Preliminary Analysis of Single-Beam Acoustic Data of Fish Spawning Aggregations Along the Western Australian Coastline

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ABSTRACT

Coastal waters of Western Australia and their associated habitats are home to many species of demersal fish that migrate to form short-lived aggregations in order to spawn. These spawning aggregations form at the same sites over successive, predictable spawning seasons. Due to the exploitation of demersal finfish spawning aggregations within the West Coast Bio-region, recent attention has been paid to using acoustic techniques for assessments of these aggregations, to help evaluate their sustainability. This management process has been raised as an important issue. A well established tool for biomass estimates, used in these evaluations, is single-beam echosounding. As part of the Management and Monitoring of Fish Spawning Aggregations project of the Department of Fisheries, acoustic data on fish aggregations have been recorded during 2004 and 2005, using a SIMRAD EQ60, single-beam echosounder, operating at frequencies of 38 kHz and 200 kHz. These recordings were made at various locations around Rottnest Island, where recurring spawning aggregations have been reported. At selected sites, towed video and physical sampling techniques were employed to ground-truth acoustic results. Initial analysis of acoustic backscatter measurements from selected sites is presented, and possible correlations between targets and individual species are discussed. Preliminary conclusions are drawn in respect to the use of a single-beam echosounder for estimating fish stocks within dense and sparsely populated aggregations.

INTRODUCTION

The discovery of spawning aggregations, with their predictably high yields from commercial fishing, has made some species particularly vulnerable to overfishing (Claydon 2004). Aggregation fishing is estimated to have eradicated around one third of local spawning aggregations in the Caribbean, and similarly resulted in the elimination of aggregations in the Indo-Pacific region (though these are poorly documented). Such losses of spawning aggregations from overfishing are often associated with the collapse of the fisheries they supported (Claydon 2004), thus illustrating the need for long term monitoring of those spawning aggregations found along the West Coast Bio-Region.

A spawning aggregation has been defined by Domeier & Colin (1997) as;

> A group of conspecific fish gathered for the purpose of spawning with fish densities or numbers significantly higher than those found in the area of aggregation during non-reproductive periods.

In terms of acoustic analysis it has also been defined as 'an acoustically unresolved, multiple fish aggregation' (Kieser et al. 1993). It is the evaluation of samson fish (*Seriola hippos*) aggregations near Rottnest Island, which satisfy both these criteria, that this paper and its associated research within the Department of Fisheries project are concerned with. It is the purpose of the study to determine preliminary estimates of abundance within the aggregations and to identify any characteristic complexities associated with the acoustic observation of the samson fish at Rottnest Island.

The use of acoustic techniques to detect aquatic organisms is a centuries old process, dating from fishermen following the sound of soniferous fish through the hulls of their wooden boats (Moulton 1964). In the past century, technological advancements in the remote detection of submerged bodies have been evolving rapidly. The first technological application of hydro-acoustics was to detect fish in a tank (Kimura 1929). Transferring these techniques to detect fish in the marine environment, trials were conducted in the Barents Sea, Norway (Sund 1935) and later (Balls 1948) to show the qualitative abundance and distribution of fish life.

Since then, single beam echosounders and the echo integration method have become an established technique in biomass stock assessments. Echo integration is experimentally linear, thus acoustic and real density are equal (Foote 1983). The echo integrator output can be converted to biomass estimates, over a required depth, by use of the Target Strength (TS) of fish within the integration region, given as;

$$TS = 10\log_{10}\left(\sigma_{bs}\right) \tag{1}$$

where σ is the backscattering cross section of the fish (m^2) at a specific fequency (Horne 2000). It has been shown that the swimbladder of a fish can contribute in excess of 90% of the overall target strength (Foote 1980) and that the back scattering cross-section increases by approximately the square of the fish lengths, leading to variations of up to 25dB of the target strength (Nakken and Olsen 1977). It is this length relationship on which most *in situ* regression target strength models have been based, in the form of;

$$TS = a\log L - b \tag{2}$$

where a and b are constants specific to each species and frequency, while L is the length of an individual fish (cm), (Johannesson & Mitson 1983; Urick 1983).

However, it is also known that the target strength varies considerably with swimbladder tilt angle, in some cases up to 30dB at a 45° tilt (Foote 1980). This characteristic, when considering a survey of an aggregation where spawning subjects make vertical diel movements, should be accounted for. When combined with other biological factors such as spawning maturity (Ona 1990) and physical factors such as feeding (Ona 1990) or multiple reflectance (Johannesson & Mitson 1983), it is paramount to develop an accurate target strength model when estimating aggregation biomass.

Stock identification is an integral component of modern fisheries assessments, and yet there is still a relative scarcity of assessments that actually implement stock identification requirements (Begg et al. 1999). Recently a European Union research project, entitled 'CLUSTER', involved the specification of standard protocols for the extraction of aggregation parameters from acoustic surveys, at a school and Elementary Distance Sampling Unit (EDSU) level (Reid et al. 2000). These protocols are now in use to characterise aggregation species by image analysis techniques and comprise a catalogue of acoustic, morphological and positional data (Iglesias et al. 2003).

METHODS

Study areas

Rottnest Island lies 18km off the Perth coast. In the waters to the west of the island is an area in which several decommissioned vessels have been deliberately sunk over the past few decades. The results presented below were compiled from data acquired from seven such sites, the locations of which are kept confidential, on behalf of the fishermen and local bodies who donated them.

Each of the surveyed wrecks lies in 110±10m of water, on a flat, sandy seabed. Unpublished reports of the seven sites, from fishermen, suggest that spawning samson fish migrate to these locations to form aggregations, specifically above these wrecks, on an annual basis. The height of these aggregations is during the summer months, between October and February, though smaller aggregations have been found in prior and subsequent months.

Data Acquisition

Single beam acoustic backscatter data were collected west of Rottnest Island between 23rd November 2004 and 27th February 2005, from a 21ft Fisheries research vessel, the 'Snipe'. The SIMRAD EQ60 echosounder was mounted on the starboard sides of the vessel. Specifications of the SIMRAD EQ60 are given in Tables 1 and the settings applied during the surveys in Table 2.

Table 1. SIMRAD EQ60 Echosounder Specifications.

Operating Frequency (kHz)	38.08	198.864
Beam width (°)	15.2	7.2
Two-way Beam Angle (dB re 1 Steradian)	-14.00	-20.50
Sample Interval (s)	0.000126	0.000025
Absorption Coefficient (dB/m)	0.0098	0.0523

Each site was surveyed by conducting grid transects (Kloser et al 2001; Doonan et al 2003) to gain the greatest available coverage of the aggregation, while survey speeds were kept to below 3 knots in order to acquire maximum backscatter from single targets. The greatest coverage was given to Sites 1 and 2, each of them surveyed on at least five occasions throughout the spawning period, providing the majority of the results.

Table 2. Settings of the SIMRAD EQ60 Echosounder during Rottnest Island surveys.

Operating Frequency (kHz)	38.08	198.864
Transducer Draft (m)	1.6	1.6
Transmit Power (W)	500	1000
Pulse Length (ms)	0.512	1.024
Ping Rate (s^{-1})	1.9	1.9
Receiver Gain (dB)	19.5	26.3

Trawling techniques are often used to ground truth fisheries acoustic surveys (McClatchie et al. 2000). However, the relatively low abundance within the Rottnest aggregations eliminates this as an option. In addition, ground truth data could not logistically be collected concurrently to the acoustic data. As such, video data acquired on days subsequent to the surveys (Delacy 2005, pers. comm., 13th June) along with direct sampling data from an ongoing, Fisheries 'Tag and Release' project (Mackie 2005, pers. comm., 17th June) have been employed to estimate samson fish characteristics at the surveyed sites.

Data Processing

Acoustic data were imported into Sonardata Echoview v3.25 software for processing. Echoview creates a 2D-Echogram from the raw data, allowing various characteristics to be exported.

Biomass Estimation

To gain abundance data derived solely from the aggregations, the transects were visually truncated from the echogram to create regions bounding only fish deemed members of an associated aggregation (Doonan et al 2003). The regions integrated by Echoview, yielding Nautical Area Scattering Coefficients (NASCs), were then manipulated to give an equivalent NASC for separate, whole aggregations.

Derived from the area backscattering coefficient (MacLennan and Fernandes 2000) the relationship between NASC and the biomass within the aggregation is as follows;

$$B = \frac{NASC}{4\pi 10^{\frac{TS}{10}}} \times W \tag{3}$$

where B = Biomass (tonnes/n.mi^2) and W =Weight of an individual fish (kg).

However, there are two major factors which indicate that these results will only offer relative estimates for each site.

i) The SIMRAD EQ60 is currently uncalibrated, thus responses will have a low level of accuracy.

ii) There is currently no standard relationship between target strength and length of the samson fish.

To help authenticate the data and provide some level of biomass estimate, target strength relationships for fish biologically similar and therefore acoustically comparable to the samson fish, were supplemented and compared. Tuna target strength at 38 kHz can be expressed as

$$TS_{YF} = 25.26 \log FL - 80.62 \tag{4}$$

$$TS_{BE} = 24.29 \log FL - 73.31 \tag{5}$$

where TS_{YF} and TS_{BE} are target strengths of Yellowfin and Bigeye tuna respectively and FL=Fork Length (cm), (Bertrand & Josse 2000). The fork length was taken as the average of statistics collected from both sets of ground truth data.

Combining this with a relationship between samson fish length (cm) and weight (kg) (Mackie 2005, pers. comm., 21st June) where

$$W = 14.512 FL^{\pi} \tag{6}$$

and equation (1) permitted estimation of biomass present at each site, on an EDSU level.

Aggregation Parameters

Data on aggregation size, shape and position were extracted and catalogued from the echogram at the school level as laid out by Reid et al. (2000). Estimation of the overall scattering area of the aggregations from these data, enabled the calculation of the population density of the aggregating fish and temporal comparison throughout the spawning period and across various sites.

RESULTS

The results obtained from the Rottnest sites broadly illustrate the advantages and disadvantages of using a single beam echosounder to study the spawning aggregations. A sample echogram from a transect at Site 2 is shown in Figure 1, including some of the outlined school parameters.

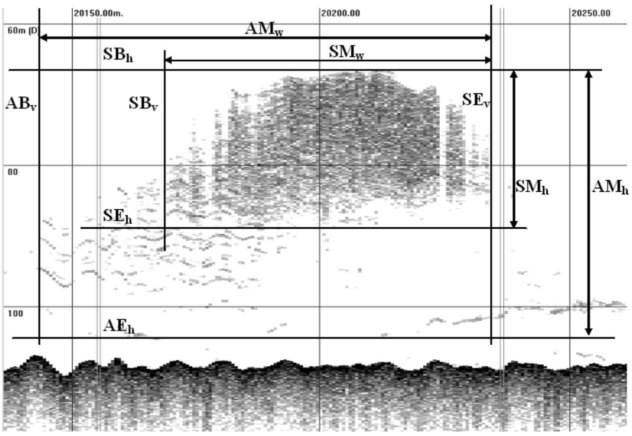

Figure 1. Echoview echogram image of a samson fish aggregation, including some morphological parameters. SB_v and SE_v are the vertical beginning and end of the densely populated school while AB_v is the vertical beginning of the aggregation. SB_h and SE_h are the horizontal school beginning and end while AE_h is the horizontal aggregation end. SM_h and SM_w are the maximum school height and width respectively, while AM_h and AM_w are the aggregation equivalent.

Most of the images obtained, however, were not conducive to the image analysis protocols set out by Reid et al. (2000), suggesting typical school parameters to catalogue. Those techniques are more amenable to discrete, densely populated schools, as opposed to the Rottnest aggregations which also contain a significant area, sparsely populated by dissociated members of the aggregation. It should be noted that this response is enhanced by the reduced speed of the surveys (~3 knots) relative to usual biomass surveys (~10 knots), (Johannesson & Mitson 1983).

Densely populated schools within the aggregations were defined with Echoview v3.25 fish detection algorithms, combining fish linking distance with a detection threshold of 60dB. However, due to a high level of spatial variability of the fish, parameters of the sparsely populated areas were visually inferred from the equivalent echograms.

Table 3. School parameters of Sites 1 and 2 taken 20/01/2005 and 02/02/2005

	20/01/2005		**02/02/2005**	
Site	1	2	1	2
Survey Start Time	10:19:08	9:23:04	10:31:14	09:23:47
$AB_{v\,Max}$ (m)	96.17	87.55	85.52	100.40
$AB_{v\,Min}$ (m)	76.81	66.62	75.56	58.40
$AE_{v\,Max}$ (m)	101.93	106.17	99.10	105.66
$AE_{v\,Min}$ (m)	97.93	99.97	93.56	94.41
$SB_{v\,Max}$ (m)	90.77	83.85	81.01	105.40
$SB_{v\,Min}$ (m)	84.45	66.95	75.56	72.78
$SE_{v\,Max}$ (m)	98.56	93.61	93.56	105.17
$SE_{v\,Min}$ (m)	92.17	83.73	89.04	93.92
$AM_{h\,Max}$ (m)	13.67	38.63	22.80	47.79
$AM_{h\,Min}$ (m)	7.38	12.37	11.49	7.67
$SM_{h\,Max}$ (m)	9.22	28.43	12.71	21.48
$SM_{h\,Min}$ (m)	5.86	7.59	12.51	14.32
Total Aggregation Area (m^2)	17,663	38,133	16,292	36,186
Dense Area (m^2)	13,204	10,481	2,744	12,863

The sparsely populated areas could not be easily dismissed, as they contributed a significant proportion of the biomass and added relationship data, between a population and its density, which may be characteristic to a particular aggregation or its spawning maturity. Several of the catalogued school parameters from these images at Sites 1 and 2 are shown in Table 3. This demonstrates the variability of aggregation characteristics between different sites and throughout the spawning period.

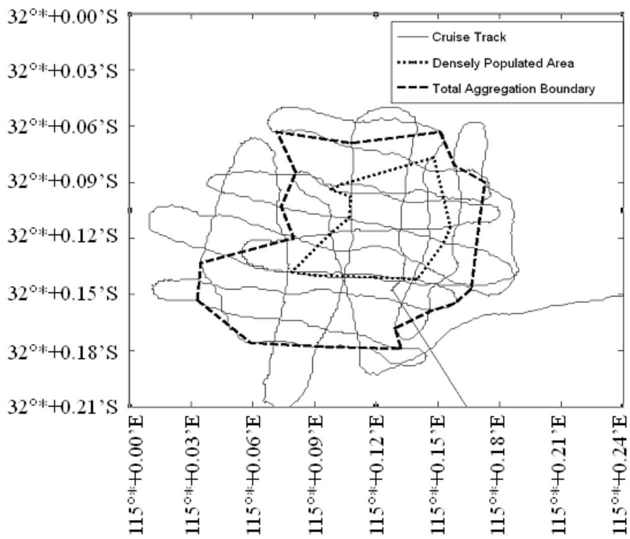

Figure 2. Area plot of the aggregation surveyed at Site 2 20/01/2005. The external plot displays the boundary of the whole aggregation surrounding the internal plot of the densely populated area.

The grid formation of transects allowed the determination of the aggregation boundaries in three dimensions. Table 3 also highlights the difference in scattering area between the densely populated portion of the aggregations and that enclosed by the disassociated members which can be visualised more easily in Figure 2.

In this example 72.5% of the area occupied by the aggregation is sparsely populated, a characteristic typical of the other survey sites, confirming that this dissociation contributes a significant proportion of population area.

Figure 3 displays two 3-D images, produced from the echograms of Sites 1 and 2, together with their respective cruisetracks. This visually illustrates the difference between backscatter strength, aggregation structure and size throughout the spawning period. Densely populated areas of the aggregations can be seen at the centre of each while sparser areas lie closer to the seabed.

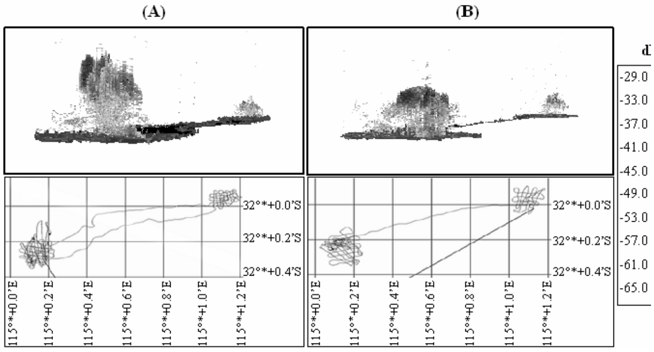

Figure 3. 3D echogram plots of samson fish aggregations and bottom picked seabeds, with associated cruisetracks of Sites 1 (right of images) and 2 (left of images) at (A) 20/01/2005 and (B) 02/02/2005. Exact location of sites remains confidential.

Biomass estimates relating to Sites 1 and 2, formed using the two tuna target strength models and calculated on an EDSU level, are displayed in Table 4. The data show consistent levels of biomass at both sites and a distinguishable difference between the two.

Table 4. Biomass estimates from Sites 1 and 2 based on target strength models of Yellowfin and Bigeye tuna. Estimates are shown in tonnes/n.mi^2.

Survey Date	Site 1		Site 2	
	TS_{YF}	TS_{BE}	TS_{YF}	TS_{BE}
23/11/2004	5,321,600	1,552,500	--	--
20/01/2005	76,100	22,200	624,900	182,300
Survey 2	--	--	530,600	154,800
23/01/2005	87,600	25,600	194,100	56,600
29/01/2005	--	--	405,400	118,300
02/02/2005	63,500	18,500	212,300	61,900
26/02/2005	62,600	18,300	--	--
27/02/2005	--	--	2,802,100	829,200

These results also highlight the difference in the final biomass estimation created by the variation in target strengths, by the two models of tuna. Such a disparity, arising from two biologically similar fish, emphasises that these figures can only be considered as relative estimations and illustrates the necessity for an accurate model of target strength for samson fish in future biomass estimates.

There are two estimates within Table 4 that are significantly higher than the remainder. The estimate for Site 2 (27/02/2005) is believed to be the result of inaccurate bottom picks through one or more of the transects, illustrating the need for a consistent and accurate bottom picking technique. The results of Site 1 (23/11/2004), however, are unsubstantiated and require further analysis.

The results shown here have assumed all acoustic backscatter has been generated by samson fish. However, ground truth data collected from the various sites confirm two further issues relating to effective estimation of samson fish present. Examination of the video data confirmed that the aggregations are not completely homogenous and comprise at least two other species, dhufish (*Glaucosoma hebraicum*) and mulloway (*Argyrosomus hololepidotus)*. Although their presence was small it could not be quantified, thereby affecting the uncertainty levels of the data. Further analysis of variation between backscatter at 38 kHz and 200 kHz of single targets may assist in differentiating between species, this will be difficult to detect within the dense aggregation.

The video data also aided confirmation of the depth to which wrecks rose from the seabed as well as complexities within the projecting wreck structure, which may assist in explaining some of the spurious results in Table 4. It also displayed evidence that several fish swim around the wrecks, at a similar depth, further complicating the bottom picking process. Although advanced algorithms are capable of accurately identifying seabed depth, the combination of bottom 'dead zone' and the beam footprint (Urick 1983; Johanesson & Mitson 1983; MacLennan & Simmonds 1992), around the wrecks in this case, suggest a requirement to manually distinguish between projecting bodies and mid water organisms around them. In some cases it is unfeasible to accurately differentiate between the two. A possible aid, however, may be to read accurate bathymetry data of the wrecks into the Echoview software and generate a new bottom picking algorithm.

CONCLUSIONS

Single beam echosounders are useful tools in providing long term monitoring of aggregations populations. The data have shown consistent levels of estimated samson fish stock levels at individual sites over the spawning period and distinguishable differences between stock levels and aggregation structure at separate sites. It also illustrated that while logistically simple, providing high coverage of local aggregations, this technique is hindered by accuracy-related limitations, many of which are reconcilable. The first requirement, before any accurate abundance estimations can be made, is to calibrate EQ60 system.

As demonstrated by the effects of the tuna target strength model, it is vital that before accurate measurements of a particular species can be conducted, an empirically proven model for its target strength is required. Compounded by the contribution of the swimbladder related to tilt angle, a prior knowledge of species-specific characteristic behaviour and reaction to external stimuli are also a necessity. Although several techniques (empirical and theoretical) are available for the determination of TS (Foote 1991), given the available logistics and the ongoing nature of the study, it is the authors' opinion that adapted *ex situ* methods such as Gauthier and Rose (2001) will acquire sufficiently comprehensive biological and behavioural data to generate accurate regressive models on which to base future abundance estimates. These models can be clarified further by theoretical analysis of acquired *in situ* data.

The species-specific, characteristic behaviour is extended to the temporal movements of the aggregation. As the beam footprint covers a small portion of the aggregation, it is important to determine collective movement before assuming uniformity.

The differentiation of targets from their habitat is also paramount. An ideal solution would be fine scale bathymetry of the seabed and any supplementary habitat. Acquiring accurate bathymetry of the wrecks west of Rottnest Island will be one of the future aims of this study, to aid in the accuracy of a manual and/or algorithmically picked bottom.

Although sections of the aggregations have proven unamenable to the protocols set out by Reid et al (2000), the image analysis technique is most accurate and least subjective when considering discrete schools, with comparatively little, or no surrounding dissociated members. It may be prudent for future studies of aggregations similar to those at Rottnest to consider decision rules to analyse linking parameters for dissociated members in sparsely populated areas of the aggregation. This would result in a comprehensive catalogue of parameters of both dense and sparsely populated areas, yielding a wider knowledge base for characterisation.

Future analysis of the data presented above will be dependent on the development of an accurate target strength model for the local samson fish. This development will be the subsequent step in the characterisation of the Rottnest spawning aggregations.

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