Using acoustics to study biological activity in the Perth Canyon, Western Australia

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ABSTRACT
The Perth Canyon, off the coast of Western Australia, is a hotspot for biological activity, high biomass and biodiversity. It is also an area that is still relatively understudied. In this study, combinations of passive and active acoustical methodologies were used to study biological activity in the Canyon; and in particular, diel vertical migration. Data from sea noise loggers and Acoustical Doppler Current Profilers (ADCPs) mounted along the Perth Canyon were collected as part of the Integrated Marine Observing System (IMOS) program. The sea noise data recorded post-sunset fish choruses and the backscatter logged by the ADCP deployments measured increased scattering in the upper layers of the waters between sunset and sunrise. These two types of data provide an insight into secondary productivity in the Perth Canyon. This study revealed a correlation between the fish chorus noise level and the increase in scattering in the water column. Future research is planned to determine the sources and the reason(s) for the temporal variation of these phenomena.

1. INTRODUCTION
The Perth Canyon is located off the coast of Western Australia. This deep submarine canyon creates an area of concentrated nutrients with the capacity to support high biomass and biodiversity (Rennie et al., 2009). Our study investigates Diel Vertical Migration (DVM). DVM is the vertical movement of certain plankton and nekton species within the water column. This movement is characterized by the plankton and nekton ascending to the epipelagic zone at dusk in order to feed and then descending back to the more protected mesopelagic zone before dawn (Webster et al., 2013). Nocturnal planktivorous fish follow the vertical movement of the plankton in order to take advantage of the abundant food source available during these migrations (Coyle et al., 2013). Many of these fish species produce sound by resonating their swim bladders or by rubbing bony body structures against each other (Wall et al., 2014). The accumulation of the noise produced by large aggregations of these animals are widely known as fish choruses (McCauley 2012). Evening fish choruses have been previously observed in the Perth Canyon by Jones et al. (1992), Erbe et al., (2015) and McCauley and Cato (in press) within the 1840 – 2520 Hz bandwidth (3 dB downpoints, McCauley and Cato, in press). While the species contributing to this chorus have not yet been confirmed, there is strong evidence that they may be produced by species of fish from the family Myctophidae (McCauley and Cato, in press).

Myctophidae are mesopelagic fishes which dominate the fish assemblages of oceanic waters in temperate and tropical areas (Olivar et al. 2012). These fish have been found to be responsible for sound scattering layers at various depths across the world's oceans (Dypvik and Kaartvedt 2013). Certain Myctophidae species also exhibit DVM (Matsuura et al., 2012, Hudson et al., 2014). Many of these species have been found to feed on crustacean and gelatinous zooplankton, pteropods and micronekton which migrate to surface waters to feed on phytoplankton (Hudson et al., 2014, Battaglia et al., 2016). Many Myctophidae have a gas filled swim bladder and musculature attached to the swimbladder (Marshall, 1960) which potentially enable them to produce sounds. The reason and conditions for the Perth Canyon chorus is unknown, although there is a possibility of a linkage between noise production and feeding behaviour (McCauley and Cato, in press). The feeding behaviour of these animals reflect the productivity of the area (Pepin 2013). Despite the important ecological role that these fish play in trophic energy transfer, little quantitative data exists to describe the Myctophidae contribution to carbon cycling as a secondary consumer.

Fish choruses and DVM have been recorded using ADCP or sea noise recordings in a number of studies worldwide, including Ashjian et al., (1998), Ressler (2002) and Fernández-Urruzola et al., (2014).

These studies have utilised the backscatter data collected by ADCPs to study the behaviour of plankton and nekton over large spatial and temporal scales. Rennie et al., (2009), McCauley (2012) and McCauley and Cato (in press) used underwater noise recordings from sea noise loggers to identify and describe fish choruses off the coasts of Australia. While ADCPs and sea noise loggers are successful acoustical tools in their own right a combination of the data from these sources may give a more complete insight into DVM and biological behaviour and provide supporting evidence for the chorus source. In this study an ADCP and sea noise logger combination was utilised to examine the relationship between DVM and fish choruses in the Perth Canyon. It was the aim of this study to analyse long-term time series acoustical data collected by sea noise loggers and ADCPs from the Australian Integrated Marine Observing System (IMOS) to identify any correlation between the periods of high fish noise levels and the increase in the backscattering intensity in the upper layer of the water column. A confirmation of a correlation between these two events will provide a baseline for further study to confirm the sources and reason(s) for the temporal variation of this biological activity in an effort to quantify and describe secondary productivity in the Perth Canyon.

2. METHODOLOGY

2.1 Study Site

The Perth Canyon is a deep submarine canyon 48 kilometres west of the Perth coast in Western Australia (Huang et al. 2014). The canyon is approximately 100 km in length and varies in depth from 200 to 4000 m (Rennie et al. 2009). The Perth Canyon is considered a main area of the Western Australian continental shelf where deep eddies are generated (Rennie et al. 2006, Rennie et al. 2007). This is a result of the canyon's strong interaction with the Leeuwin Undercurrent which generates upwelling as well as eddies at depths ranging from 400 to 800 m below the surface (Huang et al. 2014).

2.2 Sampling

The acoustical data for this study was sourced from the Integrated Marine Observing System (IMOS) National Mooring Network (Lynch et al., 2010), Passive Acoustic Facility which uses CMST-DSTO sea noise recorders developed at Curtin University. Data was collected from 13 sea noise loggers and six ADCP (RDI Workhorse Long Ranger operating at 75 kHz) deployments mounted along the seafloor of the Perth Canyon (Figure 1). Sea noise measurements were collected at 15 minute intervals during long-term deployments ranging from 2010 to 2015 at a 6 kHz sample rate. Timings and lengths of deployments of the sea noise loggers and ADCPs differed as a result of requirements for other monitoring programs and projects. However, there were periods of overlap where sea noise loggers and ADCPs were collecting data at the same time. These times of overlap were separated into five sampling periods from October 2010 to September 2014 (Table 1). Only these periods of overlap were used for this study.

Table 1: Sampling periods during which measurements from both the sea noise loggers and the ADCPs overlap.

Sampling Period	Start Date	End Date
1	26th October 2010	8th May 2011
2	16th May 2012	20th June 2012
3	14th September 2012	19th March 2013
4	28th November 2013	10th April 2014
5	11th April 2014	26th September 2014

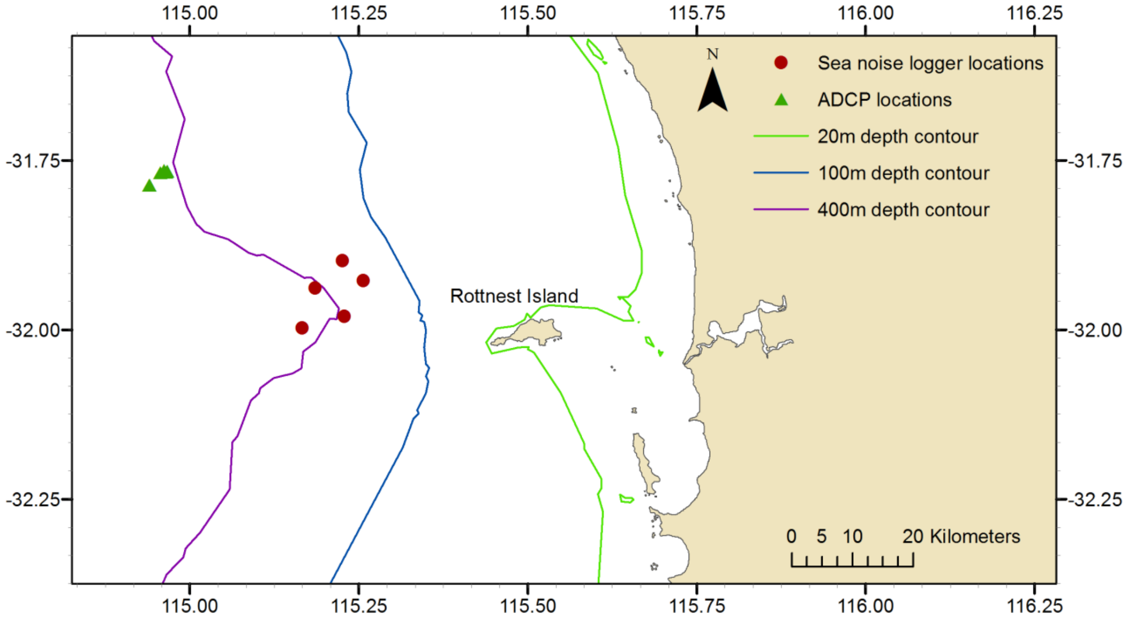

Figure 1: Location of the sea noise loggers and ADCPs deployed in the Perth Canyon off the Western Australian coast between 2010 and 2015.

Sea noise logger system response was fully calibrated by inputting white noise of a known level in series with the hydrophone, recording this in an electrically shielded and anechoic chamber, analysing the system gain with frequency, and combining this with the hydrophone sensitivity to give either the sea noise waveform in Pa or a correction for power spectral averages (frequency dependent). For each sea noise 'sample' of 200-500 s length (samples starting every 15 minutes), a time averaged power spectra was calculated using 8192 point samples (0.73 Hz resolution for 6 kHz sample rate), no overlap and a Hanning window. If extraneous noise spikes occurred within the sample these individual spectra were removed before the averaging across the sample. A pseudo 1/3 octave level was calculated by integrating across the 2 kHz 1/3-octave-band limits (1782 to 2245 Hz) and the resulting level converted to units of dB re 1 $\mu Pa^2/Hz$. The 2 kHz 1/3-octave-band was found to be the best for tracking chorus activity when using the 6 kHz sample rate (McCauley and Cato, in press). The on-board clocks of the sea noise recorders were corrected to GPS transmitted UTC time before deployment and the drift read after deployment using hardware and software, to give clock accuracy at any point in time of ± 0.25 s. All samples times used were drift corrected. Times displayed are Western Standard time or UTC + 8 hours.

2.3 ADCP processing

Calculating absolute Scattering Volume from backscatter data collected by ADCPs requires calibration (Deines 1999), however at this time some of the values needed for this calibration are unavailable. To address this problem, the influence of range needed to be removed. Removal of range dependence was achieved through correction for transmission loss and insonification volume. Transmission loss accounts for the loss in energy of sound from scattering and absorption as it travels through the water column (Lurton 2002). In a backscatter scenario (i.e. two-way travel where the source and receiver are in the same location) transmission loss is defined by Eq. 1:

$$TL = 40logR + 2\alpha R \quad (1)$$

TL= transmission loss
R= range (m)
α= absorption of energy of acoustic wave (dB/km)

The insonification volume is proportional to the range squared. So to calculate Backscatter Strength (BS) that is independent of range the Received Levels (RL), Eq. 2 can be used:

$$BS = RL + 40logR + 2\alpha R - 20logR \quad (2)$$

This reduces down to Eq. 3:

$$BS = RL + 20logR + 2\alpha R \quad (3)$$

Note this removes range dependence in an ideal case and does not take into account the actual beam pattern. So the values can still only be considered relative (rel.) backscatter strength. Figure 2 demonstrates the effect of the application of this correction, removing the influence of range on the water column (i.e. volume) backscatter data. The application of Eq. 1 normalises the effect of range until the influence of the water surface is seen at >450 m.

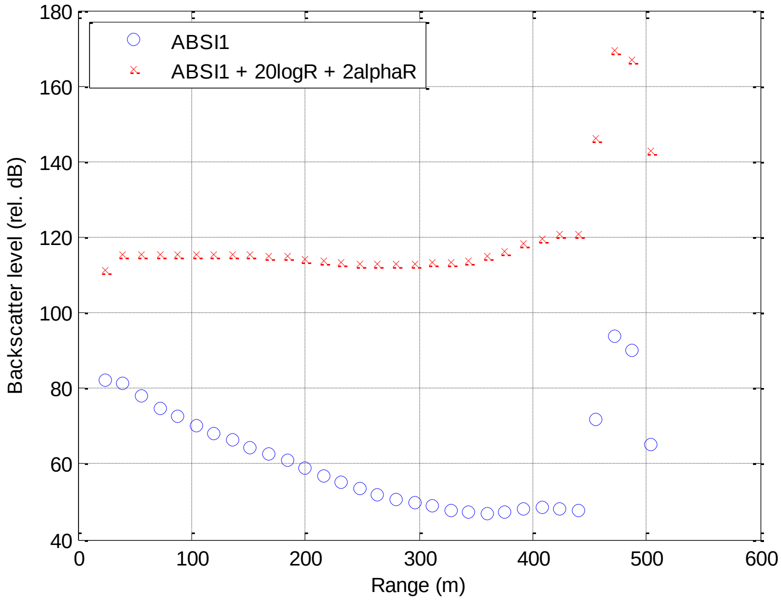

Figure 2: Mean ADCP backscatter intensity level (ABSI1) (in relative dBs) versus range (m) over a whole deployment: before (o) and after (x) correction for transmission loss

3. RESULTS

3.1 ADCP Data

Figure 3 shows the three main data streams from the ADCP: horizontal and upward seawater speed and backscatter level over a 48 hour period. Surface waves and turbulence cause the signal to saturate at the surface down to 50 m (Figure 3), this was consistent through all sampling periods. The backscatter intensity measurements (Figure 3 - bottom panel) highlights some of the scattering phenomena that have been found in the dataset. Diurnal fluctuations are clearly seen in the backscatter of the surface waters (50-200 m) at night time. In addition, scattering layers are illustrated at 200 and 400 m. These scattering layers are most likely from fish and plankton, and their presence are not captured in the seawater velocity data. The times of ascent (sunset) and descent (sunrise) of the DVM is seen in the upward seawater velocity.

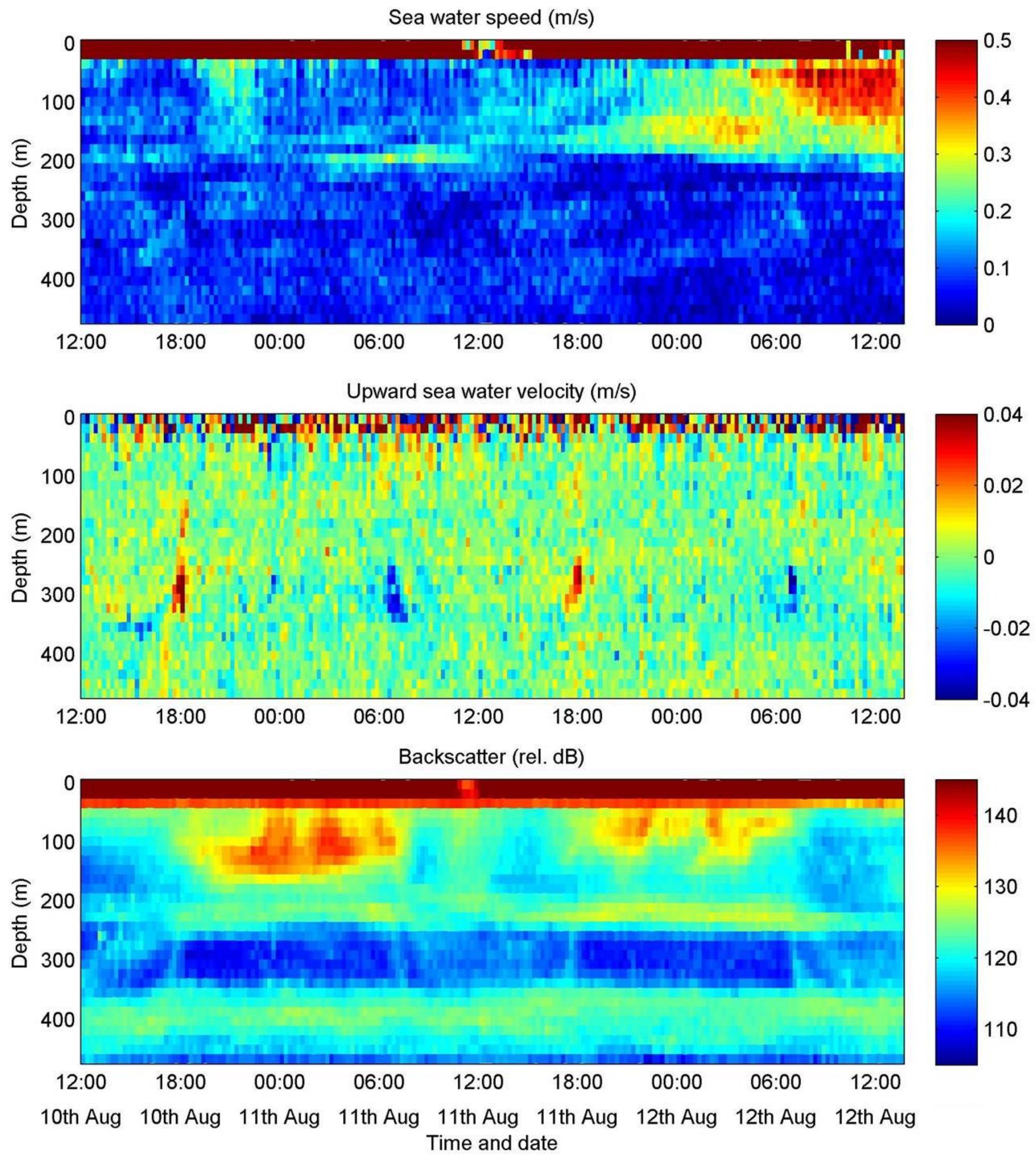

Figure 3: ADCP data including horizontal (top) and upward (middle) seawater velocity and backscatter intensity (bottom) in the water column of the Perth Canyon collected between the 10th and 12th of August 2012.

3.2 Correlation of Noise Level and Diel Vertical Migration

For this preliminary analysis, sections from the 1st and 4th sampling periods were represented, chosen randomly. Figures 4, 5 and 6 showcase a small section from a particular sampling period. They display a comparison between absolute backscatter intensity and Power Spectral Density (PSD). The PSD indicates the noise level of the fish chorus. These comparisons displayed the consistent visual correlation evident between backscatter intensity and fish chorus noise level on a daily, weekly and monthly temporal scale. The backscatter intensity and the fish chorus noise level both exhibited a distinct diurnal fluctuation. There was an increase in backscatter intensity and noise level during the evening and a decrease during the day. The most rapid increase in both events occurred at dusk (Figure 4).

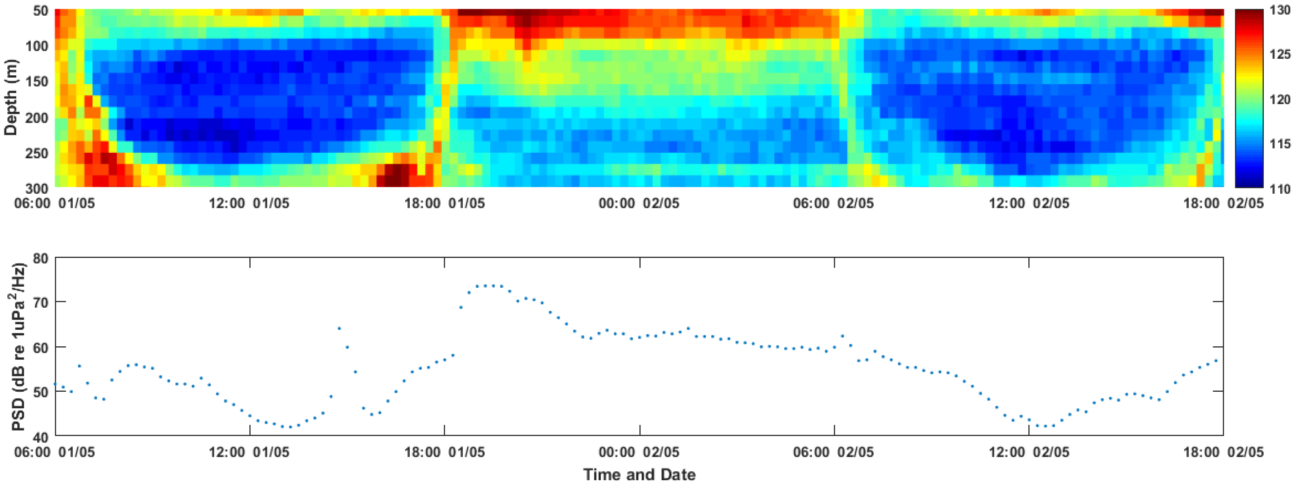

Figure 4: A comparison of the ACDP backscatter intensity of sound scattering particles from 50-250 m within the water column (top) and sea noise logger PSD level (noise) of the fish chorus identified within the 1780 – 2245 Hz frequency bandwidth (bottom) in the Perth Canyon from the 1st to the 2nd of May 2011 (times in WST).

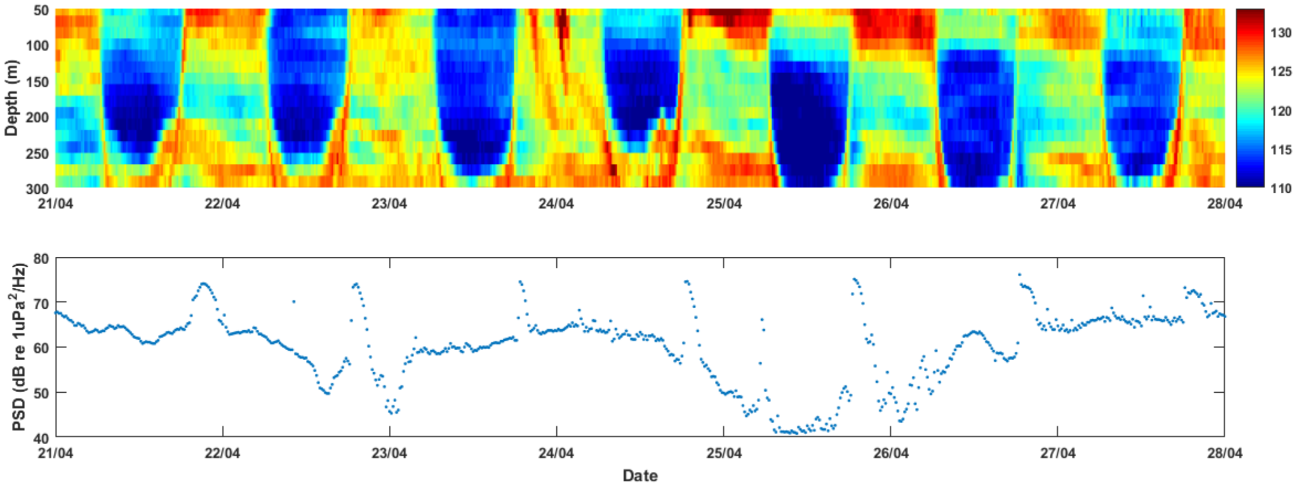

Figure 5: A comparison of the ACDP backscatter intensity of sound scattering particles from 50-250 m within the water column (top) and sea noise logger PSD level (noise) of the fish chorus identified within the 1780 – 2245 Hz frequency bandwidth (bottom) in the Perth Canyon from the 21st to the 28th of April 2011.

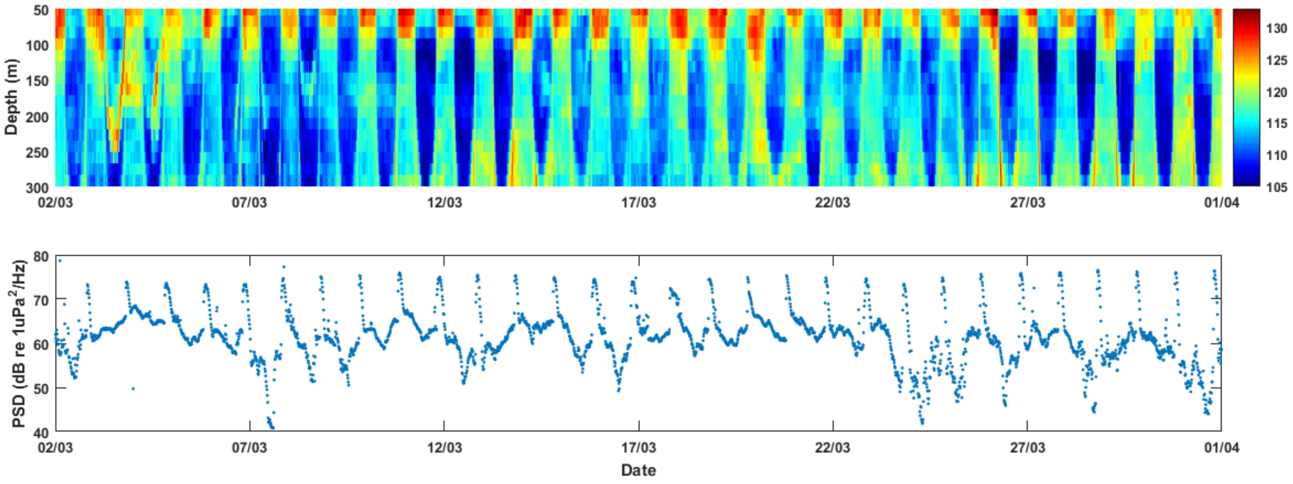

Figure 6: A comparison of the ACDP backscatter intensity of sound scattering particles from 50-250 m within the water column (top) and sea noise logger PSD level (noise) of the fish chorus identified within the 1780 – 2245 Hz frequency bandwidth in the Perth Canyon from the 2nd of March to the 1st of April 2014.

4. DISCUSSION

4.1 Perth Canyon Water Column

Water speed, upward water velocity and backscatter measurements visually describe the physical processes occurring throughout the layers of the water column in the Perth Canyon. All three ADCP data sets displayed a clear disruption of measurements within the first 50 m of the water column. This is most likely due to surface waves and turbulence causing formation of bubbles which can saturate the ADCP signal. Hence only measurements taken deeper than 50 m are discussed here.

Analysis of the backscatter data identified the presence of two deep scattering layers in the Perth Canyon at night and during the day, confirming the pattern previously reported by Rennie et al, (2009). The first was located at a depth of approximately 200 m, corresponding to the edge of the Leeuwin Current (Rennie et al., 2007) and the second ranged from 350 to 450 m.

The backscatter intensity and the level in the 2 kHz 1/3 octave band (PSD) displayed temporal variations. There was a clear increase in both, during the early evening with higher values featured during the night compared to those during the day (Figure 4). Backscatter intensity and PSD also featured sudden decreases at dawn. This type of temporal variation suggests DVM. This is congruent with the behaviour of many zooplankton and Myctophidae species which exhibit diel vertical migration (Wang et al. 2014, Battaglia et al. 2016). As speculated by McCauley and Cato, (in press) it is possible that the increase in the intensity of the fish chorus noise levels correlate with the myctophid's migration to the upper layers of the water column, possibly in order to take advantage of plentiful food sources presented by the DVM of prey species of plankton and nekton (Matsuura et al., 2012). This hypothesis is strengthened by the evidence of a clear increase in upward sea water velocity at the hours of dusk, at depths from 100 to 300 m (Figure 3), typical of the area of the water column where diel vertical migration was observed to occur.

5. CONCLUSIONS

This study has found a visual correlation that suggests the vertical migration identified by the backscatter intensity is related to the diel migration of the Deep Scattering Layer, which is in turn correlated to the timing of choruses recorded in the Perth Canyon. There is a need to carry out ground truthing to confirm the link between diel vertical migration and the choruses in the Perth Canyon and also to identify the species involved. This knowledge could increase understanding of biological processes and trophic relationships in canyon environments.

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