High Frequency Biophysical Oceanography in Western Australia*

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ABSTRACT

As part of a multi-disciplinary research effort off the West Australian coast, acoustic methodologies are being developed to characterise fine scale vertical distributions of mesoplankton (0.1 to 20 mm in length) using high frequencies: 265, 420, 700, 1100, 1800, 3000 kHz. This study combines the use of multi high frequency acoustics with discrete biological samples and physical water column parameters (temperature, salinity, fluorescence) over a multi year period. The physical samples were obtained with a specially designed Discreet In-situ Plankton Sampler (DIPS) that collects 6 samples within the water column at targeted depths. The Tracor Acoustic Profiler System (TAPS) attached to DIPS was operated at a fixed range of 1.5 m with a 5 litre sampling volume. We present our initial investigations of comparing the plankton samples to the observed values of acoustic reverberation (Sv dB re 1 m^{-1}). We examine both the affect of system noise and low densities of plankton and how they might affect our strategy for estimating distribution based on acoustic models. This comparison highlights limitations in the methodology due to the low densities of plankton generally obtained in the oligotrophic waters off Western Australia, their patchy distribution and potential heterogeneity of scattering types.

INTRODUCTION

There has been a long quest to create a simple and reliable acoustic system to study the vertical distribution of zooplankton in the sea (Holliday, 1992). Zooplankton acoustics requires the use of higher frequencies than those normally used in fisheries acoustics. To determine both size and abundance of zooplankton and micronekton, multiple frequencies must be used (Holliday and Pieper, 1995).

Studies comparing pump and net samples have been conducted with both the use of high frequency systems and standard acoustic systems such as Acoustic Doppler Current Profilers (ADCPs)(Fielding et al. 2004)

This study has been conducted as part of a multi-disciplinary research effort studying a cross-shelf transect off the Western Australian coast at Two Rocks approximately 50 km north of Perth. Western Australia's coast is heavily influenced by the Leeuwin current, a poleward flowing eastern boundary current. The waters in our study support a low level of biomass. Using a Tracor Acoustic Profiler System (Mcgehee et al. 2000) (TAPS) (Figure 1) in conjunction with a specially designed Discreet In-situ Plankton Sampler (DIPS) (Figure 1), we have attempted to map the vertical distribution of zooplankton at our study sites.

The purpose of this paper is to investigate the affect of system noise in a low zooplankton density environment. TAPS data will be related to abundance of zooplankton in several size classes. Differences in the echo statistics will be presented indicating the detection of multiple and single scatterers. Methods of improving detection limits will be discussed.

MATERIALS AND METHODS

11 vertical casts were completed during our voyage on the RV *Southern Surveyor* between 21st and 27th of January 2004. Acoustic data were collected at six frequencies using TAPS and 56 discreet zooplankton samples were collected using DIPS.

TAPS and DIPS were lowered together through the water column (Figure 1). Acoustic volume reverberation (Sv dB re 1 m^{-1}) is monitored in real-time. DIPS was operated from the surface using telemetry via a conducting cable. Samples were targeted at areas of high and low acoustic reverberation.

TAPS has 6 frequencies ranging from 265 kHz to 3 MHz (Table 1). These frequencies have been chosen to span the transition between Rayleigh and geometric scattering for fluid filled animals such as copepods. TAPS was deployed in 'cast mode'. In this mode each ping averages the acoustic volume reverberation (Sv) of five samples taken at intervals 0.125 m centred at a fixed range of 1.5 m. Four pings were averaged and displayed in real-time as the instrument was lowered through the water column.

* This paper was not peer reviewed

Figure 1. The specially designed Discreet In-situ Plankton Sampler (DIPS) that can collect 6 samples at targeted water depths and the Tracor multi-frequency (TAPS) acoustic system attached.

DIPS consists of six 120 µm mesh nets with solid cod ends in a rotating carousel (Table 2). When a sample is requested the carousel is rotated to the open position. The controller starts the submersible thruster and a pre-programmed volume of water is drawn through the net. The sample volume is measured using a flowmeter and as soon as the sample is complete the carousel is rotated to the closed position.

Table 1 Relevant specifications of the Tracor multi-frequency TAPS system when used in cast mode.

Serial number	14
Frequencies	265,420,700,1100,1850,3000 kHz
Transmit power	100 W (nominal)
Pulse length	336 µs (fixed)
Ping rate	3 s^{-1} (each channel)
Beamwidths	8 degrees @ -3dB points (nominal)
Sample volume	0.003 m^3
Maximum depth	192 m

Table 2 Relevant specifications of the Discreet In-situ Plankton Sampler (DIPS)

Sample chambers	6
Sample volume	0.25 – 4 m^3 (programmable)
Flow rate	≈ 0.017 m^3s^{-1}
Flow velocity	≈ 1 ms^{-1}
Net mesh size	120 µm
Mass in air	175 kg
Maximum depth	200 m

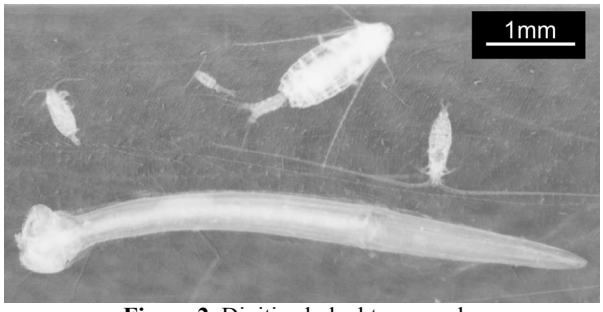

Figure 2. Digitized plankton sample.

The samples were preserved in 5% formalin. The samples were digitized using a microscope fitted with a CCD camera (Figure 2). The digital pictures are processed using ImageJ (Abramoff et al. 2004) to determine the volume and equivalent spherical radius (ESR) of each animal (Alcaraz et al. 2003). The ESR is the radius of a sphere that contains the same volume as the animal.

RESULTS AND DISCUSSION

Composition of pump samples varied in abundance, species and size classes. The abundance of zooplankton in pump samples was found to range between 6246 m^{-3} and 145 m^{-3}. Species composition changed with depth, station and time of day.

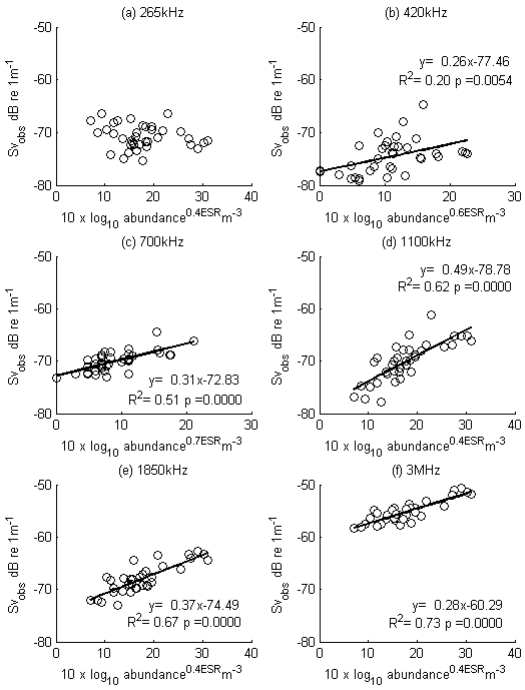

Figure 3 Regression of measured TAPS Sv_{obs} to 10log10(abundance)

To evaluate our acoustic methodology we must determine a relationship between DIPS samples and TAPS-measured Sv. We assume the relationship between observed Sv and abundance of zooplankton is given by Equation 1

$$S_{vobs} = \overline{TS} + 10\log_{10}(n_i) \qquad [1]$$

Where Sv_{obs} is the mean volume backscatter in dB re 1 m^{-1}, TS is the mean target strength of the dominant scatterer in dB re 1 m^2 and n is the number of scatterers in the i^{th} sample. Thus doubling the abundance of zooplankton would lead to

an increase of 3dB in Sv_{obs}. A stepwise linear regression against 10log abundance was performed to identify the most important ESR class for each frequency. A regression was performed against the dominant size classes (Figure 3). The regression demonstrates that there is a statistical relationship between the DIPS samples and the measured values of Sv at all frequencies apart from 265 kHz. As has been shown before (Pieper and Holliday, 1984; Holliday and Pieper, 1995) there is a stronger correlation between larger copepods (ESR 0.4 mm) and higher frequencies than at lower frequencies.

The slope values for the regressions clearly indicate the presence of a low signal to noise ratio. This can be demonstrated by adding a noise term to Equation 1.

$$Sv_{pred} = 10\log_{10}\left(10^{(\overline{TS} + 10\log_{10}(n_i))/10} + 10^{\overline{NL}/10}\right) \quad [2]$$

Where *NL* is the mean noise level in dB re 1 m^{-1}. The noise level can be estimated from samples containing low abundances.

Figure 4 shows TAPS measured Sv plotted against predicted Sv from Equation 2 for abundance values in the 0.4 mm ESR bin, the middle line indicating the regression function and the outer lines one standard deviation in the noise level. A target strength of –82 dB re 1 m^2 was assumed and estimates of noise level and noise standard deviation were made from data collected from low abundance samples. The value of R^2 has fallen from 0.73 to 0.68 but the slope is now much closer to the expected value of unity. This clearly shows that our ability to predict concentrations of zooplankton is limited by system noise, both the absolute noise level and its standard deviation.

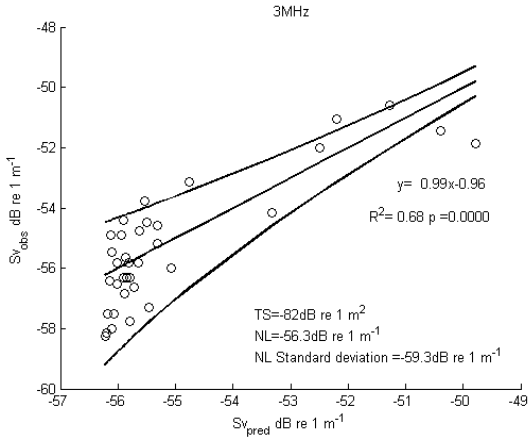

Figure 4 TAPS measured Sv at 3 MHz vs Predicted Sv including noise

Another key aspect of TAPS is the small sampling volume. The volume was chosen to exclude larger, less abundant creatures from the sample. We must be aware of the effects this can have when operating in a low abundance environment. It has been shown that reverberation from multiple scatterers is quite different to those from a single scatterer (Stanton, 1985). When a large number of randomly located scatterers are insonified the resultant echo is dependant on the integral of the acoustic beam pattern, whereas with a single scatterer the result is a function of the beam pattern. Hence when the number of scatterers in the sample volume is large their position in the acoustic beam pattern can be ignored, but when numbers of scatterers approach one, their position in the beam becomes important. To get overlapping echoes there must be more than one scatterer in a given pulse resolution volume. The critical number of scatterers needed per m^3 assuming a random distribution can be calculated by dividing 1 by the sample volume in m^3. The TAPS calibration includes the directivity index. The critical density of zooplankton can be derived in log form:

$$10\log_{10}(nc_i) = -[20\log_{10}(r_i) + 10\log_{10}(\frac{c\tau}{2}) + 7.7 - DI] \quad [3]$$

Where nc_i is the critical number of zooplankton per m^3 at a given range r_i in m, c is the speed of sound in ms^{-1}, τ is the pulse length in s and DI is the directivity index of the transducer in dB. Typical values of critical density for TAPS ranges from 217 to 811 individuals per m^3 depending on range bin and frequency.

Figure 5 compares results from two samples. Sample A was taken during the day at a depth of 29m in 40m of water, 27 km off shore. The highest abundance of zooplankton (6246 m^{-3}) during the voyage was recorded in this sample. Sample B was taken at night at a depth of 27m in 1000m of water, 85 km off shore. A much lower total abundance (523 m^{-3}) was recorded in Sample B, but with a higher concentration of larger zooplankton. A clear difference can be seen between the PDFs from the two samples. The high abundance Sample A is normally distributed in the log domain. Sample B shows two peaks which are probably related to two different scattering groups. As expected from a normal distribution, the mean and median of the acoustic Sample A are similar, unlike Sample B. It was found that the median value of Sv correlated much better with the abundance of zooplankton in the DIPS samples than did the mean value. This is probably due to the median excluding less abundant larger scatterers. Identifying these distinct PDFs can improve our ability to predict plankton abundance from acoustic backscattering.

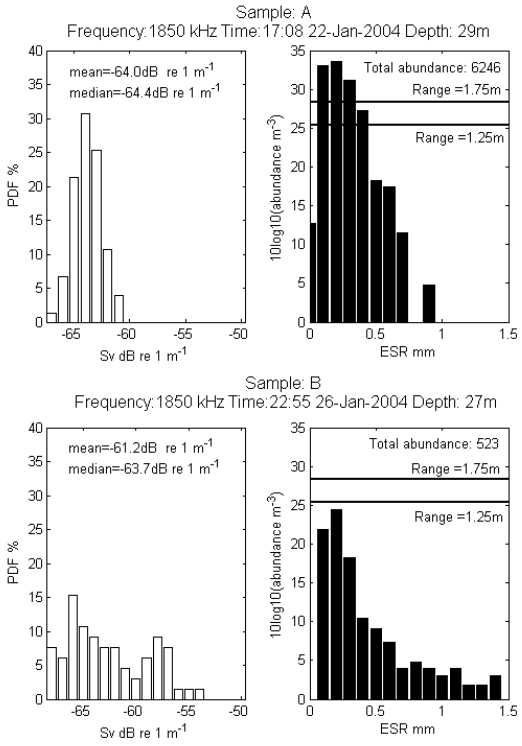

Figure 5 Comparison of PDF from high and low abundance samples

These preliminary results indicate that TAPS is limited by system noise but is still able to detect zooplankton in this

region of low plankton abundance. Ideally a signal-to-noise ratio of 9-12 dB is required for reliable sampling of zooplankton populations (Greenlaw, 1983).

Derivations of Sv rely on two main assumptions: scatterers are randomly distributed in the sample volume; and the number of scatterers is statistically large. As a rule this can be taken to be 5-30 scatterers and with averaging 20 pings then the 95% confidence interval should be approximately ±2 dB (Greenlaw, 1983). The signal returned from the biota needs to be above the noise limit for all frequencies for inverse methods to work optimally. At typical density levels experienced along the Two Rocks transect the plankton density within the 3 litre sample volume ranges from 0.4 to 18 plankton per sample volume.

TAPS' utility could be greatly improved by increasing the signal to noise ratio. This could be done in a number of ways: increase the source level, or the pulse length or reduce system noise. Perhaps the simplest of these methods would be to increase the pulse length. Doubling the pulse length would increase the signal to noise ratio by 3dB. TAPS currently uses a pulse length of 336 μs giving a sample interval of approximately 0.255 m in range. There are limits to the amount the pulse length can be increased. As pulse length increases range resolution decreases. Also the distance to the nearest sample range must be increased to avoid interference from the transducer ringing at the end of the pulse cycle. Increasing the pulse length will also decrease the number of statistically independent samples taken each ping, resulting in the need to increase the ping rate to compensate. Absorption at these high frequencies will also limit the maximum pulse length. The derivation of Sv assumes that absorption within the pulse length is negligible. At high frequencies such as 3MHz absorption can be over 2.4 dB m^{-1} effectively limiting the pulse length to less than a meter. Signal to noise ratio could be improved using an FM slide (chirp) signal (Ehrenberg and Torkelson, 2000). Another way to tackle this problem is through noise reduction (Korneliussen, 2000) which could be achieved by monitoring distant range bins, and assuming that their return represents the noise level for that particular ping.

The detection of single targets versus multiple scatterers could be greatly improved by reducing the pre-averaging that TAPS performs and sampling the echo envelope at a higher frequency. Working with raw un-averaged data would be a distinct advantage. We hope to implement some of these strategies in the next round of field work to significantly improve our detection limits.

CONCLUSION

The work presented in this paper is evolving rapidly. The data indicate a clear correlation between acoustic reverberation and zooplankton abundance and size groups. The noise level is identified as an important limiting factor and should be taken into account if data are to be used in direct model inversions. The potential to differentiate between multiple and single scatterer assemblages has been demonstrated. Ideas for improving TAPS have been put forward and are currently being pursued.

ACKNOWLEDGEMENTS

We would like to acknowledge the crew of RV Southern Surveyor. Mat Sherlock, Ian Helmond, Mark Lewis and Jeff Cordell of CSIRO for their help in designing and building DIPS. Also special thanks to Charles Greenlaw for answering many TAPS questions.

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