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SOURCE LEVELS AND SPECTRA EMITTED BY THREE COMMERCIAL AQUACULTURE ANTI-PREDATION DEVICES

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Marine finfish aquaculture fish farm facilities can suffer severe predation from seals and other animals. Underwater transmitting commercial aquaculture acoustic devices (CAADs), intended to provide protection by deterring the close approach of seals are used in many countries. Few reliable acoustic data are available with which to assess the impact of such systems on target and non-target species in the surrounding marine environment. This paper reports an April 2003 study in which 160 kHz bandwidth measurements of source level and power spectra were carried out of three CAAD devices that are currently used in British salmonid fish farm facilities. The three devices tested employed very different signalling methods and whilst the fundamental acoustic frequencies (including harmonics) appear similar, the total energy distribution, delivered into the water column differed considerably.

1. INTRODUCTION

Interactions between fish farming and the environment have been the subject of scientific and societal interest for many years [for a review see 1]. Fish farms are introduced into an environment that has a natural complement of fish-eating predators. Both common (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals have been reported to have a significant impact on some aquaculture facilities [see review by 2], either by preying on the fish directly, causing stress or permitting escape by tearing the netting of sea cages [3].

To deter seals from predating on caged-farmed fish, many farms employ various commercially available devices known as "*seal scarers/scrammers*" or "*Commercial Aquaculture Acoustic Devices*" (CAADs). These devices reportedly use high-intensity sound over a broad frequency range with source levels ranging from <180dB re 1µPa@1m to 200dB re 1µPa@1m [see review by 2].

North American studies have addressed the effectiveness of CAADs in deterring seal predation on salmon stocks [e.g. 3, 4, 5]. Although the results of these studies are conflicting, concerns have been raised about their potential effects on non-target species. Marine species that are most likely to be affected by CAADs are those that have sensitive hearing at CAAD frequencies and which have important habitat in areas where CAADs are deployed [2]. Research into the acoustic sensitivity of marine wildlife suggests that odontocete cetaceans, particularly the harbour porpoise, *Phocoena phocoena*, will be the group most vulnerable to any effects, followed by pinnipeds and possibly diving birds [see 6, 7, 8].

To date, the acoustic characteristics of only one make of CAAD have been measured in field conditions [9], and preliminary field data exist for another [4]. Furthermore, the source levels quoted by CAAD manufacturers frequently refer to non-anechoic tank conditions and often do not clearly specify the parameters that were measured. This is the first reported to obtain definitive emission characterisations of three types of CAAD currently used in British waters - including direct source level (SL) and spectrum measurements at short range and long ranges.

2. EXPERIMENTAL PROCEDURE & EQUIPMENT

Measurements were made off a fish farm in an open water tidal site in UK costal waters approximately 0.25 km from shore with a mean water depth of 30 m. The area of deployment is a 3.5 km wide Sound with a strong tidal flow between the mainland and an island coastline, where a number of commercial salmon farms are situated and two types of CAAD devices are deployed on a regular basis. For the duration of the measurements other CAAD systems within the immediate area were turned off. Additional background and anthropogenic noise included in the recordings are typical of deployment situations of these systems. Each of the systems was tested in turn with a single transducer placed 8-10 m below the surface. Measurements were made using 12.5 mm and 25 mm spherical omni-directional hydrophones at an equivalent horizontal range of 2 m. The former has a resonance around 150 kHz and the latter 75 kHz. Both receivers had reasonable mid-frequency (1-20 kHz) sensitivity response. Additional pre-amplification of 32 dB and 26 dB was used respectively including a 1 kHz *high-pass* filter stage. Each of the hydrophones was placed within the plane of the primary horizontal axis of the CAAD system. Data was acquired direct to hard disk at a 320 kS/s to a 12-bit resolution giving an equivalent 160 kHz bandwidth. Real-time monitoring and data-acquisition were carried out using SeaProDAQ software [10]. Broadband medium (0.4 km) and long-range (2.5 km and 3.5 km) measurements were also made of two of the systems (data not reported on here). Additional measurements include CTD casts and bottom grab samples.

3. RESULTS

Due to the complex and differing nature of the systems recorded, an attempt to characterise the signals in both the time and frequency domain has been carried out. In the case of spectral analysis care was taken to ensure that frequency components were considered to be continuous within the analysis window so the analysis parameters were varied, where appropriate, depending on the signal type. The presented spectral levels include the acquisition system calibration factors and therefore are representative of the equivalent rms Source Pressure Level received at the hydrophone. Equivalent source levels were calculated at 1m taking into account the appropriate transmission losses. However, in the case of time variant or very short duration signals this was not possible and only an estimation of equivalent rms Sound Pressure Level is achieved. Due to variations in background noise and restrictive time no attempt was made to estimate the long-term *(>1 hour)* total broadband energy transmitted each of the system.

3.1. dB Plus II (AIRMAR)

The AIRMAR (dB Plus II) generates a sequence of pulsed sinusoidal tonal bursts with a fundamental frequency around 10.3 kHz tonal, Fig. 1 *(upper panel*). Each tonal burst is around 1.4 ms duration with 40 ms spacing, Fig.1 (*lower panel*). A 2.25 s long sequence is then formed from 57-58 tone bursts. The sequence is then repeated with a ~50% duty cycle allowing an approximate 2 s quiet period. Typical deployment involves four transmitters each being fired in turn, each with a 2 s quiet period.

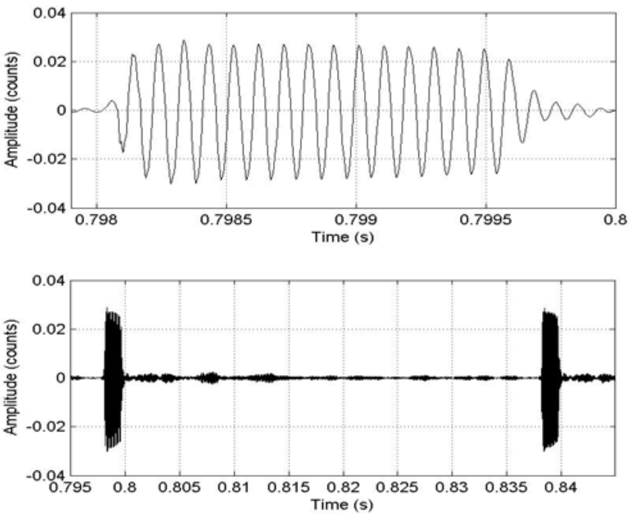

Fig. 1: (dB Plus II) AIRMAR (upper panel:10.3 kHz single tone burst, lower panel: sequence of tone bursts).

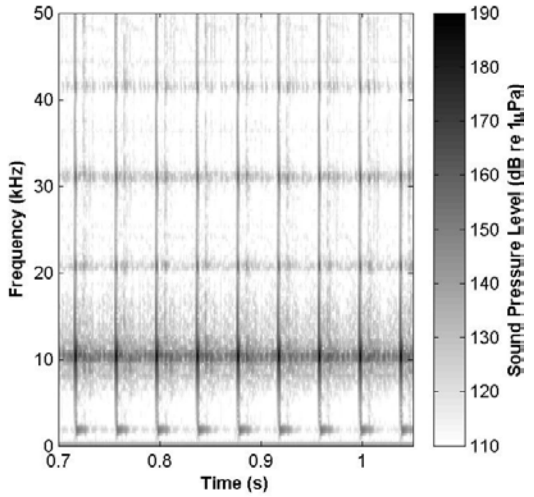

Fig. 2: AIRMAR spectral response (transmitter range 2 m).

Fig. 2. Shows the spectral response of a sequence of tonal burst. The peak frequency response is at 10.3 kHz with an equivalent source level of 192 dB re 1µPa @ 1m (± 1 dB). Additional evenly spaced harmonic components of the fundamental frequency are evident at equivalent source levels of greater than 145 dB re 1µPa @ 1m (± 1 dB) up to 103 kHz.

3.2. Silent Scrammer (ACE AQUATEC)

Fig. 3. (*lower panel*) shows a sequence containing all possible pulses. Actual transmissions are a random selection of the 28 pulses shown. The randomised sequences are transmitted with a 50% duty cycle for a 5 s period. Each pulse is formed from two or more continuous tonal components (*upper panel*) producing a closely spaced *comb* type signal. The relative length of the pulses uniformly shortens from around 14 ms to 3.3 ms followed with an up-shift in the frequency of the tonal components and their equivalent distribution to each other. Inter-pulse timing varies from 33.2 ms – 48.5 ms during the sequence related to the pulse length. Fig. 4. shows the frequency–time distribution for the entire sequence. Due to the spread of the tonal components and additional harmonics and inter-modulation products signal levels > 165 dB re 1µPa @ 1m at 30 kHz and components > 145 dB re 1µPa @ 1m at 70 kHz were observed. Fig. 5. represents the maximum observed source level for each pulse with its equivalent peak level frequency. The vertical bars represent the frequency distribution of the peak (circle) and first

two (pulses 1-13) first (pulses 14-23) major harmonic and fundamental tonal components. Pulse 19 shows the maximum observed source levels of 193 dB re 1µPa @ 1m (± 1 dB) for a 10 kHz tonal signal. In the case of the first five pulses the peak level is in the first harmonic. Individual peak level frequency components range from 5.6 kHz to 17.8 kHz.

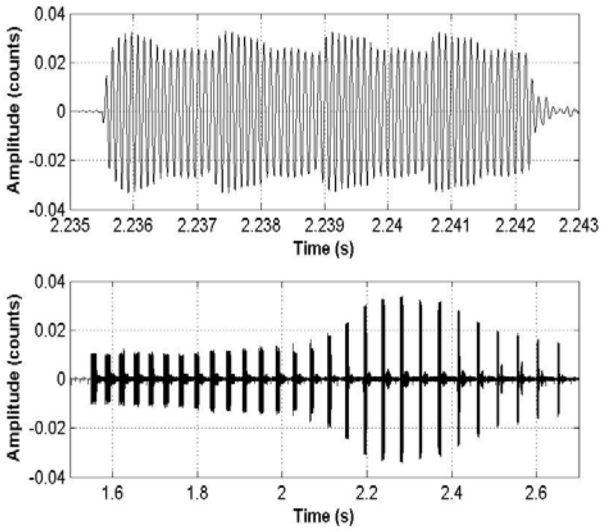

Fig. 3: (Silent Scrammer) ACE AQUATEC (upper panel: single tone burst [No.20], lower panel: sequence of complex tone bursts).

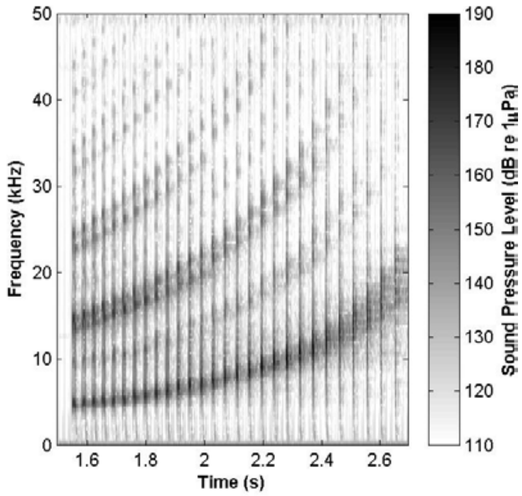

Fig. 4: Spectrogram Silent Scrammer sequence (transmitter range 2 m).

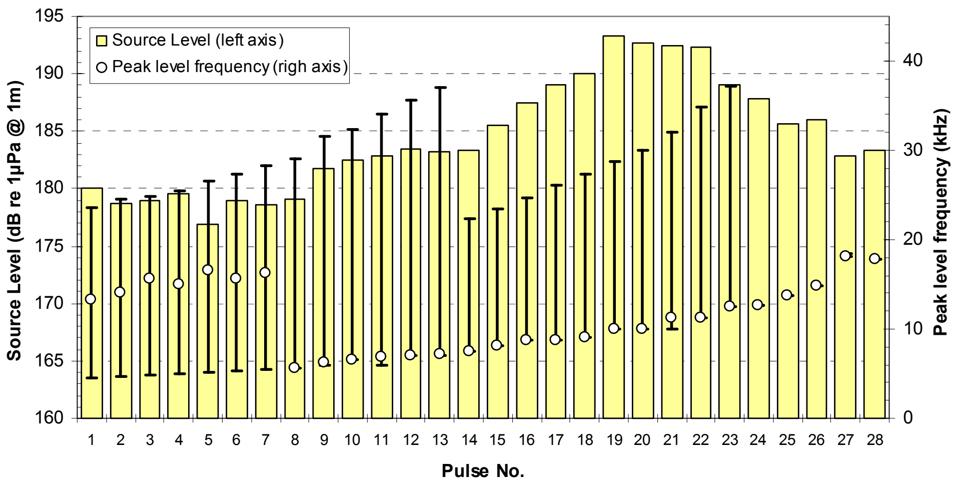

Fig.5: (Silent Scrammer) Source Level at peak level frequency for each sequence pulse.

3.3. Type DSMS - 4 (TERECOS)

The TERECOS system deploys a complex series of multi-frequency components with a high degree of randomness in the sequence timing. The system operates in four different programs. **Program 1:** Sequence (Seq.1) of repetitive five segment (16 ms duration) continuous tonal blocks forming an up and down frequency sweep. **Program 2:** *Randomly* timed sequence of continuous and time variant multi-component tonal blocks. **Program 3:** Sequences (Seq.2) of eight segment (8 ms duration) continuous tonal blocks forming an up and down frequency sweep combined with variable continuous multi-component tonal blocks.

Program 4: *Randomly* timed combined sequence of Seq.1, Seq.2 tonal blocks, continuous multi-component tonal blocks and time variant multi-component tonal blocks.

Seq. 1 has fundamental frequencies ranging from 1.8 kHz - 3.8 kHz with uniformly distributed harmonic components. The maximum levels were often seen in the second and third harmonic components with a maximum observed source level of 177 dB re 1μPa @ 1m (± 1 dB) at 6.6 kHz with no equivalent source levels of greater than 146 dB re 1μPa @ 1m at frequencies above 27 kHz. Similarly, Seq.2 has fundamental frequencies ranging from 2.4 kHz – 6.0 kHz again with uniformly distributed harmonics and maximum observed source level of 178 dB re 1μPa @ 1m (± 1 dB) at 4.9 kHz. The maximum source levels and equivalent frequency components for each segment for Seq.1 & 2 signal types are shown in Fig.6. The vertical bars represent the frequency distribution of the fundamental and the 1st four harmonics and the circles the peak level frequency. Highly *randomised* quiet periods were observed in each of the programs with different combinations of the sequence signal type during the transmission phase. Due to the randomization the *effective* duty cycle between sequences was not quantifiable.

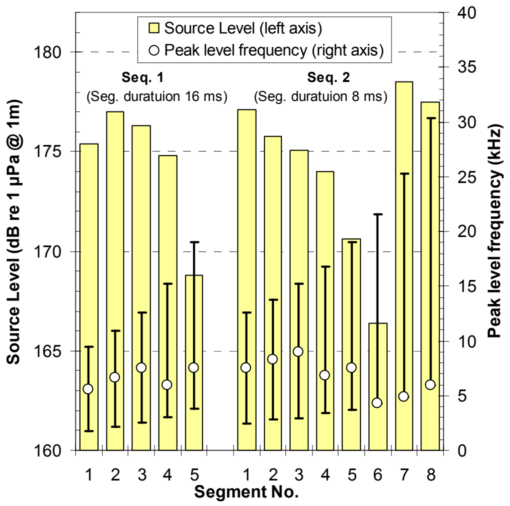

Fig. 6:(DSMS-4) TERECOS Seq.1 & Seq.2 maximum source level and peak level frequency distribution.

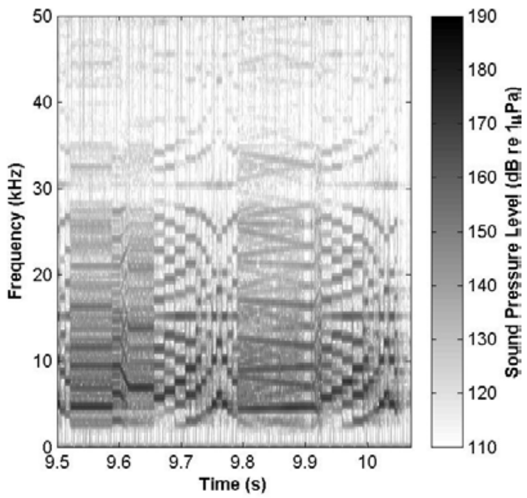

Fig.7: Combined Seq.1 & Seq.2 with continuous and time variant multi-component tonal blocks (transmitter range 2 m).

Fig. 7. shows an example of the time and frequency distribution of a combined signal containing Seq.1 and Seq.2 with both multi-component continuous tonal and time variant tonals. Two multi-component continuous tonals were observed with a peak level frequency of 4.7 kHz and 6.8 kHz with equivalent source level of 179 dB re 1μPa @ 1m (± 1 dB) and 178 dB re 1μPa @ 1m (± 1 dB) respectively. Both contain complex multiple frequency components with a broad energy distribution away from the peak level tonal component with equivalent peak source levels of less than 145 dB re 1μPa @ 1m for frequencies above 27 kHz. In addition, examples of the complex time variant signals can be seen, these appear similar in total energy distribution and maximum observed source level to the previously described tonals with the addition of complex time varying components.

4. SUMMARY

All three CAADs employ very different signalling methods resulting in complex and wide ranging spectral and temporal contents. The TERECOS has the lowest maximum observed source level. This is below the arbitrary 185 dB re 1μPa @ 1m limit stated for an Acoustic Deterrent Device [2]. The AIRMAR and AQUATEC systems utilize short tone burst sequences of pulse duration between 1.4 ms and 14 ms with at least a 50% duty cycle. All three systems have measurable and varied spectral content away from the discussed peak level frequencies.

5. ACKNOWLEDGEMENTS

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