

# Fish choruses from the Kimberley, seasonal and lunar links as determined by long term sea noise monitoring

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## ABSTRACT

Calling fish are a dominant component of Kimberley sea noise. Sea-noise loggers set in the Kimberley since 2004 under Industry and Defence funding have recorded a plethora of call types and choruses, where many fish call en masse. Fish choruses show daily and seasonal periodicity and most show lunar periodicity. At the longest site sampled over 2006-2010 from Scott Reef southern lagoon, a chorus produced by nocturnal planktivorous fishes displayed coupled daily, lunar and seasonal trends with calling most intense over late evening from October to April, least intense over June to August, but continuing at some level all year. This chorus is believed associated with feeding. As a comparison a nearshore chorus produced by fish of the family Terapontidae is only produced over November to May, again at night. This chorus is believed associated with reproduction. As has been observed before, where multiple choruses occur each night which overlap in frequency content, time separation acts to reduce competition for the 'sound space'.

## INTRODUCTION

There are many instances of calling fish reported from Australian waters including: Moulton (1962) describing the sounds of fish captured in trawl gear; Cato (1980) describing several high level fish sounds recorded from the Timor Sea; Lanzing and Dalmazzo (1985), and Lanzing and Graham (1987) reporting on isolated distress and feeding calls from a variety of southern and tropical fishes; McCauley (2001) describing calls from several tropical species; and recently Parsons (2009) describing calls and call behaviour from the temperate mullet, *Argyrosomus japonicus*.

Fish which call persistently predominantly use some form of muscular vibration of the swimbladder to produce the signal - the difference in acoustic impedance of the gas bubble and surrounding water creating a highly efficient means of generating sound. Fish calls have been shown to be involved in reproductive behaviour, feeding or aggressive interactions, and can play significant roles in the life function of many species (Myrberg 1981). In Australian waters it is common for fish to aggregate in schools and call *en masse*, to form choruses where it becomes difficult if not impossible to discriminate individual calls amongst the cacophony of noise produced by the fish school (McCauley 2001). Reproductive related fish choruses are common, with calling as a group acting to increase the 'catchment' area of the reproductive school often into the tens of km or to mediate partner selection and gamete release in night time, or turbid conditions (McCauley 2001).

The first published report of a biological fish chorus in Australasian waters is that of Cato (1969) in the Eastern Timor Sea. Wyllie (1971), then reported three instances of biological choruses, probably of fish origin, along the north coast of New Guinea (off Lae, Madang and Wewak) all having their highest levels at night time (up to 23 dB above expected level). Cato (1978) then describes predominantly evening fish 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 levels. Kelly et al (1985) then described concentrated animal calling or choruses, most likely produced by fish, from a deep water site in the eastern Indian Ocean, which reached highest levels of approximately 12 dB above expected level, at sunset. McCauley and Cato (2000) described an evening fish choruses from the Great Barrier Reef (GBR) which reached high levels, was ubiquitous and which they speculated could at times ensonify almost the entire GBR. McCauley (2001) described four fish choruses recorded from northern Australia, all reported to have been heard in North Western Australia. Parsons (2009) described reproductive choruses from mullet in the Swan River and has linked changes in the nature and intensity of choruses to physical and environmental cues.

Only McCauley (2001) directly describes fish calling behaviour and choruses from species found in the Kimberley, although several of the signal types and choruses reported by Cato (1978, 1980) are known to occur there. Since 2003 and with the advent of modern high storage capacity digital recording systems, the author has been collecting sea noise records from northern Australia, including the Kimberley. A bewildering array of fish calls and choruses are always present in the sea noise records from continental shelf waters in the Kimberley, often recorded at staggering noise levels. Fish are a dominant source of sea noise in continental shelf waters of the Kimberley. For comparative purposes this publication will briefly describe the patterns of two of these fish choruses and attempt to provide some definition of the behavioural and ecological significance of calling.

## METHODS

All of the time series patterns presented in this document used CMST-DSTO sea noise loggers, designed and built at Curtin to collect sea noise samples. The noise logger details can be found at [www.cmst.curtin.edu.au](http://www.cmst.curtin.edu.au) under products. In all deployments described here noise loggers were set on the seabed with the hydrophone (a Massa TR1025C or HighTech HTI-90U) lying external to the housing on the seafloor and

entering the housing via a bulkhead connector or gland. Sea noise loggers were lowered to the seabed and a ground line approximately twice the water depth laid out and hooked into a riser with acoustic release and floats. The hydrophone signal was amplified using an impedance matching pre-amplifier (20 dB gain), filtered with a low frequency roll-off starting at 8 Hz and the loss increasing with decreasing frequency so as to flatten the naturally high levels of low frequency ocean noise and so increase the system dynamic range. An anti-aliasing filter was applied and the signal then fed to a 16 bit analogue to digital converter. The digital signal then had 20 dB extra gain applied and was sampled according to a pre-programmed sampling schedule. Samples were written to flash card (power cheap) then when the flash card was near full, transferred to a hard disk (power hungry and electronically noisy). Most of the data described here was sampled for 200 s every 15 minutes at 6 kHz sample rate with a 2.8 kHz anti-aliasing filter applied. The system response of all noise loggers was calibrated before deployment by inputting white noise of known level through the bulkhead connector with the hydrophone in-series. This gave the system gain with frequency, which when combined with the hydrophone sensitivity allowed conversion of the saved voltage waveform into Pa. The on-board clock of each noise logger was time synchronised to UTC time transmitted by GPS before deployment and the clock drift read after deployment, with estimated clock accuracies at any point in the deployment of the order of  $\pm 250$  ms.

Locations of noise logger sites sampled in the Kimberley are shown on Figure 1. The longest continuously sampled sites are around Scott Reef, with sampling commencing in late 2006 and the sampling program running until 2010. Dates of sampling are given where appropriate in the results. The locations of sites (WGS84 datum) commonly referred to in this document are: Maret Islands  $14^{\circ} 24.804' S$ ,  $124^{\circ} 53.659' E$  sampled over Sep-2006 to Aug-2008; and inside Scott Reef  $14^{\circ} 3.0' S$ ,  $121^{\circ} 50.836' E$  sampled over Sep-2006 to May-2010. The Maret Island site was near the coast while the Scott Reef sites were west of this.

All analysis has been carried out using in-house software in the Matlab processing environment. Bathymetry is derived from the Geoscience Australia 0.0025° bathymetry grid. All times of sunrise and sunset (upper limb hitting horizon) are extracted from the Geosciences Australia web site calculator for the location of the appropriate site. Spatial analysis is carried out in Easting and Northing for small scales and great circle distances for larger scales.

To display longer term patterns in sea noise the averaged power spectral density of each sample (200 s average, every 15 minutes) has been taken at multiple frequency resolutions with a spike removal technique applied to remove any mooring artefact noise. The power spectral density for each sample is then stacked in a spectrogram (x-axis is time, y-axis is frequency on a linear or log scale, and colour is intensity) over a period of days to months to display trends (averaging across samples used if the time period is  $> 7$  days). For analysis of chorus behaviour over long periods a 1/3 octave frequency band which encompasses the main energy of the chorus source is selected. The energy in this 1/3 octave band is calculated for each sample across an evening from the averaged power spectra and interpolated at a uniform time scale to account for clock drift or missed samples. Since fish do not wear watches but rather cue their daily rhythms to the sun, the time base each evening is zeroed to the time of sunset. Trends in the chorus can then be followed across seasons with the zero time being time of local sunset.

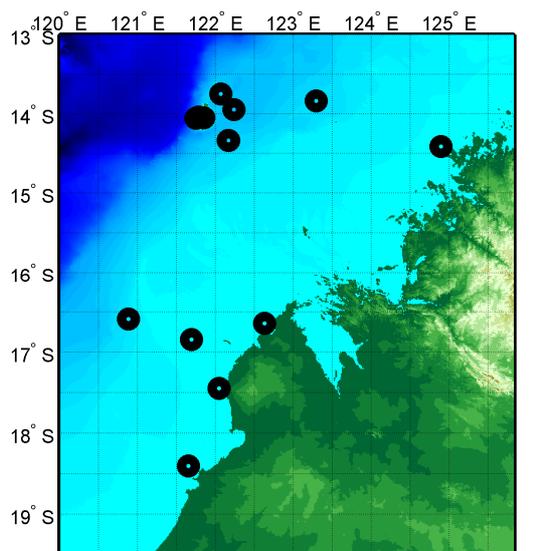


Figure 1: Locations of sites sampled for long term sea noise. The Scott Reef sites ( $\sim 14^{\circ} S$ ,  $122^{\circ} E$ ) were sampled 2006 to 2010. The Maret Islands (northern Kimberley near the coast @  $\sim 14.5^{\circ} S$ ,  $124.9^{\circ} E$ ) and a site north of Browse Island (east of Scott Reef at near  $123.3^{\circ} E$ ) were sampled over 2006-2008. Gourdon Bay is the southernmost nearshore site; James Price Point is nearshore and the next site north of Gourdon Bay; while Pender Bay is on the Broome peninsula north of James Price Point. The Lacepede site ( $\sim 16.9^{\circ} S$   $121.7^{\circ} E$ ) was west of the Lacepede Islands.

## RESULTS

Two fish chorus types are primarily presented, although there are many more choruses and calling fish types present in the Kimberley data sets. The first chorus is that described in McCauley and Cato (2000) and McCauley (2001) and attributed to an ensemble of nocturnal planktivorous fishes, believed to be of the families Holocentridae, Priacanthidae and Apogonidae. This chorus type is termed 'planktivorous fishes' here. The second chorus type has been previously recorded from the inshore Kimberley (1992), north, east and down the east Australian coast to Fraser Island by McCauley (2001). Off north Queensland and in the Gulf of Carpentaria the chorus was attributed to *Terapon theraps*, although it was suggested closely related species may produce the chorus at other locations. While the genera producing these calls and this chorus in the Kimberley has not been positively identified, the calls are so similar in characteristics and chorus pattern to the *Terapon theraps* choruses recorded in eastern Australia that the source must be a common Kimberley Terapontidae.

In the Kimberley the two fish choruses had distinctive patterns in daily timing, frequency content and call characteristics. Details of the call types are not pursued in depth here, rather the patterns of choruses were investigated. An example of a two day period of stacked sea noise spectra (spectrogram) showing the planktivorous fish chorus post dusk and the Terapontidae chorus post midnight, plus evidence of a third, weaker fish call type, is shown on Figure 2. The two chorus types were only present together at the Maret Islands site. The planktivorous fish chorus always began soon after dusk and peaked in the early evening before midnight with calling sometimes carrying on at a lower level until dawn when there was often a secondary peak in level. In contrast The Maret Island's Terapontidae chorus began after midnight

and ran until before dawn, offset in time from the planktivorous fish chorus.

The two call types differed significantly in that the planktivorous fish calls were comprised of a single broadband pulse from one contraction of the swimbladder, whereas the Terapontidae calls were a series of pulses of the swimbladder produced by anterior muscles contracting consecutively over ~ 0.2 s. The amplitude modulation resulted in the Terapontidae chorus showing the horizontal banding, as can be seen on Figure 2. The sound producing mechanism and resulting calls for both chorus sources are discussed in McCauley (2001). The spectral qualities of each chorus type are shown on Figure 3 using an example from the Maret Islands site and Scott Reef for the planktivorous fish chorus. The Terapontidae pulse repetition rate appeared in the frequency spectra as the series of closely spaced peaks with the spacing between peaks (Hz) as the inverse of time between muscle contractions. The planktivorous fish choruses differed slightly between the Maret Islands and Scott Reef, with different spectral maxima, near 600 Hz at Scott Reef and near 900 Hz at the Maret Islands. The frequency spectra of the Maret Islands planktivorous fish chorus shows a dip at near 1200 Hz but the similar 'shoulder' at near 1500 Hz to the Scott Reef chorus. The sharp dip in the spectra of the Maret's planktivorous chorus suggests the fish were calling near the surface, introducing a 'null' from the phase inverted surface bounce. The frequency of the 'dip' is the inverse of the depth of the fish divided by the sound speed, or the fish working at 1.25 m depth assuming a 1530 ms<sup>-1</sup> sound speed at the Maret Islands. In contrast the Scott Reef chorus did not have such a dip in the power spectra, suggesting the fish were working deeper in the water column such that the distance between the direct and surface arrivals was large enough that the energy in the surface bounce was sufficiently reduced relative to the direct arrival.

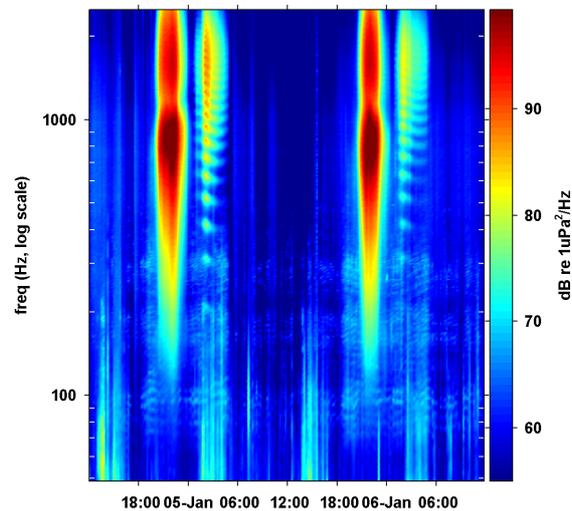


Figure 2: Spectrogram of two days of sea noise highlighting evening fish choruses. The plot uses a log frequency scale and runs over 12:00 4-Jan-2007 to 12:00 06-Jan-2007 from the Maret Islands site. The nocturnal planktivorous fish chorus, occurred over late evening with most energy near 800 Hz, while the second chorus from fish of the family Terapontidae began in the early morning with most energy over 1-2 kHz. Other, weaker fish calling with energy over 50-300 Hz was evident each evening.

The chorus levels of the spectra shown on Figure 3 are extremely high. The planktivorous fish choruses for the Maret

and Scott Reef sites reached to almost 50 dB above ambient noise levels at the frequency of their spectral maximum. For the curves shown on Figure 3 broadband chorus levels ranged from 126-135 dB re 1µPa for the Maret Island planktivorous fish, 94-118 dB re 1µPa for the Maret Island Terapontidae chorus and 128-134 dB re 1µPa for the Scott Reef planktivorous fish chorus.

The Terapontidae chorus was heard from the Maret Islands over November 2006 and 2007 into early January the following year. The Terapontidae chorus was not heard from the other inshore sites shown on Figure 1 of: 1) off Gourdon Bay; 2) NW of the Lacepede Islands; or 3) off James Price Point.

In contrast, after checking the records from all sites shown on Figure 1, the planktivorous fish chorus was detected from: 1) in and around Scott Reef (all year round); 2) Maret Islands; 3) James Price Point; and 4) the site 25 km to the SE of Scott Reef (although the choruses were weak here).

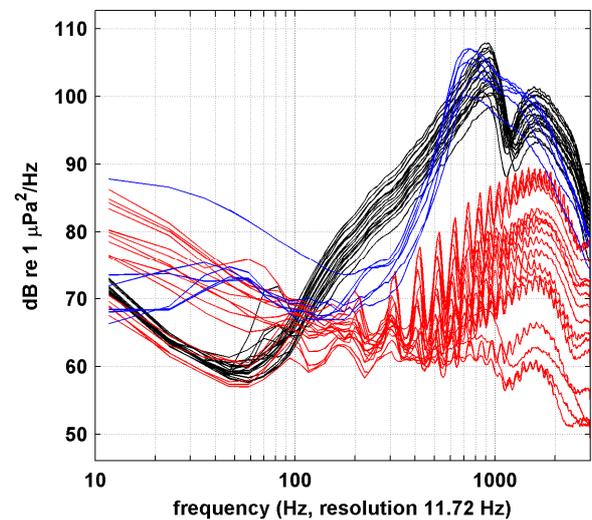


Figure 3: Spectra averaged across a sample for the planktivorous fish chorus (black lines, chorus peaking at 900 Hz) and the Terapontidae chorus (red lines with many spectral peaks at the muscle pulse repetition rate and a broad frequency peak at swimbladder resonance), from the Maret Islands site. The blue curves peaking at 700 Hz over 95-105 dB re 1µPa<sup>2</sup>/Hz are the planktivorous fish evening chorus recorded from within Scott Reef.

To investigate long term trends in the choruses over lunar and seasonal cycles the energy over the 1/3 octave band which best encompassed the frequency peak of the call energy was followed through time. For the planktivorous fish chorus the energy in the 800 Hz 1/3 octave was tracked (frequency band limits of 707-891 Hz). The trend in this chorus level over almost three years as recorded from inside Scott Reef is shown on Figure 4. On this figure the energy in the 800 Hz 1/3 octave each evening is stacked across the season on the top panel, with the evening time base zeroed to the time of local sunset. The lower panel of Figure 4 shows the integrated energy in the 800 Hz 1/3 octave across 1-7 hours post sunset each evening. A complex daily, lunar and seasonal cycle of chorusing behaviour was seen inside Scott Reef for the planktivorous fish chorus. There were other overlying sources present. For example, in the data shown on Figure 4, vessel noise featured prominently over May to August 2008 and energy from at least two other fish chorus types appeared

(ie band just after sunset each night), although this was considerably weaker.

The similar analysis was carried out for the Maret Island data and is shown on Figure 5 where energy from the planktivorous chorus dominates but energy from the Terapontidae chorus can be seen. The Terapontidae choruses appeared in these plots later each evening, beginning around 5-6 hours post sunset. It was not possible to separate out the Terapontidae choruses at the Maret Islands site using received energy alone as the planktivorous fish chorus was present most nights at this site and had energy in the 1.2 kHz 1/3 octave (Figure 3), which was the frequency band which best matched the Terapontidae chorus. The Terapontidae chorus was only present late in the evenings over summer (November to March, often with a small break and some further calling in May).

The planktivorous fish choruses had different patterns in the time of chorus onset and maximum level each night when comparing Scott Reef and the Maret Islands. The Scott Reef chorus showed a uniform shift in the time of maximum chorus level from two to almost four hours post sunset across a season. At the inshore Maret Island site there was a smaller shift in the time of maximum level each night (post sunset), with the chorus having a reasonably uniform one hour post sunset start for most of a year, but this drifting to 2-3 hours post sunset over late summer then drifting back to one hour post sunset at the onset of winter.

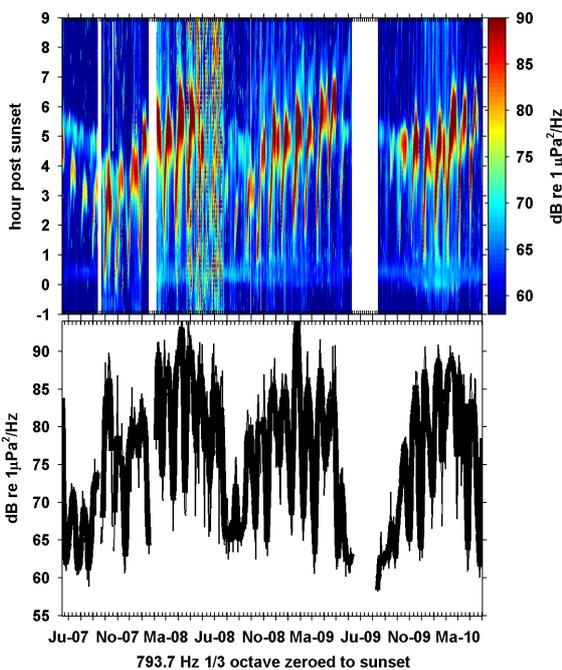


Figure 4: Pattern of the 800 Hz 1/3 octave level each evening over Jun-2007 to May-2010 (1052 days) inside Scott Reef shown by: 1) (upper panel) each evenings energy in the 800 Hz 1/3 octave, with time zeroed to time of local sunset; 2) (lower panel) the seasonal trend in chorus level shown as the integrated energy across the 800 Hz 1/3 octave chorus between 1 and 7 hours post dusk each evening. In the top panel the 800 Hz chorus dominates in the long time frame oscillatory trend with evidence of a second chorus type beginning around 5.5 hours post dusk and linearly dropping to 3.3 hours post dusk in early November when it stopped each year, and a third chorus appearing just after dusk and lasting for an hour. Only the first character of every fourth month is shown

on the time axis. The lower panel shows the daily trend (light line) and a smoothed trend (heavy line). A gap in sampling occurred in mid 2009.

The seasonal pattern of the planktivorous chorus is shown on Figure 6, by the integrated level each evening (1-7 hours post sunset at Scott Reef, 1-4 hours at Maret Islands) stacked on a single year plot. The Maret Islands data was integrated from 1-4 hours only to remove energy from the Terapontidae chorus which began around 5-6 hours post dusk (Figure 2). Offsets in the chorus patterns were seen between years at a site, this as the chorus was linked to moon phase and there was not an equal divisor of moon period into a calendar year. The chorus level across a season differed between years but showed a general trend at Scott Reef to increase to highest levels across October to May each year and at the Maret Islands site to be lowest during April to late June, then increase to highest levels over summer. At each site the pattern varied between years suggesting environmental factors altered the chorus activity between years.

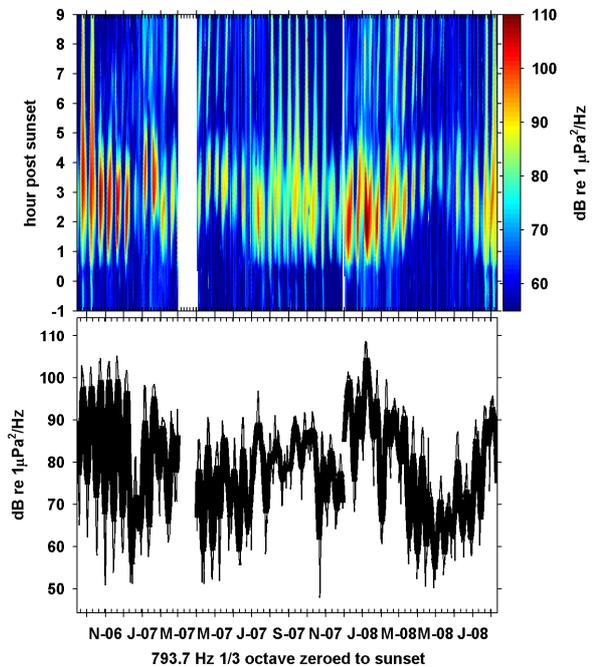


Figure 5: Pattern of the 800 Hz 1/3 octave level each evening across Sep-2006 to Aug-2008 (696 days) at the Maret Islands site, shown by: 1) (upper panel) each evenings energy in the 800 Hz 1/3 octave, with time zeroed to time of local sunset; 2) (lower panel) the seasonal trend in chorus level shown as the integrated energy across the 800 Hz 1/3 octave chorus between 1 and 4 hours post dusk each evening. In the top panel the 800 Hz chorus dominates in the long time frame oscillatory trend with energy from the Terapontidae choruses appearing later in the summer evenings. Only the first character of every second month is shown on the time axis. The lower panel shows the daily trend (light line) and a smoothed trend (heavy line). A gap in sampling occurred in Apr-2007.

To investigate links to moon phase in the planktivorous fish chorus the time of full moon was retrieved from almanacs and the alignment of integrated chorus level each evening post sunset, with respect to moon phase calculated (0 being full moon, 29 days being the next full moon). The trend for each moon phase at the two sites is shown on Figure 7. The Maret Islands site had a regular cyclical pattern of chorus level with moon phase, with a period of approximately half a

lunar phase (14-15 days) and an approximate 20 dB amplitude. The pattern was less clear at the Scott Reef site and different, with highest chorus levels beginning 2-3 days after a full moon and staying high until just after the new moon when they dropped by approximately 10 dB to begin increasing at the next full moon.

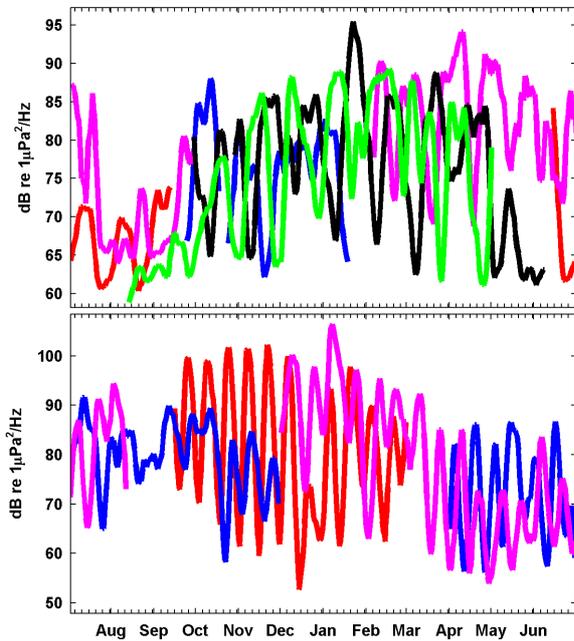


Figure 6. Integrated level of the planktivorous chorus across a year, (across 1-7 hours and 1-4 hours post dusk at the Scott Reef and Maret Island sites respectively) with all data overlaid on a 12 month time frame for the Scott Reef (top) and Maret Island (bottom) choruses. The display uses a 2 day running linear fit to smooth the curves. Different years use different colours on each plot.

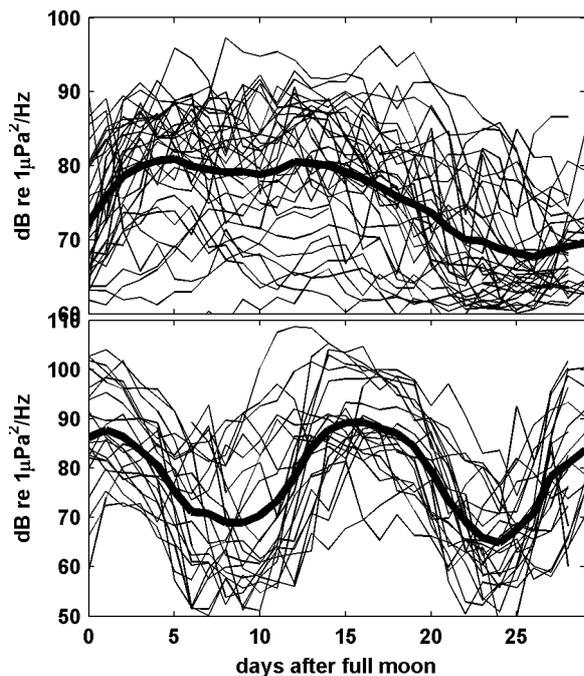


Figure 7: For the Scott Reef (top) and Maret Island (bottom) sites the trend in planktivorous fish chorus level each evening

plotted by moon phase (0 and 29 days are full moons, 14-15 days are new moons). The heavy lines are the mean trend made by averaging all lunar cycles at a site, at the same lunar phase (ignoring zero values).

**DISCUSSION**

Patterns in three fish chorus types have been briefly discussed. All choruses were capable of reaching very high levels, in excess of 130 dB re 1 μPa broadband and almost 50 dB above ambient noise levels at the frequency of the chorus spectral maximum. These are very high levels with choruses dominating the ambient sea noise spectra when they occurred. The choruses were persistent, with the type previously attributed to nocturnal planktivorous fishes by McCauley (2001) found to occur at two sites here almost year round. McCauley (2001) speculated that this chorus type was related to feeding behaviour by these fishes, which is supported by the fact the choruses were heard here year round, since the fish must feed each night. In contrast, the Terapontidae chorus is believed to be produced by spawning aggregations as part of the reproductive process, and hence only occurred over the months fish spawned (McCauley 2001).

The planktivorous fish chorus was strongly influenced by moon phase, this being more pronounced at the inshore Maret Island site where an almost sinusoidal oscillation in level occurred with a period of half a lunar cycle and 20 dB amplitude. The offshore site had differences in chorus level with moon phase but with more variability, a longer period of maximum chorus level within a moon period, from just after full moon to new moon, and a 10 dB oscillation in amplitude. These differences in chorus level with moon phase meant that when aligning chorus levels across years using our Gregorian calendar there will always be a mismatch between years, since the moon period is not divisible into one year.

The fishes which produce the planktivorous fish choruses would be considered higher order consumers in plankton ecology thus will be less driven by higher lunar light levels implying an increased predation risk than the animals they target. At least some of the animals these fish prey on, various large plankton, are known to avoid higher lunar light levels by undertaking secondary sinking movements during a night after satiating themselves (Tarling et al 1999, Tarling et al 2002, Sourisseau et al 2008). This behaviour is speculated to reduce predation risk from increased visibility in higher lunar light levels. The planktivorous fish choruses measured here reached highest levels either at full moon (Maret Islands), at new moon (Maret Islands) or from just after full moon to new moon (Scott Reef). Both sites had consistently lowest chorus levels in the latter half of the moon phase when turning from a new to full moon, when the moon rose during the day time. We can speculate that the observed lunar shifts in chorus level reflect the ability of the fish to find prey in the different light fields offered across a moon phase combined with prey behaviour in response to moonlight. For the higher order planktivorous predators producing the chorus a balance must exist between higher moonlight levels allowing easier prey location but less prey since they try to avoid higher moonlight levels, or lower light levels offering more prey but these more difficult to locate.

There was no easily apparent reason why the time the planktivorous fish choruses occurred each night should oscillate across a season for Scott Reef (Figure 4) or over 6-8 months at the Maret Island site (Figure 5). At Scott Reef the season start and end time shifted later each moon phase beginning around 2 hours post dusk in July-August, the start time creep-

ing up to 4-6 hours post dusk in March then shifting back again to the July-August start times. A simpler trend occurred at the Maret Island site where the start time of the chorus drifted from one hour post sunset to 2-3 hours over February to May then drifted back again to be one hour post sunset in late July. At Scott Reef there was a complex relationship between chorus level, chorus start and finish time, moon phase, season, and possibly other factors, which has not been fully elucidated here. While there was a simpler relationship at the Maret Island site for the chorus time each night there was no discernible reason why it should shift as it did. At Scott Reef the period of the year with the latest chorus start times correlated with the highest chorus levels, but the opposite was the case at the Maret Island site. The change in chorus start times across a season possibly reflects some change in the habits or availability of prey, which was peculiar to each site. Since no studies have been carried out on the dynamics of these nocturnal planktivorous fishes then at this stage it is difficult to fully understand the patterns of chorus nightly occurrence time observed.

At the same site there were some significant inter year differences in chorus levels reached at the same time point in different seasons. Part of this was due to misalignment of the lunar phases between years but in some instances the differences were considerably larger than the typical lunar amplitude (ie. April to late June at Scott Reef, Figure 6). These inter-seasonal differences in chorus levels suggest larger scale ecological or oceanographic factors may drive the chorus activity. Years which are particularly productive would be expected to have higher chorusing activity from reproductive choruses since the fish will be able to partition more energy into reproduction, and vice-versa. In years where secondary productivity remains high for longer or shorter than usual, then the choruses related to feeding activity will be expected to increase or decrease respectively. Fluctuations in regional scale oceanographic features driven by world scale climate shifts occur regularly in the measurement area (ie. El Niño, Indian Ocean Dipole) but their effect on productivity in this area are poorly understood.

This paper has presented a short summary of two fish chorus types recorded at two locations. The fish choruses reached extremely high levels at times for protracted periods (up to 50 dB above ambient levels over the chorus bandwidth). The choruses showed complex patterns with respect their levels, time of occurrence each night, relationships with lunar phase, and inter-year seasonal differences in levels. While two choruses were believed to be produced by the same complement of fishes, they showed different patterns in their activity at the two widely separated sites. Currently we cannot fully explain many of the patterns observed. There is clearly an enormous amount that we do not know about these fishes, their sound producing habits and how the local environment impacts on the habits. On the contrary the fish choruses can potentially tell us an awful lot about their environment, if only we knew what they were saying. The fish choruses also exemplify the importance of sound for marine fauna in the marine environment and our obligation to not pollute this with anthropogenic noise.

## ACKNOWLEDGEMENTS

The Scott Reef data collection program was funded by Woodside Energy. The Maret Island data was funded by INPEX. Frank Thomas and Mal Perry at Curtin were critical in preparing sea noise loggers and moorings.

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