunately, we were unable to conduct hearing tests to confirm our conclusion. However, it is known from the literature that there is a static relationship between the startle and the hearing threshold (Pilz et al. 1987).

Experiment 7: Testing startle sounds on wild grey seals near a haul-out site

Methods

The methods were the same as in experiment 2. Startle sounds were part of the playback sequences described in experiment 2.
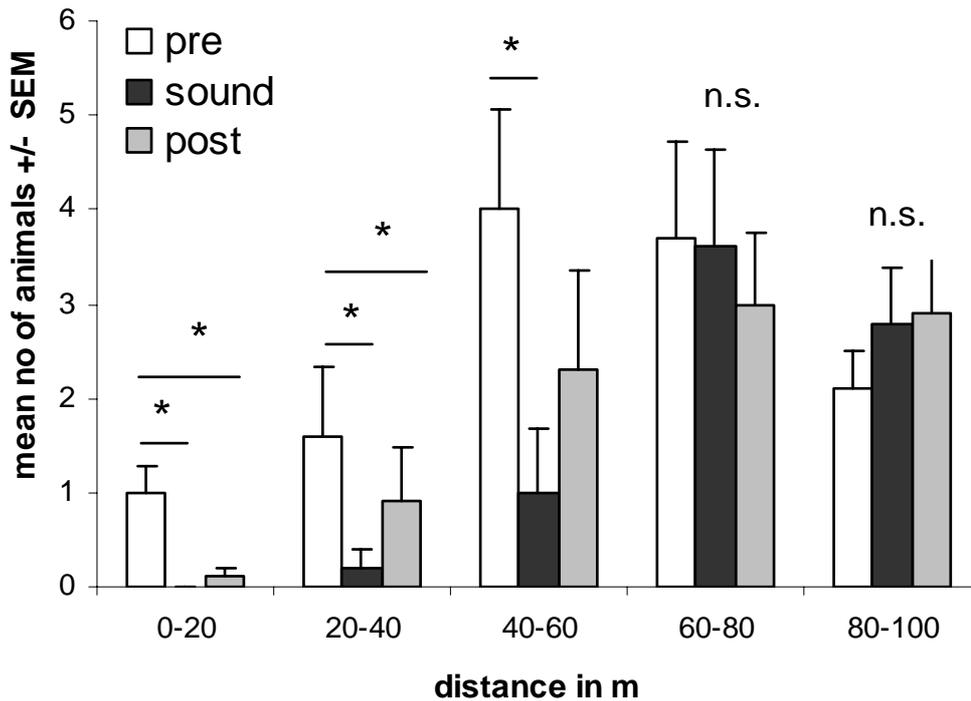
Fig. 13: Number of animals surfacing in the periods before, during, and after the playback of the startle stimulus. The decrease in seal numbers up to 60 m was significant as indicated by the asterisks (repeated measures ANOVA), n.s. = not significant.

Results

A repeated measures ANOVA showed that the sound was effective in deterring most seals from the area up to 60 m from the source. The closest ever observed approach of a seal during sound exposure was 26m. The startle sound seemed to have similar deterrence ranges as the more effective sounds in experiment 2. Only the "Square 500/530" stimulus from experiment 2 kept seals at a larger distance. It appears that the startle sound proved most effective in deterring seals from an area of 60 m around the sound source (Fig. 6).

Conclusions

The startle sound was highly effective in the wild, where no food motivation existed. In comparison with the other stimuli it appeared to be more successful in deterring animals from the vicinity of the device while having similar deterrence ranges as higher duty cycle sounds (experiment 2). While the "Square500/530" stimulus from experiment 2 affected seals at even larger distances, the animals habituated quickly to it (see experiment 1) while they sensitized to the startle stimulus. Measured received levels at the distance of the closest ever observed approach were 155 dB re 1 µPa which is quite close to the measured startle thresholds from experiment 6. This supports the hypothesis that the startle response was responsible for the observed reaction. Received levels at the edge of the exclusion zone (60m) were in the order 145 dB re 1 µPa which lie below the startle threshold.

Experiment 8: Reactions of seals and harbour porpoises to startle sounds near a salmon farm

Given the success we had with startle sounds we used them in our final test on a fish farm. We had two objectives. Firstly, we wanted to test the stimulus with seals and look at its effectiveness around a farm in the field. Secondly, we tested the stimulus in an area that was frequented by harbour porpoises, animals that have been reported to show strong reactions to commercial ADDs.

Methods

The study site was located in the Northern Sound of Mull on the west coast of Scotland. Experiments were conducted on a fish farm in Bloody Bay owned by Scottish Sea Farms Ltd in June and July 2007. The fish farm was stocked with young salmon ranging in size from 20 cm-40 cm in five cages. The fish farm cages were 15-16 m deep and had a diameter of about 25m. Seal predation was a common problem, although an acoustic deterrent device had never been used on this fish farm. Licensed shooting was used to manage seal predation instead. However, there were no shootings for the duration of our experiments.

Our ADD consisted of a Lubell 9162 loudspeaker, a Cadence Z9000 stereo high-power car amplifier, a Panasonic SL-S120 CD player and a car battery installed in a waterproof aluminium box. We placed our ADD on one of the sea-side cages of the farm. The speaker was deployed at 17m depth, which was about 2m below the deepest part of a cage in order to avoid sound shadow effects by the fish in the near field. Only the startle stimulus from experiment 5 was used here. The noise pulses were played at varying intervals ranging from 2s to 40s with an average of 2.4 pulses per minute. In order to make the sound pattern less predictable the signals were arranged digitally into 4 different playback tracks each of which was 1.5 h long. These playback tracks were assigned to different playback days and played in loop mode from the CD player. Given the signal length of 200ms, the effective duty cycle of the acoustic deterrence device was 0.08 %. The source level of the acoustic deterrent device was adjusted to 180 dB re 1μPa.

Experiments were carried out in sea states less than 3 in June/July 2007. Good weather days were chosen to use as either a control day with the equipment in place but no playbacks or an exposure day in which the stimulus was played as described above. Average observation periods were 3.5 h (SD = 0.96) on control days and 3.4 h (SD = 0.94) on days with sound exposure. The longest observation period was 5 hours, the shortest 1.5 hours. This protocol resulted in a total of 113 hours of observation with 58 h during sound exposure and 55 h during control periods. We balanced our design so that tidal state, sea state and time of day were the same for control and sound exposure observation periods.

During our observation periods, visual scans were conducted by two observers. One observer was scanning by eye while the other observer was using binoculars. If one of the observers detected a porpoise or seal we took bearings with a Topcon DT-102 digital theodolite and started logging surface positions for each surfacing bout. A group was tracked until no resurfacing occurred 15 min after the last surfacing had been logged. Group and track ID was therefore defined as a consecutive line of surfacings

that were not separated by more than 15min. If another group or species was spotted by the observers while tracking a group, they logged surfacings for both groups. The sound field was measured as in our previous experiments.

As response variables we calculated the closest observed approaches defined as the surfacing closest to the transducer and the average distance from the transducer for all surfacings within a trackline. We also compared the number of animals sighted on control and exposure days. Data were analysed in distance bins of 0-250m, 250m-1500m and more than 1500m. The distance of 1500m was chosen to enable us to compare our data with Johnston's (2002) study, while the 250m were based on the fact that received levels at this distance were similar to those that caused a behavioural avoidance response in the experiment described in experiment 7 (135-140 dB re 1µPa).

Results

Observations were carried out on 32 observation days (16 days sound exposure; 16 days control). Harbour porpoise were observed on 19 out of the 32 days, with 59 porpoise groups (136 animals) overall tracked. Seals were observed on 22 out of the 32 observation days with a total of 53 different animals tracked. Seals could not be identified to species level on all occasions. However, when it was possible to identify species these individuals were always harbour seals. The number of hours in which at least one seal or porpoise was sighted is shown in figure 14.

While the sound did not have an effect on number of hours with porpoises present (Fisher's exact test, all p>0.05), it did significantly decrease the number of seal sightings (Fisher's exact test, p<0.05, see fig 14). This is also reflected in the more detailed analysis of closest approaches and the average distance of seals (Fig 15) and porpoises (Fig 16) to the ADD. Seals clearly showed an avoidance response up to 250 m in their closest approaches and in the average distance to the device (Freeman-Halton-Fisher tests, p < 0.05) while porpoises showed no significant differences in either response variable. Porpoise groups were regularly seen swimming between the cages of the fish farm and one porpoise group approached the ADD as close as 8 m during sound exposure. The closest ever observed approach of a seal was approx 50 m during sound exposure.

We also tracked 8 minke whales (*Balaenoptera acutorostrata*) at distances of 1000-3000 m. One was seen on a control day and seven were seen on exposure days. The closest observed approach of a minke whale was during sound exposure (1109m).
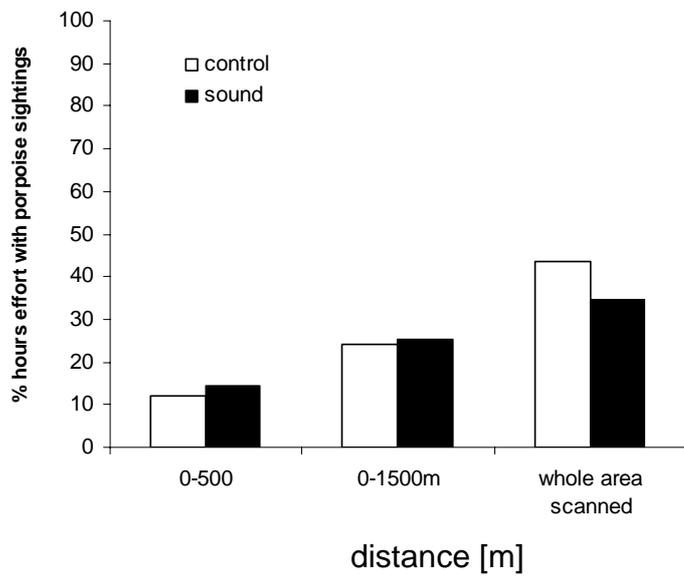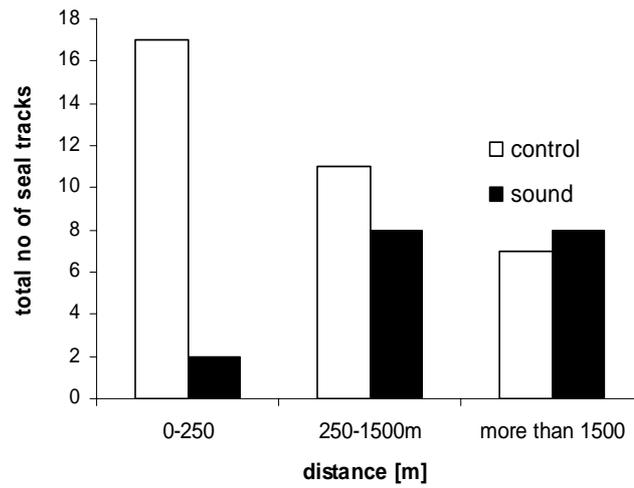
a)
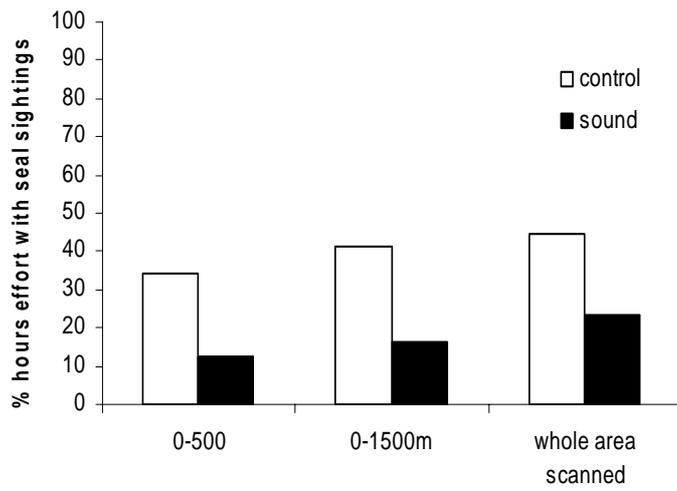
b)

Fig. 14: The percentage of hours in which at least one a) seal or b) harbour porpoise was seen in the study area.
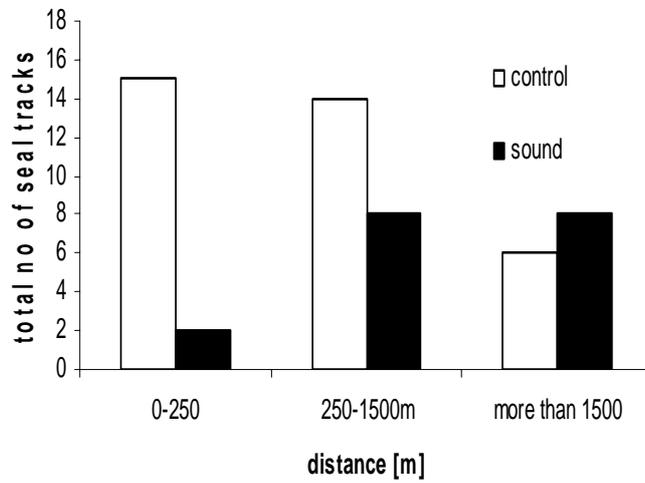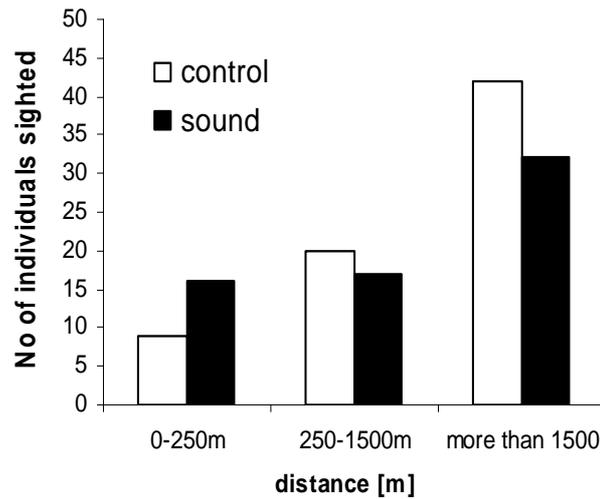
a)

b)

Fig. 15: Seals and their a) closest approaches to and b) average distance from the ADD. Increases in distances in response to the ADD are significant (Freeman-Halton-Fisher tests, $p < 0.05$).
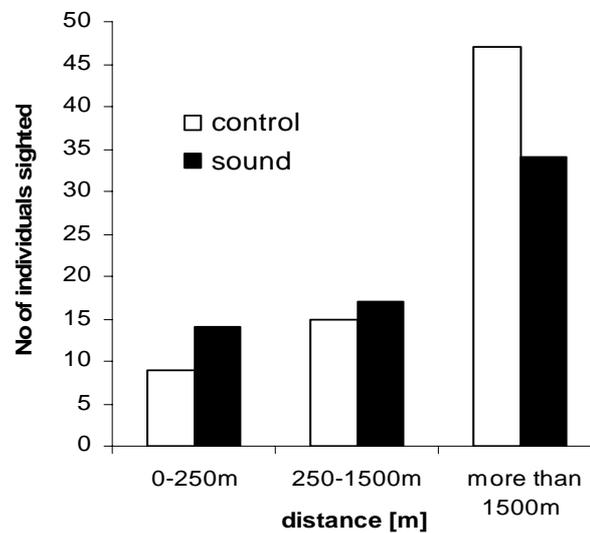
a)

b)

Fig. 16: Harbour porpoises and their a) closest approaches to and b) average distance from the ADD. Differences in distribution between control and stimulus condition were not significant (Freeman-Halton-Fisher tests, n.s.).

Conclusions

Our field trial in this experiment showed that our ADD sound did not have a negative effect on harbour porpoise distribution but was effective in reducing the number of seals in the vicinity of the fish farm. We did not see any effects on minke whales that were exposed to received levels of up to 125 dB re 1μPa. We do not have any data on reactions to higher received levels since the animals were never seen close to the farm and the sample sizes were too low. However, the fact that we saw considerably more minke whales on exposure days suggests that the animals do not avoid the stimulus.

General discussion

A variety of acoustic seal deterrent methods have been tested in this study. We included existing commercial devices, control sounds, seal sounds, novel aversive sounds, and startle sounds, based on what is currently used in ADDs and the sound aversiveness literature for mammals.

Using seal sounds, we found that those sounds that were used to mark male territories had an attractive effect on seals. In the captive study this may have been due to the fact that most of our test animals were females, but we found the same effect in the wild. Females may be attracted to male calls if they are a mating display. Males may approach a calling seal to assess its fitness and decide whether to challenge it or not. Thus, these sounds are not useful to exclude seals from areas of commercial interest.

For most other stimuli, we found that while seals reacted to them with initial avoidance, animals that were foraging habituated rapidly if sounds were played repeatedly to them. Interestingly, the captive seals habituated within the first playback session when hearing commercial ADD sounds or our novel high duty cycle sounds based on the human model of unpleasantness. This happened in spite of the fact that a variety of different sounds were presented on each day indicating that variable stimulus design is not effective in preventing habituation. Field trials showed no habituation, but the design of our study did not allow testing the same individuals over time as was the case in the experiment with captive animals. One of our sounds based on the model of unpleasantness proofed more effective than the other stimuli in the field trials. Thus, commercial ADD sounds and even more so our "novel unpleasant sounds" may be able to keep seals at a distance that are not foraging but would be less efficient with food-motivated animals.

It is important to note that some commercial ADDs use slightly higher source levels than what we tested them at in this study, which could lead to higher effectiveness with seals. However, exposing animals to higher sound pressure levels for long time periods leads to a risk of causing hearing damage. This creates a serious conservation concern, but will also decrease the animals' sensitivity to any form of acoustic deterrence device. We demonstrated here that our novel, unpleassant sounds were as effective or even more effective in deterring seals at safe noise levels as commercial ADD sounds. However, our novel sounds were designed to cause lower sensation levels in odontocetes, so that they would not affect odontocetes negatively in contrast to what has been reported for commercial ADDs. Based on our current knowledge, we therefore recommend that ADDs should use these novel, lower frequency sounds to minimize effects on odontocetes. Given the rapid habituation it is, however, doubtful whether such ADDs would help to decrease seal predation on fish farms.

Our startle stimulus presents a promising alternative. It did not only have a better deterrence effect than all other sounds in initial trials but it also led to sensitization in the majority of the animals so that avoidance reactions increased over time. Using our startle sounds would also significantly reduce underwater noise pollution since the required duty cycle is significantly lower than what is used in commercial ADDs. In addition, it would limit any strong avoidance effect to an area where sound levels exceed the startle threshold. By using differences in hearing sensitivity between species we designed stimuli that exceeded the startle threshold in seals and therefore caused avoidance in seals but not in odontocetes. Furthermore, the source level we used was

the lowest used by any of the current ADDs (180 dB re 1μPa rms) but with a much lower duty cycle. Furthermore, sensitization could also be used to pair the loud startle pulse with a softer sound stimulus that elicited the same avoidance response after a seal had been exposed to the startle sound itself. Thus, the startle sound would not have to be played all the time but could be replaced by a more benign warning sound in around 50% of playbacks. Even further reductions in noise pollution could be achieved if our method was combined with a movement trigger that only triggers a sound when seals are close to the farm. Such triggers are commercially available and should be tested with our device.

A potential disadvantage of our novel stimuli could be effects on other marine life with specialised low-frequency underwater hearing. Species with good hearing between 1 and 2 kHz can be found among baleen whales and fish with specialized hearing systems like herring or other clupeid species. The fact that we had more minke whales in our study area on sound exposure days than on control days suggests that baleen whales would at least not avoid our device. However, further tests are needed to confirm the safety of our device for minke whales close to the device. For fish, there are very few studies that could help to assess the impacts of our exact stimulus at this time. In a study on oscars (*Astronotus occelatus*), a 1 h sound exposure to continuous white noise at 180 dB re 1μPa caused some hair cell damage but exposure to the same signal at a duty cycle of 20% did not result in any damage (Hastings et al. 1996). The duty cycle in the sounds presented in our study was much lower (0.08%). Thus, effects on hearing in fish do not seem likely. We also did not observe any obvious behavioural responses of the farm fish. Salmon continued schooling in their usual pattern and did not show any signs of disturbance even when being close to the loudspeaker. This was to be expected given that salmon are unable to hear sounds of the frequencies we used (Hawkins & Johnstone 1978). Anecdotal evidence from divers that were inspecting the cages while the ADD was operating in our experiment reported the presence of schools of mackerel (*Scomber scombrus*) that were at distances of 30-200m from the ADD. A well known behavioural response to sound in fish is a c-start or startle reflex that can involve a brief, directional movement away from the source. Such startle responses in herring have been reported to reliably occur at sound pressures levels of 143 dB re 1μPa (Blaxter et al., 1981) but do not necessarily lead to an escape response (Wardle et al., 2001). In our experiment, a received level of 143 dB re 1μPa was only exceeded at distances of less than 100m. In conclusion, effects on fish need to be considered on a case by case basis but do not seem to pose a fundamental problem except for cases where a species has an important habitat within 100 m of the farm.

Given the high efficiency, the lack of effects on porpoises and the dramatic decrease in noise pollution, we recommend implementing our startle method in commercial ADDs and replacing existing devices. We also suggest that licences for ADDs should be restricted to those devices that have been shown to be efficient and target-specific by independent studies. Furthermore, the startle paradigm could be used for other applications e.g. to establish acoustic barriers to reduce seal predation of salmon in rivers, to reduce dolphin depredation and mortality in pelagic trawls and to keep marine mammals away from marine turbines. We have submitted a patent application for all novel methods presented in this report and are currently seeking industrial partners and/or investors to implement these in market products.

Recommendations for future work

1. If we decrease the centre frequency of seal deterring sounds, we potentially affect other marine life that has not been affected by previous methods. The main species of concern here are fish that are hearing specialists. An example of such a species in Scottish waters is the herring. Future work would have to investigate how lower frequencies in ADDs would affect these animals. Crustaceans are another group of potentially affected animals. Finally, there might be an effect on baleen whales. Future work should test how these animals react to the ADD sounds suggested in this report.

2. The second unaddressed issue is potential long-term habituation. We have shown here that seals often sensitize to the sounds we used. However, this was over a relatively short time period in comparison to the normal exposure for many years that are likely if the method was used on fish farms. We would have to test how this deterrent method performs over longer time periods.

3. We recommend to experimentally determine the temporal integration time for startle responses in seals. This would provide information on the shortest possible stimulus sufficient to elicit avoidance responses in seals and therefore further reduce the duty cycle and noise pollution of a deterrence device.

4. We strongly recommend expanding studies with our startle sounds to other applications e.g. preventing marine mammals from entering and drowning in pelagic trawls and keeping selected species away from tidal turbines or seismic exploration activities.

We also suggest that any seal deterrence method should work in a responsive mode, so that it only presents sounds when seals are present. This would decrease noise pollution even further and make habituation less likely. Therefore, we would recommend the technological development of such a trigger and its test under controlled conditions.

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Aversiveness of sounds in phocid seals: psycho-physiological factors, learning processes and motivation

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SUMMARY

Aversiveness of sounds and its underlying physiological mechanisms in mammals are poorly understood. In this study we tested the influence of psychophysical parameters, motivation and learning processes on the aversiveness of anthropogenic underwater noise in phocid seals (*Halichoerus grypus* and *Phoca vitulina*). We compared behavioural responses of seals to playbacks of sounds based on a model of sensory unpleasantness for humans, sounds from acoustic deterrent devices and sounds with assumed neutral properties in different contexts of food motivation. In a captive experiment with food presentation, seals habituated quickly to all sound types presented at normalised received levels of 146 dB re. 1 μPa (r.m.s., root mean square). However, the fast habituation of avoidance behaviour was also accompanied by a weak sensitisation process affecting dive times and place preference in the pool. Experiments in the wild testing animals without food presentation revealed differential responses of seals to different sound types. We observed avoidance behaviour at received levels of 135–144 dB re. 1 μPa (sensation levels of 59–79 dB). In this experiment, sounds maximised for 'roughness' perceived as unpleasant by humans also caused the strongest avoidance responses in seals, suggesting that sensory pleasantness may be the result of auditory processing that is not restricted to humans. Our results highlight the importance of considering the effects of acoustic parameters other than the received level as well as animal motivation and previous experience when assessing the impacts of anthropogenic noise on animals.

Key words: aversive, roughness, stress, discomfort, threshold, noise, habituation, seal, phocids, *Halichoerus grypus*, *Phoca vitulina*.

INTRODUCTION

Aversiveness of biological sounds has been studied in detail in the context of predator avoidance (Deecke et al., 2002; Tuttle and Ryan, 1981). By contrast, factors influencing aversiveness of other sounds are poorly understood and have only been investigated with respect to stimulus amplitude (Campbell, 1957; Kastelein et al., 2006a), practical applications (Blackshaw et al., 1990; Kastelein et al., 2001; Talling et al., 1998) or the use of sound as a reinforcing stimulus (Campbell and Bloom, 1965). An aversive stimulus is an unpleasant or noxious stimulus, which induces an avoidance response in an animal. Such behavioural responses to sounds are influenced by a variety of psychophysical factors relating to sound perception, the motivational state of an animal and basic learning processes (e.g. habituation, conditioning). Elucidating the role of these factors is not only relevant for animal welfare and conservation (Nowacek et al., 2007) but can also provide answers to fundamental questions of sound and music perception in mammals (Hauser and McDermott, 2003).

Anthropogenic noise has been found to elicit avoidance responses in marine mammals (Johnston, 2002; Kastelein et al., 2006a; Kastelein et al., 2006b; Morton and Symonds, 2002; Nowacek et al., 2004), terrestrial mammals (Talling et al., 1998) and birds (Mackenzie et al., 1993). There are few studies that have tested the effects of sound characteristics on aversiveness (Kastelein et al., 2001; Talling et al., 1998) so that detailed information on what causes aversiveness in animals is not available. However, models developed for humans could provide a first indication which psycho-physiological parameters influence the degree of pleasantness or aversiveness of sound in mammals. Zwicker and

Fastl developed a model that can be used to predict unpleasantness of sounds in humans (Zwicker and Fastl, 1990). In this model, a decrease in tonality and an increase of sharpness, loudness and roughness will contribute to 'unpleasantness'.

Tonality depends on the waveform of the sound and is highest for pure tones whereas the sensation of sharpness is caused by signals with centre frequencies close to the upper edge of the hearing range (Zwicker and Fastl, 1990). Loudness is a complex psycho-physiological parameter that depends among other factors on the hearing threshold of the test subjects. Experiments on humans showed that the contours of perceived equal loudness are roughly parallel to the hearing threshold within the most sensitive hearing range but are compressed at the high and low frequency edge of the hearing range (Fletcher and Munson, 1933; Robinson and Dadson, 1956). In other words, sounds of different frequency but similar sensation levels (i.e. pressure levels in dB by which a sounds exceeds the hearing threshold) cause similar perceived loudness within the most sensitive hearing range (Yost, 2000). However, perceived loudness also depends to some extent on bandwidth (Zwicker et al., 1957) and stimulus duration (Zwislocki, 1969). In humans, changes in electro-physiologically measurable parameters that are indicative of stress or discomfort were correlated with sensation levels of about 70–80 dB (Spreng, 1975).

A sensation of roughness is caused by fast frequency or amplitude modulations. In humans, modulation frequencies of around 70 Hz cause the strongest effect (Zwicker and Fastl, 1990). Roughness perception has received considerable attention in humans since it has also been suggested as the physiological basis for musical consonance preferences (Plomp and Levelt, 1965). In

humans, sounds that consist of partial tones, which are related by complex frequency ratios, are perceived as unpleasant or dissonant whereas sounds that consist of partials related by simple ratios are perceived as pleasant or 'consonant' (Helmholtz, 1853). Modern classical composers (e.g. Arnold Schönberg) and musical psychologists (Stumpf, 1883) tended to argue that consonance perception is a result of culture but physiologists expected more general properties of the auditory system to be responsible (Helmholtz, 1853). Plomp and Levelt developed the so-called critical band theory of consonance perception based on their findings that in musically untrained subjects dissonance is maximised if two partial tones fall within 25% of the critical bandwidth (= cochlea filter bandwidth) (Plomp and Levelt, 1965). Some evidence for a genetic rather than a cultural basis of consonance preference also comes from experiments on human babies (Zentner and Kagan, 1996). However, results from animal experiments remain controversial; while a two-alternative forced choice experiment revealed clear preferences for consonant musical intervals in rats (Borchgrevink, 1975), consonance preference could not be demonstrated in place preference experiments with tamarin monkeys (McDermott and Hauser, 2004).

Studies assessing impacts of noise on animals usually use behavioural avoidance responses as a measure of aversiveness or severity of disturbance (Nowacek et al., 2007). This is problematic because motivation and learning can minimise such responses while detrimental effects remain unchanged. For example, while seals in British Columbia showed diminishing (Mate and Harvey, 1987) or a lack of aversive responses to acoustic predator deterrent devices used to protect fish farms (Jacobs and Terhune, 2002), cetaceans were deterred by these devices for several consecutive years (Morton and Symonds, 2002). As the cetaceans did not feed on fish in farms, their motivation to stay in the area may have been lower than that of the seals. However, the signals could still have had an effect on the hearing abilities of the seals. Thus, it is important to elucidate the role of motivation and learning in the control of avoidance responses.

Our study aimed to test how stimulus properties, motivation and learning influence aversiveness of sound in phocid seals. We chose seals as test subjects for several reasons. Seals have sensitive underwater hearing over a very large frequency range covering almost eight octaves (Kastak and Schusterman, 1998; Møhl, 1968; Terhune, 1988; Terhune and Ronald, 1975). Visual energy is much less efficient to convey information underwater, and some echolocating toothed whales rely largely on sound for prey detection (Gannon et al., 2005) and communication (Janik, 2000). While seals might use hydrodynamic cues to detect prey over short ranges (Dehnhardt et al., 2001), sound plays an important role in their underwater communication system (Hanggi and Schusterman, 1994), and passive listening has been suggested to aid foraging (Schusterman et al., 2000). In addition seals are not closely related to humans within the mammalian line but have evolved adaptations to aquatic hearing (Schusterman et al., 2000). Therefore, if we find similar sound characteristics to cause aversiveness in seals and in humans it suggests that the responsible mechanism is an evolutionarily ancient characteristic within the mammalian line. Finally, there is increasing concern about the impact of anthropogenic noise on the behaviour of marine mammals (Nowacek et al., 2007), and it has been suggested that in some species mass strandings might be a secondary result of an overt behavioural response to aversive sound (Jepson et al., 2003).

In order to investigate the physiological basis of aversiveness of sounds in seals, we tested three different classes of stimuli which were presented to seals underwater at received sensation levels that were below the expected pain and acoustic startle thresholds: sounds designed to be unpleasant based on a psychophysical model of sound perception in humans (Zwicker and Fastl, 1990), control sounds with assumed neutral properties regarding perceived pleasantness, and sounds recorded from commercially available acoustic deterrent devices (ADDs) for seals. To test how motivation modifies behavioural responses, the animals were tested under three different conditions: (1) with a known accessible feeding apparatus present, (2) with a known feeding apparatus present that does not provide food, and (3) without a food source. Tests were conducted with captive and wild animals.

MATERIALS AND METHODS
Subjects and their environment
For the captive tests, we used six grey seals (*Halichoerus grypus*, Fabricius 1791) and two harbour seals (*Phoca vitulina*, Linnaeus 1758). All grey seals and one harbour seal were wild captured at a haul-out site at Abertay Sands in the UK (56°25.59′N, 2°45.59′W). The other harbour seal was caught in an estuary close by (~56°21.7′N, 2°51′W). All seals were housed in outdoor pools filled with seawater. Four out of the six grey seals were sexually mature adult females and two were juveniles (one male, one female). The juveniles were approximately 6–11 months old at the time of the experiments. The two harbour seals were adult males. The harbour seals had been in captivity for two weeks and one month, respectively, before being used in the experiment while the tested grey seals had been in captivity for a time ranging from 3 to 8 months prior to the experiments. Experiments were carried out in a 3 m-diameter, 1.5 m-deep circular, seawater-filled test pool.

Tests on wild seals were conducted at Abertay Sands. All tests on wild animals were conducted in the vicinity of one of four sites where grey seals hauled-out. Haul-out sizes during the experiments ranged from approximately 20 to 200 animals.

Playback stimuli
We tested three different types of sounds. The first class (PPM=psychophysical model sounds) were sounds predicted to be aversive based on the psychophysiological model developed by Zwicker and Fastl (Zwicker and Fastl, 1990). PPM sounds were designed to maximise roughness through selected frequency modulation patterns and had a relatively high loudness due to their broad bandwidth. The second class were control sounds with assumed neutral properties, and the third class were ADD sounds. All sounds are shown in Fig. 1. For playbacks each stimulus was presented in a continuous sound burst of 6 s duration.

PPM and control sounds were synthesised using Cool Edit pro software (Syntrillum Software Corporation, Phoenix, AZ, USA) with rise and fall times of 50 ms. ADD sounds had been recorded from active acoustic deterrent devices at sea except for the Lofitech sound which was synthesised based on a field recording. ADD sounds were played at a lower level than what the original devices produce (see below).

PPM (psychophysical model) sounds
(1) Square 500/530 FM. This stimulus consisted of two concurrent 70 Hz frequency modulated (FM) square-wave tones with a carrier frequency of 500 Hz and 527 Hz. Modulation depth was 50% of the carrier frequency. A 70 Hz frequency modulation pattern was found to cause maximum roughness in humans (Zwicker and Fastl, 1990). We tried to enhance aversiveness by selecting two partials that lay in the same critical band for auditory analysis. Critical bandwidths
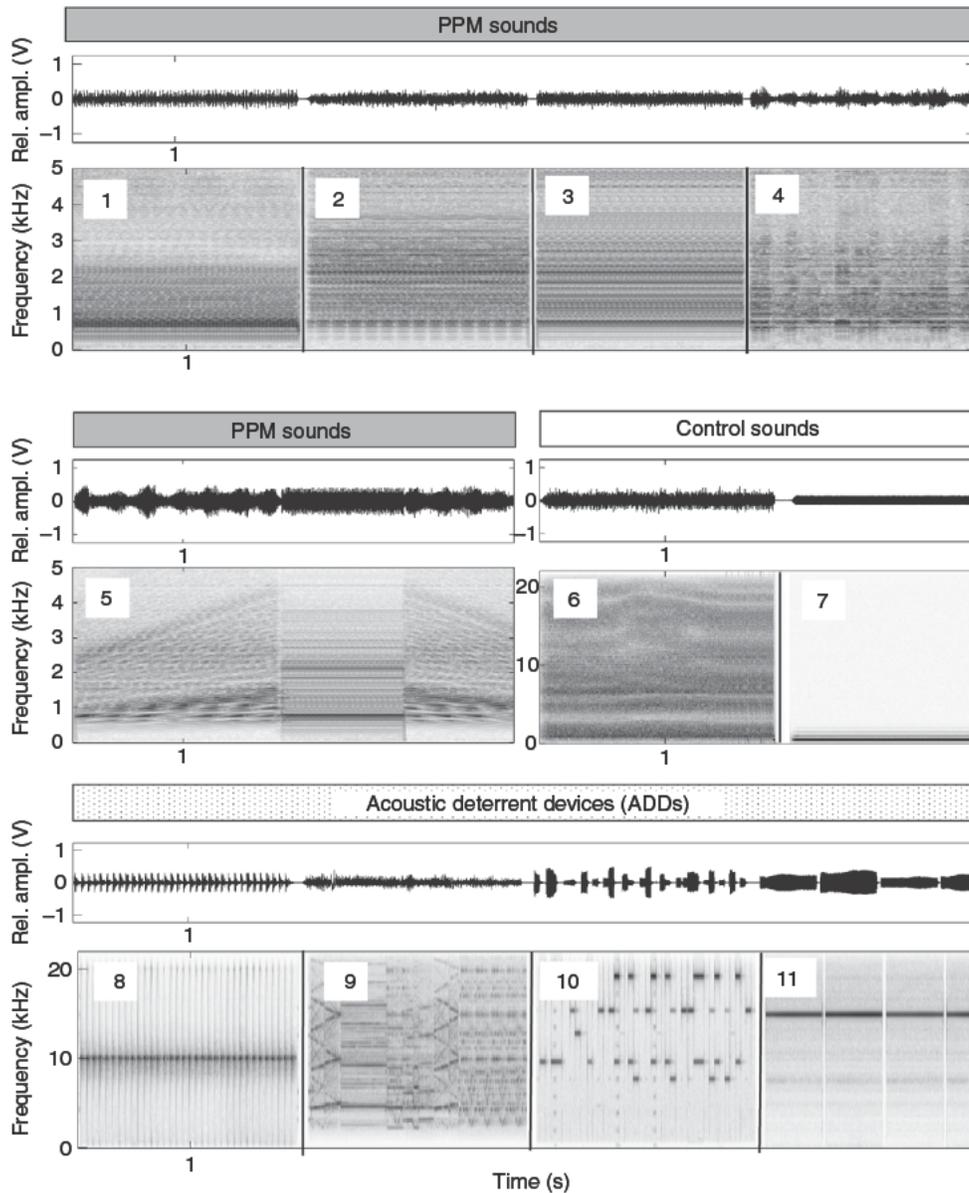
Fig. 1. Representative 2 s sections of the 11 sound types tested in the captive experiment (fast Fourier transform 512 bands). Note the different scales on the y-axis for different sound classes. Rel. ampl., relative amplitude.

for harbour seals range from 20% to 40% of the test frequency (Southall et al., 2003).

(2) Square 500/507 FM. This stimulus was identical to 'Square 500/530 FM' except that the carrier frequencies of the two partials were 500 Hz and 507 Hz, respectively. The frequency ratio of the partials for this stimulus was chosen to reflect 25% of the critical bandwidth calculated from underwater critical ratios in pinnipeds (Southall et al., 2000), which are 3% and 9% of the test frequencies.

(3) Square 500 FM. 70 Hz FM square-wave tones with a carrier frequency of 500 Hz. Modulation depth was 50% of the carrier frequency. This stimulus is the base pattern of stimuli 1 and 2.

(4) Square variable. 100–300 ms-long, constant frequency, square-wave pulses (some of which were FM) with the carrier frequency of each individual pulse ranging from 500 Hz to 1.5 kHz. Similar to the previous sound, spectral variability was used to make the sound less predictable.

(5) Sweeps FM. A complex sound consisting of FM square-wave up- and down-sweeps. The frequency modulation applied to the

square waves ranged from 0 Hz (no modulation) to 100 Hz with modulation depth between 30% and 60%. Sweeps (1–4 s duration) covered a frequency range from 400 Hz up to 3.5 kHz. This temporal and spectral variability was implemented to make the sound less predictable and to prevent habituation.

Control sounds

(6) White noise (400–20 kHz), which was slightly modified during playback due to the frequency response of the speaker.

(7) Sine-wave pure tone (500 Hz).

ADD sounds

(8) Pulse train consisting of 2–5 ms long pure tones (10 kHz) recorded from an Airmar dB Plus (Milford, NH, USA).

(9) Complex, broadband sounds with a peak frequency between 7 kHz and 9 kHz produced by a Terecos ADD (Glasgow, UK).

(10) Short tone pulses at varying frequencies with peak frequencies of either around 15.4 kHz or 9.6 kHz recorded from an Ace-Aquatec ADD (Dingwall, UK).
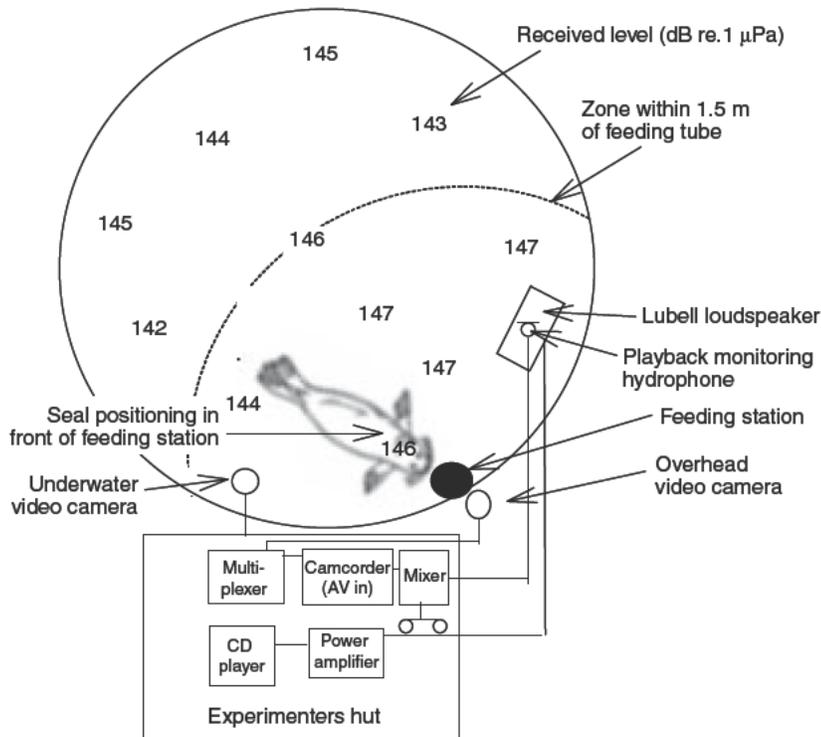
Fig. 2. Experimental setup (experiment 1). Mean measured received levels (in dB re. 1 µPa) are reported for various locations in the playback pool.

(11) Pulse train consisting of 495–500 ms-long sine-wave pulses as used in a Lofitech ADD (Leknes, Norway).

Transducer, sound field and source level

Sounds were presented underwater through a Lubell 9162 loudspeaker (Lubell Labs Inc., Columbus, OH, USA). The loudspeaker was powered by a Phonic MAR 2 power amplifier (Taipei, Taiwan) and playback sounds were played from a Panasonic SL-S120 CD player (Osaka, Japan). The loudspeaker was calibrated using all playback stimuli and a variety of test signals at broadband source levels ranging from 120 dB re. 1 µPa to 160 dB re. 1 µPa. The amplitude of some playback sounds was then readjusted in the digital domain using the calibration data in order to ensure normalised root mean square (r.m.s.) source levels.

Transducer calibration and sound field measurements were conducted using a calibrated Bruehl & Kjaer 8103 hydrophone connected to a Bruehl & Kjaer charge amplifier 2635 (Naerum, Denmark). The output from the charge amplifier was recorded on a Toshiba Satellite Pro laptop (Tokyo, Japan) using its sound card, which showed a flat response (±1.5 dB) from 70 Hz to 15 kHz. The sound card was calibrated using a Thurlby Thandar TG 230 signal generator (Huntington, UK). The output of the signal generator was confirmed with a Tektronix TDS 3022 digital oscilloscope (Beaverton, OR, USA). Recordings were made using Cool Edit Pro 1.2 software (Syntrillum Software Corporation). r.m.s. and peak-to-peak (p–p) voltages of the recorded sound and calibration signals were measured in Avisoft SAS Lab Pro v 4.32 (Avisoft Bioacoustics, Raimund Specht, Berlin, Germany). Sound pressure levels (SPL) were calculated as SPL=20log(sound pressure/1 µPa).

Sound types that contained significant energy below 600–700 Hz were equalised using the calibration data to compensate for the low-frequency response decline (<700 Hz) of the transducer using fast Fourier transform (FFT) filters in Cool Edit Pro (Syntrillum Software Corporation). The actual peak frequencies of the five 'PPM

sounds' broadcasted through the loudspeaker were between 750 Hz and 800 Hz. The –20 dB power points were between 600 Hz and 2.5–3.5 kHz, respectively.

For sound field measurements in captivity, the loudspeaker was placed at the test position in the test pool (Fig. 2) with no seal in the pool. Received levels of all playback stimuli were set to values equal or just below 146 dB re. 1 µPa and were measured four times at 11 different positions of the pool. Mean received levels (r.m.s.) in the pool ranged from 142 dB re. 1 µPa to 147 dB re. 1 µPa. Assuming the hearing threshold of harbour seals to be 72 dB re. 1 µPa at 1 kHz (see composite underwater audiogram in Fig. 3) these sounds would have a maximum sensation level of 74 dB, The sensation level is the relative SPL (in dB) by which a sound exceeds the hearing threshold of a species. Our chosen sensation level of 74 dB exceeds the discomfort but not the pain threshold in humans (see Spreng, 1975). It was also below the startle threshold in terrestrial mammals [rats (Pilz et al., 1987); humans (Berg, 1973)].

In the wild, signals were played at a broadband source level of 172 dB re. 1 µPa (r.m.s.). Sound field measurements in the wild were conducted at the haul-out site on the outer sandbars in the mouth of the river Tay (Tayport, UK) where 75% of the playbacks were carried out. All playback sounds were played consecutively, and measured received levels were averaged over all eight sounds. Received levels were measured along two depth profiles: the first parallel to the shore and a second one from the boat to the shore. Water depth along the profiles ranged from 3.5 m to 5 m for the first profile and from 4.5 m to 1 m for the second profile. The measured received levels along both profiles were also used to determine avoidance thresholds (received level at the edge of the deterrence range).

As we wanted to test the aversiveness of sounds based on parameters other than received level, we chose sound exposure levels (SELs) that were below the threshold where a temporary threshold shift (TTS) could be expected to occur in harbour seals. Kastak et al. showed that the onset of TTS occurs at SELs of 183 dB re. 1 µPa^2 s

(Kastak et al., 2005). Our exposures did not reach this level. A single emission of our sounds in the field experiment (10 s burst) would result in a SEL of 182 dB re. $1\,\mu Pa^2\,s$ (source level), and a single emission (6 s) in the captive trials would amount to a SEL of 156 dB re. $1\,\mu Pa^2\,s$ (received level at the position of the animal's head when playback starts).

Ambient noise measurements were carried out using a low-noise Reson TC 4032 hydrophone connected to a Reson VP 2000 (EC6081) voltage amplifier (RESON A/S, Slangerup, Denmark). The output from the preamplifier was recorded on an Edirol UA-25 sound card (Roland Corp., Hamamatsu, Japan) connected to a Toshiba laptop (Tokyo, Japan). In the pool and in the wild ten 5 min sections separated by 10 min intervals were recorded. Ambient noise measurements in the pool were carried out on two days, the first one with Beaufort (BF) wind of 1–2, the second with strength 3–4. In the wild ambient noise was recorded at two haul-out sites used for playbacks on a day with sea state (SS) 1–2. The recording day and time were chosen to reflect the typical playback conditions: low wind, SS 1–2, ±2 h around low water, no rain and no boat traffic within 1 km of the playback site. Power spectral density was calculated in Avisoft SAS Lab Pro v 4.32 (Avisoft Bioacoustics, Raimund Specht, Berlin, Germany) using an 8192 step FFT. The calibrated values were calculated by taking the sensitivity of the hydrophone and the gain from the preamplifier into account.

Experimental protocol

In captivity, seals were tested individually with only one seal in the test pool at a time. Experiments were started by providing a fish through an underwater feeder, which was 1 m below the surface. Animals had previous experience with the feeder and would approach it when the edge of a metal cup (that contained a fish) became visible. The cup was then lowered 2 s after the playback started making the fish accessible to the seal. Playbacks started when the tip of the animal's nose was within 40 cm of the feeder. Every playback lasted one minute with sound being presented as four sound bursts of 6 s duration each. This resulted in an effective duty cycle of 40% over the 1 min period with a 12 s interval between the presentations. A playback session consisted of 1 min playbacks of each of the 11 described sound stimuli, each separated by a quiet 5 min interval from the next one. In addition, a 1 min observation period with no sound presentation (a no sound control) was carried out. Different versions of the recorded sounds were used in different playback sessions to prevent pseudo-replication and the sound presentation sequence differed for each playback session and individual. We carried out three playback sessions with food presentation as described above, followed by one session with no food, in which playbacks still started when the animal was within 40 cm of the feeder. In the fifth playback session we provided food again while the last one was another no food session. This allowed us to investigate how motivational state affected the behaviour.

Playbacks were monitored using an HTI-96-MIN hydrophone (High Tech Inc., Gulfport, MI, USA), an analogue VN37CPH colour underwater camera (RF Concepts, Dundonald, UK) focused at the feeding station and a camera of the same model mounted 4 m above the pool that was used to view the whole pool area (Fig. 2). Video tracks from both cameras were linked to a multiplexer (CK-70C-4, Camtek-CCTV, Taipei County, Taiwan) and together with the audio track from the hydrophone recorded on a Sony (Tokyo, Japan) DV video recorder (GVD 1000E or MVX 350i). The experimenter and all equipment were hidden from the animal in a hut next to the pool. Behavioural responses were measured from the video recordings.
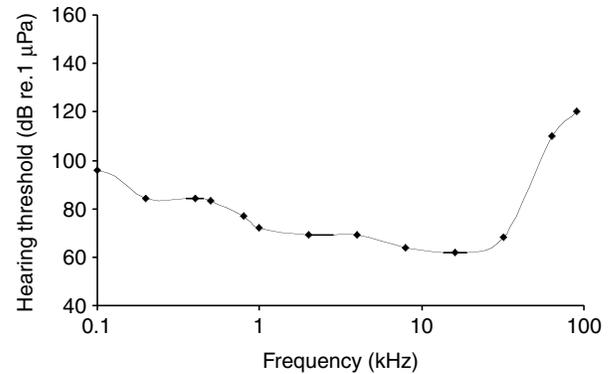

Fig. 3. Composite underwater audiogram for the harbour seal (*Phoca vitulina*) from data in Table 1.

Eight of the 11 stimuli from the captive experiment were also tested in the wild. We used all control and ADD sounds but only the two most efficient PPM sounds from the captive sessions (Sweeps FM, Square 500/530 FM). We approached the haul-out site from sea with a 6.5 m boat with two outboard engines at idle speed. The boat was anchored between 80 m and 250 m from the haul-out. The playback source was deployed at a depth of 1.5 m at the stern of the boat. We observed all animals in the water within a 100 m radius of the boat. A playback trial consisted of observations 5 min prior to playback (pre), 5 min during playback (sound) and 5 min following playback (post). A 15 min recovery period separated each trial. We used only one sound type in each playback trial. Not more than five playback trials were carried out per day. Sounds were played for 10 s followed by 10 s of silence during the 5 min playback period resulting in a duty cycle of 50%. We increased the duty cycle and trial length for the experiments in the wild to ensure that animals, which were spread out over a large area and were often very close to the surface, would be exposed for a sufficient amount of time to exhibit an avoidance response. As the main goal of the study was to investigate the effects of specifically chosen control and PPM sounds these were all tested 10 times on separate days within a period of several months. ADD sounds, which can contain a variety of complex features, were only tested six times each. Playbacks were only carried out if at least one animal was seen within 50 m of the boat during the 5 min pre-playback period. We also conducted 14 control observations with no sound playbacks in which equipment was deployed but no sound was played during the 5 min between the pre- and post-observation period. The order in which sound types were played on a given day was pseudo-randomised. No sound type was tested in more than one playback on each day. As eight different stimuli were tested not all stimuli were tested each day but sound stimuli were distributed evenly between playback days and haul-out sites.

Response variables

In captivity, an index of aversiveness was used to describe the animals' responses. The scale ranged from 0 (not aversive) to 4 (highly aversive) and was of an ordinal nature. Aversive response at a certain level always included all aversive responses at a lower level (e.g. level 3 means that the animal also exhibited a level 1 and 2 response). After reviewing the tapes, each 1 min playback was allocated one value. The levels were: (1) seal turns away from underwater loudspeaker – a change in the orientation of the line between shoulder blades and the tip of the nose by at least 100 deg.

Table 1. Hearing threshold data from three different studies on harbour seals

Studies from which values at a given frequency were averaged: Mohl, 1968 – M Kastak and Schusterman, 1998 – KS Terhune, 1988 – T	Frequency (kHz)	Threshold (dB re. 1 μPa) underwater
KS	0.01	102
KS	0.1	96
KS	0.2	84
KS	0.4	84
Interpolated from KS	0.5	83
KS	0.8	77
KS and T	1	72
Extrapolated from KS; T	2	69
Extrapolated from KS; T	4	69
KS; M; T	8	64
M; T	16	62
M; T	32	68
M; T	64	110
M; T	90	120

from the original position (nose pointing towards feeding station). (2) Escape/flight response: seal increases distance to underwater speaker at speeds of more than $3\,\mathrm{m\,s}^{-1}$. Value 2 was allocated if the animal crossed the pool diagonally swimming away from the feeding station in less than 1 s. (3) Foraging behaviour (fish take) prevented – seal does not re-approach the feeding station after flight response and fish remains in feeder for the whole minute (4) Haul-out behaviour for at least 30 s after an initial flight response.

Additionally, the following continuous response variables were measured: (a) time the animal's head was underwater and within 1.5 m of the feeding tube, and (b) dive time during playback defined as head being completely submerged. All response variables were measured from the videotapes during the 1 min sound exposure.

Because phocid seal species have similar underwater audiograms (cf. Terhune, 1988; Terhune and Ronald, 1972; Terhune and Ronald, 1975) we pooled data for all seals in the captive experiments to allow statistical testing. However, we give information on species differences in the text. Calculations of sensation levels were based on a composite behavioural audiogram using data for harbour seals from Møhl (Møhl, 1968), Kastak and Schusterman (Kastak and Schusterman, 1998) and Terhune (Terhune, 1988) (see Fig. 3 and Table 1). A general linear model (GLM) and two multifactorial analyses of variance (ANOVAs) were calculated to determine which covariables influenced the behaviour of seals in the pool. We used a modified Bonferoni method (Cross and Cjaffin, 1982) to adjust the overall P-values for the models and the P-values of those covariables/covariable combinations that were used in more than one model (treatment, individual, food/no food). Thus, all P-values in the text and figures are already adjusted if this was required. Statistical tests were calculated in Systat 11 (Systat Software Inc., Chicago, IL, USA) with the exception of the GLMs, which were calculated in JMP 4 (SAS, Cary, NC, USA). We pooled data within each sound category for some of the analyses to allow statistical testing. The term 'treatment' is used to refer to exposure to either: (1) PPM sounds, (2) control sounds, (3) ADD sounds, or (4) no sound.

In the wild, surface positions of seals were measured continuously relative to the playback boat using a laser range finder (Bushnell Yardage Pro 1000, Overland Park, KS, USA) and a handheld compass. The observer would continuously and slowly rotate around his axis resulting in a scan sampling of the area. The response
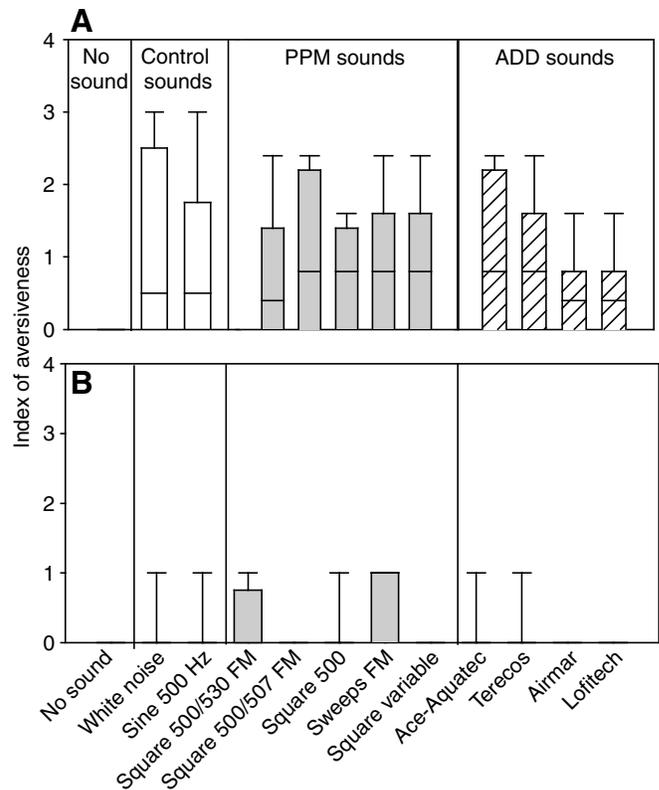

Fig. 4. Responses of the eight seals to the treatments no sound, control sounds, psychophysical (PPM) sounds and acoustic deterrent device (ADD) sounds in (A) the first playback session and (B) the second playback session (both trials included food presentation). The data are median (horizontal line), interquartile ranges (box) and 90% margins (whiskers) for all seals. Note the habituated responses in the second playback session.

measure was the number of surfacings observed, except in cases were recognisable animals exhibited a quick series of surfacings in which case only the closest approach was used. Playbacks were conducted on 18 separate days in 2006 and 2007. The data were analysed using repeated-measures ANOVAs to compare the number of seals between pre-, sound- and post-observation periods in distance classes comprising 20 m each. This was found to be a suitable method to detect seal movement around the playback boat in a pilot trial where we observed behaviour of well-marked individuals (recognisable by the pelage pattern on their head). Deterrence ranges were calculated by analysing the data in 20 m distance classes up to a distance of 100 m. The deterrence range was defined as the outer edge of the distance class within which there was a consistent, statistically significant reduction of animals during sound exposure (repeated-measures ANOVA, $P<0.05$).

RESULTS

Captive seals showed median aversive responses up to level three (turn away, flight and prevention of fish catch) in response to the first sound exposure events in the pool even though food was presented to them at the same time (Fig. 4A). All sounds had a similar aversiveness in the first trial causing the animals to move away from the loudspeaker. None of the sounds elicited a startle reflex as would have been visible by a rapid neck or body flinch at the onset of sound exposure. There was a significant difference in the index of aversiveness among the four treatments (no sound, control
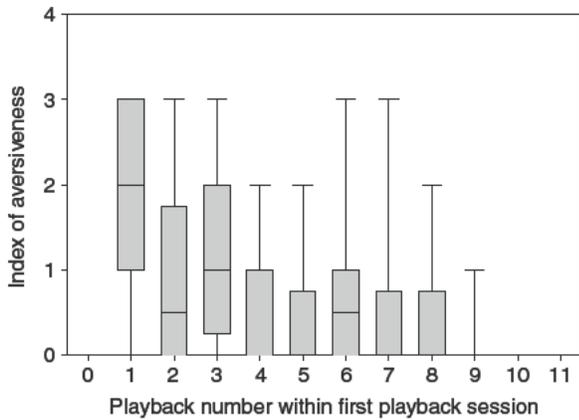
Fig. 5. Habituation of responses within the first session independent of sound type. Data are median (horizontal line), interquartile ranges (box) and 90% margins (whiskers) for all seals. As each seal had a different sequence in which sounds were presented, data are listed by playback position in the first session. The data shows the response decline to zero within the first playback session.
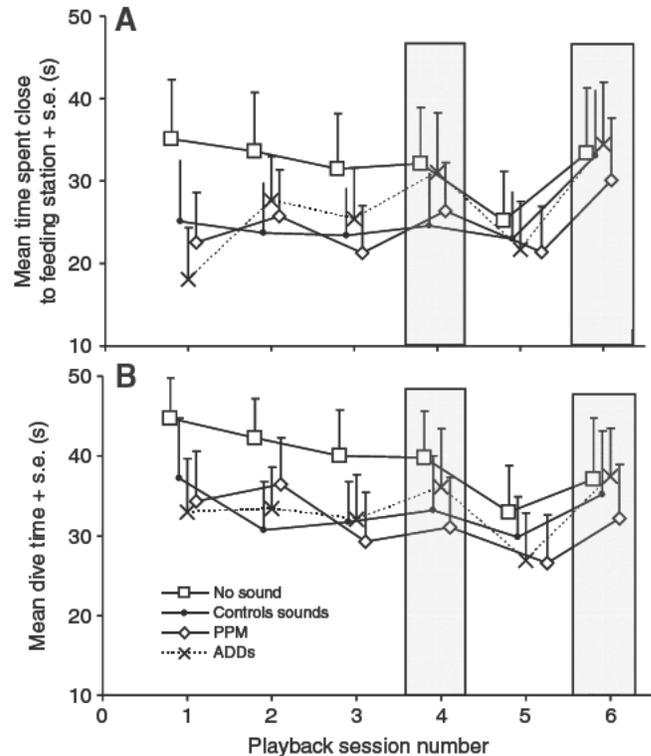

Fig. 6. Mean time spent close to the feeder (A) and dive time (B) in response to no sound, playbacks of psychophysical (PPM) sounds, acoustic deterrent device (ADD) sounds and control sounds. Data points are mean values plus standard error (+s.e.). In sessions with shaded grey bars no food was presented to the animal.

sounds, PPM sounds, ADD sounds) in the first playback session (Kruskal–Wallis H=9.383, P=0.025, d.f.=3). Median aversive responses were zero for all sounds in the second playback session (Fig. 4B) and in all subsequent sessions. There were no apparent species differences as the median response score calculated over all responses in the first playback session was 1 even if species were analysed separately. The median response score in the first playback session was 1 for adults and 1.5 for two juveniles.

The position of each specific sound within the first playback sequence had a larger effect on the index of aversiveness than the sound type. Fig. 5 shows the median responses ordered by playback position within the first playback session independent of sound type. There was a strong decline of the responses over the first 3–4 playbacks with median responses reaching zero in all trials following the seventh playback, no matter what sound type was played in that position (Kruskal–Wallis, H=25.126 P=0.005, d.f.=10). Furthermore, a Spearman rank correlation test revealed that there was a highly significant negative correlation between the median response score and playback position within the first playback session (t=−6.36, P=0.00013, R^2=0.82; Fig. 5), indicating fast habituation to hearing a playback sound independent of what the sound was. Playback position did in fact explain 82% of the variation in the index of aversiveness (R^2=0.82). Therefore, response

magnitude to a certain sound primarily depended on when it was played to a seal within the first playback session with a sound having the highest likelihood to elicit an aversive response if it was among the first 2–5 sounds a seal had heard in the test pool (Fig. 5).

In contrast to the findings for the index of aversiveness sound exposure maintained some effect on dive times and the time spent close to the feeder. Exposure to any of the three sound treatments reduced the time an animal spent close to the feeding station and caused a reduction of dive time over the course of several playback sessions (Fig. 6). To elucidate potential factors that might influence swimming and diving behaviour in the pool we calculated GLMs for these response variables over all of the sessions that involved food

Table 2. General linear model for the four food trials for the response variables 'time close to feeding station' and 'dive time'

Variable	Biological meaning of variable	Time close to feeding station		Dive time	
		F	P	F	P
Treatment	Effect of sound exposure and sound type on behaviour	4.48	**0.01**	5.51	**0.006**
Playback session number	Behavioural changes over time	2.81	**0.04**	10.2	**<0.0001**
Individual	Individuals behave differently but do not necessarily respond differently to sound	22.7	**<0.003**	30.05	**<0.003**
Treatment × Individual	Individuals respond differently to sound exposure or sound type	1.27	0.21	1.88	**0.029**
Treatment × playback session number	Habituation to sound exposure or sound type	0.66	0.74	0.98	0.47
Individual × playback session number	Individuals change behaviour differently over time	1.96	**0.0126**	2.11	**0.01**

Bold values indicate significant results (P<0.05).

Table 3. Comparison of consecutive food and no food trials for the response variables 'time close' and 'dive time' using multifactorial ANOVAs

Variable	Biological meaning	Playback session: 3 (food) vs 4 (no food)				Playback session: 5 (food) vs 6 (no food)			
		Time close		Dive time		Time close		Dive time	
		F	P	F	P	F	P	F	P
Food presentation	Reinforcement of approach behaviour	1.30	0.26	0.072	>1.0	8.61	**0.005**	7.18	**0.02**
Individual	Individuals behave differently	29.42	**<0.0003**	28.69	**<0.0003**	15.07	**<0.0003**	26.58	**<0.0003**
Treatment	Effect of sound exposure	3.33	**0.04**	3.34	0.06	0.18	>1.0	1.6	0.4

Significant difference for a variable is marked in bold.

presentation (Table 2). The model included playback session number, individual identity, treatment and all three interaction terms as variables. The model for the time spent close to the feeder was highly significant ($F_{64,124}=8.14$, $P<0.0003$) explaining 71% of the variance in the data. Individual variation in behaviour was the most important explanatory variable, followed by treatment (effect of sound exposure) and to a lesser degree playback session number. The effect of the individual was not caused by species differences. The interaction term for playback session number and individual identity was also significant. Generally, seals reduced the time spent close to the feeder slightly in later playback sessions in all four treatments. However, the interaction term of treatment and playback session was not significant showing that the effect of sound exposure on behaviour did not change over time, i.e. there was no clear habituation for the time spent close to the feeder. The parameter estimates from the model revealed that the effect of treatment was due to the difference between the no sound control and sound exposure while there was no significant difference between the sound types. The model for dive times explained 85% of the variance and was highly significant (GLM, $F_{64,124}=12.22$, $P<0.0003$). Similar to the previous model, the most important explanatory variable was individual identity (irrespective of species). However, in contrast to the previous model the second most important factor was playback session number followed by treatment. This shows that the seals decreased dive time in later playback sessions in all four treatments.

To test for differences in behaviour between consecutive playback sessions with and without food presentation, we used multifactorial ANOVAs including individual ID, treatment and food presentation schedule (food vs no food) as covariates (Table 3). The comparison model for playback sessions 3 (food) and 4 (no food) was significant for both, the time spent close to the feeder ($F_{11,63}=19.748$, $P<0.0003$, $R^2=0.77$) and dive time ($F_{11,63}=19.175$, $P<0.0003$, $R^2=0.76$). The model showed that there was strong inter-individual variability (irrespective of species) in these variables as well as an effect of treatment on time spent close but no effect of the food presentation regime was found (Table 3). The comparison models for playback sessions 5 and 6 were also significant for both response variables (dive time: $F_{11,63}=10.42$, $P<0.0003$, $R^2=0.62$; time close $F_{11,63}=18.00$, $P<0.0003$, $R^2=0.75$). In contrast to the previous models, food presentation regime (food vs no food) had an influence on both variables (i.e. dive time, time spent close). This means that seals dived longer and spent more time close to the feeder when no food was presented (Fig. 6). However, again individuals showed strong differences in their general diving and swimming behaviour.

In the wild, we found a significant decrease in the number of animals in at least one of the distance classes for almost all tested sound types. From observations of well-marked animals we found that this was an indicator of animals having moved away from the sound source during sound exposure (Fig. 7, repeated-measures

ANOVAs all $P<0.05$). Deterrence ranges for the two PPM sounds were 60 m (Sweeps FM) and 80 m (Square 500/530 FM) while ranges for the control sounds were 40 m (sine 500 Hz) and 60 m (white noise), respectively. The sounds of the Ace-Aquatec and Lofitech ADDs yielded a deterrence range of 60 m while the deterrence range for the Airmar sounds was 40 m. No significant deterrence range was found for the sound of the Terecos ADD. However, ADD sounds were only played six times resulting in a lower statistical power of these tests than for the tests of other sound types, which were played 10 times. The distribution of animals in the five distance classes did not differ significantly between the three 5 min observation periods for the no sound control (Fig. 8). This shows that the experimental setup and the behaviour of the observer did not result in changes of seal distribution. Fig. 8 also shows that while the detection rates of seals were similar at distances between 40 m and 80 m, the likelihood of sighting seals at distances of 80–100 m was lower.

To test whether animals left the overall observation area after playbacks, the number of surfacing animals in all distance classes (closer than 100 m) was compared between observation periods within each trial. A significant drop in seal numbers closer than 100 m in the playback phase compared with the pre-playback phase was found only for the Square 500/530 sound (Friedman test, $P<0.004$). PPM sounds were also the only sounds capable of reducing seal numbers in the post-playback phase compared with the pre-playback phase (Friedmann tests with Bonferroni adjustments, Square 500/530 FM: $P=0.04$, Sweeps FM: $P=0.04$). All other sounds did not have a significant effect on seal distribution after sound exposure had ceased.

Given that two sound types caused a deterrence effect that extended to at least 5 min post-sound exposure over the whole observation area, it is in theory possible that not all animals returned during the 15 min recovery periods. This could have potentially biased the following playback. However, a comparison of all 5 min pre-sound exposure observation periods for each playback day reveals that the mean number of animals within the observation area did not differ between consecutive playbacks, meaning that no drop of seal number occurred over the course of a playback day (ANOVA $F_{4,63}=1.44$, $P=0.23$). This showed that while not all animals returned during the 5 min after sound exposure ceased (post periods) the 15 min recovery time was sufficient for the animals to return to the observation area. Alternatively, it is possible that the area filled up with new arrivals during the post-playback phase. To test habituation effects to sound exposure of any kind within one playback day, the number of animals closer than 60 m from the playback source was counted for all playback sessions. No significant difference in the number of animals between playback sessions on a given day was found (Kruskal–Wallis $H_{4,17}=8.820$, $P=0.116$).

Data from sound field measurements are presented in Fig. 9. In the profile measured from the sound source towards the haul-out site on shore, received levels (in dB re. 1 μPa) at different depths did not
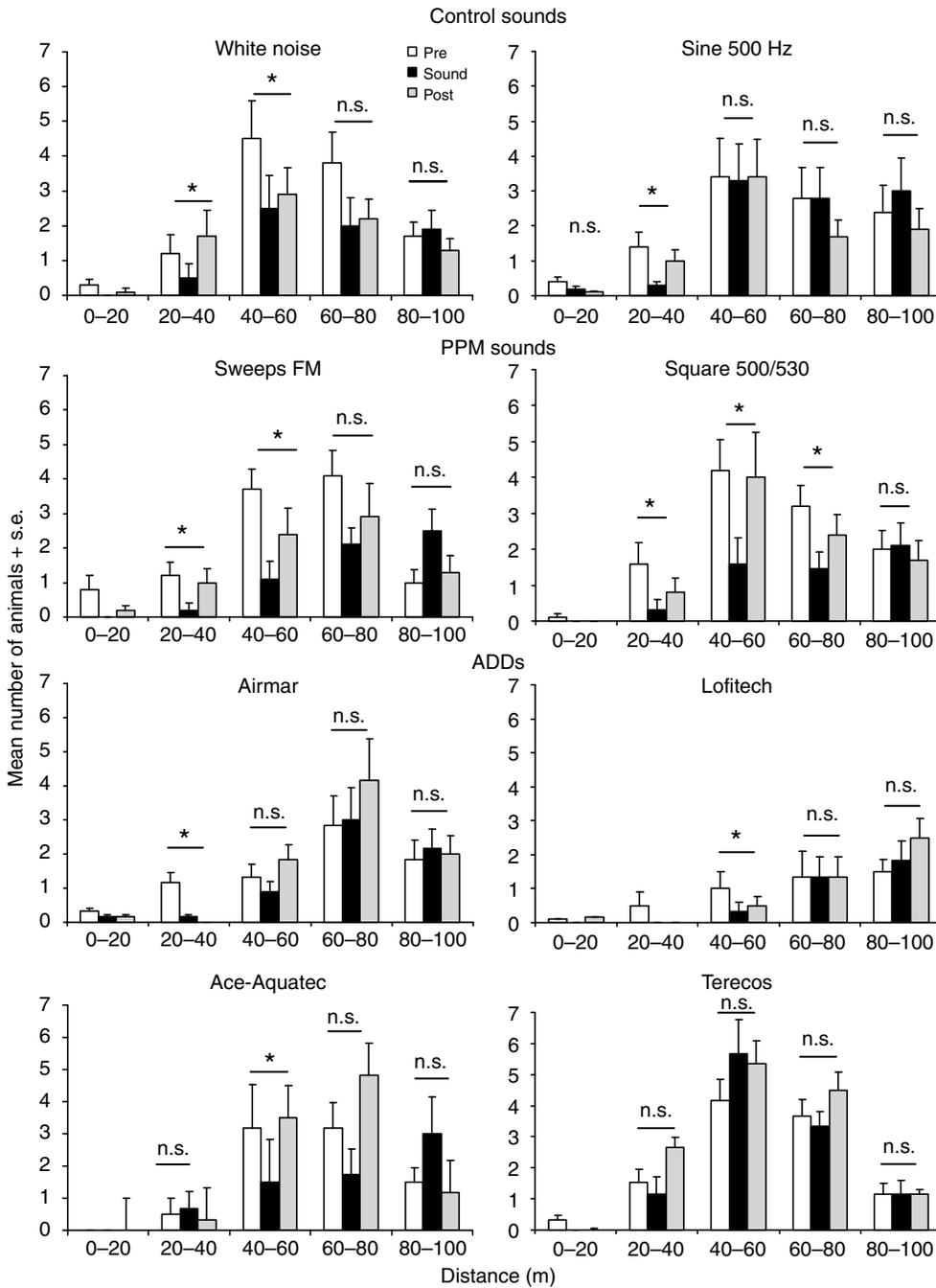
Fig. 7. Reactions to control sounds, psychophysical (PPM) sounds and acoustic deterrent device (ADD) sounds near haul-out sites where food motivation was likely to be low.

vary much. Transmission loss was higher than would be expected by either cylindrical or spherical spreading in the first 20 m but then tailed off as predicted from spherical spreading. In the profile measured parallel to the shore, transmission loss was closer to cylindrical than spherical spreading. Received levels in the top layer (0.2 m depth) tended to be lower compared with measurements at greater depth. Underwater ambient noise levels in the pool and in the wild did not differ by more than 10 dB at any of the frequencies (Fig. 10). Mean noise levels dropped off from values of 55 dB re. $1 \mu Pa^2 Hz^{-1}$ at 0.5 kHz to around 35 dB re. $1 \mu Pa^2 Hz^{-1}$ at 5 kHz when wind speed and SS were low (Fig. 10). The noise level in the test pool showed some spikes at frequencies between 800 Hz and 2 kHz, particularly when wind speed was high. At frequencies above 10 kHz ambient noise was below 35 dB re. $1 \mu Pa^2 Hz^{-1}$ in the wild and in the test pool.

DISCUSSION
Habituation and food motivation

In the captive experiments that involved food presentation, seals did not respond differentially to the sound types while wild animals exhibited differential responses. Ambient noise levels were on average between 10 dB and 20 dB below the hearing threshold and did not differ by more than 10 dB in the field and in the pool at frequencies between 200 Hz and 10 kHz (Figs 3 and 10, Table 1). The difference in behaviour is therefore more likely to be caused by the animal being motivated to approach the feeder and food acting as a reinforcing stimulus overriding any possible aversiveness of sounds in the captive experiments. Food presentation is also the most likely explanation for the fast habituation process observed in the captive experiment. A study on captive sea lions that provided
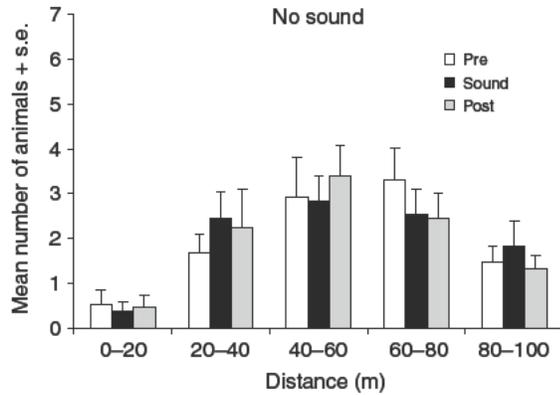
Fig. 8. Number of seals surfacing in different distance classes from the speaker (and nearby boat) in the wild in control trials when no sound was played (*N* 14 observation periods).

a foraging opportunity also found that animals habituated quickly to artificial sounds at SPLs of 165 dB re. 1 μPa (Akamatsu et al., 1996). Groves and Thompson developed a 'dual-process' theory of habituation suggesting that '…the strength of the behavioural response elicited by a repeated stimulus is the net outcome of the two independent processes of habituation and sensitisation' [p. 442 in Groves and Thompson (Groves and Thompson, 1970)]. This is consistent with our data. In captivity, the most aversive responses like flight and prevention of food retrieval habituated within the first playback session. However, the impact of sound exposure remained significant in more subtle response variables and may even indicate a weak sensitising component. Playback session number was a significant factor in the model for the food presentation trials and seals decreased their dive time and the time spent close to the feeding station in later playback sessions. An alternative explanation could be that seals learnt to retrieve fish faster with food acting as a reinforcing stimulus. This is, however, less likely because all individuals increased the time spent close to the feeder in consecutive training sessions (without sound exposure) prior to the start of the experiment.

Our data also showed that variable stimulus design was not successful in delaying habituation of flight behaviour when food was provided as habituation occurred within the first playback session (consisting of 11 different stimuli). According to Groves and Thomson's habituation theory such stimulus generalisation will depend on whether common features in the stimulus–response pathway are shared between stimuli (Groves and Thompson, 1970). Our results are in line with their predictions because all stimuli used in the present study were perceived through the auditory pathway and had similar sensation levels, which differed by not more than 15 dB.

Another possible explanation for the apparent habituation of food avoidance can be found in learning theory. Food presentation can be interpreted as an unconditioned stimulus while the playback of the sound right before foraging or the lowering of the fish cup can be interpreted as a conditioning stimulus. Thus, the animal could have been conditioned in the Pavlovian sense (Pavlov, 1927). In addition an operant component was present in the experimental setup as the animals learnt to position itself in front of the feeder and manipulate the cup in order to retrieve a fish. The food rewards would have therefore acted as a reinforcement of approach and retrieval behaviour. Such apparent conditioning has been observed
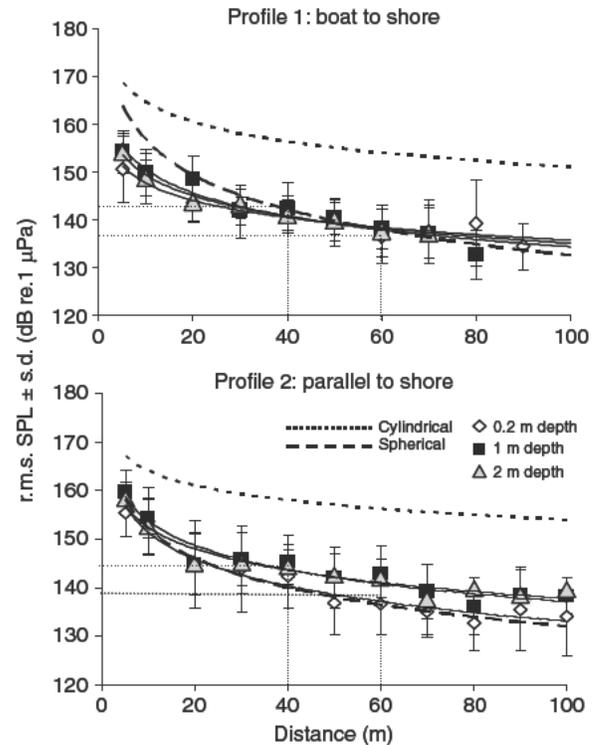

Fig. 9. Measured received levels along two profiles from the sound source to the shore and parallel to the shore at 0.2 m, 1 m and 2 m depth (solid lines). The expected received levels (in dB re. 1 μPa) based on cylindrical and spherical spreading are depicted by dashed lines. Source level was 174 dB re. 1 μPa. Dotted lines show the received level at the edge of the most common deterrence ranges (area within which significantly fewer seals were sighted).

in the wild where seals can be attracted to an ADD in the so-called diner bell effect (Jefferson and Curry, 1996). It was also striking that seals spent more time close to the feeder in the last playback session when no food was provided compared with the preceding food session. Thus, non-foraging seals may prevail in areas ignoring sound exposure if they had found food in the area before.

Previous studies (Kastelein et al., 2006a; Kastelein et al., 2006b) on captive harbour seals yielded no evidence for habituation over several consecutive playback sessions even though received levels were fundamentally lower than the ones in our experiment. However, these studies did not provide food when presenting sounds. In our experiment with wild animals where food motivation was likely to have been low, there was also no evidence for habituation. A simple explanation for the lack of habituation in the wild could be that animals were displaced by our sound exposure and replaced by new arrivals. However, since we also observed some well-marked individuals in several playbacks, this would not explain the behaviour of all animals. Our data therefore show that food motivation or reinforcement has an accelerating effect on habituation to aversive stimuli.

Aversiveness and unpleasantness of sounds

The aversiveness of each individual sound stimulus is best evaluated from our experiments with wild animals where no food presentation was involved and ambient noise levels were generally 10–20 dB below the known hearing threshold (Figs 3 and 10, Table 1). The following discussion is based on the assumption that

avoidance behaviour in the field was not caused by longer dive times but by animals moving away. We think this is justified because we commonly observed well-marked individuals surfacing at greater distances than before when the sound was playing. In two further cases, a seal was seen underwater close to the boat moving away quickly when the sound was switched on. To evaluate the aversiveness of sound features other than received level, we have to control for the frequency-dependent hearing sensitivity of seals. To achieve this, we need to consider that our test stimuli had different frequency spectra. We therefore use sensation levels, which is the level in dB by which a sound exceeds the composite hearing threshold (Figs 3 and 10, Table 1) at a given frequency, to compare the effects of different sound stimuli on the animals.

The maximum sensation level caused by each sound in an animal at 1 m distance was calculated by measuring the maximum difference between a composite hearing threshold (see Fig. 3 and Table 1) and the referenced power spectrum of the sound type in 1/3 octave bins (from 100 Hz up to 24 kHz). Deterrence ranges were defined as the upper edge of the distance class furthest away from the loudspeaker within which the number of animals was significantly reduced during sound exposure. The avoidance threshold in units of sensation levels therefore gives the sound pressure level in dB above the hearing threshold at which a sound causes a deterrence effect. Avoidance thresholds expressed in sensation levels were calculated by subtracting the measured transmission loss (Fig. 9) from the maximum sensation level. Table 4 summarises these features for all of the tested sounds. For the ADD sounds, it is important to note that deterrence ranges given here are based on the features of the sound played at a much lower source level than in an actual ADD. Thus, our results do not describe the effectiveness of the actual ADDs in the field.

The maximum sensation level of our stimuli at 1 m distance (~110 dB) was below the sensation level threshold for a temporary auditory threshold shift in harbour seals [132.5 dB SEL-sensation level (Kastak et al., 2005)]. We found little avoidance beyond the first trial when seals were motivated to forage in our captive experiments. However, in the wild, we found that seals repeatedly avoided sounds when sensation levels ranged from 59 dB to 79 dB (depending on sound type) with a mean value of 70 dB. Interestingly, this mean value of 70 dB above the hearing threshold matches the discomfort thresholds obtained from electro-physiological measurements in humans (Spreng, 1975). The initial avoidance responses in captivity and the sustained avoidance behaviour in the
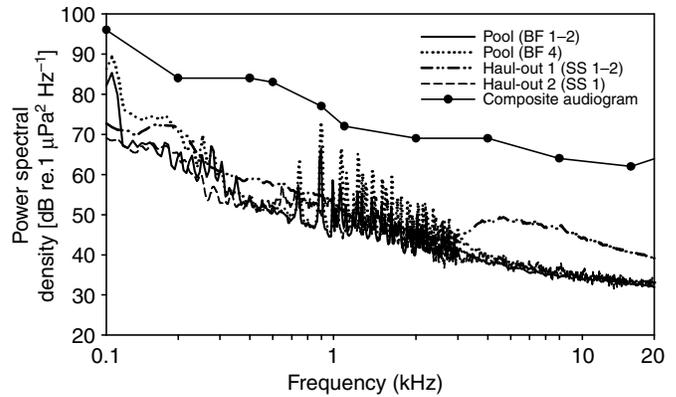

Fig. 10. Ambient noise at two playback sites in the field (haul-outs) and in the test pool at different sea states (field) and wind speeds (pool). The composite underwater audiogram of a phocid seal from the Fig. 3 is also shown. BF Beaufort wind scale, SS sea state.

wild could therefore be caused by a physiological mechanism marking the onset of discomfort and stress. It is important to note that the initial responses in captivity and most responses in the wild were unlikely to have been the result of a startle reflex because the mean avoidance threshold (sensation level of 70 dB) and the maximum avoidance threshold (79 dB sensation level) were below the startle threshold measured in rats (sensation level: 87 dB) (Pilz et al., 1987) and humans (sensation level: 92 dB) (Berg, 1973). In addition, the rise times of 50 ms used in the control and PPM sounds would have been too long to elicit a startle reflex (Fleshler, 1965). It is also important to note that avoidance thresholds in captive harbour seals and harbour porpoises when no food was presented were found at sensation levels below 50 dB (Kastelein et al., 2005; Kastelein et al., 2006a). This is similar to what has been found in rats where sensation levels of only 50 dB caused signs of aversive responses (Campbell, 1957). Further experiments are needed to explain the differences in avoidance thresholds between these studies.

Avoidance thresholds ranged from sensation levels of 59–79 dB (re. hearing threshold) depending on sound type. Some of the differences in deterrence ranges can be attributed to differences in the hearing thresholds at the different frequencies of the test sounds (Table 4). For instance, the sine 500 Hz sound had a lower deterrence range than white noise but the sensation level at which it caused

Table 4. Comparison of psychophysical features of the tested sound types

Parameter	White noise	Sine 500	Sweep FM	Square 530/500	Airmar	Lofi-tech	Ace-Aquatec	Terecos
Deterrence range (m)	60	40	60	80	(40)	(60)	(60)	(<20)
Maximum sensation level at 1 m distance (dB re. hearing threshold)	108	92	100	96	110	110	111	107
Avoidance threshold:								
Sensation level (dB re. hearing threshold)	74	64	66	59	(79)	(75)	(74)	?
Sound pressure level (dB re. 1 µPa)	138	144	144	135	(144)	(138)	(138)	?
Tonality	Low	High	Low	Low	Medium	High	High	Low
Roughness	Low	Low	High	High	Low	Low	Low	Medium
Sharpness	Low	Low	Low	Low	Low	high	Medium	High
Bandwidth effect on loudness	High	Low	Medium	Medium	Low	Low	Medium	High

The maximum sensation level was calculated as the highest value obtained when subtracting the hearing threshold in the composite audiogram (see Fig. 3) from measured root mean square (r.m.s.) source levels in 1/3 octave bands. Avoidance thresholds refer to the levels at the edge of the deterrence range. Values that are based on only six repetitions of playbacks are shown in brackets. Note that the original acoustic deterrent devices (ADDs) produce higher source levels than what was tested here.

deterrence was in fact lower than for white noise. Nevertheless, the data also demonstrate the influence of features deemed unpleasant in humans following the model by Zwicker and Fastl (Zwicker and Fastl, 1990). In the field trials the number of seals within the overall observation area (<100 m) was lower during the 5 min post-playback observation period compared with the pre-sound exposure period for PPM sounds but not for any of the other sounds. This shows longer lasting deterrence effects caused by the PPM sounds. Also, the most aversive sound type was the Square 500/530 stimulus causing the largest deterrence ranges (up to 80 m). By contrast, the control sound sine 500 Hz caused deterrence effects up to 40 m and white noise did so up to 60 m. Square 500/530 was able to deter seals at a sensation level of 59 dB while control sounds needed to have sensation levels of 64–74 dB to cause a similar effect. Thus, roughness appears to be an aversive feature of sounds in seals similar to what was found by Zwicker and Fastl in humans (Zwicker and Fastl, 1990). Roughness sensation can be caused by frequency or amplitude modulation of a signal at modulation frequencies between 20 Hz and 300 Hz (Terhard, 1976). Amplitude modulation patterns originating from mixing of two partial tones whose frequency difference is less than a critical band give also rise to roughness and are likely to be the cause of music being perceived as dissonant in humans (Helmholtz, 1853; Plomp and Levelt, 1965). Dissonance perception appears in fact to be maximised if two partial tones fall within 25% of the cochlea filter bandwidth (Plomp and Levelt, 1965). Roughness therefore originates when the amplitude or frequency fluctuation rate of a signal falls well within the critical band at a certain carrier frequency. If we find behavioural evidence for such perceptional similarities between pinnipeds and humans, these sensations may also be common in other mammals. It is therefore possible that some aspects of human art are not purely a result of culture but have been primed by how our sensory systems evolved in order to process information. This is also supported by recent findings from humans who perceive such roughness as unpleasant independent of their culture (Fritz et al., 2009). Some evidence for the aversiveness of roughness in other mammals may come from right whales who exhibited strong aversive responses to FM stimuli (some of which are capable of causing roughness) but no response to playbacks of ship noise (Nowacek et al., 2004). However, the animals might have been habituated to boat noise. Habituation could also be a factor explaining the mixed results for ADD sounds in our study. In ADD sounds, the degree of unpleasant features as predicted by the Zwicker and Fastl (Zwicker and Fastl, 1990) model did not correlate with their deterrence effects (Table 4). We think that the most likely explanation for this is a varying degree of previous experience with these sounds in the wild leading to habituation to some ADD sounds but not to others.

Behavioural responses observed in this study were surprisingly consistent with predictions obtained from human psycho-physiological studies. This indicates that some aspects of sound perception such as roughness may result primarily from physiological properties of the cochlea that evolved early in the mammalian line and have been conserved in spite of specific adaptations to the aquatic habitat. Place preference experiments or two-alternative forced-choice experiments with captive animals would help to further investigate the evolution of sound perception in mammals.

LIST OF ABBREVIATIONS

ADD	acoust c deterrent dev ce
ANOVA	ana ys s of var ance
BF	Beaufort
FFT	fast Four er transform
FM	frequency modu ated
GLM	genera near mode
PPM	psychophys ca mode
r m s	root mean square
SEL	sound exposure eve
SPL	sound pressure eve
SS	Sea state
TTS	temporary thresho d sh ft

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To: ███████████

Subject: Could you broker a meeting with SNH for us to explain new ADD?

Dear ███

We appreciate your continuing interest in and support for the development of the new ADD device, and meeting with us and ██████ last month. I hope you might help us a little more.

██████████ has just applied for a licence to undertake field trials of the Genuswave SalmonSafe equipment - I gather its SNH ref no 28383 – and I attach a copy of the application for information.

Whilst we are not looking to short-circuit any normal procedures within SNH it would be useful to get as early approval as might be possible for this application so it fits in with the production cycle of ██ and the imminent availability of the new ADD.

Our experience to date tells us that many people find it difficult to assess and understand the key difference between the new, and existing ADDs, unless it is well-explained to them (normally by ██████ assisted by a demonstration video of the seal-tank experiments – ██████████ ██████████████████████████████████

In order that SNH work from a well-informed perspective we feel it would be useful to have a meeting with a senior member (head?) of SNH to present how the SalmonSafe device has been designed, how it will operate and exactly how it differs from existing equipment.

I cannot recall the named SNH contact you provided when we last met, but I think you might meet the individual on a regular basis. Would you be able to broker a meeting in early course with him/her so we could discuss the new ADD, as this might help SNH with their decision on ██████ licence application?

Your assistance on this would be really helpful, and I look forward to hearing further.
Many thanks & kind regards,

████

████████████
████████████████

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A field study to test efficiency of a new acoustic deterrent device designed to mitigate adverse impacts on odontocetes

1 General description of the project and previous work

Current acoustic deterrent devices (ADDs) used on fish farms to avoid seal damage show highly varying success (Götz & Janik, 2013). ADDs have also been highlighted as a serious conservation concern since they inflict large-scale habitat exclusion in porpoises and other *delphinids* (Johnston et al. 2002). Furthermore, high duty cycle devices like most currently used ADDs may in some cases cause hearing damage in target and non-target species (see Götz & Janik, 2013 for a review). In two separate projects funded by the Scottish Government we investigated potential solutions which could contribute to an increase in efficiency and target-specificity of acoustic predator control methods (Janik & Götz 2008, 2013). In a series of response trials we generally found that seals habituated quickly to most deterring sounds including those of commercial ADDs (Götz & Janik, 2010). There was, however, one notable exception. Seals which were repeatedly exposed to sounds that elicited an oligo-synaptic reflex arc in the brainstem (acoustic startle reflex) showed the opposite reaction. These animals generally sensitized i.e. they increasingly developed flight responses and place avoidance of the area around a simulated food source (Götz & Janik, 2011). The method of using startling pulses is advantageous because the reflex will only be elicited if the received level crosses the startle threshold. Hence, any deterrence effect can be limited to a confined area around the site of interest. Furthermore, the use of infrequent, isolated pulses instead of almost continuous emissions reduces noise pollution and therefore mitigates effects on hearing. The startle reflex method was consecutively tested around a stocked salmon farm where it led to a strong reduction in the number of seals within 250m of the loudspeaker over a 2 month period (Janik & Götz 2008). In a final series of fish farm experiments, a prototype device which operated at a duty cycle of less than 1% succeeded in protecting a salmon farm on the Scottish west coast over a one year period (Janik & Götz 2013).

Habitat exclusion in odontocetes caused by current ADDs can be explained by differences in species hearing sensitivity and the fact that odontocetes typically lack food motivation to approach farm sites (Götz & Janik, 2013). All currently available seal scarers operate in a frequency band where odontocete hearing is more sensitive

than hearing in seals. Hence, these devices will cause higher perceived loudness in delphinids than in seals (Götz & Janik, 2013, see fig 1). Therefore, when optimising target-specificity it is advantageous to move to a frequency band between 700Hz and 2 kHz where seals are more sensitive than odontocetes (see fig 1). While this makes the sound more audible to baleen whales, we found that minke whales entered the sound of Mull readily in our first test of the device (Janik & Goetz 2008). The startle threshold roughly follows the hearing threshold (see fig 1 for audiograms). Hence, it was possible for us to design a sound which exceeds the startle threshold in seals but not in odontocetes. These theoretical considerations have been confirmed by empirical data from at least two different study sites. In a first study in the Northern Sound of Mull (SNH license 8111) porpoise distribution was not affected by playback of startling sounds (source level 180 dB re 1 µPa) centred at 1 kHz (Janik & Götz 2008). In fact, porpoises were regularly seen between the fish farm cages very close to the ADD while it was active. In a 2nd study on the west coast of Scotland a basic prototype device (with 3 transducers operating at 179 dB re 1 µPa) was installed on a fish farm for a one year period and marine mammals were monitored at regular intervals (Janik & Götz, 2013). There was no difference in porpoise distribution as the result of sound exposure. Interestingly, seals were seen within <50-100m of the farm but the farm did not suffer predation during most of the experimental period. This shows that effects on odontocetes can be mitigated and seals will only be affected in a small area around the fish farm.

The deterrent technology developed and tested in these studies is currently in the process of being commercialised through Genuswave Ltd. An industrial prototype is in development and will be ready for testing in March 2014. The aim of the proposed

Fig 1. Audiograms of odontocetes, pinnipeds and fish typically found around fish farms (reproduced from Götz & Janik, 2013). The graphs depict the threshold of hearing with low numbers reflecting high auditory sensitivity.

study is to run a full-scale commercial trial on an operating fish farm. The experiment will involve monitoring of predation levels before, during and after deployment of the deterrent device. The trial should be conducted in an area where license restrictions previously prevented the industry from using deterrents. This is important because a real evaluation of the technology requires a farm site that has previously not operated a seal scarer. This is important as seals predating on farms which operate high-duty cycle ADDs may have hearing damage.

2 Experimental procedures

The experiment involves deployment of a full-scale commercial deterrent device (based on the startle technology) on a fish farm operated by ██████████████████ ██████ The maximum deployment time would be the length of a production cycle (~18 month). We are interested in potentially running experiments at ███████████ ███ ███ The deterrent device will consist of ██████████████████████████████████████ ███████████████████████████████████ Initially, three units will be deployed but ultimately the number of units will be determined by the number of stocked cages on the farm site. The acoustic features of startle pulses will be the same as in the previous experiments (Janik & Götz, 2008, 2013). The individual units will emit isolated, band-limited noise pulses of 200 ms duration at a source level of ~178 to 182 dB re 1 µPa (rms). This source level is ~10-15 dB lower than in an Airmar device (see Götz & Janik, 2013). █████████████████████████████████████ ███

████████████████████ This represents a reduction in emission time by at least one order of magnitude (factor 10) compared to current commercially available devices (Götz & Janik, 2013). ██████████████████████████████████████ ███ ███ ███ ███ ███ ██████████████████ (see Götz & Janik, 2011). This would then make it possible to further reduce the time during which the startle pulse needs to be played ███████████ ███ ████████████████████████████ This will decrease noise pollution even further.

Since our studies showed no effect on odontocetes we do not expect any responses in their distribution around the fish farm. Nevertheless, the commercial trial will involve a basic marine mammal monitoring scheme. This will be implemented in form of a questionnaire survey asking farm staff to opportunistically report sightings (see appendix I). Our previous data shows that presence of porpoise can be reliably estimated from such questionnaire surveys (Janik & Götz 2013).

References

Götz, T., and V. M. Janik. 2010. Aversiveness of sound in phocid seals: psycho-physiological factors, learning processes and motivation. Journal of Experimental Biology 213:1536-1548.

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Janik, V. M., and Götz, T. (2013). Acoustic deterrence using startle sounds: long term effectiveness and effects on odontocetes. Report to Marine Scotland. http://www.scotland.gov.uk/Publications/2013/11/9261/

Johnston, D. W. (2002). The effect of acoustic harassment devices on harbour porpoises *(Phocoena phocoena)* in the Bay of Fundy, Canada. Biological Conservation 108, pp. 113-118.

From:	■ @st-and.ac.uk
To:	Ben Leyshon
Subject:	Ardesier
Date:	05 March 2014 09:36:51
Attachments:	SNH description.doc

Hi Ben,

I hope this finds you well. I just heard that you are involved in the assessment of the activities around the Ardesier harbour. ███████████ ██ ████████████████████████████ I attach this here. It mainly talks about our work on regarding porpoises, but tests with captive Tursiops showed that they react in the same way as porpoises, i.e. they are not affected by the pulse. You can read about this in the 2013 Scot Gov report that is cited in the attached document with a webling. In this project, we also tried to startle captive dolphins (which only worked with high frequency signals, and did not lead to an avoidance). Let me know if you have any further questions about it. My phone number is 01334 ██████

all the best

██████

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████████████
Sea Mammal Research Unit
Scottish Oceans Institute
School of Biology
University of St Andrews
Fife KY16 8LB
UK

http://biology.st-andrews.ac.uk/bmac/
http://www.smru.st-and.ac.uk/

The Genuswave Acoustic Deterrent Device

Current acoustic deterrent devices (ADDs) used on fish farms to avoid seal damage show highly varying success (Götz & Janik, 2013). ADDs have also been highlighted as a serious conservation concern since they inflict large-scale habitat exclusion in porpoises and other *delphinids* (Johnston et al. 2002). Furthermore, high duty cycle devices like most currently used ADDs may in some cases cause hearing damage in target and non-target species (see Götz & Janik, 2013 for a review). In two separate projects funded by the Scottish Government the University of St Andrews investigated potential solutions to this problem. The aim was to increase ADDs in efficiency and target-specificity (Janik & Götz 2008, 2013). In a series of response trials, Dr Goetz and Dr Janik found that seals habituated quickly to most deterring sounds including commercial seal scarers (Götz & Janik, 2010). There was, however, one notable exception. Seals which were repeatedly exposed to sounds that elicited an oligo-synaptic reflex arc in the brainstem (acoustic startle reflex) showed the opposite effect. Animals exposed to such sounds generally sensitized i.e. they increasingly developed flight responses and place avoidance of the area around a simulated food source (Götz & Janik, 2011). The method of using startling pulses is also advantageous because the reflex will only be elicited if the received level crosses the startle threshold. Hence, any deterrence effect can be limited to a user-defined area around the site of interest. Furthermore, the use of infrequent, isolated pulses instead of almost continuous emissions reduces noise pollution and therefore mitigates concerns related to hearing damage. The startle reflex method was consecutively tested around a stocked salmon farm where it led to a strong reduction in the number of seals within 250m of the loudspeaker over a 2month period (Janik & Götz 2008). In a final series of fish farm experiments a prototype device which operated at a duty cycle of less than 1% succeeded in protecting a salmon farm on the Scottish west coast over a one year period (Janik & Götz 2013) while not affecting porpoise behaviour around the farm.

Habitat exclusion in odontocetes caused by current ADDs can be explained by differences in species hearing sensitivity and the fact that odontocetes typically lack food motivation to approach farm sites (Götz & Janik, 2013). All currently available seal scarers operate in a frequency band where odontocete hearing is more sensitive than hearing in seals. Hence, these devices will cause higher perceived loudness in delphinids than in seals (Götz & Janik, 2013, see fig 1). Therefore, when optimising

target-specificity it is desirable to move to a frequency band between 700Hz and 2 kHz where seals are more sensitive than odontocetes (see fig 1). The startle threshold roughly follows the hearing threshold (see fig 1 for audiograms). Therefore, it was possible for the researchers to design a sound which exceeded the startle threshold in seals but not in odontocetes. These theoretical considerations have been confirmed by empirical data from at least two different study sites. In a first study in the Northern Sound of Mull (SNH license 8111) porpoise distribution was not affected by playback of startling sounds (source level 180 dB re 1 µPa) centred at 1 kHz (Janik & Götz 2008). In fact, porpoises were regularly seen between the fish farm cages, and approached the ADD to just a few metres while it was active. In a 2nd study on the west coast of Scotland a basic prototype device (with 3 transducers operating at ~179 dB re 1 µPa) was installed on a fish farm for a one year period and marine mammals were monitored at regular intervals (Janik & Götz, 2013). There was no difference in porpoise distribution during the experiment while the farm did not suffer any significant seal predation for the entire year. This shows that effects on odontocetes can be mitigated and seals will only be affected in a small area around the fish farm. By adjusting the source level of the ADD, this deterrence area can be set by the user of the ADD, so that seals outside of this area are not affected.
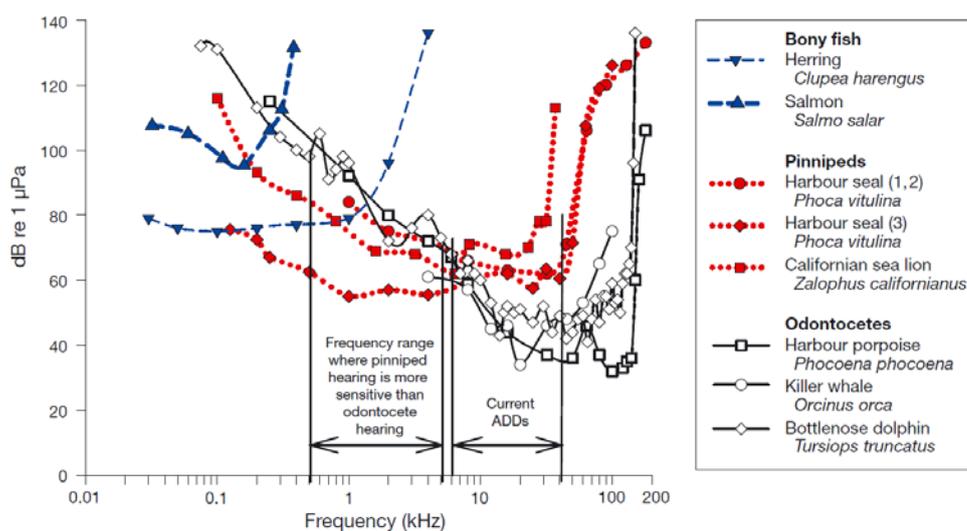

Fig 1. Audiograms of odontocetes, pinnipeds and fish typically found around fish farms (reproduced from Götz & Janik, 2013). The graphs depict the threshold of hearing with low numbers reflecting high auditory sensitivity.

References

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Johnston, D. W. (2002). The effect of acoustic harassment devices on harbour porpoises *(Phocoena phocoena*) in the Bay of Fundy, Canada. Biological Conservation 108, pp. 113-118.

From:	■@st-and.ac.uk
To:	LICENSING
Subject:	licence application Ref 28383
Date:	05 March 2014 09:28:05
Attachments:	SNH_license_2014_revision.doc

Dear colleagues,

thank you for the acknoledgment of our licence application ref 28383. After reviewing our applicaiton, it realised that some reference values were missing in our initital description. I therefore revised the description and attach the new version here. Please replace the old one with this new description. The licence application form itself should remain as is.
Apologies for my oversight in this. I am looking forward to hearing from you in due course.

Kind regards,

████████████

--
████████████
Sea Mammal Research Unit
Scottish Oceans Institute
School of Biology
University of St Andrews
Fife KY16 8LB
UK

http://biology.st-andrews.ac.uk/bmac/
http://www.smru.st-and.ac.uk/

A field study to test efficiency of a new acoustic deterrent device designed to mitigate adverse impacts on odontocetes

1 General description of the project and previous work

Current acoustic deterrent devices (ADDs) used on fish farms to avoid seal damage show highly varying success (Götz & Janik, 2013). ADDs have also been highlighted as a serious conservation concern since they inflict large-scale habitat exclusion in porpoises and other *delphinids* (Johnston et al. 2002). Furthermore, high duty cycle devices like most currently used ADDs may in some cases cause hearing damage in target and non-target species (see Götz & Janik, 2013 for a review). In two separate projects funded by the Scottish Government we investigated potential solutions which could contribute to an increase in efficiency and target-specificity of acoustic predator control methods (Janik & Götz 2008, 2013). In a series of response trials we generally found that seals habituated quickly to most deterring sounds including those of commercial ADDs (Götz & Janik, 2010). There was, however, one notable exception. Seals which were repeatedly exposed to sounds that elicited an oligo-synaptic reflex arc in the brainstem (acoustic startle reflex) showed the opposite reaction. These animals generally sensitized i.e. they increasingly developed flight responses and place avoidance of the area around a simulated food source (Götz & Janik, 2011). The method of using startling pulses is advantageous because the reflex will only be elicited if the received level crosses the startle threshold. Hence, any deterrence effect can be limited to a confined area around the site of interest. Furthermore, the use of infrequent, isolated pulses instead of almost continuous emissions reduces noise pollution and therefore mitigates effects on hearing. The startle reflex method was consecutively tested around a stocked salmon farm where it led to a strong reduction in the number of seals within 250m of the loudspeaker over a 2 month period (Janik & Götz 2008). In a final series of fish farm experiments, a prototype device which operated at a duty cycle of less than 1% succeeded in protecting a salmon farm on the Scottish west coast over a one year period (Janik & Götz 2013).

Habitat exclusion in odontocetes caused by current ADDs can be explained by differences in species hearing sensitivity and the fact that odontocetes typically lack food motivation to approach farm sites (Götz & Janik, 2013). All currently available seal scarers operate in a frequency band where odontocete hearing is more sensitive

than hearing in seals. Hence, these devices will cause higher perceived loudness in delphinids than in seals (Götz & Janik, 2013, see fig 1). Therefore, when optimising target-specificity it is advantageous to move to a frequency band between 700Hz and 2 kHz where seals are more sensitive than odontocetes (see fig 1). While this makes the sound more audible to baleen whales, we found that minke whales entered the sound of Mull readily in our first test of the device (Janik & Goetz 2008). The startle threshold roughly follows the hearing threshold (see fig 1 for audiograms). Hence, it was possible for us to design a sound which exceeds the startle threshold in seals but not in odontocetes. These theoretical considerations have been confirmed by empirical data from at least two different study sites. In a first study in the Northern Sound of Mull (SNH license 8111) porpoise distribution was not affected by playback of startling sounds (source level 180 dB re 1 µPa) centred at 1 kHz (Janik & Götz 2008). In fact, porpoises were regularly seen between the fish farm cages very close to the ADD while it was active. In a 2nd study on the west coast of Scotland a basic prototype device (with 3 transducers operating at 179 dB re 1 µPa) was installed on a fish farm for a one year period and marine mammals were monitored at regular intervals (Janik & Götz, 2013). There was no difference in porpoise distribution as the result of sound exposure. Interestingly, seals were seen within <50-100m of the farm but the farm did not suffer predation during most of the experimental period. This shows that effects on odontocetes can be mitigated and seals will only be affected in a small area around the fish farm.

The deterrent technology developed and tested in these studies is currently in the process of being commercialised through Genuswave Ltd. An industrial prototype is in development and will be ready for testing in March 2014. The aim of the proposed
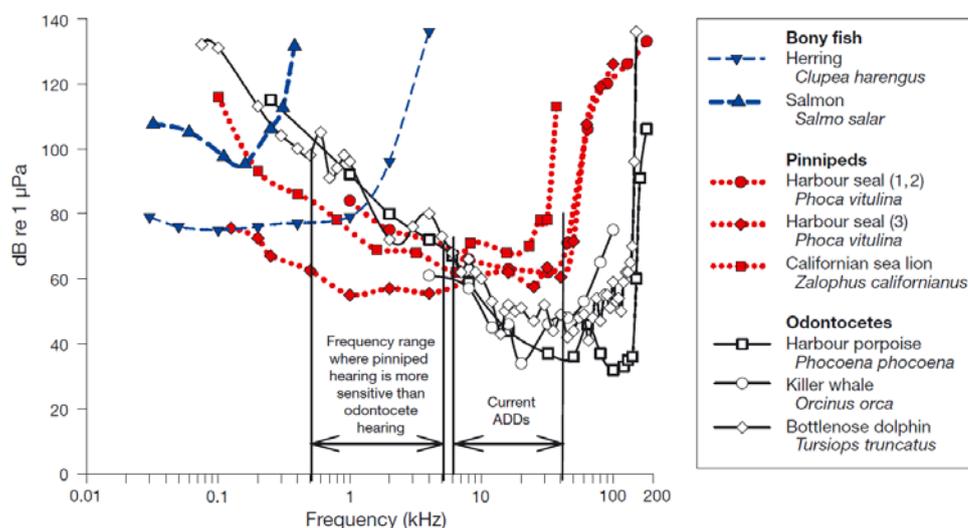

Fig 1. Audiograms of odontocetes, pinnipeds and fish typically found around fish farms (reproduced from Götz & Janik, 2013). The graphs depict the threshold of hearing with low numbers reflecting high auditory sensitivity.

study is to run a full-scale commercial trial on an operating fish farm. The experiment will involve monitoring of predation levels before, during and after deployment of the deterrent device. The trial should be conducted in an area where license restrictions previously prevented the industry from using deterrents. This is important because a real evaluation of the technology requires a farm site that has previously not operated a seal scarer. This is important as seals predating on farms which operate high-duty cycle ADDs may have hearing damage.

2 Experimental procedures

The experiment involves deployment of a full-scale commercial deterrent device (based on the startle technology) on a fish farm operated by ███████████████

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Since our studies showed no effect on odontocetes we do not expect any responses in their distribution around the fish farm. Nevertheless, the commercial trial will involve a basic marine mammal monitoring scheme. This will be implemented in form of a questionnaire survey asking farm staff to opportunistically report sightings (see appendix I). Our previous data shows that presence of porpoise can be reliably estimated from such questionnaire surveys (Janik & Götz 2013).

References

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Johnston, D. W. (2002). The effect of acoustic harassment devices on harbour porpoises *(Phocoena phocoena)* in the Bay of Fundy, Canada. Biological Conservation 108, pp. 113-118.

Dear Peter,

thanks for your message. I attach a map that shows the location (the red rectangle on it).

Kind regards,

▇▇▇

On 12/03/2014 08:43, Peter Jahn wrote:
> Dear ▇▇▇
>
> I have been assigned the licence application no 28383. I would like to ask for the clarification of the location ▇▇▇▇▇▇▇▇▇▇▇▇▇▇▇ Can you send me the coordinates in the same format as for ▇▇▇▇▇▇▇▇▇▇▇▇▇▇ or the national grid reference, please?
>
> Kind regards,
>
> Peter Jahn
>
> ---
> Peter Jahn
> Licensing Officer
> Wildlife Operations Unit
> Scottish Natural Heritage
> Great Glen House
> Leachkin Road
> Inverness
> IV3 8NW
>
> Tel: 01463 725029
>
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>
> -----Original Message-----
> From: ▇ @st-and.ac.uk [mailto ▇ @st-andrews.ac.uk]
> Sent: 05 March 2014 09:29
> To: LICENSING
> Subject: licence application Ref 28383
>
> Dear colleagues,
>
> thank you for the acknoledgment of our licence application ref 28383.
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> Apologies for my oversight in this. I am looking forward to hearing from you in due course.
>
> Kind regards,
>
> ▇▇▇▇
>
> --
> ▇▇▇▇
> Sea Mammal Research Unit
> Scottish Oceans Institute
> School of Biology
> University of St Andrews

> Fife KY16 8LB
> UK
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> Scotland welcomes the world in the Year of Homecoming Scotland 2014
> The year-long programme of events will celebrate the very best of Scotland's food and drink,
> active and natural resources as well as our creativity, culture and ancestral heritage.
>
> homecomingscotland.com
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> This email and any files transmitted with it are confidential and
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>
> Please note that for business purposes, outgoing and incoming
> emails from and to SNH may be monitored.
>
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>
> Tha am post-dealain seo agus fiosrachadh sam bith na chois
> dìomhair agus airson an neach no buidheann ainmichte a-
> mhàin. Mas e gun d? fhuair sibh am post-dealain seo le
> mearachd, cuiribh fios dhan manaidsear-siostaim no neach-
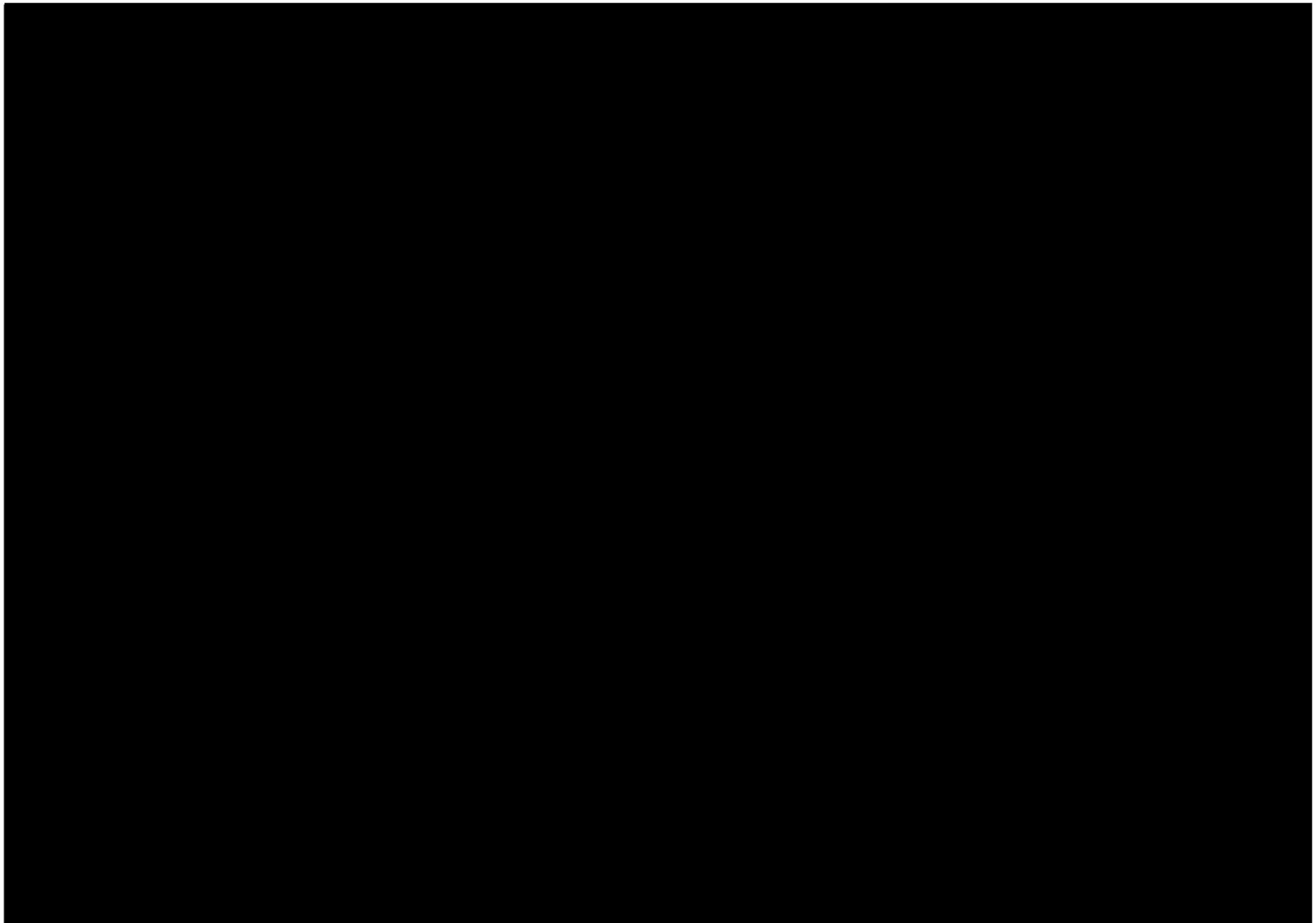> sgrìobhaidh.
>
> Thoiribh an aire airson adhbharan gnothaich, ?s dòcha gun tèid
> sùil a chumail air puist-dealain a? tighinn a-steach agus a? dol a-
> mach bho SNH.
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███████████
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Scottish Oceans Institute
School of Biology
University of St Andrews
Fife KY16 8LB
UK

http://biology.st-andrews.ac.uk/bmac/
http://www.smru.st-and.ac.uk/

From:	▉@st-and.ac.uk
To:	Peter Jahn
Cc:	▉.
Subject:	Re: licence application Ref 28383
Date:	11 April 2014 15:35:43
Attachments:	SNH_license_2014_revision.doc
	SNH application form 2014.doc

Dear Peter,

thank you for your reply and your questions regarding our recent SNH license application for running the Genuswave ADD on farms in ▉

1) The changes in the sound protocol will lead to a slightly higher duty cycle ▉ ▉ We think that this is advantageous since it would decrease the exposure level to the animals, i.e. an animal would be exposed to less sound energy over time. But this would increase the duty cycle of the device. We also propose to temporarily increase the duty cycle to up to ▉ with startle pulses if there are attacks on the farm.

2) In our application we suggest to implement " a questionnaire survey asking farm staff to opportunistically report sightings (see appendix I). Our previous data shows that presence of porpoises can be reliably estimated from such questionnaire surveys (Janik & Götz 2013). " To explain this further, we have conducted detailed theodolite tracking of seals and porpoises in our two previous deployments on farms. In both cases, there were no effects on porpoises and a limited deterrence for seals as described in our application. In these previous trials at two different farms of over a year of deployment time we also compared our results from intense marine mammal tracking efforts with result from sighting questionnaires filled in by farm staff, in which they indicated whether they had seen porpoises on any given day. We found that the questionnaires are a reliable indicator of porpoise presence. Therefore, we will only implement the questionnaire method in the proposed trials. ▉

3) ▉

Best wishes

▉

On 04/04/2014 16:06, Peter Jahn wrote:

> Hi ▉
>
> Sorry for the late response, I waited for a long time for
> comments from our advisors. There are not many concerns and we
> appreciate that this research may have long-term positive
> impacts for cetaceans. I have only three more questions:
>
> This work is proposed to run from now to December 2015, and
> during this time the sound exposure protocol will be changed.
> Can you clarify what these changes will be?
>
> Can you clarify how the impact on cetacean will be monitored?
> Will you use visual observation to monitor cetacean activity?
> Our advisor suggests to observe the area prior to the trial,
> then during the early stages to check for any behavioural

change, and then perhaps when the noise output characteristics will be changed. Alternatively you can deploy static C-pods to monitor echolocation click occurrence before and during the trial.

Can you also confirm whether in-field noise measurements of the device output will be obtained such that actual levels and frequency characteristics in the marine environment can be validated?

Thank you very much and please accept my apology for the late response.

Kind regards,

Peter Jahn

-----Original Message-----
From: ██@st-and.ac.uk [mailto:██st-andrews.ac.uk]
Sent: 13 March 2014 09:14
To: Peter Jahn
Subject: Re: licence application Ref 28383

Dear Peter,

thanks for your message. I attach a map that shows the location (the red rectangle on it).

Kind regards,

████████

On 12/03/2014 08:43, Peter Jahn wrote:

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>
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>   ███████ Can you ███████████████████████████████
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>   ███████or the national grid reference, please?
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> Kind regards,
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> Peter Jahn
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> --
> ---------
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> -----O__ginal Message-----
> From: ██@st-and.ac.uk [mailto:██@st-andrews.ac.uk]
> Sent: 05 March 2014 09:29
> To: LICENSING
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Kind regards,

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Scotland welcomes the world in the Year of Homecoming Scotland
2014
The year-long programme of events will celebrate the very best
of Scotland's food and drink,
active and natural resources as well as our creativity, culture
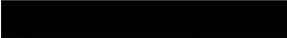and ancestral heritage.

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Fife KY16 8LB
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http://biology.st-andrews.ac.uk/bmac/
http://www.smru.st-and.ac.uk/

Licensing Section
Scottish Natural Heritage
Great Glen House
Leachkin Road
Inverness
IV3 8NW
01463 725000
LICENSING@snh.gov.uk

Other animals – Scientific and Surveying (this includes research, education, monitoring, tagging, & taking)

Licence application form

Wildlife and Countryside Act 1981 (as amended) or The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended), as required by species

Please send the completed and signed form by **post** to the above address

SNH will hold your contact details on our Customer Database. All licence application forms, licences issued and correspondence relating to licensing decisions will be stored in our electronic filing system. We will use this information to undertake licensing functions. To do this we may have to discuss applications with relevant third parties.
We manage personal information in accordance with the Data Protection Act 1998. The Act gives individuals the right to know what data we hold on them, how we use it and to which third parties it is disclosed.

Section A - Applicant details

Please give the complete details of the person who will hold the licence.

Title	▮. *please select one*		
Surname	▮		
First name	▮		
Address	*House name or number*	Scottish Oceans Institute	
	Street	East Sands	
	District	University of St Andrews	
	City or Town	St Andrews	
	County	Fife	
	Post Code	KY16 8LB	
	Country	UK	
Date of birth *(dd/mm/yyyy)*	▮		
Home telephone number	▮		
Work telephone number	▮		
Mobile number			
E-mail address	▮@st-and.ac.uk		
Organisation & position *(if applicable)*	University of St Andrews, ▮		

Section B – Species and activities

Please indicate the species you wish to disturb and details about the location of your work.

Species *(incl. scientific name, if known)*	Coastal marine mammals in Scotland, primarily Phocoena, Tursiops, Phoca, Halichoerus
Proposed licence start date:	01/03/2014 **End date:** 31/12/2015
Location of work *council area or specific area*	see attached information
Grid reference *6 or 8 digit (e.g. NN 123456)*	see attached information
Brief description of proposal	see attached information
Brief explanation of why works need to be undertaken	see attached information
Details of how the work will be undertaken *(including equipment, methodologies, etc.)*	see attached inforamtion

If a licence is sought to **ring, mark,** or **tag** a wild animal, please provide details below.

Do you intend to ring, mark or tag any animals?	☐ Ring	☐ Mark	☐ Tag	☐ No to All
Specify the type of rings or marks that will be used and where they will be obtained				
Provide details of your experience in ringing or marking in this way				

If a licence is sought to **kill** or **take** wild animals, please provide details below.

Do you intend to kill or take any specimens?	☐ Kill	☐ Take	☐ No to both
How will the specimens be taken / killed?			
How and where will the specimens be kept?			
If applicable, how and where will the specimens be released?			

Any further information

Is there any further information you would like to provide in support of your application?	**see attached information**

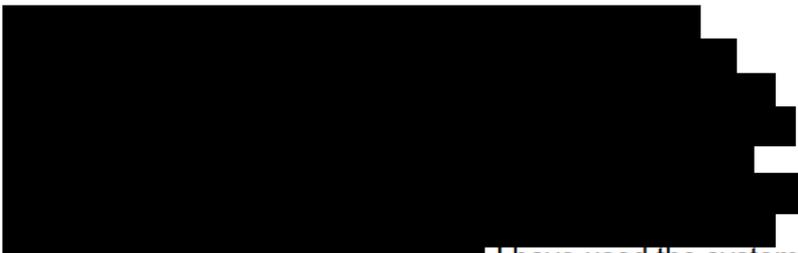**If attaching a separate report, please ensure that it includes all of the information required above.**

Section C Additional persons

If there are any additional persons to be included in this licence, please include their details below, in full. Indicate if they are to be included as an **Agent** or **Assistant.** An Agent may work independently of the licence holder; the licence holder is responsible for ensuring that Agents have the appropriate training and experience. Assistants must work under the personal supervision of the licence holder. If more than one Agent or Assistant is to be included, please use the extra tables at the end of this application and print off pages accordingly.

Status		Agent
Title		■
Surname		■
First Name		■
Address	*House name or number*	Scottish Oceans Institute
	Street	East Sands
	District	University of St Andrews
	City or Town	St Andrews
	County	Fife
	Post Code	KY16 8LB
	Country	UK
Date of birth *(dd/mm/yyyy)*		■
Telephone number		■
Mobile number		
E-mail address		■ @st-and.ac.uk
Organisation & position *(if applicable)*		University of St Andrews, ■
Are there any restrictions you require to be placed on the activities of this person? *(e.g. action, species, location)*		no

Section D – Previous experience
Please give details of your relevant experience in carrying out this type of work.

Details of relevant skills / experience	[redacted] I have used the system we describe here in Scottish waters, showing that it deters seals over a limited range and that it does not affect harbour porpoises. These projects were conducted at different fish farm sites in Scotland under SNH licence.		
Worked under someone else's licence	No	☐ Agent	☐ Assistant
Licence number			
Details of this licence			

Have you held any wildlife licences previously? Please tick the most relevant box for 'YES'.

Have you held an SNH licence, to do this type of work, in the last 5 years?	☒
Have you held an SNH licence, to do this type of work, *more than 5 years ago*?	☒
Have you held a licence, to do this type of work, in England, Wales or Northern Ireland?	☐
Have you never held a licence to do this type of work before?	☐

If you have held a licence previously, please give details below.

Licence number	6495, 8111, 10778, 13645	**Country:**	Scotland
Brief detail of most recent / relevant licence held	The most relevant licence was 8111.		

Section E – Referees
If you have *not held* an SNH licence for similar type of work in the last five years, please give the names and contact details of two referees. These should be **familiar with your experience carrying out this type of work** and are able to advise on your suitability to receive this licence.

Title	SELECT
Surname	
First name	
Address	*House name or number*	
	Street	
	District	
	City or Town	
	County	
	Post Code	
	Country	
Telephone number	
E-mail address	
Organisation & position *(if applicable)*	
Licence number *(if held)*	

Title	SELECT
Surname	
First name	
Address	*House name or number*	
	Street	
	District	
	City or Town	
	County	
	Post Code	
	Country	
Telephone number	
E-mail address	
Organisation & position *(if applicable)*	
Licence number *(if held)*	

Checklist of Attachments

Details of project or works proposed	⊠

Declaration

Applicants should note that it is an offence under Section 17 of the Wildlife and Countryside Act 1981 and under Regulation 46 of the Conservation (Natural Habitats &c) Regulations 1994 to knowingly or recklessly provide false information in order to obtain a licence.

- *I understand that failure to comply with any conditions included on any licence granted in respect of this application may constitute an offence.*

- *I declare that the particulars given in this application and any accompanying documents are true and accurate to the best of my knowledge and belief, and I apply for a licence in accordance with these particulars.*

- *If a licence is granted, I agree to send to SNH a written report of the licensed activities within one month of the expiry of the licence.*

DATE: 11/02/2014	**SIGNATURE:**

This application must be printed and signed by the applicant and a hard copy must be posted into the Licensing Team at GGH. Digital signatures are <u>not</u> accepted at this time.

Where appropriate we may use your information within SNH for other purposes for example: sending you our magazine, inviting you to an event or asking for your feedback.

Do you wish to receive our quarterly magazine? ⊠ *Yes*

Do you wish to receive other appropriate mailings from us? ⊠ *Yes*

Section C - Additional Persons continued, *as needed only*
Please only use these pages if you have several agents or assistants to add. If you have more than a further three, please use these tables and print off accordingly.

Status	SELECT		
Title	SELECT		
Surname			
First name			
Address	*House name or number*		
	Street		
	District		
	City or Town		
	County		
	Post Code		
	Country		
Date of birth *(dd/mm/yyyy)*			
Telephone number			
Mobile number			
E-mail Address			
Organisation & position *(if applicable)*			
Are there any restrictions you require to be placed on the activities of this person? *(e.g. action, species, locations)*			

Status	SELECT		
Title	SELECT		
Surname			
First name			
Address	*House name or number*		
	Street		
	District		
	City or Town		
	County		

	Post Code	
	Country	
Date of birth (dd/mm/yyyy)		
Telephone number		
Mobile number		
E-mail Address		
Organisation & position (if applicable)		
Are there any restrictions you require to be placed on the activities of this person? (e.g. action, species, locations)		

Status	SELECT	
Title	SELECT	
Surname		
First name		
Address	House name or number	
	Street	
	District	
	City or Town	
	County	
	Post Code	
	Country	
Date of birth (dd/mm/yyyy)		
Telephone number		
Mobile number		
E-mail Address		
Organisation & position (if applicable)		
Are there any restrictions you require to be placed on the activities of this person? (e.g. action, species, locations)		

A field study to test efficiency of a new acoustic deterrent device designed to mitigate adverse impacts on odontocetes

1 General description of the project and previous work

Current acoustic deterrent devices (ADDs) used on fish farms to avoid seal damage show highly varying success (Götz & Janik, 2013). ADDs have also been highlighted as a serious conservation concern since they inflict large-scale habitat exclusion in porpoises and other *delphinids* (Johnston et al. 2002). Furthermore, high duty cycle devices like most currently used ADDs may in some cases cause hearing damage in target and non-target species (see Götz & Janik, 2013 for a review). In two separate projects funded by the Scottish Government we investigated potential solutions which could contribute to an increase in efficiency and target-specificity of acoustic predator control methods (Janik & Götz 2008, 2013). In a series of response trials we generally found that seals habituated quickly to most deterring sounds including those of commercial ADDs (Götz & Janik, 2010). There was, however, one notable exception. Seals which were repeatedly exposed to sounds that elicited an oligo-synaptic reflex arc in the brainstem (acoustic startle reflex) showed the opposite reaction. These animals generally sensitized i.e. they increasingly developed flight responses and place avoidance of the area around a simulated food source (Götz & Janik, 2011). The method of using startling pulses is advantageous because the reflex will only be elicited if the received level crosses the startle threshold. Hence, any deterrence effect can be limited to a confined area around the site of interest. Furthermore, the use of infrequent, isolated pulses instead of almost continuous emissions reduces noise pollution and therefore mitigates effects on hearing. The startle reflex method was consecutively tested around a stocked salmon farm where it led to a strong reduction in the number of seals within 250m of the loudspeaker over a 2 month period (Janik & Götz 2008). In a final series of fish farm experiments, a prototype device which operated at a duty cycle of less than 1% succeeded in protecting a salmon farm on the Scottish west coast over a one year period (Janik & Götz 2013).

Habitat exclusion in odontocetes caused by current ADDs can be explained by differences in species hearing sensitivity and the fact that odontocetes typically lack food motivation to approach farm sites (Götz & Janik, 2013). All currently available seal scarers operate in a frequency band where odontocete hearing is more sensitive

than hearing in seals. Hence, these devices will cause higher perceived loudness in delphinids than in seals (Götz & Janik, 2013, see fig 1). Therefore, when optimising target-specificity it is advantageous to move to a frequency band between 700Hz and 2 kHz where seals are more sensitive than odontocetes (see fig 1). While this makes the sound more audible to baleen whales, we found that minke whales entered the sound of Mull readily in our first test of the device (Janik & Goetz 2008). The startle threshold roughly follows the hearing threshold (see fig 1 for audiograms). Hence, it was possible for us to design a sound which exceeds the startle threshold in seals but not in odontocetes. These theoretical considerations have been confirmed by empirical data from at least two different study sites. In a first study in the Northern Sound of Mull (SNH license 8111) porpoise distribution was not affected by playback of startling sounds (source level 180 dB re 1 µPa) centred at 1 kHz (Janik & Götz 2008). In fact, porpoises were regularly seen between the fish farm cages very close to the ADD while it was active. In a 2nd study on the west coast of Scotland a basic prototype device (with 3 transducers operating at 179 dB re 1 µPa) was installed on a fish farm for a one year period and marine mammals were monitored at regular intervals (Janik & Götz, 2013). There was no difference in porpoise distribution as the result of sound exposure. Interestingly, seals were seen within <50-100m of the farm but the farm did not suffer predation during most of the experimental period. This shows that effects on odontocetes can be mitigated and seals will only be affected in a small area around the fish farm.

The deterrent technology developed and tested in these studies is currently in the process of being commercialised through Genuswave Ltd. An industrial prototype is in development and will be ready for testing in March 2014. The aim of the proposed
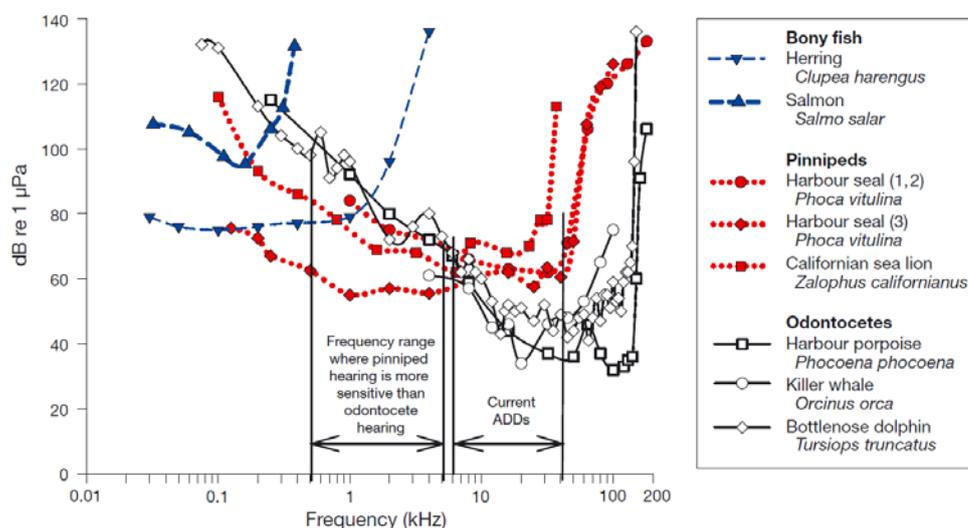

Fig 1. Audiograms of odontocetes, pinnipeds and fish typically found around fish farms (reproduced from Götz & Janik, 2013). The graphs depict the threshold of hearing with low numbers reflecting high auditory sensitivity.

study is to run a full-scale commercial trial on an operating fish farm. The experiment will involve monitoring of predation levels before, during and after deployment of the deterrent device. The trial should be conducted in an area where license restrictions previously prevented the industry from using deterrents. This is important because a real evaluation of the technology requires a farm site that has previously not operated a seal scarer. This is important as seals predating on farms which operate high-duty cycle ADDs may have hearing damage.

2 Experimental procedures

The experiment involves deployment of a full-scale commercial deterrent device (based on the startle technology) on a fish farm operated by ████████████████ ██████ The maximum deployment time would be the length of a production cycle (~18 month). We are interested in potentially running experiments at ████████ ███ ██ The deterrent device will consist of ████████████████████████████ which will be deployed on each cage of the fish farm. Initially, ████████████████████ but ultimately the number of units will be determined by the number of stocked cages on the farm site. The acoustic features of startle pulses will be the same as in the previous experiments (Janik & Götz, 2008, 2013). The individual units will emit isolated, band-limited noise pulses of 200 ms duration at a source level of ~178 to 182 dB re 1 µPa (rms). This source level is ~10-15 dB lower than in an Airmar device (see Götz & Janik, 2013). ████████████████████████████████ ██ ████████████████████ This represents a reduction in emission time by at least one order of magnitude (factor 10) compared to current commercially available devices (Götz & Janik, 2013). ██ ██ ██ ██ ██ ██ ████████████████████ (see Götz & Janik, 2011). This would then make it possible to further reduce the time ██ ██ ████████████████████████████ This will decrease noise pollution even further.

Since our studies showed no effect on odontocetes we do not expect any responses in their distribution around the fish farm. Nevertheless, the commercial trial will involve a basic marine mammal monitoring scheme. This will be implemented in form of a questionnaire survey asking farm staff to opportunistically report sightings (see appendix I). Our previous data shows that presence of porpoise can be reliably estimated from such questionnaire surveys (Janik & Götz 2013).

References

Götz, T., and V. M. Janik. 2010. Aversiveness of sound in phocid seals: psycho-physiological factors, learning processes and motivation. Journal of Experimental Biology 213:1536-1548.

Götz, T. and Janik, V. M. (2011). Repeated elicitation of the acoustic startle reflex leads to sensitisation in subsequent avoidance behaviour and induces fear conditioning. BMC Neuroscience 12:30.

Götz, T. and Janik, V. M. (2013). Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. Marine Ecology Progress Series 492:285-302.

Janik, V. M., and Götz, T. (2008). An investigation of target-specificity and effectiveness of seal deterring sounds. Report to Marine Scotland

Janik, V. M., and Götz, T. (2013). Acoustic deterrence using startle sounds: long term effectiveness and effects on odontocetes. Report to Marine Scotland. http://www.scotland.gov.uk/Publications/2013/11/9261/

Johnston, D. W. (2002). The effect of acoustic harassment devices on harbour porpoises *(Phocoena phocoena)* in the Bay of Fundy, Canada. Biological Conservation 108, pp. 113-118.

From: ██ @st-and.ac.uk [mailto██@st-andrews.ac.uk]
Sent: 11 April 2014 15:35
To: Peter Jahn
Cc: ████████
Subject: Re: licence application Ref 28383

Dear Peter,

thank you for your reply and your questions regarding our recent SNH license application for running the Genuswave ADD on farms in █████████

1) The changes in the sound protocol will lead to a slightly higher duty cycle since we propose to sometimes play a much quieter but longer warning sound instead ███████ ██████████ We think that this is advantageous since it would decrease the exposure level to the animals, i.e. an animal would be exposed to less sound energy over time. But this would increase the duty cycle of the device. We also propose to temporarily increase the duty cycle to up to ██ with startle pulses if there are attacks on the farm.

2) In our application we suggest to implement " a questionnaire survey asking farm staff to opportunistically report sightings (see appendix I). Our previous data shows that presence of porpoises can be reliably estimated from such questionnaire surveys (Janik & Götz 2013). " To explain this further, we have conducted detailed theodolite tracking of seals and porpoises in our two previous deployments on farms. In both cases, there were no effects on porpoises and a limited deterrence for seals as described in our application. In these previous trials at two different farms of over a year of deployment time we also compared our results from intense marine mammal tracking efforts with result from sighting questionnaires filled in by farm staff, in which they indicated whether they had seen porpoises on any given day. We found that the questionnaires are a reliable indicator of porpoise presence. Therefore, we will only implement the questionnaire method in the proposed trials. ████████████████████████
██

3) ██
██

Best wishes

████████████

On 04/04/2014 16:06, Peter Jahn wrote:

> Hi ████████
>
> Sorry for the late response, I waited for a long time for
> comments from our advisors. There are not many concerns and we
> appreciate that this research may have long-term positive
> impacts for cetaceans. I have only three more questions:
>
> This work is proposed to run from now to December 2015, and
> during this time the sound exposure protocol will be changed.
> Can you clarify what these changes will be?
>
> Can you clarify how the impact on cetacean will be monitored?
> Will you use visual observation to monitor cetacean activity?
> Our advisor suggests to observe the area prior to the trial,
> then during the early stages to check for any behavioural
> change, and then perhaps when the noise output characteristics
> will be changed. Alternatively you can
> deploy static C-pods to monitor echolocation click occurrence
> before and during the trial.

Can you also confirm whether in-field noise measurements of the device output will be obtained such that actual levels and frequency characteristics in the marine environment can be validated?

Thank you very much and please accept my apology for the late response.

Kind regards,

Peter Jahn

-----Original Message-----
From: ██@st-and.ac.uk [mailto:██@st-andrews.ac.uk]
Sent: March 2014 09:14
To: Peter Jahn
Subject: Re: licence application Ref 28383

Dear Peter,

thanks for your message. I attach a map that shows the location (the red rectangle on it).

Kind regards,

████████

On 12/03/2014 08:43, Peter Jahn wrote:
    Dear ████████

    I have been assigned the licence application no 28383. I woul███████████████████████████n of
    ██████on ██████████████████████████████
    ████████Can you █████████████████████████
    ███████rmat as for ███████████████████████████
    █████████or the national grid reference, please?

    Kind regards,

    Peter Jahn

    Peter Jahn
    Licensing Officer
    Wildlife Operations Unit
    Scottish Natural Heritage
    Great Glen House
    Leachkin Road
    Inverness
    IV3 8NW

    Tel: 01463 725029

    -----O ginal Message-----
    From: ██@st-and.ac.uk [mailto: ██@st-andrews.ac.uk]
    Sent: March 2014 09:29
    To: LICENSING
    Subject: licence application Ref 28383

    Dear colleagues,

    thank you for the acknoledgment of our licence application ref 28383.
    After reviewing our applicaiton, it realised that some reference values were missing in our initital description. I therefore revised the description and attach the new version here. Please replace the old one with this new description. The licence application form itself should remain as is. Apologies for my oversight in this. I am looking forward to hearing from you in due course.

    Kind regards,

    ████████████

    --

Sea Mammal Research Unit
Scottish Oceans Institute
School of Biology
University of St Andrews
Fife KY16 8LB
UK

http://biology.st-andrews.ac.uk/bmac/
http://www.smru.st-and.ac.uk/

Scotland welcomes the world in the Year of Homecoming
Scotland 2014
The year-long programme of events will celebrate the
very best of
Scotland's food and drink, active and natural
resources as well as our creativity, culture and
ancestral heritage.

homecomingscotland.com

The year-long programme of events will celebrate the very best
of Scotland's food and drink,
active and natural resources as well as our creativity, culture
and ancestral heritage.

homecomingscotland.com

  .

███████████
Sea Mammal Research Unit
Scottish Oceans Institute
School of Biology
University of St Andrews
Fife KY16 8LB
UK

http://biology.st-andrews.ac.uk/bmac/
http://www.smru.st-and.ac.uk/

Dear ██████

Please find your licence attached for you to print out as required. Please read over this carefully and ensure that you fully understand the licence and any conditions contained in the licence. Please note that based on our information, ADDs had been previously used at the ███████ site.

Your attention is drawn to 'SNH survey, education and research licences - accompanying notes' which you will find on SNH's website. Please follow this link or paste into your browser http://www.snh.gov.uk/protecting-scotlands-nature/species-licensing/forms-and-guidance/forms-notes-for-licence-holders/

It is a condition of this licence that you must provide SNH licensing team with an annual return, using the appropriate return form found here: http://www.snh.gov.uk/protecting-scotlands-nature/species-licensing/forms-and-guidance/forms-notes-for-licence-holders/. The return must include: Number of cetaceans disturbed and time of year; and number and type of samples taken and method employed. Returns should be emailed to licensing@snh.gov.uk and the final return must be submitted within one month of the expiry of this licence.

If you have any queries, please get in touch - our full contact details are on your licence.

Best wishes,

Peter Jahn

SNH Licensing Team

We would welcome some feedback. Please reply to this email rating our service (1 = poor, 5 = perfect). If it is not a 5, please tell us how we could make the service perfect.

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad

Scottish Natural Heritage
Species Licensing
Great Glen House
Leachkin Road
Inverness
IV3 8NW
01463725000
e-mail: licensing@snh.gov.uk

Animal Licence		
Licence Number: 28383	**Valid from :17-APR-14**	**Valid to :31-DEC-17**

Licence Holder : ███████████	
Address:	Sea Mammal Research Unit Gatty Marine Lab St Andrews Fife KY16 8LB

Additional Persons		
Name	**Role**	**Additional Conditions**
███████	Agent	

This Licence is Granted under the following Legislation:

The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended): Regulation 44 (2) (a)

Project Details

This licence permits the disturbance of cetaceans while carrying out a study to test efficiency of a new acoustic predator deterrent device. All works must be carried out in accordance with the document "A field study to test efficiency of a new acoustic deterrent device designed to mitigate adverse impacts on odontocetes" (submitted 11 April 2014) and subsequent correspondence agreed in writing between SNH Licensing Team and the licence holder, but subject to modifications or amendments imposed by the conditions of this licence.

Activities, species and locations covered by this licence are listed in Annex 1

Conditions

1	The licence holder must follow the guidance given in the documents entitled: "SNH survey, education and research licences - accompanying notes".
2	All working methods, mitigation and compensation measures must be carried out in accordance with those set out in the licence application and supporting documents as listed in the project details of this licence, and any subsequent correspondence agreed in writing between SNH Licensing Team and the licence holder, but subject to any modifications or amendments imposed by this licence.
3	The in-field sound field must be checked prior to longer term deployment to ensure the devices are operating to the specified frequencies, therefore giving minimising the risk of disturbance to cetaceans.

4	When carrying out work permitted under this licence, the licence holder must make all efforts to ensure that disturbance to marine wildlife is kept to a minimum, including breaking off engagement if animals continue to show signs of disturbance or active avoidance or if the group or adults and young become separated.
5	The licence holder must adhere to the Scottish Marine Wildlife Watching Code when photographs of cetaceans are not being taken.
6	The licence holder may employ unnamed assistants to operate under the terms of this licence.
7	While engaged in work authorised by this licence, the licence holder and agents if appointed, must each be able to produce a copy of this licence to any Police Officer, authorised person, or official of SNH on demand.
8	All results from this work must be made publically available by the end date of this licence. These must include detail of predation levels, including stock loss and/or equipment damage.
9	The licence holder must provide SNH licensing team with annual returns, summarising the work carried out under this licence. The final return must be submitted within one month of the expiry of this licence. The interim and final returns must include: Number of cetaceans disturbed and time of year; and number and type of samples taken and method employed and should be emailed to licensing@snh.gov.uk within one month of the expiry of this licence. The licence holder should use the appropriate return form found here: Click Here.
	Notes
Licence holders or any other persons covered by this licence should note the following;	
1	This licence is granted subject to compliance with the conditions as specified. Anything done otherwise than in accordance with the terms of the licence may constitute an offence.
2	Agents may work independently of the licence holder. It is the responsibility of the licence holder to ensure that agents have the appropriate training and experience and that they understand the terms and conditions of this licence.
3	Assistants must work under the personal supervision of the licence holder or agents. The number of assistants that can be appropriately supervised is at the discretion of the licence holder or agent.
4	Nothing in this licence shall confer any right of entry on to land or property.
5	This licence may be modified or revoked at any time by SNH.
6	This licence only exempts any legal provision contained in the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended).
7	A rigorous monitoring programme that would yield more robust results of non-disturbance of cetaceans is recommended.

This licence is granted subject to compliance with the terms and conditions specified

Licence no:28383

Authorised on behalf of Scottish Natural Heritage by: Date: 17-APR-2014

Licence no:28383

Annex 1: Permitted activites

Action	Purpose	Species	Location	Grid Reference	Method
Disturb	Science, Research and Education	All Cetaceans	███████████████	████████	N/A

This licence is granted subject to compliance with the terms and conditions specified

Licence no:28383

Authorised on behalf of Scottish Natural Heritage by: Date: 17-APR-2014

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad

LICENCE RENEWAL AND /OR AMENDMENT FORM

Please send the completed and signed form by **post** to the above address

SNH will hold your contact details on our Customer Database   All licence application forms, licences issued and correspondence relating to licensing decisions will be stored in our electronic filing system   We will use this information to undertake licensing functions   To do this we may have to discuss applications with relevant third parties

We manage personal information in accordance with the Data Protection Act 1998   The Act gives individuals the right to know what data we hold on them, how we use it and to which third parties it is disclosed   Where appropriate we may use your information within SNH for other purposes for example   sending you our magazine, inviting you to an event or asking for your feedback

Is this an application to RENEW a licence about to expire? Renewals can include any changes to contact or licence details   Please remember to send in your licence returns or no renewed licence will be granted

Or

Is this an application to AMEND an existing valid licence? Make changes to contacts, species, and activity details on a licence still valid

Please mark the relevant box

RENEW ☐   and/or   AMEND ☒

Section A – Current or previous licence details

Licence holder name	▆▆▆▆▆▆▆
Licence number	28383
Licence dates valid *(dd/mm/yyyy)*	17/04/2014 to 31/12/2017
Species	all cetaceans
Brief description of what activities the licence covered	A field study to test efficiency of a new acoustic deterrent device designed to mitigate adverse impacts on odontocetes The study will use a startle ADD on an operating fish farm to investigate its efficiency. Previous studies have shown that this ADD does not affect cetaceans, but cetacean presence will be monitored in this project to confirm our previous results.

Please only fill in those fields below which require <u>changing</u>.

Section B –Changes
Contact details of the licence holder

Title		SELECT *please select one*
Surname		
First name		
Address	House name or number	
	Street	
	District	
	City or Town	
	County	
	Post Code	
	Country	
Date of birth *(dd/mm/yyyy)*		
Home telephone number		
Work telephone number		
Mobile number		
E-mail address		
Organisation & position *(if applicable)*		

Licence dates

Proposed licence start date:		End date:	

Area covered by licence

Area currently covered	██████████████████████████████
New area(s) to be covered	██████████████████████████████
Why is a change required?	████████████████████████ As outlined in the original application, our system will not affect cetacean behaviour in the area.

Section C – Additional persons
Please copy and paste tables to add extra Agents or Assistants as necessary

To change role

Name		Previous role	☐ Agent	☐ Assistant
		New role	☐ Agent	☐ Assistant

To add or remove

Name		☐ Agent	☐ Assistant
		☐ Remove	☐ Add

To add contact details of new Agents/Assistants or change contact details of existing Agents/Assistants   The licence holder is responsible for ensuring that Agents have the appropriate training and experience   If more than one Agent or Assistant is to be included, please use the extra tables at the end of this application and print off pages accordingly

Status	SELECT
Title	SELECT
Surname	
First name	
Address	*House name or number*	
	Street	
	District	
	City or Town	
	County	
	Post Code	
	Country	
Date of birth *(dd/mm/yyyy)*	
Telephone number	
Mobile number	
E-mail address	
Organisation & position *(if applicable)*	
Are there any restrictions you require to be placed on the activities of this person? *(e g action, species, location)*	

Section D – Other changes or modifications to licence

Details of any other changes requested	
Justification for why changes are being sought	

Declaration*

Applicants should note that it is an offence under the Protection of Badgers Act 1992 (as amended), Section 17 of the Wildlife and Countryside Act 1981, and Regulation 46 of the Conservation (Natural Habitats &c) Regulations 1994 to contravene or fail to comply with any condition imposed on the grant of a licence.

- *I understand that failure to comply with any conditions included on any licence granted in respect of this application may constitute an offence.*

- *I declare that the particulars given in this application and any accompanying documents are true and accurate to the best of my knowledge and belief, and I apply for a licence in accordance with these particulars.*

- *If a licence is granted, I agree to send to SNH a written report of the licensed activities within two weeks of the expiry of the licence.*

DATE: 04/06/14	SIGNATURE: █████████████

This application must be printed and signed by the applicant and a hard copy must be posted into the Licensing Team at GGH Digital signatures are not accepted at this time

*for applications to renew or amend licences for work with bats, you **must** sign and date the additional declaration on the following page.

Do you wish to receive our quarterly magazine?   Yes   ☒

Do you wish to receive other appropriate mailings from us? Yes   ☒

Dear ██████

Please find your licence attached for you to print out as required. Please read over this carefully and ensure that you fully understand the licence and any conditions contained in the licence.

Your attention is drawn to 'SNH survey, education and research licences - accompanying notes' which you will find on SNH's website. Please follow this link or paste into your browser http://www.snh.gov.uk/protecting-scotlands-nature/species-licensing/forms-and-guidance/forms-notes-for-licence-holders/

It is a condition of this licence that you must provide SNH licensing team with an annual return, using the appropriate return form found here: http://www.snh.gov.uk/protecting-scotlands-nature/species-licensing/forms-and-guidance/forms-notes-for-licence-holders/. The return must include: Number of cetaceans disturbed and time of year; and number and type of samples taken and method employed. Returns should be emailed to licensing@snh.gov.uk and the final return must be submitted within one month of the expiry of this licence.

If you have any queries, please get in touch - our full contact details are on your licence.

Best wishes,

Peter Jahn

SNH Licensing Team

We would welcome some feedback. Please reply to this email rating our service (1 = poor, 5 = perfect). If it is not a 5, please tell us how we could make the service perfect.

Scottish Natural Heritage
Species Licensing
Great Glen House
Leachkin Road
Inverness
IV3 8NW
01463725000
e-mail: licensing@snh.gov.uk

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad

Animal Licence		
Licence Number: 34448	Valid from :09-JUN-14	Valid to :31-DEC-17
This Licence has been amended from Licence Number : 28383		
Licence Holder : ██████████		
Address:	Scottish Oceans Institute Scottish Oceans Institute St. Andrews Fife	

Additional Persons		
Name	Role	Additional Conditions
██████████	Agent	

This Licence is Granted under the following Legislation:
The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended): Regulation 44 (2) (a)

Project Details
This licence permits the disturbance of cetaceans while carrying out a study to test efficiency of a new acoustic predator deterrent device. All works must be carried out in accordance with the document "A field study to test efficiency of a new acoustic deterrent device designed to mitigate adverse impacts on odontocetes" (submitted 11 April 2014) and subsequent correspondence agreed in writing between SNH Licensing Team and the licence holder, but subject to modifications or amendments imposed by the conditions of this licence.
Activities, species and locations covered by this licence are listed in Annex 1

Conditions	
1	The licence holder must follow the guidance given in the documents entitled: "SNH survey, education and research licences - accompanying notes".
2	All working methods, mitigation and compensation measures must be carried out in accordance with those set out in the licence application and supporting documents as listed in the project details of this licence, and any subsequent correspondence agreed in writing between SNH Licensing Team and the licence holder, but subject to any modifications or amendments imposed by this licence.
3	The in-field sound field must be checked prior to longer term deployment to ensure the devices are operating to the specified frequencies, therefore giving minimising the risk of disturbance to cetaceans.

4	When carrying out work permitted under this licence, the licence holder must make all efforts to ensure that disturbance to marine wildlife is kept to a minimum, including breaking off engagement if animals continue to show signs of disturbance or active avoidance or if the group or adults and young become separated.
5	The licence holder must adhere to the Scottish Marine Wildlife Watching Code when photographs of cetaceans are not being taken.
6	The licence holder may employ unnamed assistants to operate under the terms of this licence.
7	While engaged in work authorised by this licence, the licence holder and agents if appointed, must each be able to produce a copy of this licence to any Police Officer, authorised person, or official of SNH on demand.
8	All results from this work must be made publically available by the end date of this licence. These must include detail of predation levels, including stock loss and/or equipment damage.
9	The licence holder must provide SNH licensing team with annual returns, summarising the work carried out under this licence. The final return must be submitted within one month of the expiry of this licence. The interim and final returns must include: Number of cetaceans disturbed and time of year; and number and type of samples taken and method employed and should be emailed to licensing@snh.gov.uk within one month of the expiry of this licence. The licence holder should use the appropriate return form found here: Click Here.

	Notes
Licence holders or any other persons covered by this licence should note the following;	
1	This licence is granted subject to compliance with the conditions as specified. Anything done otherwise than in accordance with the terms of the licence may constitute an offence.
2	Agents may work independently of the licence holder. It is the responsibility of the licence holder to ensure that agents have the appropriate training and experience and that they understand the terms and conditions of this licence.
3	Assistants must work under the personal supervision of the licence holder or agents. The number of assistants that can be appropriately supervised is at the discretion of the licence holder or agent.
4	Nothing in this licence shall confer any right of entry on to land or property.
5	This licence may be modified or revoked at any time by SNH.
6	This licence only exempts any legal provision contained in the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended).
7	A rigorous monitoring programme that would yield more robust results of non-disturbance of cetaceans is recommended.

This licence is granted subject to compliance with the terms and conditions specified

Licence no:34448

Authorised on behalf of Scottish Natural Heritage by: Peter Jahn Date: 09-JUN-2014

Licence no:34448

Annex 1: Permitted activites

Action	Purpose	Species	Location	Grid Reference	Method
Disturb	Science, Research and Education	All Cetaceans	███████████████	██████████	N/A

This licence is granted subject to compliance with the terms and conditions specified

Licence no:34448

Authorised on behalf of Scottish Natural Heritage by: Peter Jahn Date: 09-JUN-2014

Planning and Regulatory Services
Argyll and Bute Council

By email only to: centralvalidationteam@argyll-bute.gov.uk
Cc: Alicia.kerr@argyll-bute.gov.uk

Date: 3 September 2018

Our ref: CDM151650 / A2697075
Your ref: 18/01561/MFF

Dear Sir / Madam,

18/01561/PP - Relocation and enlargement of existing marine fish farm (currently comprising; 12 No. 80 metre circumference cages and feed barge) by re-equipment with 12 No. 120 metre circumference cages and feed barge (Increase in biomass from 600 Tonnes to 2500 Tonnes of Atlantic salmon). East Tarbert Bay, Gigha.
TOWN AND COUNTRY PLANNING (SCOTLAND) ACT 1997 (AS AMENDED)

Thank you for your consultation dated the 25th July 2018 requesting comments on the above proposal.

1. Background

We understand the proposal is to remove all existing cages from the existing fish farm and to install new cages and associated farming equipment approximately 300 m east of original fish farm site. The new site will comprise 12 x 120 m cages held in 65 m x 65 m grid formation and a feeding barge will be installed adjacent to the site. It is also understood that the proposal wishes to increase the maximum standing biomass from 600 tonnes to 2500 tonnes.

The East Tarbert Bay fish farm proposal lies within the Sound of Gigha proposed Special Protection Area (pSPA) selected for its qualifying interest of wintering great northern diver, red-breasted merganser, eider and Slavonian grebe.

SNH previously provided advice on the proposal at Screening / Scoping stage.

2. Summary of Advice

2.1 Protected species. The proposal could affect a nationally important population of a protected species as described in the accompanying confidential Annex A. Note that we either **object to the**

proposal until the further information we have requested is supplied, and/or **we object to the proposal unless conditions are put in place to mitigate the potential impacts on the population**. Note the former requested information may negate the need for the latter position. Our advice on this matter can be found in Annex A - Confidential.

2.2 Sound of Gigha proposed Special Protection Area.
This proposal could be progressed with appropriate mitigation. However, because it could affect internationally important natural heritage interests, **we object to this proposal unless it is made subject to conditions so that the works are done strictly in accordance with the mitigation detailed in our appraisal below** (and Annex B)**.**

The relocation of the proposed fish farm will cause a Likely Significant Effect for the designated species of interest as a result of potential effects on mortality, disturbance from vessel movements, displacement of foraging areas and loss or damage to supporting habitat. Therefore, Argyll and Bute Council will be required to undertake an Appropriate Assessment for the Sound of Gigha pSPA. If mitigation procedures, as advised in Annex B, are followed, the magnitude of the effects are predicted to be low, such that we would anticipate that no adverse effect on site integrity is expected following the Appropriate Assessment. Our advice on this issue is contained in Annex B.

2.3 Benthic Impacts / Horse mussel beds Priority Marine Feature habitat. Horse mussels occur in the general area, but we consider it unlikely that this proposal will result in any significant impacts on the national status of the horse mussel beds PMF habitat. We provide our advice on this matter in Annex C.

2.4 Inner Hebrides and the Minches candidate Special Area of Conservation.
This proposal is likely to have a significant effect on the harbour porpoise interest of the site. Consequently, Argyll and Bute Council, as competent authority, is required to carry out an appropriate assessment in view of the site's conservation objectives for its qualifying interest. In our view, based on the information provided, the proposal will not adversely affect the integrity of the site. We provide our advice on this matter in Annex D.

2.5 We accept the findings of the Landscape and Visual Impact Assessment.

If you have any queries regarding this advice, please contact Stan Phillips at our Lochgilphead office, contact details as per our address or telephone number at the foot of the first page.

Yours sincerely,

[by email]

David MacLennan
Area Manager
Argyll and Outer Hebrides

Annex A – Confidential

Please see separate confidential document.

Annex B – Sound of Gigha proposed Special Protection Area.

The East Tarbert Bay fish farm proposal lies within the Sound of Gigha proposed Special Protection Area (pSPA) selected for its qualifying interest of wintering great northern diver, red-breasted merganser, eider and Slavonian grebe.

Background

This is a request for advice on an Environmental Impact assessment Report (EIAR) to relocate and enlarge an existing marine fish farm from 12 x 25.5m cages arranged within a 50m grid to 12 x 38m cages arranged within a 65m grid, 280m east of the current location.

The total proposed increase in moorings area is 188,372m^2. Installation of a feed barge is also proposed to be installed at the relocated site, which is predicted to decrease boat traffic to and from the site as well as potentially lessening the amount of excess feed reaching the seabed. The fishfarm will be active 22 months out of every 24.

Decommissioning of the old site is expected to take 7-10 days. Installation of the relocated site is expected to take a further 7-10 days. The developer intends these activities to take place between June and August.

SNH position

In our view, this proposal is likely to have a significant effect on the wintering great northern diver, red-breasted merganser, eider and Slavonian grebe populations of the Sound of Gigha proposed Special Protection Area. Consequently, Argyll and Bute Council, as competent authority, is required to carry out an appropriate assessment in view of the site's conservation objectives for its qualifying interest(s). To help you do this, we advise that in our view on the basis of the appraisal carried out to date, if the proposal is undertaken strictly in accordance with the following mitigation, then the proposal will not adversely affect the integrity of the site:

- **Gillnets are NOT used as a method for recovering escaped fish, as proposed in the EIAR, when wintering birds are present** (mid-August-mid-May; the period which encompasses all qualifying species).
- **No anti-predator nets to be used.**
- **The proposed decommissioning and installation timing of between June and August is adhered to.**
- **The code of conduct laid out in the Table 32 of the EIAR for boat movements should be strictly adhered to.**

The appraisal we carried out considered the impact of the proposals as outlined below.

Consequently, **we object to this proposal unless it is made subject to conditions** which address the issues above.

Summary

The relocation of the fishfarm will cause a Likely Significant Effect (LSE) for the designated species of interest as a result of potential effects on mortality, disturbance from vessel movements, displacement of foraging areas and loss or damage to supporting habitat. Therefore, **an Appropriate Assessment will be required from Argyll and Bute Council for the Sound of Gigha pSPA.**

The magnitude of the effects are predicted to be low providing strict mitigation and best practice procedures are followed, such that we would anticipate that no adverse effect on site integrity is expected following the Appropriate Assessment. However, no cumulative assessments for designated species of interest were carried out for the EIAR: this will need to be considered within the AA, and may change the outcome of predicted no Adverse Effect on Site Integrity.

It is recommended that gillnets are NOT used as a method for recovering escaped fish, as proposed in the EIAR, when wintering birds are present (mid-August-mid-May; the period which encompasses all qualifying species). **Nor should any anti-predator nets be used.** The daily checking of net tensions to mitigate against bird entanglements is welcomed. Any instances of entanglement should be reported immediately to SNH.

It is also **recommended that their proposed decommissioning and installation timing of between June and August is adhered to**, to avoid the non-breeding timings of the qualifying species of interest. However, the developer is to note that eiders are in moult from mid-June to October, and so are less able to move away from vessels during this period. The best practice procedures laid out for vessel movements and also for ensuring strict water quality procedures are welcomed.

Summary table

Protected site	Potential effect	Species	Likely Significant effect?	Predicted Adverse Impact on Site Integrity?
Sound of Gigha pSPA	Mortality	Great-northern diver Common eider Red-breasted merganser Slavonian grebe	YES	NO, provided mitigation followed.
	Disturbance from vessel movements	Great-northern diver Common eider Red-breasted merganser Slavonian grebe	YES	NO, provided boat-based practices followed.
	Displacement from foraging areas	Great-northern diver Common eider Red-breasted merganser Slavonian grebe	YES	NO
	Loss or damage to supporting habitat	Great-northern diver Common eider Red-breasted merganser Slavonian grebe	YES	NO, provided mitigation followed but requires cumulative assessment to ascertain if combined effects would cause AESI.

Appraisal of protected site and qualifying features

The Sound of Gigha proposed Special Protection Area (pSPA) selected for its qualifying interest of wintering great northern diver, red-breasted merganser, eider and slavonian grebe.

Qualifying species:

Great northern diver: non-breeding season is October to mid-May (inclusive). Sound of Gigha pSPA supports the second largest aggregation of non-breeding great northern divers in Scotland. The proposed area for the relocation of the fish farm is within the greatest density of great northern divers (SNH, 2016).

Common eider: non-breeding season is September to mid-April, with moult taking place for eider between mid-June to October. The proposed area for the relocation of the fish farm is within the greatest density of eiders (SNH, 2016).

Red-breasted mergansers: non-breeding season is mid-August to March (inclusive). Distribution of red-breasted mergansers is low in the proposed fish farm location (SNH, 2016).

Slavonian grebe: non-breeding season is mid-September to April (inclusive). Slavonian grebes were an additional species following the original site selection documentation. Slavonian grebe numbers are found in large numbers in the region near the fish farm.

Potential impacts:

Overall approach:
The developer's appraisal on ornithological species of interest is summarised in Table 31 of the EIAR. The EIAR has assessed that no Likely Significant Effects are present for any of the qualifying features of the pSPA for any of the potential effects. We disagree with this assessment and would advise that Likely Significant Effect is a more precautionary concept than how it has been assessed in the EIAR.

Mortality through entanglement

Operation
Bird nets: mesh sizes given in the supporting document uses 25mm mesh for bottom of walls, 100mm mesh for top 3m of wall and top section to have mesh of 300mm. Bird and cage netting daily checks for tensioning and high site husbandry standards, as stated in the EIAR, are welcomed and are necessary in order to mitigate potential entanglement effects. An email from the developer on 13th August 2018 stated that *"There have been no incidences of recorded bird entanglement associated with operations at the existing East Tarbet site".* Whilst the current fish farm set up have stated that no known morality incidences have occurred as a result of their mitigation, recent guidance indicates that we cannot necessarily accept mitigation as a means to avoid Likely Significant effects. Procedures on daily net checks and monitoring should continue, as should reporting to SNH should any entanglement event occur.

The suggested use of gillnets as a way of recapturing escaped fish is contrary to the recommended management measure for the new pSPA which states:

Prohibiting the use of set (gill) nets for capture of farm fish in the event of escape is recommended.

https://www.nature.scot/sites/default/files/2017-12/Marine%20Protected%20Area%20%28Proposed%29%20-%20Advice%20to%20support%20management%20-%20Sound%20of%20Gigha.pdf

We therefore recommend that **no gill nets are to be used in the event of escaped fish when wintering birds are present** (mid-August-mid-May; the period which encompasses all qualifying species).

Furthermore, in the Predator Control Plan it is stated that the use of anti-predator nets is not common practice for The Scottish Salmon Company. It should be reiterated that **anti-predator nets should not be used in this proposal**.

Due to the fact no entanglements have been recorded for the current fish farm, it is unlikely that there will be mortality through entanglement to such a level which would cause *significant* mortality to the qualifying features, as stated in the conservation objectives. Therefore, we would anticipate that no adverse effect on site integrity would be concluded following an appropriate assessment due to mortality. However, this should be reviewed if any future mortality events occur, following the relocation of the fish farm.

Disturbance from vessel movements

Red-breasted merganser and Slavonian grebes are classified as having a very high sensitivity to vessel movements, great northern diver is classified as high, and common eider as medium (Jarett *et al.* 2018).

The EIAR notes that great northern divers and eiders have been seen around the site but red-breasted mergansers have not been recorded (Table 32, page 46). Slavonian grebes were not mentioned. The distribution maps recorded in the Sound of Gigha pSPA site selection documentation demonstrates that the fish farm is in the densest area of the pSPA for eiders and great-northern divers, but in a low density area for red-breasted mergansers (SNH, 2016). Shore-based counts show that Slavonian grebes are in large numbers in the area close to the proposed fish farm location (mean of 15.7 birds over 18 winter surveys between 2008-2013). The EIAR also notes that "there does not appear to have been any significant impact, in terms of disturbance, of the qualifying species of the SPA", but no indication as to how this has been quantified has been given.

Installation
The greatest disturbance is likely to occur during the decommissioning of the old fish farm and the installation of the new fish farm. The developer intends to carry this out between June and August to avoid the non-breeding periods of the qualifying species. This is welcomed, although it should be noted that eiders start to moult from mid-June onwards and are less able to move away from disturbance in this period. **The code of conduct laid out in the Table 32 for boat movements should be strictly adhered to.**

Operation
No additional increase in boat journeys are predicted: 2 trips per day to and from the site using a Polarcirkel work boat or RIB is expected. As the relocated fish farm is proposed to be further from the shore than its current location, the boat journeys will take marginally longer than before, but probably not notably so. We welcome the use of best practice procedures as laid out in Table 32 and would ensure that that is implemented into the management of the site.

Again, there is the potential for disturbance to occur, particularly for those species with high overlapping distributions (great northern diver and eider) during the operation of the fish farm. All species are predicted to be sensitive to disturbance caused by vessel activity, which could cause displacement from areas used for foraging, moult and shelter. Therefore, Likely Significant Effects are predicted for all species. However, there is not expected to be *significant* disturbance of the features so that the distribution of the species and ability to use the site is compromised. Therefore, we would anticipate that no adverse effect on site integrity would be concluded following an appropriate assessment due to vessel noise, provided best practice measures are implemented. It is welcomed that the route of any larger vessels servicing the proposed East Tarbet site will be similar to the current route and that measures will be taken to avoid any roosting sites of divers, eiders, or Slavonian grebes.

Displacement from foraging areas
Operation
The EIAR assessed the availability of the area that will be now limited to birds as being 0.052%, but this calculation was based on the entirety of the Sound of Gigha pSPA area which is not a true representation of the amount of area available to the qualifying species. The birds will to some extent be accustomed to where the current fish farm is, so may be displaced as a result of the relocation.

The depth profile from Figure 2 suggests that the fish farm footprint will be in water depths of between 10-50m, with the cages themselves being lowered to 10m within water of 50m depth. Great northern divers are capable of diving to depths in excess of 60m, whereas eiders and red breasted mergansers are more likely to feed at depths not exceeding 15m (SNH, 2016), and Slavonian grebes up to 25m depth (Furness *et al.* 2012). Red-breasted merganser distribution is low and none have previously been recorded in the site. Great northern divers and eiders are known to be in the area and therefore there is the potential for them to be displaced. Slavonian grebes are recorded in greatest densities to the east of the proposed site and are also have the potential to be displaced. The qualifying species will be feeding on a variety of fish but also on crustaceans and molluscs. As it is a relatively small area that they will be displaced from in relation to the entirety of the pSPA, it is unlikely to compromise the conservation objectives. Therefore, we would anticipate that no adverse effect on site integrity would be concluded following an appropriate assessment due to displacement during the operation of the fish farm.

Loss or damage to supporting habitats

The benthic habitat survey carried out as part of this proposal revealed burrowed mud, a potential horse mussel bed and muddy sand, all of which are high quality environments for diving birds. The increase of moorings area with the expansion of the fish farm is 188,372m^2.

Installation

The area of the horse mussel bed, if within the diving depths of the eiders, would be a potential foraging area for them. Depending on the anchoring set up of the fish farm this area could become damaged, which would reduce this food resource for the eiders in particular. From the benthic survey it appears this horse mussel bed has already been disturbed by fishing activity in the area, and it is not known how important this horse mussel bed is for the eiders.

Operation

Loss or damage to supporting habitat can occur due to organic waste from excess feed and farmed fish faeces is released into the environment. With the introduction of an automated feed system from the new feeding barge, it has been predicted that there will be less waste feed reaching the seabed. This potentially means the supporting habitat will not be as affected as much as the current set up. The EIAR also notes that the hydrographic conditions at the site means the dilution and dispersion of nutrients occurs within the water column. Mitigation measures are being put in place to minimise waste, and this is welcomed.

Damage to the habitat can also occur due to chemicals used in the treatment of the farmed fish. The developer intends to use emamectin benzoate or EMBZ. This chemical has been known to reduce crustacean abundance, which could have implications for the birds feeding on them. It is also a known neurotoxin to birds. It is the remit of SEPA to assess the potential effects of these chemicals on the surrounding environment and to ensure that measures are in place to minimise their effects.

There is a potential to affect the habitat. However, due to the relatively small area of the fish farm in relation to the overall pSPA, we would anticipate that no adverse effect on site integrity would be concluded following an appropriate assessment, provided mitigation procedures are strictly adhered to and following SEPA's own assessment on water quality and environmental effects of the fish farm.

Cumulative effects:

The EIAR did not take into consideration the cumulative effects of nearby fish farms in relation to potential effects on the qualifying species; it was only taken into consideration in relation to water quality (page 32). There is another fish farm less than 1km from the proposed new location and so there is the potential for a combined effect of disturbance and displacement from foraging areas. As the existing fish farm is also close to the additional SSC Druimyeon Bay site, there is not expected to be much change from the existing set up in terms of cumulative effects. Therefore, though Likely Significant Effects are predicted for all species, there is not expected to be such significant further impacts on the features that the site is compromised, provided the mitigation measures outlined above are implemented. Therefore, we would anticipate that no adverse effect on site integrity would be concluded following an appropriate assessment due to cumulative effects, **provided the mitigation measures outlined above are implemented**.

References

Furness, R.W., H.M., Robbins, A.M.C., Masden, E.A., (2012) Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. *ICES Journal of Marine Science*, 69, 1466–1479, https://doi.org/10.1093/icesjms/fss131.

Jarrett, D., Cook, A. S. C. P., Woodward, I., Ross, K., Horswill, C., Dadam, D. and Humphreys, E.M. (2018) Short-Term Behavioural Responses of Wintering Waterbirds to Marine Activity (CR/2015/17) Scottish Marine and Freshwater Science Vol 9 No 7
https://data.marine.gov.scot/sites/default/files//SMFS%200907.pdf

SNH (2016) Sound of Gigha Site Selection Documentation. https://www.nature.scot/sound-gigha-proposed-marine-spa-supporting-documents

Annex C – Benthic Impacts - Horse mussel beds Priority Marine Feature habitat.

Benthic Impacts

The majority of the benthos directly beneath the site consists of mud habitat, some of which may represent the PMF habitat, Burrowed Mud. However, this is not a high quality example of the habitat. Due to the widespread distribution of this PMF in Argyll, including areas of much higher quality habitat, we do not consider any potential impacts as a result of this proposal to be of regional or even local significance.

Areas of horse mussel were identified to the north of the proposal. These largely consisted of aggregations of horse mussels forming scattered clumps. We disagree with the survey report, which states that the horse mussels present would not be considered as a bed. We define horse mussel beds as being formed from clumps of horse mussels and shells covering more than 30% of the seabed over an area of at least 5 m x 5 m. Some of the areas identified in the survey appear as though they may meet this criteria and would therefore represent areas of the PMF habitat, horse mussel beds. This is supported in the seabed survey report which identifies many locations as having over 30% cover (some locations consist of 100% cover). Table 11 of the seabed survey report estimates the average cover of each transect and the average cover of the entire survey area. These figures range between 4.54-7.66% which is well below the 30% cover required for the habitat to be classified as a bed. However, these figures are misleading as they are estimates of average cover over the entire area, including areas where no horse mussels are present. If these figures are correct they may demonstrate that the entire area does not consist of a horse mussel bed. However, they do not demonstrate that no areas of horse mussel bed are present in the survey area. Contrary to this the survey report presents information which indicates that some areas of the horse mussels present may well in fact represent areas of horse mussel bed.

The benthic modelling report for this proposed expansion / relocation indicates that the vast majority (>99%) of the waste will be exported out with the modelled domain and will be dispersed widely before being deposited on the seabed. As such the benthic footprint for the proposal is very small and is restricted to within the direct footprint of the cages.

The information provided in the EIAR documentation does not provide a very clear representation of the areas of horse mussel in relation to the fish farm cages or AZE. However, using what information is available I estimate the closest horse mussel record to be approximately 80-100m from the closest cage edge. The occurrence and density of horse mussels generally increases with distance from the proposed development location, with the denser areas appearing to occur mostly beyond approx. 150m from the cage edge.

Horse mussels are considered to be sensitive to the pressures associated with finfish aquaculture. However, the energetic nature of this location is predicted to result in a very limited benthic footprint. The vast majority of waste is predicted to be transported out with the modelled domain and subsequently dispersed widely within and beyond the Sound of Gigha. The residual current runs in a south / south easterly direction and therefore much of the waste is likely to be transported away from the horse mussel records. In addition, the closest Horse mussels are positioned approx. 80-100m from cage edge with the density and occurrence generally increasing with distance from the proposed development. Taking these factors in to account we can consider the risk of any significant impacts occurring on any areas of horse mussel bed to be low. It is therefore unlikely that this proposal will result in any significant impacts on the national status of the horse mussel beds PMF habitat.

However, we note that it would appear as though the moorings could overlap with the most southerly records of horse mussels. This area appears to consist of fewer, less dense records of horse mussels and it is likely to be possible to avoid impacting these areas through the placement of moorings by using drop down video to microsite the moorings to avoid any areas of horse mussel.

Annex D – Inner Hebrides and the Minches candidate Special Area of Conservation.

The East Tarbert Bay fish farm proposal lies close to the Inner Hebrides and the Minches candidate Special Area of Conservation (cSAC) selected for its qualifying interest, harbour porpoise.

The site's status means that the requirements of the Conservation (Natural Habitats, &c.) Regulations 1994 as amended (the "Habitats Regulations") or, for reserved matters, The Conservation of Habitats and Species Regulations 2017 apply. Consequently, Argyll and Bute Council is required to consider the effect of the proposal on the cSAC before it can be consented (commonly known as Habitats Regulations Appraisal). The SNH website has a summary of the legislative requirements (https://www.snh.scot/professional-advice/safeguarding-protected-areas-and-species/protected-species/legal-framework/habitats-directive-and-habitats-regulations).

There are natural heritage interests of international importance on the site, but in our view, these will not be adversely affected by the proposal.

In our view, this proposal is likely to have a significant effect on the harbour porpoise interest of the site. Consequently, Argyll and Bute Council, as competent authority, is required to carry out an appropriate assessment in view of the site's conservation objectives for its qualifying interest.

To help you do this we advise that, in our view, based on the information provided, the proposal will not adversely affect the integrity of the site. The appraisal we carried out considered the impact of the proposals on the following factors:

Risk of entanglement in cage nets and / or secondary predator nets
We are not aware of any cases of harbour porpoise becoming entangled in nets associated with the fish farming industry in Scotland. Therefore entanglement with cage nets or anti-predator nets is not considered to be a significant risk and we do not consider there to be a likely significant effect.

Risk of disturbance / exclusion of harbour porpoise as a result of the use of ADDs
The proposed fish farm site is located outside the cSAC and will only impact on the periphery of the southern boundary. The proposal itself is located within Gigha Sound, approximately 1 km from the boundary of the cSAC. However, the area of the cSAC which could be impacted by the use of ADDs is open and unconstrained in nature and is not considered to be at high risk of cumulative impacts. However, the sound frequencies emitted from the ADDs proposed at this site will extend to within the boundary of the cSAC. Harbour porpoise are known to be sensitive to the frequencies of sound that are emitted by most 'standard frequency' ADD devices. On this basis we conclude that the use of ADDs at this proposed has potential to result in the disturbance of harbour porpoise within the cSAC.

If ADDs are to be activated continuously, whilst the farm is stocked, then this could result in a significant disturbance and a long term exclusion of harbour porpoise from an area within the cSAC. However, in this instance, the applicant has submitted a detailed ADD deployment plan. The plan outlines an appropriate decision making process that will ensure that ADDs are not activated continuously. Instead, if they are required, they will be activated and deactivated in response to the identification of fish mortalities that can be attributed to seal predation. In doing so this will ensure that ADDs will not be activated continuously, over a long term period. We conclude that this will avoid the risk of resulting in any significant disturbance to the harbour porpoise feature of the cSAC.

In addition, the applicant has committed to keeping a record of ADD use at this site. This will ensure Argyll and Bute Council has a mechanism to review the use of ADDs at this site in the future.

In summary, provided the mitigation outlined in the ADD deployment plan is adhered to, we conclude that this proposal will not result in any adverse effect on the integrity of the Inner Hebrides and Minches cSAC.