# FEASIBILITY AND ACCURACY OF PREDICTION OF OCEAN NOISE ON A SHORT-TIME SCALE

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**Abstract:** *This study aims to examine the feasibility and accuracy of ocean ambient noise models to predict underwater noise spectra in a statistical way on a relatively short time scale from an hour to one day. The area around Perth Canyon west of Rottnest Island in Western Australia was chosen to verify a composite regional model of ocean noise. The model comprises components of physical origin, such as wind, sounds of great whales and fish choruses as biological components, and ship noise. Meteorological noise components are modelled using data from a weather station on Rottnest Island and models of wind driven underwater noise. Ship noise is modeled using Automatic Identification System data, including vessels' type, size, position and speed, typical acoustic signatures of a few most common ship types, such as tanker, cargo and passenger ships and some smaller vessels, and underwater sound transmission models. The regional model of noise from whale calls was built using data on seasonal variations in the presence of great whales in the area and spectra of their typical sounds. Fish noise and its diel and seasonal variations linked to the sunset and sunrise times were modelled using data of long-term underwater noise measurements made in the area. Modelling predictions were compared with ocean noise measurements conducted in this area for nearly 10 years within the Integrated Marine Observing System program. The comparison has demonstrated that the model is capable of predicting the 50% percentile spectrum levels of ocean noise in 1/3-octave bands within a few decibels on a daily basis.*

**Keywords:** *Ocean ambient noise, short time scale model, statistics of noise spectrum level*

## 1. INTRODUCTION

This modelling study aims to develop means for predict spectrum levels of ocean ambient noise in a statistical way on a relatively short-time scale from several hours to a few days, using (1) empirical models of wind and rain driven underwater noise, which assimilate meteorological data from the nearest weather station, weather forecasts or models, (2) models of seasonal and diel variations of noises from marine animals, e.g. fish and whales, typical for the area of interest and (3) a model of ship noise assimilating data from the Automated Information System (AIS) for marine traffic.

The area around Perth Canyon west of Rottnest Island was chosen to develop and validate the predictive model of ocean noise because (1) sea noise data have been collected in this area nearly continuously from 2009 as part of the Integrated Marine Observing System (IMOS, http://imos.org.au/facilities/nationalmooringnetwork/acousticobservatories/) and (2) meteorological data (wind speed and precipitation) are available from the Rottnest Island weather station, which is about 50 km away from the acoustic recording site (Fig. 1).

All sea noise recordings at the IMOS passive acoustic observation site (Fig. 1) were made using autonomous underwater sound recorders designed and built at the Centre for Marine Science and Technology (CMST), Curtin University, and set on the seafloor at a sea depth of about 430-450 m. The recorders were programmed to make 300 s to 500 s long recordings at a sampling frequency of 6 kHz repeated with 900 s intervals.

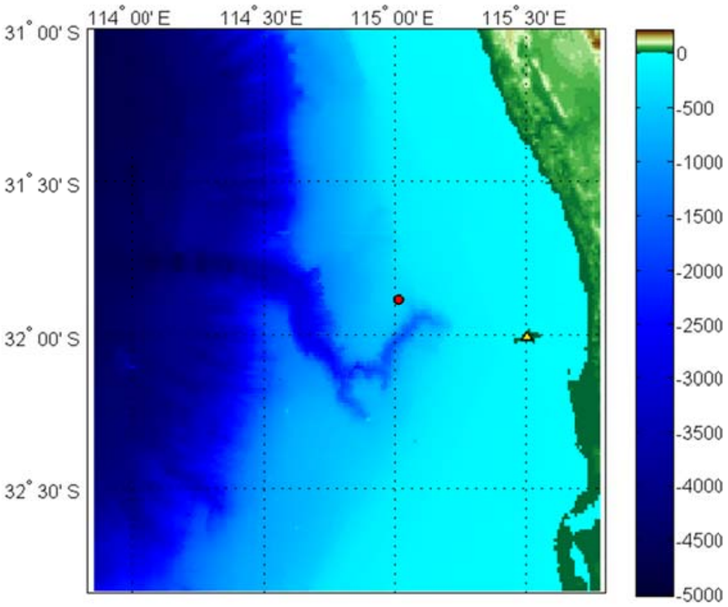

*Fig. 1: Bathymetry around the Perth Canyon area. The red dot shows the location of the IMOS acoustic site and the yellow triangle indicates the location of the Rottnest Island weather station.*

Section 2 of the paper presents a model of wind driven underwater noise. Underwater noise from rain was also modelled but not considered in this paper. Section 3 introduces models of noises of biological origin observed in the study area. In particular, the contribution of regular evening fish choruses and sounds from pygmy blue whales to the local underwater soundscape is modelled. The method to model underwater noise from vessels of various classes and speed cruising across the study area off Rottnest Island is considered in Section 4. Numerical predictions from a composite model of wind driven, biological and shipping underwater noises are compared with measurement data in Section 5.

## 2. WIND DRIVEN NOISE

The model of spectral levels of wind driven noise suggested by Doug Cato [1] was employed in the composite underwater noise prediction model. One IMOS dataset of underwater acoustic recording collected in 2016 was chosen to perform a more accurate analysis of the correlation between spectral levels of underwater noise and wind speed. The entire set was manually reviewed to localise time periods when sources of underwater noise other than wind and rain did not noticeably contribute to underwater noise spectra above 100 Hz. The Power Spectrum Density (PSD) levels of sea noise measured during those periods were selected for further analysis. As a result, the correlation coefficient of underwater noise level in a broad, 200 Hz – 3 kHz frequency band and wind speed has increased up to nearly 0.8 compared to approximately 0.55 obtained for all sea noise recordings in the dataset.

Then the selected noise spectra were clustered by the wind speed data measured at the same time at the weather station on Rottnest Island and falling within ranges of 5±2.5 knot (kt.), 10±2.5 kt., 20±2.5 kt. and 30±2.5 kt. As a result, approximately 2,000, 5,000 and 3,000 sea noise PSDs were found for the 5, 10 and 20-kt ranges respectively and about 400 for the 30-kt range. The mean 1/3-octave PSD levels and their standard deviation are shown for four wind speed ranges in the error-bar plot in the left panel of Fig. 2. As one can see, Cato's model accurately predicts the PSD levels at higher wind speeds of 20 to 30 kt. At lower wind speeds, the prediction is more or less accurate only above frequencies of about 100 Hz (10 kt.) and 200 Hz (5 kt.). Below those frequencies, the contribution of underwater noise of nondescript character, such as cumulative low-frequency noise from distant shipping and great whales, becomes significant compared to the wind driven noise.

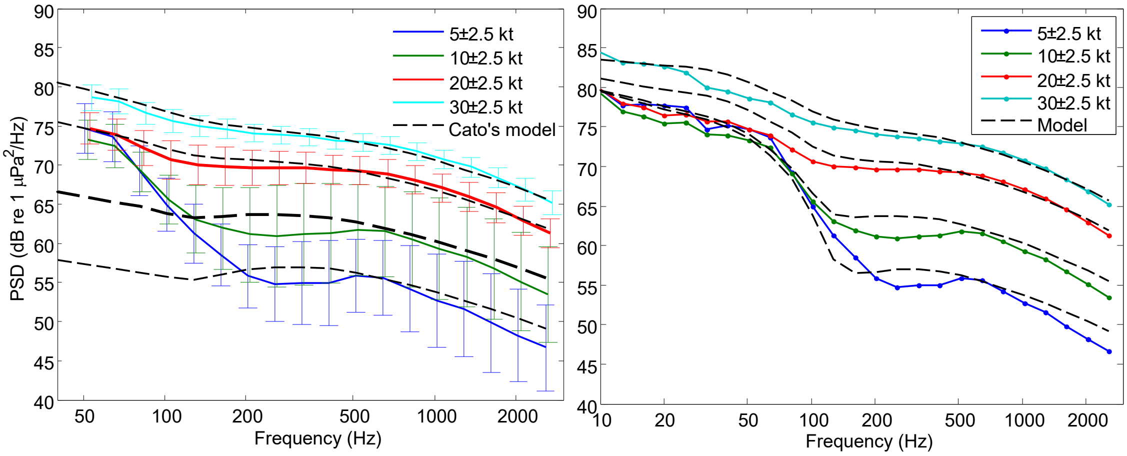

*Fig. 2: (left panel) mean values and standard deviation of PSD levels of sea noise measured at the IMOS Perth Canyon site at four magnitude ranges of wind speed measured at the Rottnest Island weather station; (right panel) mean values of PSD levels and their predictions from the composite two-component model.*

This nondescript low-frequency noise is persistent at any particular part of the ocean, although its spectral levels may gradually (seasonally and/or inter-annual) vary with time, e.g. due to changes in the ship traffic intensity. It is difficult to define the statistics of spectral levels of nondescript noise and its long-term changes in the nearly permanent presence of other sources of underwater noise. Therefore the spectrum level model of the nondescript noise was assumed to be such as it could approximate PSD of sea noise observed at lowest wind speeds. We assume that the resulting PSD of sea noise is:

$$S = S_B(f) + 10^{SL_C(f)/10}\ , \qquad (1)$$

where $S_B(f)$ is PSD of the nondescript low-frequency noise and $SL_C(f\ )$ is the PSD level predicted by Cato's model for wind driven noise. A model of 1/3-octave spectrum level of nondescript noise was derived from the PSD of sea noise measured at the lowest wind speed.

The right panel of Fig. 2 demonstrates a comparison of the predictions from the model of spectrum level comprising nondescript and wind driven noise (10log($S$) in Eq. 1) and the measured mean spectrum levels of sea noise in four different ranges of wind speed variation. The difference between the measured and modelled levels does not exceed 4 dB in any 1/3-octabe band. The composite two component noise model tends to overestimate the noise level below ~100 Hz at moderate wind speeds of about 20 kt., which is due to the contribution from the nondescript noise model.

## 3. NOISES OF BIOLOGICAL ORIGIN

Baleen whales of different species and fish are the major sources of underwater noise of biological origin observed in the Perth Canyon area. Toothed whales can also be found in this area, but their contribution to the local soundscape is minor.

Noticeable noise from fish sound is present in the ocean ambient noise in the study area only in the form of evening fish choruses which are produced by the same but as yet uncertain fish species in a frequency band of 2-3 kHz [2].

The baleen whales observed acoustically in the area are: pygmy blue whales (PBW) of the eastern Indian Ocean population, humpback whales, fin whales, Antarctic blue whales and an as yet unidentified whale producing the so-called “spot” call [3]. Noise from PBW sounds can be observed in sea noise data collected in this area from December to early July, dominating in ambient noise in a frequency band from about 17 Hz to 70 Hz from February to late-June. In the sea noise model presented in this report, only noise from PBW sounds is included, because it is most significant at low frequencies in the local underwater soundscape and lasts over a prolonged time period of more than six months.

It has been noticed that the start time of evening fish choruses is strongly linked to the sunset time. The start time of the fish chorus is around 1 hour after sunset (see Fig. 5 in [2]). The sound intensity of fish chorus varies slightly over time within each year, but the variation pattern is more or less consistent between different years, with the maximum intensity observed in May-June and the minimum intensity in September-October (Fig. 3). The duration of choruses and hence the variation of sound intensity within each chorus vary noticeably (see Fig. 8 [2]).

There are many factors that may affect the start time and duration of fish choruses, including the moon phase, which are considered in [2]. However, the yearly mean pattern of the variation of sound intensity during the chorus seems to be similar in different years (Fig. 3, right panel). This observation can be used in a simplified model of fish chorus noise present in the Perth Canyon area. The model suggested here is based on the following assumptions:

1) The chorus always starts 1 hour after sunset;
2) The pattern of sound intensity vs time in each chorus does not vary;
3) The intra-annual variation of chorus intensity is taken into consideration using monthly mean values measured in 2016.
4) The sound level and its variation are similar in two 1/3-octave bands with the central frequencies of about 2 kHz and 2.6 kHz.

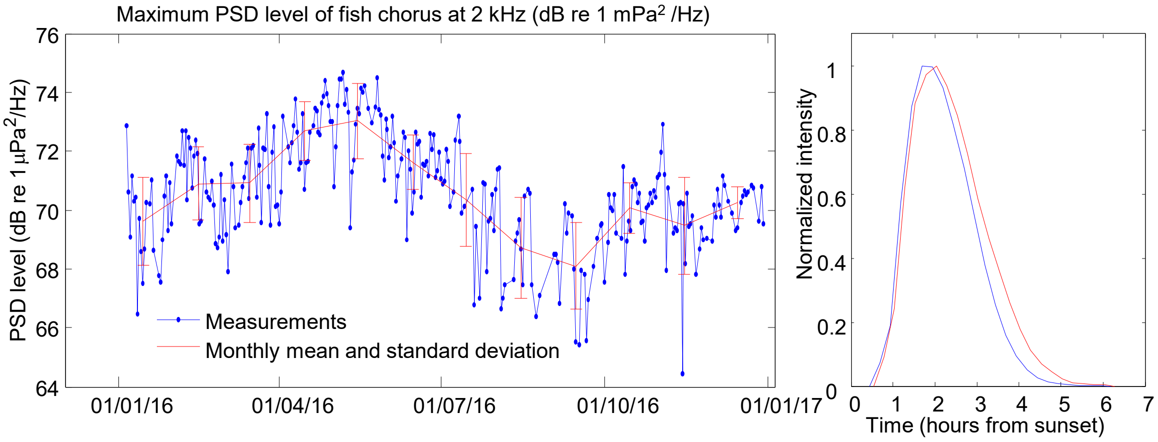

*Fig. 3: (left panel) intra-annual variation of the PSD level of evening fish choruses in a 1/3-octave band around 2 kHz observed in 2016.The blue line and dots show daily mean levels and the red line and error bars show the monthly mean and standard deviation respectively. Correction for background noise was made using sea noise intensity measured in the same frequency bands right before each chorus; (right panel) normalised envelope of fish chorus intensity vs time since sunset averaged over sea noise recordings made in 2014 (blue) and 2016 (red).*

PBWs produce stereotypic sounds in a series of themes forming a long lasting song [4]. Each theme may consist of three or two so-called units (or individual sounds). Unit 2 is always present in a theme. A theme consisting of only unit 2 was recently observed in PBWs songs, but it is relatively rare. The power density spectrum of units 2 and 3 is representative of all three units in 1/3-octave bands. This spectrum was chosen as a reference one for further modelling of PBW noise. The model of PBW noise and its variation over time is built using the following approach:

1) PBW calls were detected using an automatic detector of unit 2 [5] during the entire year of 2016. In addition to logging the detection time, the detector also measures the received RMS pressure of sound in each detected unit 2;
2) Assuming the relationship between the sound intensity of units 2 and 3 in each detected call to be similar to calls of different intensity of unit 2 received at different ranges from vocalising whales, the $PSD$ of each detected call ($n$) was calculated using the following formula:

   $$PSD(n) = PSD_{ref} \cdot [P(n)/P_{ref}]^2,$$

   where $PSD_{ref}$ is the PSD of the reference signal in linear units (μPa²/Hz), $P(n)$ is the RMS pressure of detected call $n$ and $P_{ref}$ is the RMS pressure of unit 2 in the reference signal;
3) An average $\langle PSD(n) \rangle$ was calculated for each calendar day in 2016.

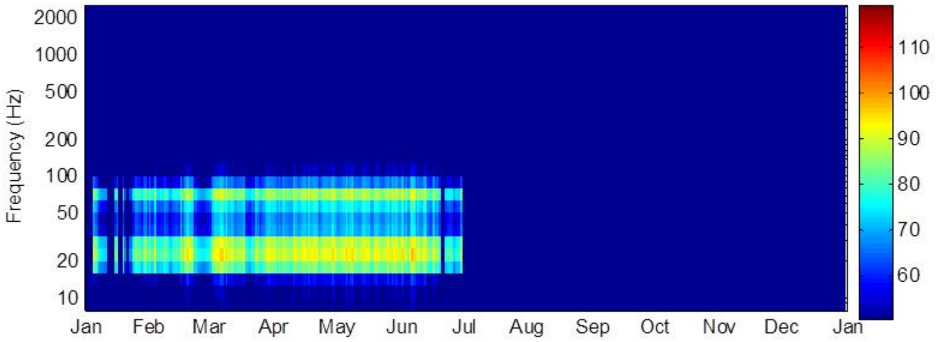

*Fig. 4: Daily average 1/3- octave PSD levels of PBW sound in 2016, used as a PBW noise model for sea noise prediction.*

The resulting model is shown in Fig. 4. It is important to notice that the model does not imply any contribution of PBW sounds to ocean ambient noise in December. This took place because no true detections of PBW sounds were made in December 2016; however, some datasets collected in the previous years showed the presence of PBW in the study area in December and even in late November.

## 4. SHIP NOISE

In the model presented here, ship noise and its spectra are predicted using the following approach:

1) AIS data for marine traffic in the Perth offshore area were acquired for a time period from August 2012 to October 2016. There were more than 110,000 records representing more than 9,000 different vessels found within a 50 km radius from the acoustic observation location.
2) The presence and intensity of ship noise in ocean noise data were associated with the presence of vessels in the AIS dataset. For selected ship passages, when noise from a single vessel dominated in a sea noise recording, the PSD of ship noise received at different ranges was calculated and corrected for the PSD of background noise measured in the absence of ships within the search area. The vessel ID (MMSI), type, length and speed were associated with the measured PSD. A total of 110 passages of ships at distances from about 1 km to 15 km were selected representing 95 different vessels: cargo ships of different length, including vehicle carriers; tanker ships of different length; passenger ships; various tugs; and search and rescue (SAR) vessels.
3) Sound transmission loss was numerically modelled in 1/3-octave frequency bands from 8 Hz to 2.6 kHz (central frequency). The modelling was carried out using a parabolic equation (PE) solution implemented in RAMGeo (http://cmst.curtin.edu.au/products/underwater/) with 8 Padé coefficients applied to more accurately model the transmission loss at short distances. The vertical sound speed profiles in the water column were calculated using the World Ocean Atlas 2013 yearly mean climatology data of water temperature and salinity (https://www.nodc.noaa.gov/OC5/woa13/). The seafloor was modelled as medium grain sand with the sound speed of 1770 m/s, density of 1850 kg/m$^3$ and attenuation of 0.47 dB/$\lambda$. The sound receiver was placed on the seafloor (sea depth of 436 m), as in the measurements. The sound source was placed at 5 m below the sea surface, which is a typical mean source depth for modelling sound emission from larger vessels. The sound propagation environment was assumed to be range and azimuth independent for simplicity.
4) The sound source PSD was calculated for each of 95 vessels selected in (2), using the PSD of received noise signals and the modelled transmission losses. Some ships had a number of sound source PSDs corresponding to different passages with different cruising speeds.
5) The ship noise prediction model firstly searches for vessels with the same type and similar length as those in the catalogue of 95 vessels with the estimated source PSD within the observation time period and the search radius of 25 km. If a vessel of the same type, similar length and speed is found, then its source PSD is used for forward sound transmission modelling and prediction of the received PSD of ship noise. If it is not present within the search time and distance frames, then a vessel of similar length and speed is chosen from the catalogue to carry out the forward sound transmission modelling using the AIS data on vessel's location.

## 5. COMPOSITE MODEL: COMPARISON WITH MEASUREMENT DATA

The composite model incorporates all modelled components in the same way as formulated in Eq. 1:

$$SL = 10log\left[SL_B(f) + 10^{SL_C(f,t)/10} + 10^{SL_R(f,t)/10} + 10^{SL_F(f,t)/10} + 10^{SL_{PBW}(f,t)/10} + 10^{SL_S(f,t)/10}\right]$$

where $SL_F\,(f,t)$ is the PSD level of fish chorus, $SL_{PBW}\,(f,t)$ is the PSD level of PBW noise and $SL_F\,(f,t)$ is the PSD level of ship noise predicted versus frequency $f$ and time $t$.

An example of the composite noise model predictions compared to measurement results is shown in Fig. 5.

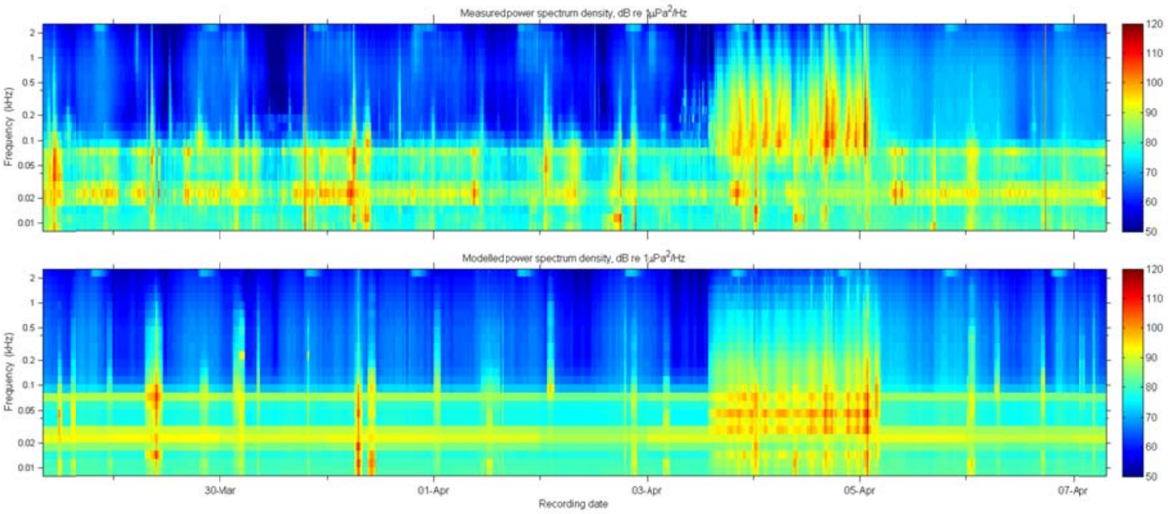

*Fig. 5: Measured (top) and modelled (bottom) long-time (5 min) average spectrograms of sea noise in a 10-day period in March-April 2016*

The agreement of the noise spectrum levels and their variation over time is reasonably good in general, except for minor discrepancies. For example, the spectra of the long lasting ship noise from the slowly moving vessels seen in Fig. 5 are somewhat different in the measured and modelled results. This is due to the use of another vessel of similar class and length in the model, which might have a different source spectrum. Also the model does not predict time periods of high intensity noise from PBW calls. This takes place because the PBW noise is modelled on a daily mean basis, so that any short-term presence of intense PBW sounds results in PBW noise of longer duration but lower intensity in the model.

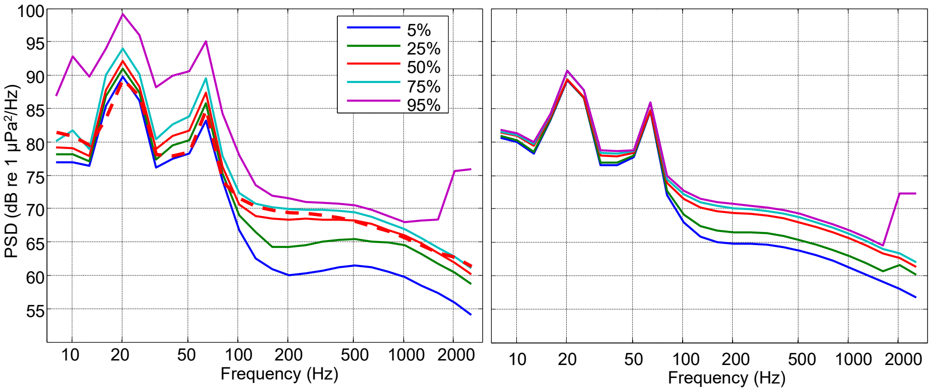

*Fig. 6: Measured (left) and modelled (right) PSD levels of sea noise at five different percentile values for a 1-day time period in May 2014. The median values (50%) of the measured (solid red) and modelled (dashed red) PSD levels are compared in the left panel.*

PSD levels of sea noise of different percentile values measured and modelled for one day in May 2014 are compared in Fig. 6. The median (50%) spectrum levels in measurement and modelling results differ from each other by less than 2 dB. At the highest percentile value of 95%, the difference is noticeably larger at frequencies below 100 Hz. This is because the model is based on daily average noise levels from PBW calls, whereas some measurements made every 15 min contained sounds of high intensity from calls produced by PBWs located nearby.

## 6. CONCLUSIONS

The composite model of underwater noise and its spectra developed for the Perth Canyon area west of Rottnest Island in Western Australia and presented in this paper includes noises generated by wind, fish choruses, blue whale sounds and noise from ship traffic. It demonstrates reasonably accurate predictions of spectral levels of sea noise in a frequency band from 8 Hz to 3 kHz, especially for a median percentile value of 50%. However, it requires further, more comprehensive testing using some other data sets of sea noise measurements in the study area to make more confident conclusions with respect to model performance.

Underwater noise from humpback whale songs needs to be included in the next generation of the model, as it contributes considerably into the local soundscape at frequencies from about 50 Hz to 700-800 Hz from mid-June to mid-October. This is the main challenge for the further development of the model, as the approach applied to the sounds from pygmy blue whales is not suitable for the noise from humpback whale songs. In contrast to the PBW calls, the sounds produced in humpback whale songs are much less stereotypic and, moreover, vary considerably over years. Hence, it is very difficult (and likely impossible) to suggest a universal automatic detector of humpback whale sounds.

## 7. ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the Maritime Division of the Defence Science and Technology Group.

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