Evening choruses in the Perth Canyon and their potential link with Myctophidae fishes.

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Abstract

An evening chorus centered at near 2.2 kHz was detected across the years 2000 to 2014 from seabed receivers in 430-490 m depth overlooking the Perth Canyon, Western Australia. The chorus reached a maximum level typically 2.1 hours post-sunset and normally ran for 2.1 hours (between 3 dB down points). It was present at lower levels across most of the hours of darkness. Maximum chorus spectrum levels were 74-76 dB re 1µPa^2/Hz in the 2 kHz 1/3 octave band, averaging 6-12 dB and up to 30 dB greater than pre-sunset levels. The chorus displayed highest levels over April to August each year with up to 10 dB differences between seasons. The spatial extent of the chorus was not determined but exceeded the sampling range of 13-15 km offshore from the 300 m depth contour and 33 km along the 300 m depth contour. The chorus comprised short damped pulses. The most likely chorus source is considered to be fishes of the family Myctophidae foraging in the water column. The large chorus spatial extent and its apparent correlation with regions of high productivity suggest it may act as an acoustic beacon to marine fauna indicating regions of high biomass.

Keywords - ocean choruses, fish, myctophidae, bioacoustics, foraging

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I. INTRODUCTION

Choruses produced by marine fauna have long been reported from continental shelf waters. For example continental shelf fish choruses have been reported by Knudsen et al. (1948), Cato (1978), McCauley and Cato (2000), Parsons et al., (2009, 2013) and McCauley (2012), while invertebrate chorus are also commonly reported (Everest et al. 1947, Fish 1964, Castle and Kibblewhite 1975, Radford et al. 2008). Some whale species are now so abundant on their summering breeding grounds that whale calls form seasonal choruses (e.g. Au et al. 2000 for Hawaiian humpbacks or Širović et al. 2015 for blue and fin whales). In the deep ocean or along deep parts of the continental shelf slope biologically driven increases in ambient noise sustained over hours or more have been shown to be produced by blue whales at a seasonal scale in the Southern Ocean (Gavrilov et al., 2012), sperm whales (Cato, 1978) and on a daily basis by D'Spain and Batchelor (2006) for fish in southern California. Choruses produced by fish on the shelf break or deep ocean are not commonly reported in the literature, although this is probably due to a lack of sampling, lack of reporting or uncertainty of the source rather than lack of choruses.

The first published report of a biological chorus in Australasian waters is that of Cato (1969) in the Eastern Timor Sea. Wyllie (1971) reported three instances of biological choruses along the north coast of Papua New Guinea all having their highest levels at night time (up to 23 dB above expected, no-chorus ambient level). Cato (1978) describes predominantly evening choruses from three tropical locations: the eastern Indian Ocean; the Timor and Arafura Seas; and the West Pacific. These choruses had most energy between 400 Hz - 4 kHz and reached up to 30 dB above expected normal ambient levels. D'Spain and Batchelor (2006) describe a night-time chorus (spectral peaks at 1.5 kHz and between 4-5 kHz) from a site termed the "43 fathom shoal" detected at several km range using a billboard array which allowed determination of the vertical sound field structure and a bearing to source. The choruses produced strong horizontal components to the local sound field which were absent during periods of no-chorus.

Choruses typically occur when many individuals of the same species vocalise near-simultaneously in reasonably close proximity to each other (from a sound transmission perspective) to produce a cacophony of sound. There are different definitions of choruses for fishes (discussed in McCauley 2001) relating to how they impact on ambient noise measurements and if their signals overlap or not. When detected at moderate range the noise of an individual within a chorus is often lost in the general background din of the chorus, like the distant roar from a packed and vocal football stadium. Because of the generally large area the sources occur over, the transmission of chorus noise is not as for a point source and one may have to go a considerable distance from the source (at least the dimension of the area of animals making the chorus) before the chorus level begins to drop appreciably. Marine choruses may thus ensonify large radii and so areas, for example fish choruses in poor sound transmission environments have been detected at the 10's of km range scale (McCauley and Cato 2000, McCauley 2001) or more than 10 times the maximum detection range of an individual fish signal in that environment (McCauley 2001).

Marine biological choruses are characterised by showing daily patterns, predominantly, although not always, occurring at night and usually with some seasonal component. Often a chorus may have a strong lunar component (ie. McCauley, 2012 for tropical nocturnal fishes) suggesting the source is responding, directly or indirectly, to light levels in the water column driven by the moon or tidal regime. General reasons for animals to produce a chorus have been speculated by McCauley (2001) as including: aids in spawning events; aids in feeding; by-products of feeding; to maintain loose school structure during periods of low visibility; or to advertise spawning events over scales far beyond that which an individual source is capable of.

Here we report on one chorus type consistently recorded on the continental shelf slope in deep water west of Perth, Western Australia (latitude 32^{o} S), but also sporadically from other Australian shelf slope locations. The emphasis in this publication has been in attempting to define the probable chorus source. Jones et al. (1992) in a site evaluation for a naval acoustic tracking range first described this chorus while Erbe et al. (2015) present a short summary of this chorus type from the Perth Canyon. Neither Jones et al. (1992) or Erbe et al., (2015) attributed a source to the chorus.

II. METHODS

Underwater noise loggers were placed on the seabed in 430-490 m water depth over the years 2000 to 2014 overlooking the Perth Canyon (Canyon hereafter) as shown on Fig. 1. In addition, loggers were drifted across the Canyon in 2004 with the receiver at 60 or 300 m depth crossing water depths at 21:00 each evening of 680 m (site 1), 515 m (site 2), 1220 m (site 3), 503 m (site 4) and 870 m (site 5) (Fig. 1). The Canyon begins 48 km west of the coast of Fremantle Western Australia and dissects the continental shelf westwards, dropping quickly at its head to 1000 m depth then snaking out to meet the abyssal plain at 4000 m depth. Details of hydrophone deployments in the Canyon are listed in Table I. In total 2378 nights across a period of 5353 days (14.7 years) were available for analysis of chorus levels from the sea floor loggers in the primary sites overlooking the Canyon. For comparison several nearby sites were analysed for chorus levels to help define spatial patterns, including the drifters and the site on the eastern boundary of the map in Fig. 1. The seabed mounted noise loggers were set to isolate the hydrophone from movement of the mooring line by using a long weighted ground line (900 m) coupled to an acoustic release (ORE, CART, EdgeTech), dump weight and floats. In all seabed deployments the hydrophone was external to the housing containing system electronics and batteries, and lay freely on the seabed or was attached to a plate on the seabed. For drifting recordings the hydrophone was suspended below the housing, and the housing linked to the surface by three springs of 10 mm bungee cord set along 300 m of 9 mm line with a drogue placed above the housing. The drifting gear surface floats included a ComBeacon GPS buoy which transmitted position to the deployment vessel every 10 minutes.

In 2000 the sea noise recording system comprised a General Instruments C-32 hydrophone connected to custom built electronics comprising an A-D converter and Tattletale microprocessor with SCSII hard disk data storage (Greeneridge Sciences Inc., 10 kHz sample rate, 10 minute sample interval). This receiving system had a high electronic noise floor which impinged on low level ambient noise measurements. All post-2000 data sets used sea noise loggers designed and built at Curtin University (see http://cmst.curtin.edu.au/products/usr.cfm for specifications). These instruments comprised an external calibrated hydrophone, either a High Tech Inc. HTI U90, Massa TR1025C or on occasion a General Instruments C-32, entering the housing with data sampled at 6 to 24 kHz. The most common sample rate used was 6 kHz with a 2.8 kHz anti-aliasing filter setting. The frequency response of all systems was calibrated from 1 Hz to the Nyquist frequency using white noise of known level input with the hydrophone in series. These calibrations were carried out in a shielded box and anechoic chamber to remove electronic and extraneous noise contamination. Post 2001 system clocks were calibrated using hardware and software which set the on-board clock to GPS transmitted UTC time (GPS Genius, Rojone Pty. Ltd.) before deployment and the clock drift read from comparison with GPS broadcasted UTC time after recovery, to give instrument timing errors of ± 250 ms at any point in time (with the error primarily due to the clock time jumping due to the sharp temperature change when deployed and recovered). All deployments were individually calibrated for frequency response and clock drift.

All analysis presented has been carried out using custom built Matlab (The MathWorks Inc.) software. Spatial analysis used Easting and Northing from zone '50 J' or great circle calculations in the Matlab mapping toolbox using WGS84 chart datum. All times presented are Australian Western Standard Time (WST or UTC + 8 hours). Bathymetry has been retrieved from the Geoscience Australia 0.0025^{o} grid (Whiteway 2009). Times of local sunset were retrieved from a Geoscience Australia (GA) web calculator for the receiver latitude and day of years 2000-2014 using the sun's upper limb crossing below the horizon to define sunset (http://www.ga.gov.au/geodesy/astro/). Times of moonrise and moonset were retrieved from the GA website for that latitude and each day of the years 2000-2014 for the moons upper limb crossing the horizon. For calculations of moonlight, moon azimuth and moon elevation, an astronomy and astrophysics package for Matlab (Ofek, 2014) was used.

The observed choruses had a frequency spectral peak at about 2 kHz. To display chorus trends through time spectrum levels averaged over the 2 kHz 1/3 octave band have been used. The 2 kHz 1/3 octave band spans 1.782 - 2.245 kHz which is below the 2.8 kHz anti-aliasing filter applied when using the most commonly used, 6 kHz sample rate. For brevity the term "2 kHz 1/3 octave band" is referred to as "2 kHz 1/3 octave" for the remainder of this document. All 1/3 octave values are presented as spectrum level units (dB re 1μPa^2/Hz) and were derived from time averaged power spectra made across each noise logger sample. When using the 6 kHz sample rate, average spectra were derived by taking a sequence of spectra using 8192 point samples with no overlap and a hanning window, then averaging 'clean spectra' in the linear domain across each frequency, converting back to dB and correcting for the spectral bandwidth, to give units of dB re 1μPa^2/Hz. 'Clean samples' were those spectra without noise artefacts, which was determined by finding spectra which had vales at 10 Hz < $M + (1.1 * sd)$ where M was the median spectral value at 10 Hz for all averages across a sample (in dB) and *sd* the standard deviation (of dB values) at 10 Hz. Noise artefacts tended to have energy down to DC, whereas real sounds of interest, the chorus, had little to no energy at 10 Hz. For comparing time trends the recordings of each evening's time base were zeroed to the time of sunset (upper limb passing below horizon).

Chorus levels were standardized in time at a 10 minute increment around sunset for various computations by interpolating the 2 kHz 1/3 octave level over the period from -2 to 8 hours post time of sunset. This accounted for instrument clock drifts, occasional missed samples and different sample increments used (a minimum of 10 minutes was used). The average chorus level over 0.4 to 5 hours post local sunset was calculated. Parameters of the start and end of each evening's chorus were calculated from the interpolated 2 kHz 1/3 octave level curve across an evening by: 1) removing short time spikes in the curve (spikes with a jump between 10 minute samples of > 3 dB were interpolated from neighbouring values to remove extraneous sources); 2) finding the maximum level each evening over the period 0 to 6.5 hours post sunset; and 3) finding the 3 dB down points about the maximum value to give the chorus start and end points. The 3 dB down points about the maximum level for an evening's 2 kHz 1/3 octave curve gave a repeatable measure of chorus start and end, and so duration across an evening. The exact chorus start and end times were difficult to derive consistently due to extraneous noise sources and variable ambient noise levels. When following trends across days an evening's chorus start, maximum and end times still contained some jumps across days driven by extraneous noise spikes, so were respectively filtered within each data set to remove daily outliers by interpolating points where a jump of > 1 hour occurred for a day when compared with neighbouring values. For measuring chorus spectral content, only evenings' where the standard deviation of the 2 kHz 1/3 octave level for one hour pre-sunset was < 2 dB were used, in order to remove extraneous noise sources.

An estimation of light levels entering the ocean was made using Matlab code to generate moonlight levels Ofek (2014) and combining this with the moons elevation across each evening for all data, with light and elevation calculated at 10 minute increments across an evening. The critical angle for light entering the ocean is approximately 48^{o} (below the vertical) for a calm sea (Sathyendranath and Platt 1990). To account for light reflecting or entering the ocean a simple estimate of light levels entering the ocean was made using: moon elevation (above horizon) < 30^{o} passing 0% of light; 30-38^{o} elevation passing 10% of light; 38-42^{o} elevation passing 25% of light; and > 42^{o} elevation passing 100% of light. While this relationship was an estimate for light entering the ocean as we did not account for cloud cover attenuating and scattering light in the atmosphere (unknown) and sea state changing sea surface light scattering, it was considered sufficient to determine if the observed chorus levels tracked moonlight levels in the ocean.

Several moorings in the Canyon involved three or four noise loggers deployed at the same time on the plateau shown on Fig. 1, with three noise loggers placed in an approximate equilateral triangle of 5 km sides and when a fourth mooring was present, one in the triangle centre ('tracking grids'). For each grid Table I gives details of one of these four moorings only, this chosen to be: 1) as close as possible to 31^{o} 52.5' S, 115^{o} 01' E; 2) to give the longest time coverage possible; or 3) to be a technically good data set. The hardware and calibrations of those tracking grid loggers not listed in Table I were the same as described above. The tracking grid arrangement has been used for tracking pygmy blue whales in the Canyon (McCauley et al., 2004, Gavrilov et al., 2012). For a simple analysis of spatial variation in the chorus described here, 6 kHz samples of four tracking grid noise loggers over 19:00 to 23:00 hours (made every 15 minutes) for 15 days in 2010 and 2011 were overlapped in time using the GPS corrected clock drifts, then an average power spectra made across the overlapping period of samples from each of the four locations (1024 points for 5.86 Hz resolution, 1804-2240 averages depending on time overlap, hanning window, no overlap). The average power spectra were used to give estimates of the 2 kHz third octave level.

Over 29-January to 04-February 2004 the Australian research vessel *RV Southern Surveyor* was used on six occasions to tow an Engel high rise mid water trawl net (50 m spread, 10 m height) through the Canyon in attempts to catch the source of evening choruses. The trawl paths are shown on Fig. 1 with durations and tow distances given in Table II. Tow depths ranged from the surface to 800 m. A Scanmar acoustic net monitoring system was used to measure door spread, wingspread, headline height and net depth which combined with cable length deployed, gave distance behind the vessel. Data was fed to a screen in the bridge, monitored by the Fishing Master and detailed notes kept of: of time (UTC); headrope depth; net spread (mouth opening); and net vertical opening.

During the 2004 *RV Southern Surveyor* trip Simrad EK500 (38 kHz transducer), EA (12 kHz), and ES60 sonars (70, 120 and 200 kHz) logged backscatter for most of the time (barring bad weather downtime and electrical problems). Sonar data was read using either Echoview (Echoview Software Pty Ltd) and output to *.csv files of calibrated volume backscatter (S_v), or the calibrated S_v read directly into Matlab using software developed by Rick Towler, (NOAA, Alaska, http://hydroacoustics.net/viewtopic.php?f=36&t=131) which accounted for all geometric corrections. All sonar analysis was conducted using purpose built Matlab code. All volume backscatter presented uses units of dB re 1m^{-3}. Spatial gridding of sonar data was carried out to give an indication of where areas of highest primary productivity occurred in the Canyon. While the data set was not collected to provide a spatial map of secondary productivity (sampling was focused on day oceanography casts and night net tows) and has been assembled from several consecutive nights data, the gridded data is useful for indicating where highest productivity was in relation to the sea noise logger locations. To spatially grid data, good files were ascertained (free of artefacts, net or CTD rosette in record, noise etc.) and the 12 kHz data split into 30 minutes post sunset to 30 minutes pre-sunrise, 30 minutes post sunrise to 30 minutes pre-sunset and depth categories of: 50-380 m depth; 380-600 m depth; and 600-1000 m depth. Only the 12 kHz transducer was capable of sampling to 1000 m depth and the 38 kHz sonar had a large number of bad data points so the 12 kHz data has been gridded to display highest regions of backscatter. Relatively high level of sonar backscatter were found deep along the Canyon axis, down to 1000 m, which could only be sampled by the 12 kHz frequency. The sonar data in the top 500 m of the water column was used to calculate S_v differences ($S_{v120\text{-}38}$) by averaging data in bins to normalise the range and depth scale then subtracting the two matrixes (38 kHz minus 120 kHz) to give difference values. This technique gives an indication of species complement through the water column (Kang et al. 2002, Fielding et al. 2012). Several sonar runs were averaged with depth along their tracks to determine trends in backscatter in relation to the Canyon. These used 38 or 70 kHz (the 38 kHz was often confounded by bad data), averaging in 50 m range bins over 10-250 m depth. Values averaged were the mean of the dB values, with all bad data and values below the seafloor removed (a bottom tracking algorithm set all values below the seafloor to very small values).

III. RESULTS

A. Chorus character

The chorus spectral character is shown on Fig. 2 which displays time averaged spectra (200-500 s) of chorus activity at 22:00 hours on seven evenings for a receiver using a 20 kHz sample rate. The 2 kHz 1/3 octave has been used to follow trends in chorus activity since it contains the spectral peak and spans the dominant energy of the chorus. The 2 kHz 1/3 octave spectral levels have been displayed on Fig. 3 for a ten day period starting on 31-Mar-2003. The chorus is clearly evident each evening reaching levels around 15-20 dB above the usual ambient noise. Identifying individual signals in the choruses was difficult as usually individual signals merged into a continuous chorus or noise. Some individual signals were identified in the drifting noise loggers sets, in seabed mounted noise loggers set to sample once per day at 20 kHz and in 6 kHz seabed receivers with high amplitude choruses. The waveforms of ten individual signals retrieved from several evenings of set 2727 (on the seabed) are displayed on the top panel of Fig. 4 and three signals probably from the same source are shown on the lower panel of this figure. All signals analysed were short and of a few cycles only, rapidly reaching a peak then showing an oscillating decay typical of a damped bubble pulse, although the decay was less evident on lower amplitude signals. By defining the signal length as the time for 90% of the signal energy to pass, the median signal length was 4.7 ± 2.73 ms (N=448 signals, ± s.d.). In the higher level signals only 2-3 cycles of the waveform were evident before other signals overlapped.

The seven choruses displayed on Fig. 2 had the highest spectral level at 2058 ± 18.0 Hz (± s.d.) although when looking at a wider spread of data, chorus spectral maximum frequency varied considerably. Using 4140 chorus spectra across 789 evenings the average maximum spectral level was 2208 ± 107.0 Hz (± s.d.), with 3 dB down points of 1894 ± 56.2 Hz and 2676 ± 58.0 Hz for a 3 dB bandwidth of 783 ± 67.9 Hz. While some evenings displayed little change in the maximum chorus frequency across an evening, when averaged across evenings there was a significant ($p < 0.001$, F statistic on linear regression, 789 evenings), ~ 100 Hz drop in chorus spectral maximum frequency (0.5 to 4 hours post sunset), ranging from 2264 Hz at 0.5 hours post-sunset to 2166 Hz at 4 hours post-sunset. The presence of the 'dips' in the time averaged chorus spectra following the chorus frequency maximum value seen on Fig. 2 were always evident in time averaged chorus spectra. The first two frequency nulls occurred at around 110 Hz and 750-900 Hz above the frequency of spectral maximum. Another interpretation of the spectral shape is that there are secondary peaks in the chorus spectra, one at about 2300 Hz and the other at 3150 Hz.

B. Temporal patterns in chorus

The nightly 2 kHz 1/3 octave spectrum level as a function of time (zeroed to local sunset) was averaged across all nights within each individual data set listed in Table I (drifting data sets not included) to display the evening trend in chorus activity, which is shown on Fig. 5. There was a clear daily cycle in chorus activity with highest chorus levels received 1-4 hours post sunset and the chorus levels increasing above pre-sunset levels to at least 8 hours post sunset. The chorus levels can be seen to routinely reach > 12 dB above pre-sunset levels. To investigate the chorus influence on sea noise levels, each evening's mean 2 kHz 1/3 octave levels over 2 hours pre-sunset to sunset was calculated. If the standard deviation of the 2 hour pre-sunset mean was < 2 dB (to avoid times with the presence of spurious noise sources such as vessels) then the difference between the pre-sunset mean level and the maximum chorus level reached between 0.4 to 5 hours post sunset was calculated. The distribution of these levels over 2034 nights, in 2 dB increments, is shown on Fig. 6. Based on Fig. 6 the chorus typically reaches 6-12 dB above pre-sunset levels but on occasions can be > 30 dB above pre-sunset levels.

For the data displayed on Fig. 5 the averaging involved across the independent data set length (33-265 days) and the ad-hoc start and end dates for each set of samples will hide lunar and seasonal trends. In order to display these trends the 2 kHz 1/3 octave level has been stacked across each night over the period 20-Feb-2009 to 03-Nov-2014 (2082 days or 5.7 years) where the data set is near continual. This is shown on Fig. 7, with each evening's 2 kHz 1/3 octave level shown as a colour image stacked against the next to form a spectrogram on the upper panel and the average chorus level across 0.4 to 5 hours post sunset each evening on the lower panel, with this curve smoothed using a 3 day running linear fit. Features evident in the ~5.5 years of chorus activity shown on Fig. 7 were: a reasonably constant time of occurrence of the chorus, although with short term variation in chorus start time, chorus duration and chorus end time evident; a seasonal pattern of chorus level; and large differences in chorus levels when comparing different seasons.

The average times of chorus onset, maximum chorus level and chorus length are given in Table III. These values were derived using all evenings 2 kHz 1/3 octave levels where the standard deviation of level for 2 hours pre-sunset was < 1 dB and the maximum chorus level that night reached at least 6 dB above the pre-sunset level. Using this data the distribution of time of maximum chorus level and chorus length are shown on Fig. 8.

An expansion of one data set (Nov-2013 to Nov-2014) with relatively high level chorus activity is shown on Fig. 9 (a) with the moon phase overlain and the chorus start, maximum and end times shown. If the chorus source was responding to local light levels, for example if it was associated with the deep scattering layer, then we may expect to see some correlation between chorus timing parameters and moon phase and brightness over the period 0-5 hours post sunset (time when the chorus peaked). No correlation could be found between moon phase and chorus start or end time, time of maximum level, or maximum level when using all data combined. As found for moon phase, no consistent correlation could be found between moonlight entering the ocean and chorus timing or levels for the 5.7 year section analysed. An example of the moonlight levels entering the ocean and chorus parameters for a 340 day period were shown on Fig. 9 (b).

The seasonal pattern of the evening 2 kHz 1/3 octave chorus level can be seen on Fig. 10 where the curves of averaged 2 kHz 1/3 octave level each evening (0.4 to 5 hours post sunset) have been smoothed (10 day running linear fit about each point) and overlain for 12 different seasons using Julian day as the time base. There was up to 10 dB differences between seasons and a general trend of greater chorus levels over approximately March to October each year with highest levels in the period April to August. A yearly mean of the daily integrated 2 kHz 1/3 octave over 0.4 to 5 hours post sunset was calculated for days between 01-April to 01-June using all data sets and is shown on Fig. 11. There was a base seasonally averaged chorus level of near 68 dB re 1μPa^2/Hz in the Canyon but in 2003, 2009, 2011 and 2014 the mean seasonally averaged chorus level increased to 70-73 dB re 1μPa^2/Hz. The 2003, 2009 and 2011 level peaks were believed due to greater chorus activity in the Canyon whereas the higher 2014 measures were believed partially related to receiver location as discussed below, and partially to a seasonal level increase.

C. Chorus spatial scale

Some spatial scale sampling was made during the drifting recordings in 2004, noting these were made on different nights over the six day field trip. In addition recordings were made with a seabed logger in 113 m water depth for 72 days (29-Dec-2004 to 13-Mar-2005) at a site 11 km SW of the head of the Canyon, or 12 km inshore (east) of the 300 m depth contour. The drifting noise logger sites 1-5 shown on Fig. 1 were sampled at 22 kHz with a 60 s sample every 3 minutes over consecutive night-time periods. The equipment was not deployed until just before midnight at site 1 so results for that site have been excluded from comparisons. At sites 2-5 the mean chorus levels reached over 21:00 to 22:00 hours were: site 2 (in 515 m of water), 31-Jan-2004, 69 dB re 1μPa^2/Hz; site 3 (1220 m water depth), 01-Feb-2004, 66 dB re 1μPa^2/Hz; site 4 (503 m water depth), 02-Feb-2004, 68 dB re 1μPa^2/Hz; and site 5 (869 m water depth), 03-Feb-2004, 69 dB re 1μPa^2/Hz. There was agreement of the mean chorus levels between the three sites measured along the Canyon northern rim (68-69 dB re 1μPa^2/Hz) but a 2-3 dB lower level at site 3 situated to the south over the Canyon gulley in an area with gentler bathymetry. Site 3 with the lower chorus levels was 11 km from site 2, 25 km from sites 4 and 5 and 14 km from the 300 m depth contour.

The site sampled 12 km east of the 300 m depth contour for 72 days in 2004-2005 was on the continental shelf in 113 m of water (see Fig. 1) and was not included in the above analysis as it was in significantly shallower water than the sites in the Canyon. This location had the nightly choruses present over its recording duration but at a much lower level than in the Canyon (around 10 dB lower at 60-65 dB re 1μPa^2/Hz) and for a short period only each evening, reaching highest level around 1 hour post sunset.

Several mooring deployments in the Canyon involved three or four noise loggers located as a grid on the plateau shown on Fig. 1. The simultaneous levels measured at three sites across three evenings in 2010 are shown on Fig. 12 for one of these grids along with the locations at which they were sampled. The trends for six days in 2010 and nine days in 2011 made in February to April were identical during the period of evening chorusing in that there was consistent spatial differences in the simultaneous levels received which followed the trend best seen on 02-Mar-2010 on Fig. 12. In the samples analysed, the northern site-3 closest to the 300 m depth contour had highest chorus levels, the south west site-2 furthest from the 300 m depth contour had lowest chorus levels (up to 6-7 dB lower than the northern site) and the south east and central sites 1 and 4 had intermediate chorus levels (~ 3 dB lower than measures at the northern site). The trend of levels pre-chorus (before sunset) were identical between the four receivers in most days sampled indicating that system calibration was correct. These spatial differences in chorus levels are consistent with the 2014 chorus levels being approximately 3 dB higher than for the other years (Fig. 11), since the 2014 data were recorded near the 300 m depth contour and the other years from receivers at locations further from the 300 m depth contour (see Fig. 1 for locations).

D. Chorus advent with deep sound scattering layer movements

In several instances sonar backscatter was logged over sunset and early evening to track the deep scattering layer (DSL) rising up. As an example, during the RV *Southern Surveyor* trip in early 2004 the 12 kHz echosounder data was used to display the rise of the deep scattering layer to the surface and to link these times to the chorus start and maximum times as derived from drifting sea noise loggers deployed around the Canyon. The chorus times measured over three evenings suitable for analysis were consistent, starting (3 dB down from time of maximum level) at 20:33 hours and reaching a maximum level at 21:46 hours (mean values). Sunset times varied by only a few minutes around 19:23 hours. The deep scattering layer as displayed by the 12 kHz sonar data, began rising around 19:04 hours (~ 20 minutes before sunset) and finished rising at approximately 20:16, or a mean of 20 minutes before the chorus 3 dB down point on the developing chorus, was reached. Only one evening, 03-Feb-2004, was suitable for establishing a time when the chorus initially rose above background noise, due to strong winds raising ambient levels or vessel noise contaminating records early in the evening (high noise masked chorus onset). On the 03-Feb-2004 the chorus first began to be apparent at 19:47, some 24 minutes after sunset and at approximately the same time as the DSL backscatter stabilised to its evening vertical location.

E. Canyon volume backscatter

Canyon volume backscatter (S_v) was used for two purposes: 1) to identify where regions of highest backscatter occurred in the Canyon; and 2) using multi-frequency S_v differences to give an indication of the fish compliment in the water column. The gridded night time depth averaged (50-380 m depth) 12 kHz S_v using the 2004 *RV Southern Surveyor* data set is shown on Fig. 13 and indicates that the highest levels of night time in-water scatterers were located approximately midway between the 200 and 500 m depth contours on approximately the 300 m contour. The 380-600 m depth gridded S_v showed the same trend, with night time backscatter higher towards the eastern end of the Canyon. To reinforce the trend seen with the gridded 12 kHz sonar data, the mean S_v values for two long sonar runs were analysed to follow trends of backscatter on moving to seaward of the Canyon. For the first night example over 33 km running from 23:00 to 03:00 the following day using the 70 kHz transducer (38 kHz was too noisy), backscatter S_v (dB re 1m^{-3}) decreased from ~ -75 dB at the shelf slope to -84 dB at 15 km from the slope edge. In a second run during the day, of 51 km passing from deep water offshore and running down the Canyon gully and up the slope over 12:00 to 15:00 hours, the mean 38 kHz S_v (dB re 1m^{-3}) along the line increased approximately linearly from a low value of ~ -80 S_v (dB re 1m^{-3}) at 30 km from the shelf slope to ~ -70 S_v at the shelf slope, or again an ~ 10 dB drop on moving well offshore, reinforcing that biomass, as indicated by sonar backscatter, aggregated along the shelf slope. Interestingly the daytime gridded 380-600 m S_v showed high levels of backscatter down the Canyon deep axis, with this largely disappearing during night time.

One transect down the Canyon slope was sampled twice with sonar during the *RV Southern Surveyor* trip, in the day, 15:19 to 16:02 hours and night, 22:22 to 22:59 hours. The 38 kHz day/night S_v values from this run are shown on Fig. 14 and highlight the increase in scatterers in the upper part of the water column during night time, coincident with the DSL rising. The difference in mean volume backscatter for the 120 kHz minus 38 kHz was calculated ($S_{v120-38}$) along these runs after using a common 2.5 m range and 2.5 m depth increment to average the S_v values for the respective frequency. Scaling off target strength curves given in Kang et al. (2002) we would expect swimbladder fish of length 80-100 mm to give an $S_{v120-38}$ value of -4 to 3 dB, depending on fish tilt. Values of $S_{v120-38}$ in this range were found in the upper part of the water column (top 180 m to avoid seabed on slope) twice as commonly at night compared with during the day (6.4% of cells during night, 3.2% of cells during day). To investigate where these potential fish were in the water column, the incidence of $S_{v120-38}$ values were summed with range in each depth cell, normalised to the number of range cells and are shown plotted on Fig. 15 for the day/night transects shown on Fig. 14. While a surface group of probable fish was present day and night, the night time trend with depth showed far greater probable fish targets over the 70-160 m depth range, with several peaks in depth abundance, compared with almost no fish in this depth range during the day.

F. Deep water net catches in Canyon

Deep water pelagic fish trawls (Engel net) were run from the *RV Southern Surveyor* through the Perth Canyon in 2004 in an attempt to catch potential chorus sources. During six tows catches were poor ranging from no fish caught (the shortest tow) to a typical maximum of 1-6 kg of fish, a few large squid in the longer tows, in several tows a handful of trevally and in one tow, a sunfish. The fish component of catches were dominated by two species of Myctophidae (lanternfish) of ~ 80-100 mm length, *Neoscopelus sp*. and *Diaphanus* sp. with the *Neoscopelus sp*. always having a gut full of krill. Krill are found along the Canyon rims and in some years associated with comparatively high numbers of feeding pygmy blue whales (tens of) over March to June (Rennie et al., 2009). The Engel net was not designed to catch Myctophidae fishes, with the leading panels of the net having mesh sizes easily large enough to pass fish < 150 mm length, yet the small Mytocphidae dominated net catches, albeit in comparatively low numbers.

G. Detections of chorus in Australian waters

Aside from the Perth Canyon, long term sampling of sea noise in deep water around the Australian shelf break at a bandwidth suitable for locating these choruses has been made by one of the authors (McCauley) at: 12-14° S (Kimberley region Western Australia or WA); 18-21° S (Monte Bello Islands to Exmouth WA); across southern Australia (130-145° E); and off the NSW shelf break (32° S, eastern Australia). All of these regions have locations sampled for in excess of two years and some sites have been sampled continuously for upwards of six years. Choruses of various types (chorus types differ in their spectral content, temporal patterns and behaviour) have been detected from all sites (ie. McCauley, 2012 for two Kimberley fish chorus types) but only the Perth Canyon has recorded the chorus type discussed here persistently year-round. The chorus type discussed here has been recorded at other locations (specifically in deep water off the Kimberley, Monte Bello Islands, Exmouth and off the NSW coast) but only for brief periods of days to months duration.

IV. DISCUSSION

There have been few offshore marine chorus reported and none which have had the source directly defined, thus there is little to compare this work to. The analysis presented here has been aimed at identifying the chorus source. This was not able to be ascertained directly or definitively but relies on multiple clues regarding the chorus source and its behaviour. Potential clues attesting to the chorus source are discussed below with implications following. Clues are:

- The chorus comprised large numbers of similar amplitude damped pulses, implying a numerically common source occurring across a large area in the Canyon;
- The change in chorus spectral maximum frequency across an evening suggested a source in the water column with a shift in frequency driven by a corresponding change of source depth;
- The evening appearance of the chorus matched the rise of the DSL into surface waters;

- There was spatial co-location of the chorus source and regions of highest consistent sonar backscatter and known productivity in the Canyon (Rennie et al., 2009);
- Myctophidae fishes dominated mid-water trawl catches within the Canyon;
- There was a seasonal match of maximum seasonal chorus level and known primary productivity in the region (Koslow et al., 2008).

Waveforms of individual signals were found amongst the chorus but it was difficult to locate high amplitude clean signals owing to their low signal to noise ratio amongst the presence of large numbers of overlapping calls. The clean signals which were found suggested the chorus comprised short signals (~ 4.7 ms for 90% of energy to pass) appearing as damped oscillations suggesting a source in which resonance plays a role. The most likely such source is a gas bubble. McCauley (2001) has published swimbladder pulses for different fish species with different levels of damping and surface bounce interference. The few chorus source signals found here show similar decay patterns to damped swimbladder pulses, suggesting a small fish as the source here, vibrating its swimbladder with a single strike or pulse driving it. When averaged over 789 evenings, the chorus maximum frequency decreased across an evening, which if the source was a gas filled bubble (fish swimbladder), implied the source moved up in the water column through an evening (see below). This shift in chorus maximum frequency largely rules out a seabed or invertebrate source, as there would be no mechanism for altering the chorus spectral content if the source was not able to alter is depth distribution or was not produced by an oscillating bubble.

Invertebrate signals are usually broadband, rasping, stridulatory signals (ie. several species, Fish, 1964 or rock lobster signals, Meyer-Rochow and Penrose, 1976) most commonly produced by fauna on or in the substrate. Sounds of snapping shrimps differ from the rasping, stridulatory signals in that they are produced by the collapse of a cavitation bubble (Versluis et al., 2000) and so have some similarity in generation mechanism to that of fish swim bladders. Typical snap waveforms are different to those of Fig.4, with fewer cycles, and the spectrum far more broadband, with a higher frequency spectral peak. Also, the shrimps tend to be near the bottom in shallow water. The typical spectrum of snapping shrimp sounds was not observed. The signals received here were not shrimp like single pulses nor rasping or stridulatory in nature. Sea urchin signals presented by Radford *et al*. (2008) resemble the signals produced here but these were from coastal urchins, not deep water animals as here and all sea urchins are located on the seabed, not in the water column. All receivers used in analysis here were either on the seabed (430-490 m depth) or drifted at 300 m depth in deep water. If the source was located on or near the seabed then we would have expected to occasionally see higher intensity individual signals as the source neared the deep receiver. No such signals were observed suggesting the source was either at a long horizontal range from the receivers or in the water column. Thus based on signal character the source was unlikely to be an invertebrate as it was not fixed on the seabed and did not have a rasping or stridulatory nature and was most likely a small fish working in the water column, producing single oscillations of its swimbladder over a variable depth range through an evening.

Spatial extrapolation of the location of highest volume backscatter (S_v) observed in the Canyon based on sonar data collected in 2004 (ie. Fig. 13), agreed with the measured chorus spatial level differences made from grids of four receivers placed on the Canyon rim. The receiver closest to the shelf slope where highest night-time in water S_v occurred in the top portion of the water column, always had higher chorus levels than receivers set further away. Two receivers at intermediate range had intermediate chorus levels and the receiver located at longest range from the zone of highest S_v had lowest chorus levels. This combined with the chorus source appearing to be located in the water column suggested the chorus emanated from within the region of highest volume backscatter along the shelf slope.

It is well known that a large number of diverse zooplankton fauna and small fishes which have spent the day deep in the water column (at a hundred to several hundreds of m depth) rise up of an evening to forage in the photic zone of the upper water column (the deep scattering layer, DSL, summarised in Raymont, 1983). This evening DSL rise was observed in the sonar observations here, with daytime depth of the DSL below 200 m and down to 500 m or deeper, depending where in the Canyon was sampled. The chorus timing, approximating the rise of the deep scattering layer higher in the water column and the chorus location potentially coinciding spatially with the dense region of sonar backscatter in the Canyon, suggest the chorus was affiliated with the evening rise of the DSL.

Small fishes with swimbladders were the most likely candidate to produce the damped pulses observed in the nearby chorus signals detected and to show the change in spectral content of chorus maximum level observed. Given the acoustic impedance difference between gas and water (~ 100,000 times greater in sea water), swimbladders are highly efficient sound generators or reflectors of sound (Hall, 1981). The chorus nature implied a large number of sources operating relatively close together across a large spatial scale (that at which the choruses were measured). One of the numerically dominant components of the DSL worldwide are fishes of the family Myctophidae (Catul et al. 2011). Two Myctophidae species dominated mid-water trawl catches in the Canyon. Myctophidae fishes are known to have a variety of swimbladder forms across and within species, for example *Diaphanus theta* has been found with thin walled inflated swimbladders and thick walled non-inflated swimbladders (Butler and Pearcy, 1972). There are reports that Myctophidae taken from near surface waters have a significantly higher incidence of thin walled inflated swimbladders than animals taken from greater depths (Neighbours, 1992). Many Myctophidae are believed to transition from a thin walled swimbladder in younger animals to a thick walled regressed swimbladder in older animals (Marshall, 1960, Neighbours, 1992). The diversity of swimbladder forms found across and within Mytophdiae species appears to be a reflection of the large pressure changes they do, or do not, undertake during vertical migrations and the depth range over which they commonly feed at. Marshall, (1960) presents swimbladder morphology for individuals of 22 Myctophidae species, with swimbladder dimensions as length and width at the widest point. Using these dimensions and assuming the swimbladder shape approximates a prolate spheroid ($V = \frac{4}{3}\pi ab^2$, where a and b are the major and minor radii respectively) we can estimate swimbladder volume. Using a derivation from the summary of scattering by swimbladders given by Hall (1981) we get a relationship which estimates swimbladder resonance (Hz) from volume and depth in the ocean as $f_o = 4.5\sqrt{P_a}/a$, where f_o is resonant frequency (Hz), P_a is pressure (atmospheres) and a is the radius of a sphere of equivalent volume to the swimbladder (in m). Medwin and Clay (1998) derive almost the same relationship but with the multiplier 4.5 replaced with 3.25. The swimbladder dimensions given by Marshall (1960) for Myctophidae of length 24-69 mm were used to estimate swimbladder volume, which were scaled (linear regression, r^2=0.94) to fish length sampled here (80-100 mm). The equivalent radius values were calculated and source depths of 10, 70 and 160 m (surface peak and deeper fish bounds as shown on Fig. 15) were used with the relationships of Hall (1981) and Medwin and Clay (1998) to give estimates of mean swimbladder resonant frequency. At 10 m depth swimbladder resonant frequencies of 1.2-2.0 kHz were calculated, at 70 m 2.5-3.8 kHz and at 160 m 3.6-5.6 kHz. Given the uncertainties associated with the swimbladder resonance frequency estimation (swimbladder damping, exact dimensions when inflated and shape) and potential differences in swimbladder volume between the measures of Marshall (1960) and fish found in the Canyon, then the calculated frequencies are in reasonable agreement with the measured chorus maximum frequency of 2.2 kHz or the secondary peaks in chorus spectra observed at higher frequencies. The decrease in the frequency at which the maximum chorus level was observed through an evening suggests on average the source moved higher in the water column across each evening.

If we assume that Myctophidae fish do produce the chorus then that implies the fish have some mechanism for driving the swimbladder to produce the damped signals observed. This implies either muscles attached to the swimbladder or the swimbladder being driven by other body movements, for example contractions of the lateral body muscles. Marshall (1960) presents detailed drawings of Myctophidae swimbladders which do show muscles attached to the swimbladder via an "oval" which is present at the anterior swimbladder end. This "oval" plays a role in gas exchange in the swimbladder and has radial (tying to the body cavity) and circular muscles attached to its anterior side. The capability of the "oval" muscles to rapidly contract the swimbladder and produce a single pulse exists, but it is not known if they do this.

As the chorus source is not definitively identified we can only speculate on what function the signal plays for the species producing it. McCauley (2001) in studying northern Australia fish choruses (not this one) speculated that evening fish choruses found near to tropical reef systems could be produced for: 1) maintaining a loose school structure which allowed groups of fish operating at night to track plankton patches; 2) as a possible aid in the feeding process; 3) at certain times of the year or moon phase, as potentially having some reproductive function; or 4) as a by-product of the feeding process (by driving the swimbladder during planktivorous feeding). Alternatively one could suggest that the signal type produced was related to stridulation or swimming behaviour, although the signals analysed did not have characteristics of these signal types but resembled the pulse of an air bubble oscillation. While the chorus being related to the feeding process is an attractive hypothesis here and is supported by the correlation of maximum seasonal chorus levels and evidence of spatial correlation with highest primary productivity in the area we do not know what the chorus function is.

The chorus timing was consistent across years, reaching highest levels at approximately 2 hours post sunset each evening but with this time varying considerably, between 0.75 to 5.25 hours post sunset. The time of chorus onset varied similarly. Considerable effort was put into trying to correlate variability of chorus start and end time, time of maximum chorus level and maximum chorus level, with moon phase and light levels entering the ocean, with no clear correlations evident. The DSL is known to change depth and 'behaviour' in relation to light levels in the ocean (Raymont, 1983). The lack of correlation of chorus timing with light observed may have been a result of the unknown amount of cloud cover causing light levels to vary considerably from those predicted (which assumed no cloud cover) plus variable sea surface scattering of light. Cloud cover and sea surface scattering would significantly alter light levels entering the ocean and thus if the chorus source was responsive to light via changing the presence of smaller zooplankton, would have weakened any potential correlation.

There was a seasonal peak in chorus level over approximately April to August each year which coincided with the seasonal peak of maximum chlorophyll-A given by Koslow, et al. (2008) for a site just to the north. The chorus 2 kHz 1/3 octave integrated evening level, when averaged across 01-April to 01-June each year (peak chorus time) had a base level of around 68 dB re 1μPa^2/Hz with some years having averaged levels 2-5 dB higher. This suggests in some years conditions favoured a significantly greater amount of sound production. Given the match of chorus yearly timing with highest primary productivity, the possible Myctophidae chorus source and the fish's association with feeding behaviour on zooplankton, then the observed yearly chorus level difference could be speculated to reflect seasonal changes in secondary productivity in the Canyon. While we know the Canyon is a region of enhanced productivity compared with the surrounding regions and have some understanding of Canyon scale drivers for increased productivity (Rennie et al. 2009), we currently do not fully understand the larger scale and longer term seasonal drivers of productivity and so differences in productivity between seasons. If the chorus is related to foraging fishes then it may offer a simple proxy to define secondary productivity.

The spatial extent of the chorus was not ascertained. In the main study area (at the eastern end of the Canyon) the chorus appeared to be produced primarily along the Canyon rims which are known to be the region of greatest primary productivity there (Rennie et al., 2009) but levels were still high over the Canyon gulley at 33 km from the main study area (roughly paralleling the 300 m depth contour) and 13 - 15 km to the closest point on the 300 m depth contour. Jones et al (1992) measured the chorus at similar levels in 1992, 37 km to the south of the southern-most location sampled here (see Fig. 1) in a similar water depth. In 72 days of sampling made 11 km SW of the head of the Canyon back into shallow continental shelf waters the chorus was detectable but approximately 10 dB below levels reached in the Canyon, suggesting this was long range transmission from the edge of the Canyon. Interestingly, at this site on the shelf the chorus reached highest levels one hour post sunset as opposed to 2 hours in the main study area. The spectral content and nature of the choruses were similar so it is not clear why this occurred. This earlier chorus time (compared with deep water) could potentially have been due to some of the sources rising up close to the 200 m depth contour thus allowing chorus energy to transmit back onto the shelf, but then moving offshore quickly. On moving to seaward from a continental shelf edge with a steep slope, the energy from a relatively shallow source would be quickly lost for transmission into shallower shelf waters due to losses incurred at the shelf slope.

Since we have limited information on where the chorus source was actively present in the Canyon, with the evidence suggesting this was primarily along the shelf slope at the eastern Canyon end but not ruling out some presence in deeper water, then the best we can say on its spatial extent is that the chorus was detectable over a large area, at least at the many tens of km scale. The detections of this chorus at other deep water sites along the Western Australian coast have not been as consistent as at the Perth Canyon. At other sites this chorus type has only been detected over the time scale of weeks to months, on occasions fading away then re-appearing at some sites. The Canyon chorus presence coinciding at a fine and large scale with the region of highest productivity in the Canyon and matching the known seasonal primary productivity trend in the region suggests it tracks areas of high primary productivity. Thus the ephemeral chorus occurrence at other sites suggests the chorus source may be responding to variable ocean productivity, with high chorus levels in regions of high productivity and no to little chorus activity in regions with low productivity. This, combined with the large scale of transmission of the chorus signal implies that the chorus would be audible for considerable distances and could act as a 'beacon' for regions of high productivity, on the scales of tens of km, perhaps at the many tens of km scale. In regions where the chorus is present, any marine animal with hearing thresholds down to lowest ambient levels in the 1-3 kHz range could use the evening chorus sounds to indicate the presence and direction of high productivity at a minimum of tens of km ranges and possibly at larger scales.

V. CONCLUSIONS

A chorus suggested to be produced by small fishes foraging in the water column during the evening was quantified over 14.7 years from the Perth Canyon, at ~ 32^{o} S on the Western Australian coast. The chorus had maximum intensity at ~ 2.2 kHz but spanned 1-5 kHz and typically reached levels around 6-12 dB above pre-sunset levels in the 2 kHz 1/3 octave, although on occasions it was up to 30 dB above pre-sunset levels. The chorus occurred each evening, reaching highest levels around 2.1 hours post sunset although this varied considerably and could not be correlated with moon phase or estimated lunar light levels entering the ocean. While over an evening highest chorus levels were normally recorded within 5 hours post sunset the chorus often continued all night at lower levels and sometimes had pre-dawn peaks in level. The chorus was tracked across seasons and showed highest seasonal levels over April to August each year which matched what is known of primary productivity in the area via satellite derived and measured chlorophyll-A measures (Koslow et al. 2008). There was variation in chorus levels between seasons suggesting seasonal changes in the chorus driver, possibly reflecting variable secondary productivity. The chorus spatial extent was not determined but the chorus occurred over the scale of sampling, around 35 km along and 13-15 km into deeper water from the 300 m depth contour. At a local scale within the Perth Canyon a drop in chorus levels across spatially separated receivers sampling simultaneously suggested the chorus emanated from the region known to be of highest primary and secondary productivity in that area, along the steep shelf slope. The chorus appeared to be comprised of short damped pulses. The chorus timing and location suggested the source was associated with the evening rise of the deep scattering layer into the upper part of the water column, which when coupled with the chorus nature suggested a small fish as the source. Myctophidae fishes were found to be the most common fish within the water column in the Canyon from evening net tows. Many of these fishes have swimbladders of approximately the correct dimensions to produce the chorus signal type, have swimbladder musculature which may be capable of producing the signals detected and which have behaviours matching all aspects of the chorus studied. While we do not have direct evidence that these fishes produce the chorus discussed, they seem to be the most likely candidate given the lack of alternative potential sources. If the choruses are associated with regions of high productivity as the sampling to date suggests, then they offer marine animals a detectible long range beacon as to where areas of high productivity occur. The ranges at which these chorus may be detectable may be several multiples of the sampling scale undertaken here, conservatively in the 30-60 km + scale for choruses of similar levels and spatial extent as found here.

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TABLE I: Details of sea noise logger deployments used in analysis with: 1) set number; 2) latitude; 3) longitude (chart datum WGS 84); 4) the start day of recording; 5) the end day of recording; 6) the number of recording days; 7) the sample length (s); 8) the time interval between consecutive sample start (minutes); and 9) the sample rate.

#	Lat. S	Long. (E)	Start day	End day	days	Length (s)	Interval (min)	Sample rate (kHz)
2466	31 55.130	114 59.960	08-Mar-2000	10-Apr-2000	33.0	90.0	10	6
2617	31 51.720	114 59.190	18-Feb-2003	14-May-2003	84.7	205.1	15	6
2628	31 52.760	114 59.720	10-Jun-2003	06-Oct-2003	118.2	154.0	15	6
2655	31 52.774	114 59.990	07-Nov-2003	08-Jan-2004	61.9	204.9	15	6
2643 -1	drifted	drifted	29-Jan-2004	30-Jan-2004	1	62.3	3	24
2643-2	drifted	drifted	31-Jan-2004	02-Feb-2004	3	62.3	3	22
2643-3	drifted	drifted	02-Feb-2004	04-Feb-2004	2	62.3	3	24
2672	31 52.124	115 0.040	30-Dec-2004	08-Jul-2005	190.4	205.0	15	6
2724	31 54.083	115 1.143	01-Jan-2007	25-Apr-2007	113.4	204.9	15	6
2727	31 54.083	115 1.143	01-Jan-2007	25-Apr-2007	113.4	200	1440	22
2802	31 53.858	114 1.000	26-Feb-2008	21-Apr-2008	54.7	204.9	15	6
2825	31 53.046	115 0.137	20-Feb-2009	02-Oct-2009	223.6	512.1	15	6
2884	31 55.039	115 1.863	13-Nov-2009	22-Jul-2010	251.1	460.9	15	6

2962	31 54.139	115 1.607	06-Aug-2010	08-May-2011	275.0	409.7	15	6
3004	31 54.350	115 1.538	14-Jul-2011	19-Jun-2012	341.6	307.2	15	6
3154	31 53.053	115 0.813	10-Aug-2012	14-Jun-2013	307.9	306.3	15	6
3376	31 50.530	115 0.824	28-Nov-2013	03-Nov-2014	340.5	307.2	15	6

TABLE II: Engel net tow, deployment and recovery date and times, elapsed time, tow distance and approximate net depth based on logged headrope depth.

	Date / time deployed, recovered	Elapsed (min)	Tow distance (km)	tow depth range (m)
1	29-Jan-2004 19:34:56 to 20:46:55	72	5.9	266-316
2	31-Jan-2004 20:44:04 to 01:27:04	283	26	50-250
3	01-Feb-2004 17:50:03 to 19:56:03	126	11.3	150-200
4	02-Feb-2004 20:40:00 to 22:28:00	108	10.5	~ 100
5	02-Feb-2004 23:15:59 to 00:57:59	102	9.1	510-570
6	03-Feb-2004 17:19:01 to 19:49:01	150	12.9	200-300

TABLE III: Statistics of chorus times given as hours post sunset, using all data where the standard deviation of 2 kHz 1/3 octave levels for two hours pre-sunset was < 1 dB and the difference between maximum chorus level reached and the pre-sunset level was > 6 dB.

event	**Mean**	**95%**	**SD.**	**median**	**N**
3 dB down chorus onset	1.3	0.03	0.61	1.2	1292
Maximum chorus level	2.1	0.05	0.85	2.0	1239
duration	2.1	0.04	0.67	2.0	1239

Figure Captions

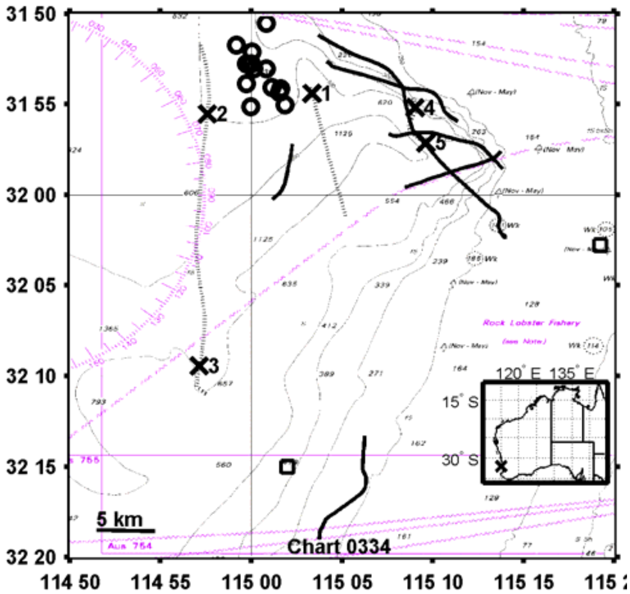

FIG. 1. General location of Perth Canyon in Western Australia (cross on inset) and location of drifting loggers (dotted lines) during time in the water (30-Jan to 03-Feb 2004). The crosses mark 21:00 each evening sampled (UTC + 8 hours) and the numbers represent consecutive evenings. The Engel trawl net tow locations are shown by the solid black lines. Circles show the locations of noise loggers used in analysis (Table I) set on a plateau of 430-500 m depth. The northern most location was set 3376 (Table I). The black square to the south is the location of recordings made by Jones et al. (1992). The site 12 km SW of the Canyon head (black square at 32° 2.785' S, 115° 19.223' E) was sampled for 72 days in 2004. Generated in MatLab from Australian Hydrographic Service chart AUS 0334 under Seafarer GeoTIFF license No 2618SG, with depths in m.

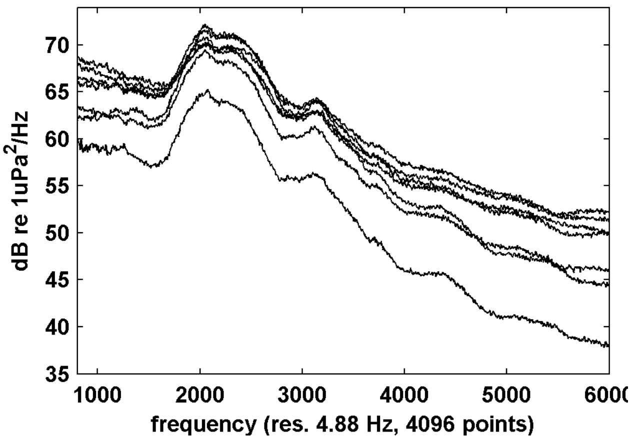

FIG. 2. Spectra of comparatively low level choruses made over seven evenings, as evident across 1.5 – 3.5 kHz.

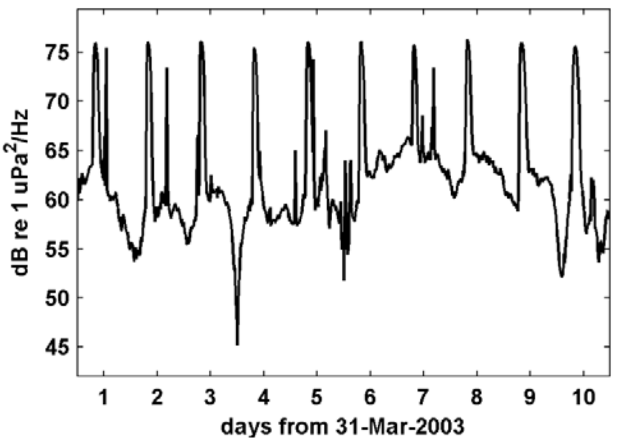

FIG. 3. Spectrum level in the 2 kHz 1/3 octave over a 10 day period shown starting on 31-Mar-2003.

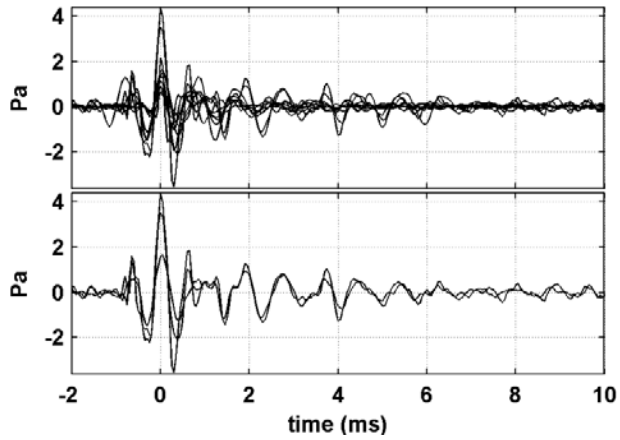

FIG. 4. (top) Ensemble of ten waveforms of chorus source signals identified from data set 2727 made over four evenings and aligned by maximum positive peak and (bottom) three signals overlaid from one evening which were probably produced by the same source.

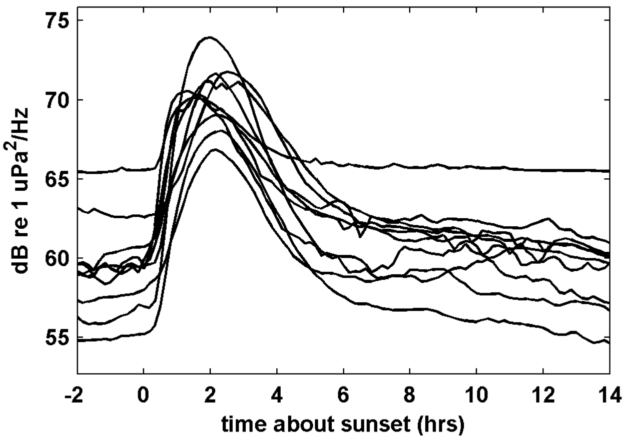

FIG. 5. Spectrum level of the 2 kHz 1/3 octave as a function of time, averaged at the same time each evening relative to local sunset for each night of the data sets listed in Table I, from two hours pre-sunset to 14 hours post-sunset. Note that the curve at near 65 dB re $1\mu Pa^2/Hz$ had an artificially high electronic noise floor (set 2466, Table I).

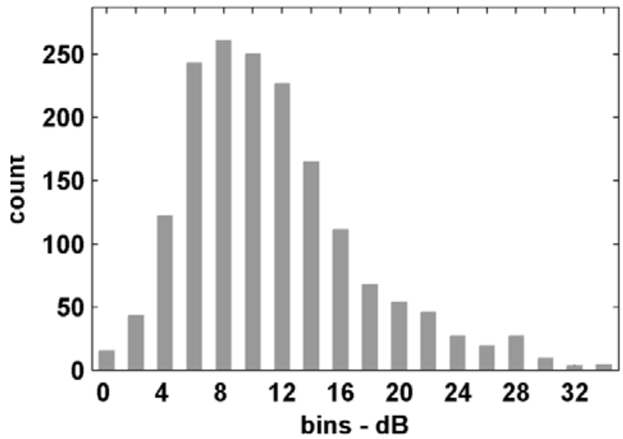

FIG. 6. Distribution of difference between chorus maximum 2 kHz 1/3 octave level over 0.4 to 5 hours post sunset compared with mean 2 kHz 1/3 octave level from 2 hours pre-sunset to sunset the same evening. The distribution has been calculated in 2 dB increments.

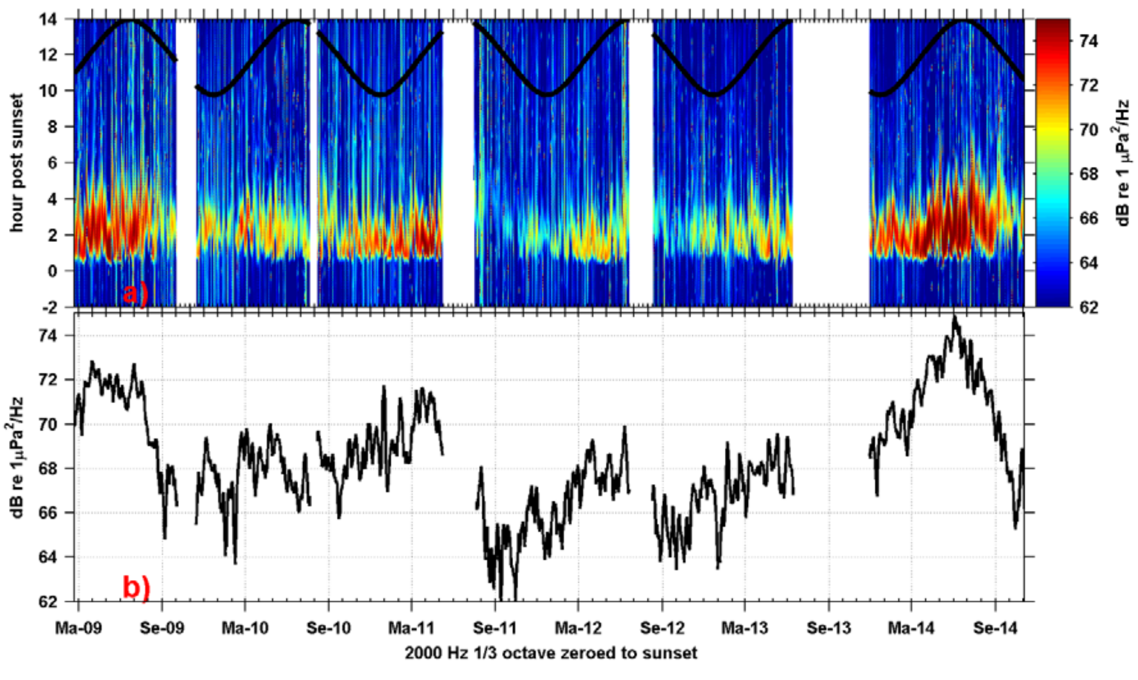

FIG. 7. (a): Level across an evening in the 2 kHz 1/3 octave stacked over the period 20-Feb-2009 to 03-Nov-2014 (2082 days or 5.7 years) with each evenings times zeroed to time of local sunset. The heavy black line is the time of sunrise. (b) The integrated level in the 2 kHz 1/3

octave each evening over 0.4 to 5 hours post sunset. The curve has been smoothed using a 3 day running linear fit.

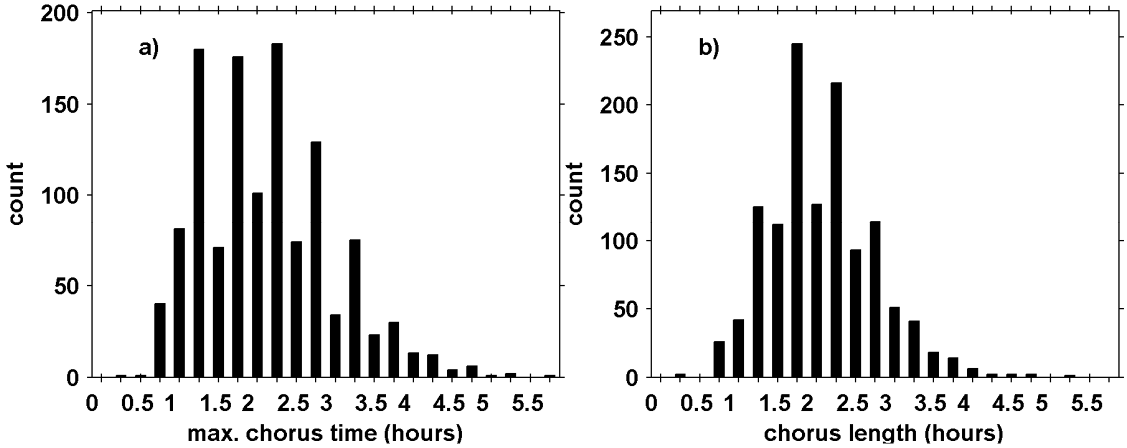

FIG. 8. Using the 2 kHz 1/3 octave to define chorus temporal patterns (see text) the distribution of all valid times of maximum chorus level post sunset (a) and chorus length (b) as given by the 3 dB down points.

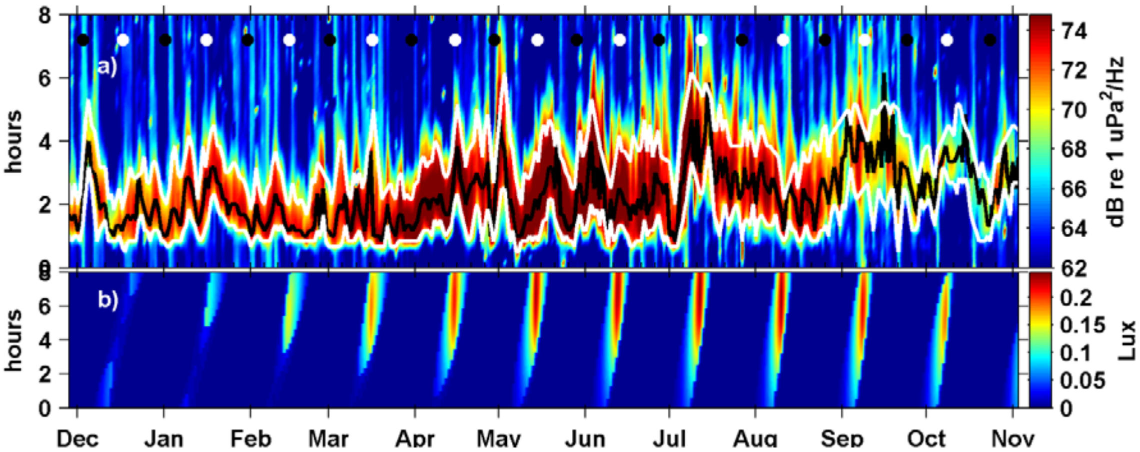

FIG. 9. a) Spectrum levels of the 2 kHz 1/3 octave each evening (data set 3376) for a 340 day period with the evenings time base zeroed to time of local sunset. The moon phase is shown by the circles (white for full, black for new). The black line follows the time of maximum chorus level, the white lines the chorus start and end times as given by the 3 dB down points about the time of maximum chorus level. b) An estimate of light levels entering the surface of the ocean

across each evening (see text for calculations) with the evening time base zeroed to time of sunset.

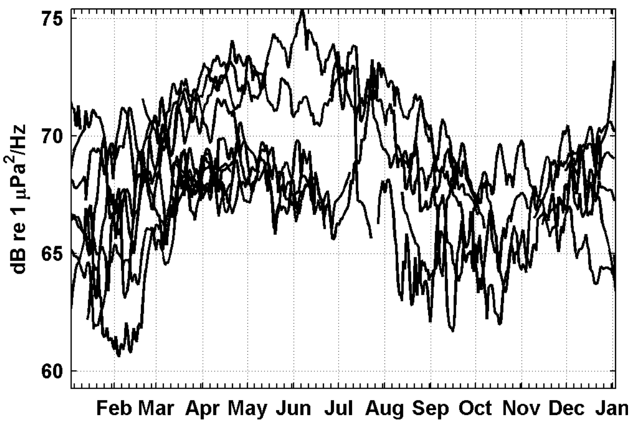

FIG. 10. The seasonal pattern of the 2 kHz 1/3 octave for 12 seasons overlain and aligned by Julian day, with non-leap year x-axis labels show. The curves are derived from each evening's integrated chorus level over 0.4 to 5 hours with the raw trend smoothed using a running 10 day linear fit about each point. Minor ticks are five day increments.

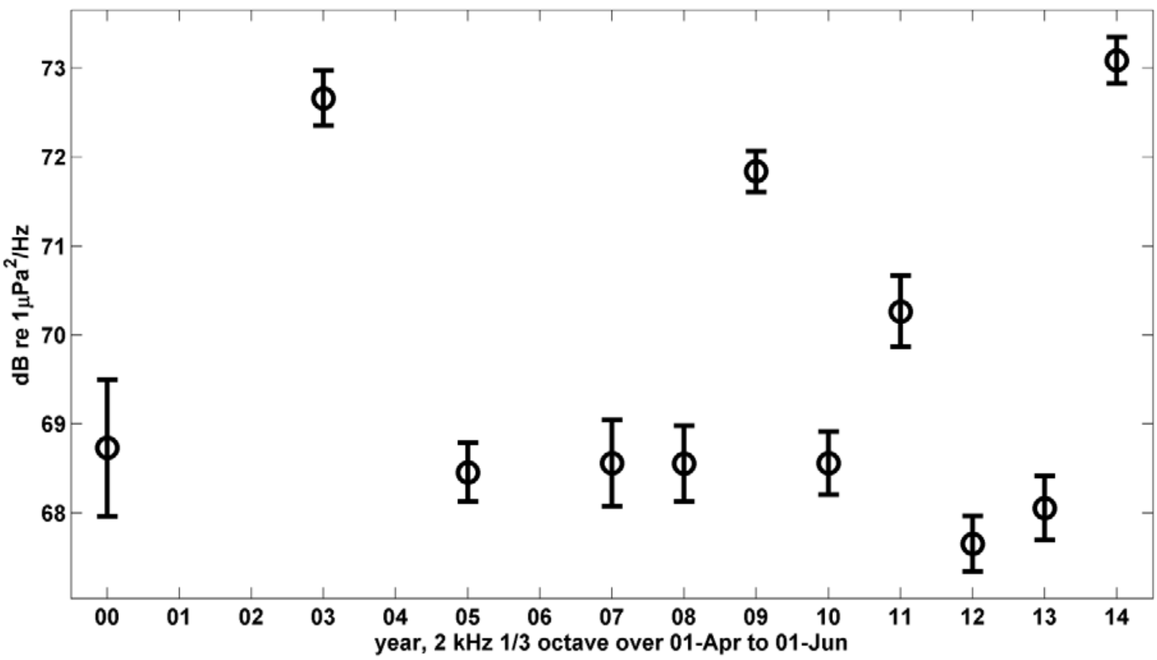

FIG. 11. The chorus seasonal trend shown by the mean of the 2 kHz 1/3 octave averaged each evening over 0.4 to 5 hours post sunset and each day from 01-April to 01-Jun. The error bars are 95% confidence limits.

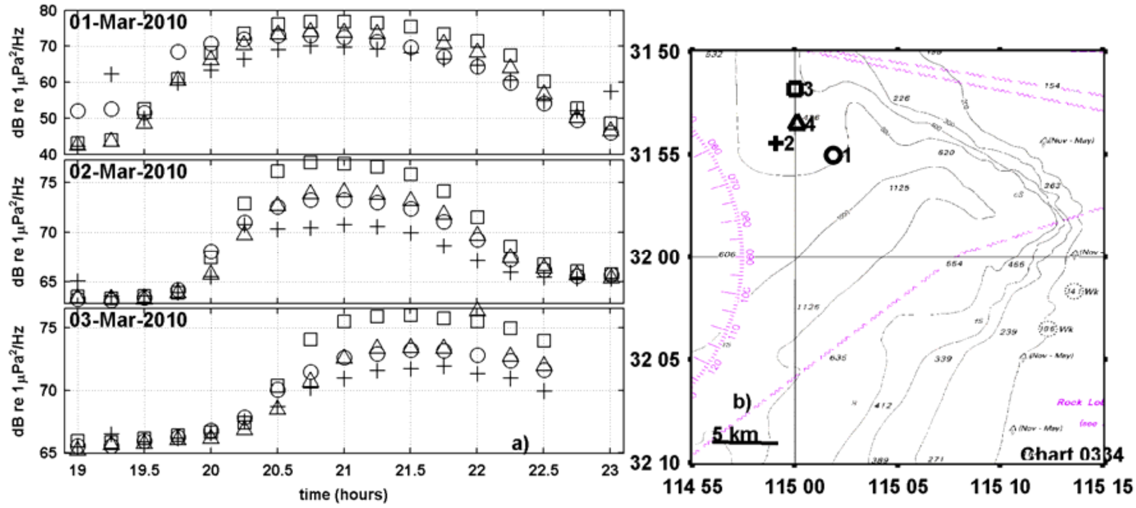

FIG. 12. a) Simultaneous average spectral levels in the 2 kHz 1/3 octave across three evenings at the sites shown on b). The symbols on a) are coded to match the numbering on b) as per: circles - site 1; plus signs - site 2; squares - site 3; triangles - site 4. b) The locations of sites sampled overlaid on Australian Chart AUS 0334. Sunset fell at 18:56, 18:54 and 18:53 for the three days shown with the previous full moon on 28-Feb-2010.

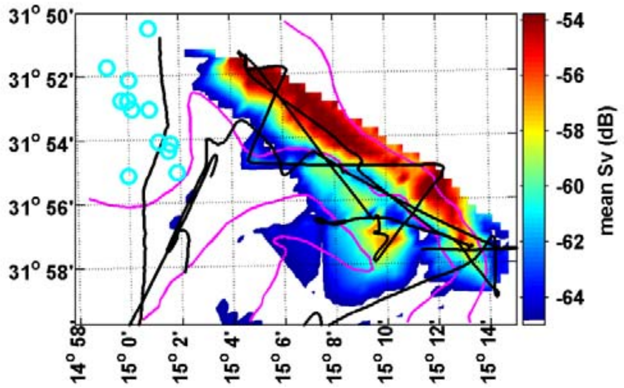

FIG. 13. Gridded night time (sunset plus 30 minutes to sunrise minus 30 minutes), 12 kHz depth integrated volume backscattering (*Sv*) from Canyon made over 29-Jan-2004 to 03-Feb-2004 over 50-380 m depth. The black lines are sonar tracks available, the cyan circles are sea noise logger locations used here. The magenta lines are depth contours with the 200 m (easternmost), 500 m (middle contour) and 1000 m (gulley in lower portion image) shown.

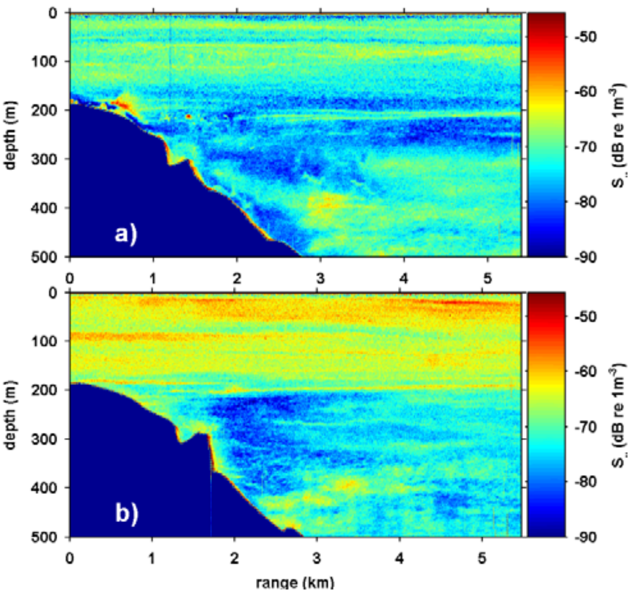

FIG. 14. Sonar backscatter using 38 kHz transducer during: a) day, 03-Feb-2004 15:17:38 to 16:30:00; and b) night, 03-Feb-2004 22:17:30 to 23:26:48. The colour scales are matched. The area below the seabed was set to a low value.

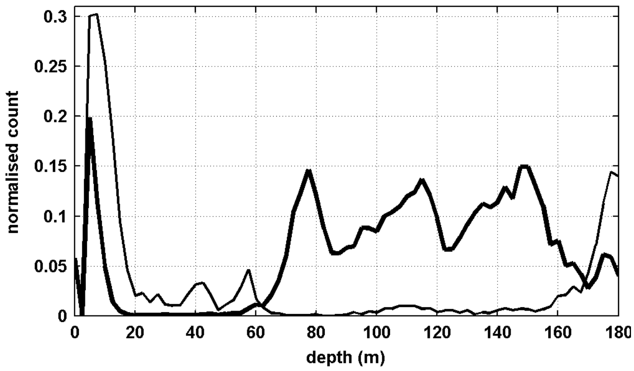

FIG. 15. The number of $S_{v120-38}$ values in the range -4 to 3 dB (probable fish) summed for each depth cell along the transects shown on FIG. 14, normalised for the number of range cells. The light curve is day and heavy curve night trends. The depth was truncated at 180 m to avoid the seabed.