FACT SHEET

Low frequency deterrents

RING, FLEX OR SPEAKER

Our award-winning Ace Deterrents are:

- Low frequency, MMPA compliant
- Highly targeted with a trigger system, with ramp-down that minimises noise pollution
- Simple, reliable and easy to set-up with remote monitoring and management

Your first choice for animal welfare

What it is

A unique low-frequency deterrent, which targets marine predators (seals, sea lions), whilst avoiding the specialised hearing ranges of dolphins and porpoises.

Why we developed it

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How it works

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- Delivers a range of randomised frequencies and tonal patterns to avoid habituation issues

Key features

- MMPA complaint
- Remote monitoring and control portal
- Ramp down, slow start
- Triggering options available
- Modulated frequency and randomised tonal patterns avoid habituation
- Avoids specialised hearing range of porpoise and dolphins
- Modular, easy to deploy – plug and play
- Battery back-up allows operation of up to 24 hours of use with access to mains

Welfare benefits

- Avoids habituation – modulated frequency range, randomised tonal patterns
- Targets seal hearing range while avoiding the specialised hearing range of porpoise and dolphins – very low impact on high frequency cetaceans
- Will not affect farmed fish species – outside of their hearing range
- Helps protect fish from predation which can cause serious injury, mortality, fish escape and increased stress

Sustainability factors

- Often fewer low frequency systems are required meaning less power draw
- Rechargeable batteries
- Trigger ensures the devices are only being used when required

Ideal set up

Depending on the level of predation - or predators in the region - fewer low-frquency units may be required on a pen group.

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"It's so important to have a real deterrent and so far we've had zero mortalities attributed to seals. The web portal is accessible from the shore and gives us total control over each individual unit. This is a huge improvement on any other systems I have used in the past."

[redacted]y

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ACE AQUATEC

Universal technical specifications

Power draw	12V deep-cycle non-spillable gel battery Each pelicase and top box system will draw a maximum of 250W
Input voltage	AC mains input is a universal supply from 90–260 volts (single phase)
Connections	16A 230V Mains Amphenol Ecomate C016
Average current draw	Average power draw = 100-150W Average daily consumption = 2.4kW hours
Effective Range	Range: 50 – 1,000m from source Measured displacement over ranges of >1km depending on species. Sound detectable at 7km
UW Extension cable	Polyurethane Jacket
UW Ext. cable length	30m / made to measure for specific sites
Battery coverage	12/24 hours – varies on scram rate Real Time Clock for data logging
Range	approx. 15,000m²
Materials used	TopBox - 316 Stainless Steel Peli = HDPE; QuadBox = POM Ring = Polyurethane; Pod + Cage = Nylon
Depth rating	From 10m to Unlimited
User rate	12-144 scrams per hour Avg. tone length = 2 seconds

Frequency range	Formatting Setting1: 0.8kHz - 1.2kHz Setting2: 1.0kHz - 2.0kHz
Volume/ Tone output 1	Average within a transmission: 185dB re 1uPa rms @ 1m
Volume/ Tone output 2	Average within a transmission: 183dB re 1uPa rms @ 1m
Minimum/Max duty cycle	Duty Cycle: 0.7% to 8% max
Tone profile	9x short duration, randomised pulses of sound that avoids habituations and hearing loss
Ramp-up/soft-start time	15 minutes
Operating temperature	-20ºC to 40ºC
Manufacture license certifications	ISO 9001:2005 Low Voltage Directive (LVD) 2006/95/EC – EN61010-1:2001 Electromagnetic Compatibility Directive (EMC) 2004/108/EC EN61000-3-2:2000 EN61000-6-2:2001 EN61000-6-4:2001
Waterproof rating	IP68(fully submersible) Pelicase = IP68 TopBox = IP68
Fault reporting	Warning light, email, online alerts

Individual technical specifications

	Ring	Flex	Speaker
Weight Air/Water	Ring+Pod+Cage = 42KG/14KG	Flex+Pod+Cage = 36KG/11KG	Speaker+Pod+Cage = 41KG/7KG
Dimensions	Ring+Pod+Cage = 846mm H x 500mm W	Flex+Pod+Cage = 931mm H x330mm W	Speaker+Pod+Cage = 1032mm H x 450mm W

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Mid frequency deterrents
US3

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- Helps protect fish from predation – which can cause serious injury, mortality, fish escape, increased stress

Sustainability factors
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Ideal set up
- Simple, reliable and easy to set-up with remote monitoring and management
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Scottish Sea Farms

"We have worked with Ace Aquatec for a number of years to reduce the impact seals have on our Orkney farms. Their system survived some severe winter storms, and the fact that we can monitor remotely is an added bonus."

[redacted]

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ACE AQUATEC

US3 Technical Specifications

Power draw	12V deep-cycle non-spillable gel battery Each pelicase and top box system will draw a maximum of 250W
Input voltage	AC mains input is a universal supply from 90–260 volts (single phase)
Connections	16A 230V Mains Amphenol Ecomate C016
Average current draw	Average power draw = 100-150W Average daily consumption = 2.4kW hours
Effective Range	60m/5000m
UW Extension cable	Polyurethane Jacket, fully submersible
UW Ext. cable length	20m/40m + Made to measure for specific sites
Battery coverage	12/24 hours – varies on scram rate Real Time Clock for data logging
Range	one US3 covers c. 8,000 sq.m.
Materials used	Surface Control Box = 316 Stainless Steel Peli = HDPE; QuadBox = POM Pod = Nylon
Depth rating	fully submersible to 100m
User rate	12-144 scrams per hour Avg. tone length = 2 seconds
Weight Air/Water	14kg/5kg

Dimensions	Surface Control Box = 150 x 260 x 50mm Peli = 361mm x 289mm x 165mm Pod = 190mm diameter, 520mm height
Frequency range	8-11kHz
Volume	Average within a transmission: 180dB re 1uPa rms @ 1m
Minimum/Max duty cycle	Duty Cycle: 0.7% to 8% max
Tone profile	9x short duration, randomised pulses of sound that avoids habituations and hearing loss
Ramp-up/soft-start time	15 minutes
Manufacture license certifications	ISO 9001:2005 Low Voltage Directive (LVD) 2006/95/EC – EN61010-1:2001 Electromagnetic Compatibility Directive (EMC) 2004/108/EC EN61000-3-2:2000 EN61000-6-2:2001 EN61000-6-4:2001
Waterproof rating	IP68 (fully submersible) Pelicase = IP67; TopBox = IP68
Fault reporting	Warning light, email, online alerts

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Input voltage	AC mains input is a universal supply from 90–260 volts (single phase)
Connections	16A 230V Mains Amphenol Ecomate C016
Average current draw	Average power draw = 100-150W Average daily consumption = 2.4kW hours
Effective Range	70m radius (15000 sq m)
UW Extension cable	Polyurethane Jacket
UW Ext. cable length	30m / made to measure for specific sites
Battery coverage	12/24 hours – varies on scram rate Real Time Clock for data logging
Materials used	TopBox - 316 Stainless Steel Peli = HDPE; QuadBox = POM Ring = Polyurethane; Pod + Cage = Nylon
Depth rating	From 10m to Unlimited
User rate	12-144 scrams per hour Avg. tone length = 2.8 seconds
Frequency range	Flex (Setting 1): 0.8 kHz – 1.2 kHz Ring (Setting 2): 1.0 kHz – 2.0 kHz
Sound level	Average within a transmission: (re 1uPa rms @ 1m) Flex: 176 dB re 1uPa rms@1m Ring: 180dB re 1uPa rms@1m
Duty cycle (min/max)	0.9% to 11%
Tone profile	9x short duration, randomised pulses of sound that avoids habituations and hearing loss
Ramp-up/soft-start time	15 minutes
Operating temperature	-20ºC to 40ºC
Manufacture license certifications	ISO 9001:2005 Low Voltage Directive (LVD) 2006/95/EC – EN61010-1:2001 Electromagnetic Compatibility Directive (EMC) 2004/108/EC EN61000-3-2:2000 EN61000-6-2:2001 EN61000-6-4:2001
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Input voltage	AC mains input is a universal supply from 90–260 volts (single phase)
Connections	16A 230V Mains Amphenol Ecomate C016
Average current draw	Average power draw = 100-150W Average daily consumption = 2.4kW hours
Effective Range	50m radius (8000 sq m)
UW Extension cable	Polyurethane Jacket, fully submersible
UW Ext. cable length	20m/40m + Made to measure for specific sites
Battery coverage	12/24 hours – varies on scram rate Real Time Clock for data logging
Materials used	Surface Control Box = 316 Stainless Steel Peli = HDPE; QuadBox = POM Pod = Nylon
Depth rating	fully submersible to 100m
User rate	12-144 scrams per hour Avg. tone length = 2.6 seconds
Weight Air/Water	14kg/5kg

Dimensions	Surface Control Box = 150 x 260 x 50mm Peli = 361mm x 289mm x 165mm Pod = 190mm diameter, 520mm height
Frequency range	8-11kHz
Sound level	Average within a transmission: 181dB re 1uPa rms @ 1m
Duty cycle (min/max)	0.9% to 10%
Tone profile	9x short duration, randomised pulses of sound that avoids habituations and hearing loss
Ramp-up/soft-start time	15 minutes
Manufacture license certifications	ISO 9001:2005 Low Voltage Directive (LVD) 2006/95/EC – EN61010-1:2001 Electromagnetic Compatibility Directive (EMC) 2004/108/EC EN61000-3-2:2000 EN61000-6-2:2001 EN61000-6-4:2001
Waterproof rating	IP68 (fully submersible) Pelicase = IP67; TopBox = IP68
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PREDICTED NOISE PROPAGATION OF OTAQ *PATROL MODE* SEALFENCE™ ACOUSTIC HARASSMENT DEVICE AT MOWI CARRADALE SALMON FARM, SCOTLAND

Prepared on behalf of

TECHNICAL REPORT 14

July 2020

Action	Name	Function	Date	Signature
Author	[redacted]	Project Manager	06/07/20	[redacted]
Audit	[redacted]	Document Review	06/07/20	[redacted]
Author	[redacted]	Senior Analyst	06/07/20	[redacted]

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Client:
OTAQ Aquaculture Limited
Crombie Lodge
Aberdeen Innovation Park
Campus Two
Bridge of Don
Aberdeen
AB22 8GU
UK
W: www.otaq.com

FAO:
[redacted]
Chief Commercial Officer
OTAQ Group
T: [redacted]
M: [redacted]
E: [redacted]@otaq.com

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For further information, contact:
[redacted] (Managing Director)
[redacted] (Managing Director)

Ocean Science Consulting Limited (OSC) Spott Road
Dunbar
East Lothian
EH42 1RR
Scotland
UK

T: +44 (0)1368 865 722 (switchboard)
M: [redacted]
M: [redacted]

E: [redacted]
E: [redacted]
W: www.osc.co.uk

Company number: SC318365
VAT number: 928 894 167
Registered in Edinburgh, Scotland, UK

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS/UNITS/TERMS

ADD Acoustic Deterrent Device
AHD Acoustic Harassment Device
ca. Circa or approximately
CTD Conductivity-Temperature-Depth (meter)
dB deciBel
EMODnet European Marine Observation and Data network
HF High Frequency
Hz Hertz
kHz kiloHertz
LF Low Frequency

LOA Length Over All
µPa microPascal
m Metre
MV Motor Vessel
N Geometric Spreading Attenuation Factor
N/A Not Applicable
NE North East
NL Noise Level
NPL National Physical Laboratory
OSC Ocean Science Consulting Limited
OTS Over-The-Side
OCW Other Carnivores in Water
p-p Peak-to-Peak
PCW Phocid Carnivores in Water
PhD Doctorate of Philosophy
PSD Power Spectral Density
PSU Practical Salinity Units
PTS Permanent Threshold Shift
re Reference
RMS Root Mean Squared
s Second
SE South East
SEL Sound Exposure Level
SL Source Level
SPL Sound Pressure Level
TL Transmission Loss
TM Trade Mark
TTS Temporary Threshold Shift
U Unweighted
UBA UmweltBundesAmt
UK United Kingdom
UTC Coordinated Universal Time
VHF Very High-Frequency
W Weighted
WGS World Geodetic System

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SUMMARY

Acoustic Harassment Devices (AHDs) are used worldwide to deter pinnipeds from predating fish-aquaculture facilities, but there are concerns raised about impacts of underwater noise on non-target marine species, such as marine mammals. Consequently, OTAQ Aquaculture Limited (OTAQ) contracted Ocean Science Consulting Limited (OSC) to perform desk-based predictive-noise propagation modelling of a new *patrol mode* version of the OTAQ SealFence™ AHD and its potential impact on marine mammals.

In April 2019, OSC performed empirical underwater-noise field measurements for the OTAQ *patrol mode* SealFence™ AHD at an active, salmonid-stocked, Scottish west coast fish farm, and results from that study were used here to inform expected noise propagation of the same type of AHD at Carradale, west coast of Scotland.

Predictive modelling results showed that underwater-AHD noise propagated primarily in a north-to-south direction between Carradale and the Isle of Arran. Over a 24-hour period, using the reported duty cycle (on for 1.5 seconds off for 10 seconds), predicted maxima next to the AHD source for Sound Exposure Level (SEL) was 114 dB re 1 μPa^{2}s, and for Sound Pressure Level (SPL) was 73 dB re 1 μPa.

Predicted SEL and SPL are below sound exposure thresholds specified by Southall *et al.* (2019) for marine mammals in each hearing group. According to thresholds, no marine mammals are expected to experience Temporary or Permanent Threshold Shifts (TTS or PTS respectively) to hearing from the *patrol mode* version of the OTAQ SealFence™ AHD at any range.

On the basis of noise propagation modelling carried out here, it is unlikely that use of the *patrol mode* OTAQ SealFence™ AHD will have a significant effect on marine mammals in the vicinity of Carradale; however, this study did not account for any other cumulative, non-OTAQ AHD models that may be operating in the region. All assessments of AHD noise around fish farms should be made on a case-by-case basis.

1. INTRODUCTION

Impacts of common (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals on aquaculture facilities in the United Kingdom (UK) are well documented (see reviews by Gordon and Northridge, 2002; Northridge *et al.*, 2013; Coram, 2014; Gordon *et al.*, 2019), and include direct predation, fish injury, reduced fish-growth rates, fish pen damage, loss of fish stocks and two-way genetic contamination/disease transmission between wild and farmed fish stocks (Würsig and Gailey, 2002). Effects are costly to industry, so considerable effort has been put into reducing likelihood of interactions. One method of achieving this, is development of devices that emit sound to deter seals from approaching aquaculture pens, often with mixed success (Nelson *et al.*, 2006; Northridge *et al.*, 2010; Coram, 2014; Harris *et al.*, 2014; Gordon *et al.*, 2019).

1.1. Marine mammals & sound

Marine mammals, and in particular cetaceans (whales, dolphins, and porpoises), use different sound frequency bands for a number of activities, which include, but are not limited to: communication, navigation, foraging, and a range of activities within the wider social group such as cohesive actions, warnings, and maternal relationships (Southall *et al.*, 2007; André *et al.*, 2010). Sound perception and production is also an important sensory modality for pinnipeds – eared seals and sea lions (Schusterman and Van Parijs, 2003). In most cases, hearing range of cetaceans is less well understood than that of pinnipeds, but it is assumed generally that they hear over similar frequency ranges to sounds they produce. Odontocete (toothed) cetaceans are considered to be more sensitive to underwater sound and produce sound at higher frequencies than pinnipeds (Southall *et al.*, 2007; NMFS, 2016).

Underwater man-made (anthropogenic) noise generated by offshore activities has capacity to impact marine wildlife. Effects depend greatly on the characteristics of the sound. A useful distinction can be made between continuous (long duration), transient (short duration), and repeated transient sounds (de Jong *et al.*, 2011). According to Southall *et al.* (2019), there are mainly two sound types that are relevant for marine mammal noise exposure criteria (**see Section 1.3**): pulse (single or multiple) and non-pulses. Fish-farm-associated vessel activity, for example, would be classified as continuous non-pulsed noise, while AHD noise is classified as multiple pulses. Potential direct effects of AHD noise on marine mammals include damage to auditory systems, avoidance of habitats, behavioural alterations, and masking of biologically-important sounds (Southall *et al.*, 2007; Branstetter *et al.*, 2013; Tougaard *et al.*, 2016; Mikkelsen *et al.*, 2017). While anthropogenic noise in general could also affect marine mammals indirectly through impact to both adult and juvenile/larval stages of prey such as fish and invertebrates (Packard *et al.*, 1990; Mooney *et al.*, 2010; Simpson *et al.*, 2010; Radford *et al.*, 2011; Holles *et al.*, 2013), AHD noise is unlikely to cause injury to the well-studied Atlantic salmon, *Salmo salar* (Wahlberg and Westerberg, 2005), which is a 'hearing generalist' (Popper and Higgs, 2009), with poor hearing above 150 Hz (Hawkins and Johnstone, 1978). Consequently, this is one of the main reasons why AHDs are considered an acceptable marine mammal mitigation technique on fish farms.

1.2. Empirical noise measurements vs. noise modelling

In April 2019, OSC performed *in situ* empirical underwater noise measurements of a new version of the OTAQ SealFence™ AHD, which can work in a function called '*patrol mode*'. Underwater noise measurements of this system were performed from a fully-operational salmonid fish farm on the west coast of Scotland (Todd *et al.*, 2020). Field trials took place on 19th and 20th April 2019 using an Over The Side (OTS) noise-measurement system. Measurements were performed along two linear transects, originating from one of the 16 *patrol mode* SealFence™ AHD units located on the outer corner of the fish farm, as near to the AHD sound source as possible (2–7 m). Measurements were taken at several distances out to a maximum distance of 4.2 km. During that study, vessel-based underwater noise measurements, Conductivity-Temperature-Depth (CTD) casts, and Van Veen grab samples were undertaken at locations along transects, with vessel engines off. Noise measurements were taken for calculation and displays of signals in the time and frequency domain (sound pressure in Pascal, Pa), Root Mean Squared Sound Pressure Level (RMS SPL), and Power Spectral Density (PSD) in dB/Hz as presented in Todd *et al.* (2020). *Patrol mode* empirical *in situ* Source Levels (SLs) were estimated to be 79.7–82 dB re 1μPa RMS for the two transects, but there were significant differences in SLs estimated between the two days of trials, which is a consequence of changes in environmental conditions, *e.g.* seabed type/grade/slope, tide, temperature, background noise level, *etc.*

Field trials are costly, and numerical modelling is a considerably less expensive way to provide prediction of underwater acoustic fields, which can then be used to assess theoretical impacts on marine life; however, as demonstrated by Todd *et al.* (2020), sound propagation can vary between locations due to the complexity of underwater environments affected by, *inter alia*, geographical, bathymetrical, oceanographical, and climatical conditions. Consequently, modelled data groundtruthed with empirical environmental data and in-field noise measurements, are the most effective method to quantify potential effects of anthropogenic noise sources on marine mammals.

1.3. Marine mammals & noise criteria

Species, and individuals within species, are sensitive to sound at different frequencies. To account for differential sensitivity in humans, measures of sound may be normalised or 'weighted' by applying a filter that matches plots of perceived loudness. Weightings are applied numerically by adding or subtracting specific values on the decibel (dB) scale. Most commercial studies of potential effects of underwater noise use the Southall *et al.* (2007) criteria, which until recently, was the most widely used benchmark to assess potential effects of noise on marine mammals. This has since been superseded by Southall *et al.* (2019).

Southall and his co-workers (2007) produced a comprehensive review of impacts of underwater noise on marine mammals and proposed criteria for preventing injury, based on both peak sound levels and Sound Exposure Levels, SEL (Southall *et al.*, 2007). SEL is defined as 'the time integral of the square pressure over a time window long enough to include the entire pressure pulse'. SEL is therefore the sum of acoustic energy over a measurement period, effectively accounting for both sound level, and duration over which sound is present in the acoustic environment. These SEL criteria can then be applied to either a single transient pulse or cumulative energy from multiple pulses.

To account for wide-frequency dependence in auditory response of marine species, M-Weighting frequency functions were proposed for five functional hearing groups (Southall *et al.*, 2007). A useful synopsis of functional hearing groups (**Table 1**) and definitions of terms is provided in **Section 1.5.3.** of OSC's Marine Mammal Observer and Passive Acoustic Monitoring Handbook (Todd *et al.*, 2015).

Hearing group	**Example species**
Low-Frequency (LF) cetaceans	Baleen whales (mysticetes)
High-Frequency (HF) cetaceans	Toothed (odontocete) dolphins, beaked and bottlenose whales (*Hyperoodon* sp.)
Very High-Frequency (VHF) cetaceans	Odontocete true porpoises, dwarf sperm whale (*Kogia* sp.), river dolphins, *Cephalorhynchus* dolphins
Phocid Carnivore in Water (PCW)	Seals
Other Carnivore in Water (OCW)	Sea lions, fur seals, walrus, otters, polar bears

Table 1: Marine mammal functional hearing groups, adapted from Southall *et al.* (2019).

The Southall *et al.* (2007) criteria were developed using this weighting scheme, estimating onset of auditory injury, called Temporary and Permanent Threshold Shifts (TTS and PTS respectively) for these groups, based on measurements and extrapolation from terrestrial mammals. A caveat is that these criteria are based

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on audiograms of only a few individuals of a few species, but audiogram literature is ever increasing, as is number of test subjects of the same species.

The Southall *et al.* (2019) assessment criteria propose values for onset of TTS and PTS for non-impulsive and impulsive noise (**Table 2**).

Hearing Group	**Non-impulsive**		**Impulsive**			
	TTS threshold	**PTS threshold**	**TTS threshold**		**PTS threshold**	
	SEL (W)	**SEL (W)**	**SEL (W)**	**SPL (U)**	**SEL (W)**	**SPL (U)**
LF	179	199	168	213	183	219
HF	178	198	170	224	185	230
VHF	153	173	140	196	155	202
PCW	181	201	170	212	185	218
OCW	199	219	188	226	203	232

Table 2: Temporary and Permanent Threshold Shift (TTS and PTS respectively) onset for each marine-mammal hearing group present in UK waters when exposed to non-impulsive and impulsive noise. Sound Exposure Level (SEL) thresholds in dB re 1 μPa^{2}s. Peak Sound Pressure Level (SPLs) thresholds are in dB re 1 μPa. LF = Low-Frequency cetacean, HF = High-Frequency cetacean, VHF = Very-High-Frequency cetacean, PCW = Phocid Carnivore in Water, OCW = Other Carnivore in Water. W = Weighted, U = Unweighted. Adapted from Southall *et al.* (2019).

1.4. Rationale

The aim of this report is to use the OTAQ *patrol mode* SealFence™ AHD noise values measured empirically in the Todd *et al.* (2020) study to model predicted noise at Carradale. These estimates will be used to investigate ranges at which marine mammals in each of the Southall *et al.* (2019) assessment criteria are predicted to experience TTS and PTS from AHD noise.

2. MATERIALS & METHODS

2.1. Fish-farm location

Carradale salmon farm is located in Carradale, opposite the Isle of Arran, west coast of Scotland, UK (**Figure 1**).

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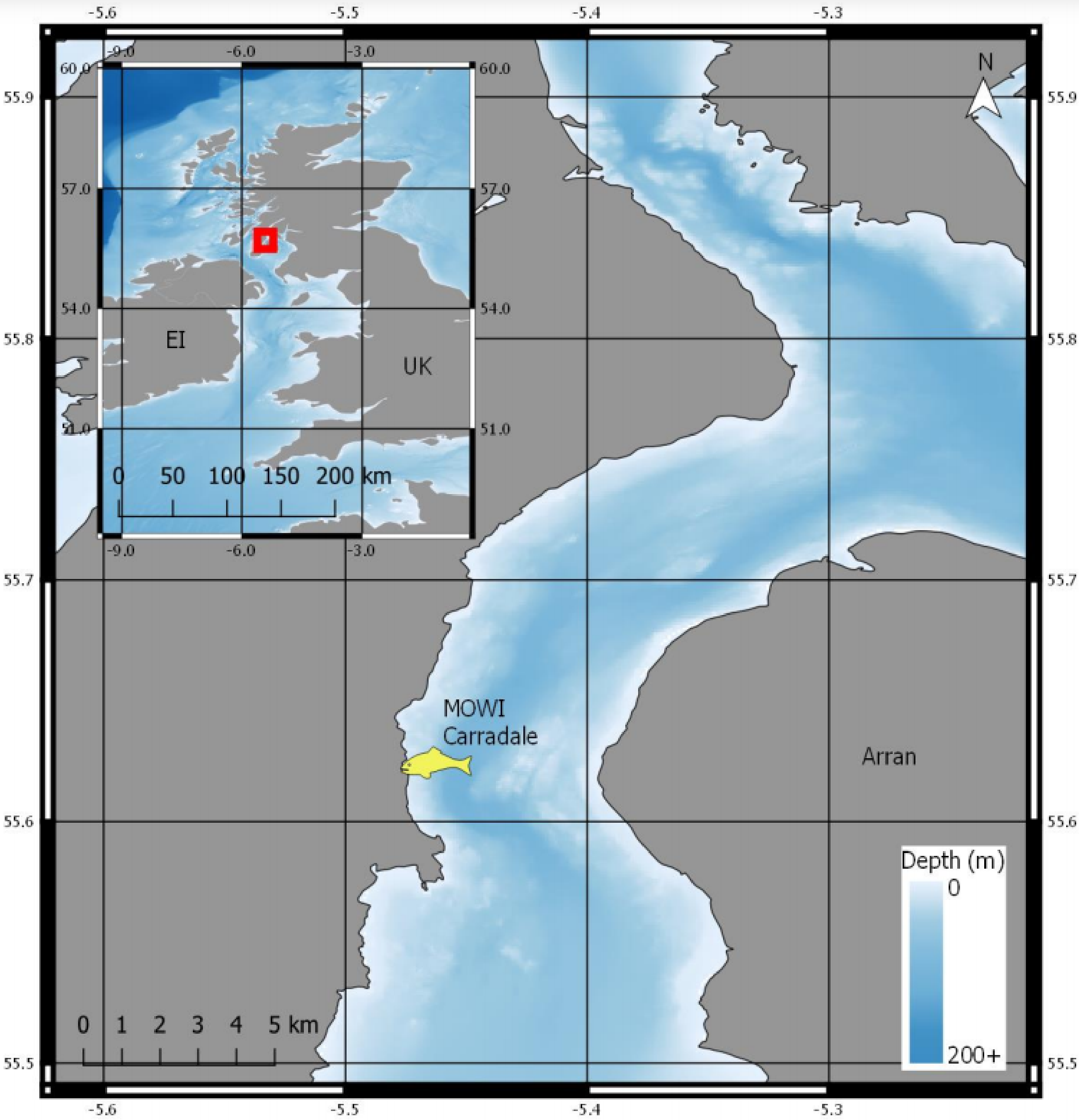

Figure 1: Fish farm location at Carradale, Scotland. Latitude and longitude in World Geodetic System (WGS) '84. *Source*: OSC (2020).

2.2. AHD noise-source details

Since the Todd *et al.* (2020) study yielded SLs between 79.7 and 82 dB re 1μPa RMS on the two different noise-measurement transects performed on different days, the highest levels were used as the input values for modelling in this report. Moreover, far-field noise values measured at 500 m from AHD source in that study were used here because near-field source measurements are considered too unreliable. Transmission Loss (TL) was calculated at the original field site in each 1/3 octave band and added to measured sound levels at 500 m from the AHD source. These values were then used as inputs for modelling at Carradale. The AHD sound source was assumed to be placed at half water depth (15 m) at the site. A duty cycle of AHD source on for 1.5 seconds and off for 10 seconds was used to model exposure over a 24-hour period. This resulted in the AHD being on for a total of 11,270 seconds over 24 hours.

2.3. Bathymetry & oceanography

Bathymetry data for the site and surrounding area were downloaded from European Marine Observation and Data network (EMODnet) www.emodnet.eu (EMODnet Bathymetry Consortium, 2018). Maps of seabed habitats, used to infer sediment type, were also searched for from EMODnet, www.emodnet-seabedhabitats.eu (EMODnet Seabed Habitats, 2019). A sound-speed profile was calculated using empirical Conductivity Temperature Depth (CTD) measurements from Todd *et al.* (2020), to inform modelling here. Since the Todd *et al.* (2020) study was performed in the month of April, environmental parameters for this study were also assumed to be the same season.

2.4. Underwater-noise modelling

High and low frequencies were modelled using different solvers (custom-developed mathematical software). Normal modes were used for low frequencies (up to 500 Hz), and ray tracing for high frequencies (up to 160 kHz), as described in Jensen *et al.* (2011).

2.5. Marine mammal assessment criteria

All underwater-noise data were reported in a format that allowed both analysis using un-weighted metrics such as SEL and SPL as well as analysis in a biologically significant format (e.g. Southall *et al.*, 2007; Finneran and Jenkins, 2012; NOAA, 2013; Wensveen *et al.*, 2014; Tougaard *et al.*, 2015; NMFS, 2016; NMFS, 2018; Southall *et al.*, 2019), using time domain frequency filters for representative species of marine mammals. This presented measured noise in terms of sound level in the auditory bandwidth of receptor hearing groups.

This was achieved by:

1) Using sound spectra and SL estimated from data obtained during the Todd *et al.* (2020) empirical field measurements;
2) Applying the appropriate M-weighting filter as described by Southall *et al.* (2019); consequently, noise level was also calculated for each hearing group;
3) Calculating SEL at different ranges by subtracting TL; and
4) Calculating cumulative SEL over 24 hours assuming AHD operates continuously.

3. RESULTS

3.1. Bathymetry & oceanography

Carradale fish farm lies in water depths of *ca.* 30 m, in an area of mostly sandy mud substrate. No *in situ* environmental data were available to inform modelling, but it is likely that Carradale experiences similar environmental conditions as the salmon farm in the Todd *et al.* (2020) study. The model used in this report is relatively independent of current speed, unless currents are deemed to be very strong, *e.g.* tidal races.

3.2. Underwater-noise modelling

Figure 2 shows that predicted SEL propagates primarily in a north-to-south direction within the area, with other directions being obscured by land masses. **Figure 3** shows that predicted SPL propagates primarily in the same way as SEL, which is to be expected, since both noise parameters are subject to the same physical constraints.

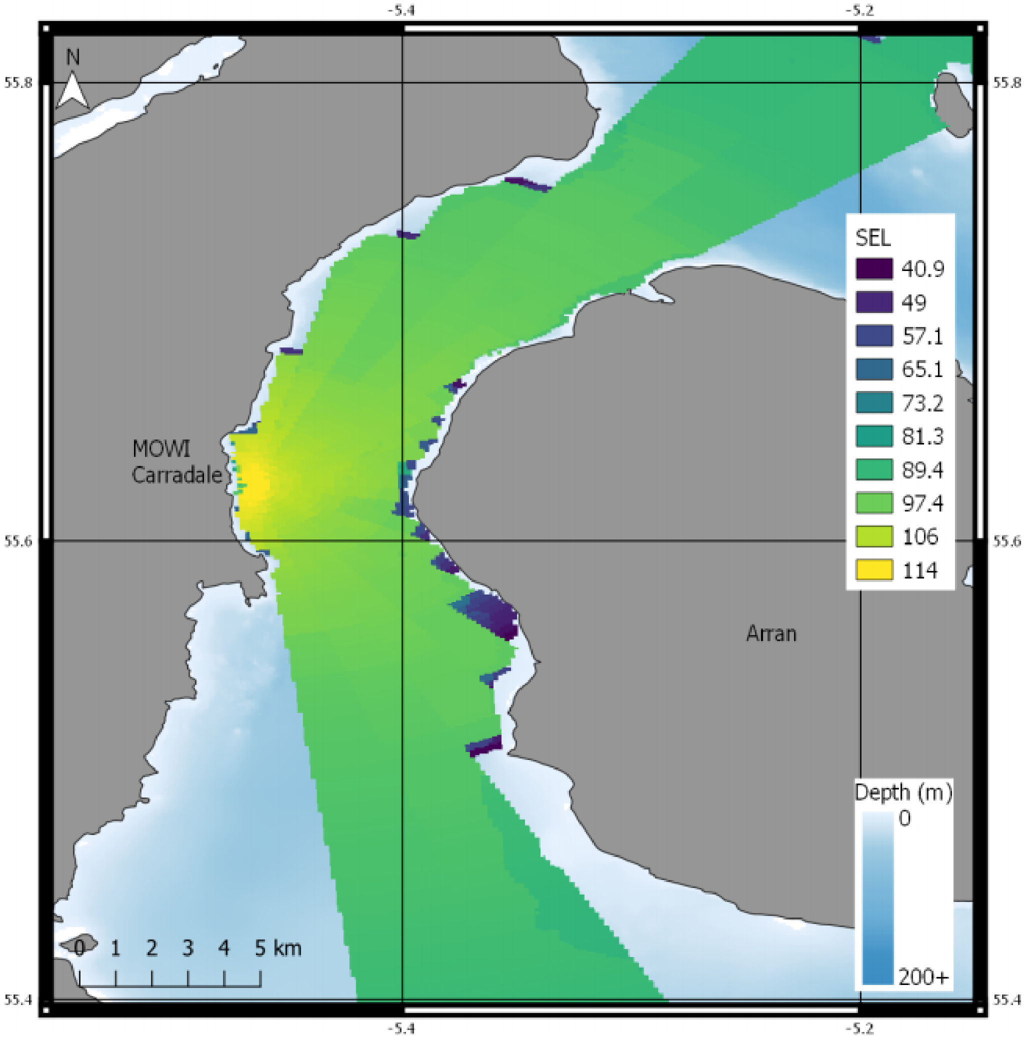

Figure 2: Chart of predicted Sound Exposure Level (SEL) in dB re 1 μPa^{2}s of the *patrol mode* OTAQ AHD at Carradale salmon farm. *Source*: OSC (2020).

Modelled propagation of SealFence™ at Carradale

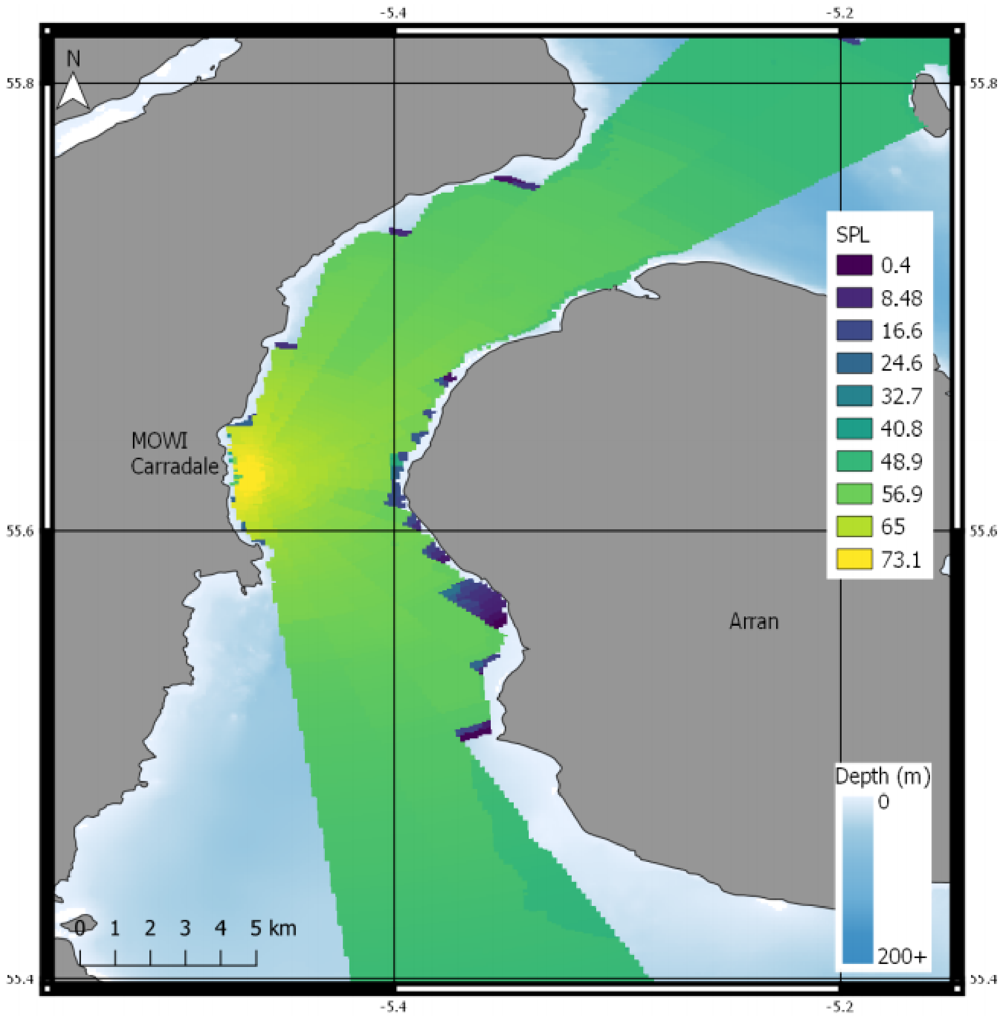

Figure 3: Chart of predicted Sound Pressure Level (SPL) in dB re 1 μPa of OTAQ AHD in *patrol mode* at Carradale salmon farm. *Source*: OSC (2020).

3.3. Marine mammal assessment criteria

Predicted ranges of Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) were calculated based on the Southall *et al.* (2019) assessment criteria for each hearing group and are presented in **Table 3**.

Marine mammal hearing group	**PTS (m)**	**TTS (m)**
LF	0	0
HF	0	0
VHF	0	0
PCW	0	0
OCW	0	0

Table 3: Predicted potential auditory-impact ranges (m) from the noise source (at 0 m) for LF = Low-Frequency cetaceans, HF = High-Frequency cetaceans, VHF = Very-High-Frequency cetaceans, PCW = Phocid Carnivores in Water (true seals), and OCW = Other Carnivores in Water (eared seals, otters, *etc.*) from the OTAQ *patrol mode* SealFence™ AHD. *Source*: OSC (2020).

According to these standards, no marine mammals in any of the hearing groups are expected to exhibit PTS/TTS at any distance from the OTAQ *patrol mode* SealFence™ AHD.

4. DISCUSSION

Previous empirical measurements of the *patrol mode* version of the OTAQ SealFence™ AHD were collected from an operational salmon farm on the west coast of Scotland, and SL was estimated to be 79.7–82 dB re 1µPa RMS (Todd *et al.*, 2020). These values, along with some empirical oceanographic data from that fish farm, were used as inputs in desk-based noise propagation modelling to investigate predicted impacts of the *patrol mode* OTAQ SealFence™ AHD on marine mammals around Carradale. In that study, predicted SL differed by 3 dB on the two measurement days, which is indicative of minor changes in bathymetry, water characteristics, weather, ambient noise. Consequently, modelling results presented
here are intended only to provide an indication of predicted noise propagation.

4.1. Oceanography

Sound speed in the ocean is an important oceanographic variable and is dependent on three main physical factors: temperature, depth (hydrostatic pressure), and salinity. Since empirical, site-specific oceanographic data were not available for this study, values used in the modelling were taken from real measurements from the Todd *et al.* (2020) study performed at a similar Scottish west coast site. Sound speed increases with temperature, depth and salinity; however, in general, temperature decreases with depth, and the strongest sound-speed dependence is on temperature. This leads to a complex variation of sound speed with depth, which means that animals traversing though the water column three-dimensionally, can be affected by differential levels of sound, depending on their physical position in the water. During winter, the water column in coastal areas is generally well-mixed vertically, with less permanent thermoclines, which means that sound speed profiles are likely to be invariant with depth, but in other seasons this varies. A sound speed profile may be divided into several layers: just below the surface is what is sometimes called the 'surface layer', where sound speed is susceptible to diel (24-hour) changes due to heating, cooling, and wind action, which are all usually measured empirically on the day of noise measurements, and again are absent in a desk-based model. This is followed by a seasonal thermocline, a region characterised by a negative sound speed gradient due to decreases in temperature with depth. Below the main thermocline and extending into the deep ocean is the deep isothermal layer, which is nearly constant in temperature at about 4 ºC. In this layer, sound speed increases with depth due to increasing hydrostatic pressure. Between the thermocline and the isothermal layer is a sound speed minimum, toward which sound tends to be bent by the action of refraction. Some of the sound from a source placed in this channel can be trapped within the duct and travel great distances without appreciable losses due to surface or bottom reflections. Whilst spreading losses still occur, they are reduced from spherical spreading and in certain cases may approximate to cylindrical spreading.

Variation with salinity is less of an influence in deep water but can have a strong influence where water layers of different salinity are mixing, for example in estuaries, or at the mouths of fresh-water rivers, again of importance in the inshore Carradale site, and not accounted for in a desk-based model because of the absence of *in situ* measurements. This can be measured using an instrument such as a velocimeter, which calculates time for a high frequency pulse to travel over a known path, or alternatively, a measurement is made of the conductivity (to derive salinity), temperature and depth using a CTD meter with the sound speed calculated from empirically-derived relationships. Again, CTD data inputted into the model were derived empirically from a different site, adding uncertainty to the model. Additional noise present during high wind or rainfall was not considered in this study, because it was not able to be inputted into the model.

As a result of the above, the region of influence of a sound source can vary dramatically depending upon operating site and depth, and on seasonal changes in water properties; therefore, model predictions are intended to be used to evaluate potential region of influence of the noise source. The importance of taking *in situ* oceanographic and noise measurements to ground-truth the model and generate more realistic results cannot be underestimated.

4.2. Underwater-noise modelling

Predictive modelling showed that cumulative SEL calculated over a 24-hour period presented values of up to 114 dB re 1 $\mu Pa^2 s$ in the immediate vicinity of the AHD source. SPL was predicted to be a maximum of 73 dB re 1 µPa at the AHD source (**Figure 3**).

When AHDs are used around fish farms, or areas with multiple manmade structures such as cages and nets, then sound transmission may be blocked or reflected in alternate directions, making distance travelled harder to predict (Terhune *et al.*, 2002).

4.3. Marine mammal assessment criteria

According to the Southall *et al.* (2019) assessment criteria, the OTAQ *patrol mode* SealFence™ AHD produces noise at levels below thresholds of PTS/TTS for all hearing groups; therefore, marine mammals in each hearing group are not expected to exhibit PTS or TTS at any distance during the AHD's transmission.

4.4. Potential impact of the AHD on marine mammals

On the basis of this report, the OTAQ *patrol mode* SealFence™ AHD is relatively 'quiet' compared to other AHD models, and expected on its own, to have a negligible effect on marine mammal species in Carradale, yet its efficacy on deterring seals from fish farms is reportedly excellent (OTAQ unpublished observations). Despite the low sound levels and marginal predicted propagation fields presented here, it is important to stress that only sound fields from one AHD system were modelled; introduction of anthropogenic noise into the marine environment in conjunction with other (cumulative) sources should always be considered, and empirical measurements on a case-by-case basis are always advised.

This report only considered acoustic disturbance caused directly by the OTAQ *patrol mode* SealFence™ AHD. In terms of general operating activities around a fish farm, it is important to note that other activities, such as feed barges and vessels, also introduce underwater noise. Vessel traffic is known to disturb porpoises, with strongest reactions observed in the presence of high-speed vessels (Oakley *et al.*, 2017; Wisniewska *et al.*, 2018). Concomitant to this, however, additional vessel traffic will contribute to increased ambient noise, and reduce distance at which the *patrol mode* OTAQ SealFence™ AHD can be detected.

5. CONCLUSIONS & RECOMMENDATIONS

On the basis of noise propagation modelling carried out here, it is unlikely that use of an OTAQ *patrol mode* SealFence™ AHD will have a significant effect on marine mammals in the vicinity of Carradale.

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OTAQ Aquaculture Ltd
Crombie Lodge,
Aberdeen Innovation Park,
Campus Two,
Bridge of Don,
Aberdeen AB22 8GU,
Scotland, UK
+44 (0) 1224673301
info@otaq.com

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Contents

Figures

No table of figures entries found.

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1 Introduction

1.1 Scope

This document was authored by Ocean Science Consulting Ltd following their field trials in Scotland in April 2019. The report is completed and unedited.

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FIELD TRIALS: SOURCE LEVELS AND SPECTRA EMITTED BY OTAQ SEALFENCE™ ACOUSTIC HARASSMENT DEVICE AT PORTREE SCOTTISH SALMON FARMS

Prepared on behalf of

TECHNICAL REPORT 5: SUMMARY

June 2019

Action	Name	Function	Date	Signature
Author	[redacted]	Project Manager	03/06/19	[redacted]
Audit	[redacted]	Document Review	28/05/19	[redacted]
Author	[redacted]	Research Analyst	27/05/19	[redacted]
Author	[redacted]	Report Writer	27/05/19	[redacted]
Author	[redacted]	Team Manager	28/05/19	[redacted]

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Client:
OTAQ UK
Scottish Marine Institute
Dunbeg
Oban
Argyll
PA37 1QA
Scotland
UK
W: www.otaq.co.uk

FAO:
[redacted]
Commercial Director
T: +44 (0) 1631 559 399
M: +44 (0) 7802 492 541
E: [redacted]@otaq.co.uk

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For further information, contact:
[redacted] (Managing Director)
[redacted] (Managing Director)

Ocean Science Consulting Limited (OSC) Spott Road
Dunbar
East Lothian
EH42 1RR
Scotland
UK

T: +44 (0)1368 865 722 (switchboard)
M: [redacted]
M: [redacted]

E: [redacted]
E: [redacted]
W: www.osc.co.uk

Company number: SC318365
VAT number: 928 894 167
Registered in Edinburgh, Scotland, UK.

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CONTENTS

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LIST OF ACRONYMS/ABBREVIATIONS/UNITS/TERMS

α Total Sound Absorption
�� Absorption
A Amps
ADD Acoustic Deterrent Device
AEP Auditory Evoked Potential
AHD Acoustic Harassment Device
ANSI American National Standards Institute standards
BACI Before After Control Impact
BD Bottlenose Dolphin
BNC Bayonet Neill–Concelman
c Speed of sound in water (celerity)
C Celsius
ca. Circa or approximately
cm Centimetre
Contrib. Contribution
CS Common seal
cSAC Candidate Special Area of Conservation
CTD Conductivity-Temperature-Depth (meter)
dB deciBel
D Depth of water (m)
DAQ Data AcQuisition
DT Detection Thresholds
E sound Exposure
EC European Commission
E_{cum} Cumulative sound exposure
EIA Environmental Impact Assessment
E_n un-weighted sound Exposure
E_{ref} reference sound Exposure
EU European Union
F Frequency
GPS Global Positioning System
GS Grey Seal
h Hour
H Average sea depth
H&S Health & Safety
HD Habitats Directive
HF High Frequency
HP Harbour Porpoise
Hz Hertz
IWC International Whaling Commission
JNCC Joint Nature Conservation Committee
kHz kiloHertz
km^{-1} Per kilometre
KW Killer Whale
LAT Lowest Astronomical Tide
LF Low Frequency
LOA Length Over All
Lp Peak Level

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μPa microPascal
m Metre
MB Mega Bytes
MF Mid Frequency
Mhf High-frequency cetaceans (Southall criteria)
MHz MegaHertz
Mlf Low-frequency cetaceans (Southall criteria)
Mmf Mid-frequency cetaceans (Southall criteria)
Mpa Pinnipeds in air (Southall criteria)
Mpw Pinnipeds in water (Southall criteria)
ms Milliseconds
MU Management Unit
MV Motor Vessel
N Geometric Spreading Attenuation Factor
N/A Not Applicable
NASA National Aeronautics and Space Administration
NE North East
NL Noise Level
NOAA National Oceanic and Atmospheric Administration NPL
National Physical Laboratory
OSC Ocean Science Consulting Limited
OSCAR Ocean Surface Current Analysis Real-time
OTS Over The Side
OW Otariid pinnipeds (NOAA criteria)
�� nondimensional pressure correction factor
p-p Peak-to-peak
p(t) Instantaneous sound pressure
PhD Doctorate of Philosophy
p_{ref} Reference sound pressure
PSD Power Spectral Density
PSSF Portree Scottish Salmon Farm
PSU Practical Salinity Units
PTS Permanent Threshold Shift
PW Phocid pinnipeds (NOAA criteria)
R Range (distance to source)
R&D Research & Development
RMS Root Mean Squared
S Second
SCI Site of Community Interest
SD Standard Deviation
SE South East
SEL Sound Exposure Level
SL Source Level
SNH Scottish Natural Heritage
SPL Sound Pressure Level
SSC The Scottish Salmon Company
SST Sea Surface Temperature
T Temperature (°C)
t Time
TL Transmission Loss
T_{ref} Duration

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TTS Temporary Threshold Shift
UK United Kingdom
UTC Coordinated Universal Time
V Volts
VAC Volts Alternating Current
w Windspeed
WGS World Geodetic System
WS West Scotland

SUMMARY

In 2018, an application was submitted by the Scottish Salmon Company (SSC) to place an OTAQ SealFence™ AHD system at the Portree Scottish Salmon Farm (PSSF) on the Isle of Skye, west coast of Scotland. This site is located within the European Union (EU) Habitats Directive (HD) Inner Hebrides and Minches candidate Special Area of Protection (cSAC) and Site of Community Importance (SCI), for which the harbour porpoise (*Phocoena phocoena*) is a primary species of concern. Consequently, Ocean Science Consulting Limited (OSC) was commissioned by OTAQ to perform two desk-based modelling studies (OSC, 2018; 2019) to determine distance at which an OTAQ SealFence™ AHD system could potentially be heard by marine mammals when functioning in three modes: '*patrol*', '*standard*' and '*enhanced*'. Those studies also investigated potential audible detection distances, disturbance or injury to five species of marine mammals known to be present in the region: harbour porpoise, bottlenose dolphin (*Tursiops truncatus*), killer whale (*Orcinus orca*), common (*Phoca vitulina*) and grey (*Halichoerus grypus*) seal. Based on these desk-based studies, OTAQ further commissioned OSC to perform empirical field measurements of the SealFence™ *in situ* at PSSF to better inform the desk-based model and improve accuracy of predicted results. This report details field trial methods, and quantitatively compares data to results presented in the desk-based study.

Field trials took place on 19th and 20th April 2019 when PSSF was fully operational, stocked with salmonid (*Salmo salar*) smolts, and equipped with an active operating OTAQ SealFence™ AHD system comprising 16 units. Measurements took place from the Length Over All (LOA) 10 m Motor Vessel (MV) *Gracie Eva* along a southeast (SE) and a northeast (NE) linear transect, originating from one of 16 SealFence™ AHD units located on the north-east corner of PSSF, as near to the AHD sound source as possible (2-7 m). Measurements were taken at several distances out to a total distance of 4.2 km.

Vessel-based underwater noise measurements, grab samples, and Conductivity Temperature-Depth (CTD) casts were undertaken at locations along transects with vessel engines off. Noise measurements were taken for calculation and displays of signals in the time and frequency domain (sound pressure in Pascal, Pa), Root Mean Squared (RMS), Sound Pressure Level (SPL), and Power Spectral Density (PSD) in dB/Hz. Potential impact to marine mammals was estimated using both Southall et al. (2007) and NMFS (2018) assessment criteria, which split marine mammals into groups with similar hearing capacities of low (LF), mid (MF) and high frequency cetaceans (HF) and phocid seals in water (PW) for NMFS (2018) assessment criteria.

Ambient noise time-domain sound pressure, SPL and PSD, showed consistent results, with only small variation at very low frequencies, which can be due to influences of the environment.

Near to the source at 7 m, in both *patrol* and *standard modes*, the OTAQ SealFence™ AHD source was distinguished easily in the time domain as regularly

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timed and spaced pulsed signals in both *patrol* and *standard mode*, and this diminished with distance until it was unrecognisable at 4.2 km.

Patrol mode ⅓ octave band SPLs were identified easily at 10 kHz, reducing with increasing distance, and were not clearly distinguishable above background noise beyond 500 m; however, in *standard mode*, this 10 kHz peak ⅓ octave band SPL was still obvious at 4.2 km.

Patrol and *standard mode* PSD 10 kHz operating frequency was observed at all ranges, albeit stronger for *standard* mode, and always decreasing with distance, as expected.

Empirical *in situ* Source Levels (SLs) were estimated to be 79.7–82 dB re 1µPa RMS for *patrol mode* and 136.5–141.5 dB re 1µPa RMS for *standard mode*. These are much lower than SLs provided by OTAQ from tank calibrations in *standard mode* of 189 dB re 1µPa RMS. No previous tank calibrations where known for *patrol mode*, but it was expected that this could be operated between 125–170 dB re 1µPa RMS.

In *patrol mode*, range of all marine mammal species potential audibility was 0 km. When the effect of Transmission Loss (TL) was compounded onto the empirically derived reduced *patrol mode* SL, the signal at 1 m from the device was 43.41 dB re 1 µPa RMS, which is below the hearing threshold of each species.

In *standard mode*, when applying the new, empirically derived SLs from both SE and NE transects (applying the annual average Beaufort sea state 3), the OTAQ SealFence™ AHD is potentially audible to marine mammals at the following distances: harbour porpoise = 5–9.2 km, bottlenose dolphin = 13.5–19.6 km, killer whale = 4.3–8.3 km, common seal = 3.7–7.4 km, and grey seal = 0.23–0.7 km. Audible detection ranges generally decreased with increasing sea state.

Audibility for *patrol mode* based on *in situ* measurements are 0 km for each species, while for predictions of *patrol mode* based on tank calibrations range from 0.02– 4.3 km for lower estimates of SL (125 dB re 1µPa RMS) and 26–65 km for higher estimates of SL (170 dB re 1µPa RMS). The same pattern is true of *standard mode* in which measurements place audibility between 0.2–20 km while predictions were between 55–116 km.

When comparing empirically-derived field results to desk-based simulations (OSC, 2018; 2019), distances at which each species of marine mammal was predicted to sustain auditory injury/Permanent Threshold Shift (PTS) or behavioural disturbance/Temporary Threshold Shift (TTS) were in fact much smaller. This difference is due mainly to the new, considerably reduced measured SLs. According to the Southall et al. (2007) assessment criteria, marine mammals in each hearing group were not expected to exhibit auditory injury or behavioural response at any distance when the OTAQ Sealfence™ AHD was operated in *patrol mode*. When operating in *standard mode*, all cetaceans may exhibit a behavioural response up to 1 m from the source, while pinnipeds may exhibit a behavioural response up to 7 m from the source.

According to NMFS (2018) assessment criteria, and applying the empirically derived field results, marine mammals in each hearing group were not expected to exhibit auditory PTS or TTS at any distance during operation of the OTAQ Sealfence™ AHD in *patrol mode* for both SE and NE transects. In *standard mode* for the SE transect, PTS was only expected for HF marine mammals (e.g. the harbour porpoise) at a distance of 24 m, and TTS for LF, MF, and PW at ranges of 3–5 m, and at 258 m for HF marine mammals. In *standard mode* for the NE transect, PTS was expected for LF marine mammals and PW at < 1 m, and at <28 m for HF marine mammals, and TTS for LF, MF, and PW at ranges of 5–8 m, and at 205 m for HF marine mammals.

Comparing estimates of disturbance based on empirically measured data with those from tank calibrations of the AHD, the most noticeable decrease in impact distances is observed in *standard mode* particularly according to the NMFS (2018) criteria where each hearing group will potentially experience TTS at a maximum of 258 m, as opposed to over 150 km.

When compared to desk-based theoretical modelling, results of empirical noise measurements greatly reduced the predicted range at which marine mammals may be exposed to disturbance from the OTAQ SealFence™ AHD. On the basis of this report, the OTAQ SealFence™ AHD is expected to have a negligible effect on marine mammal species in the sound of Raasay channel; however, cumulative effects of other noise sources should be considered, and it is advised that reduction of OTAQ SealFence™ AHD usage during summer/periods when not required/low seal predation, or used at lower SLs (e.g. *patrol mode*) would likely reduce overall impact of disturbance on all non-target species of investigated cetaceans in the region. Additionally, at other times of year (particularly winter, when ambient noise levels are often elevated), it may be possible to operate the OTAQ SealFence™ AHD at higher SLs of *standard mode* without affecting the harbour porpoise population significantly.

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