QUANTIFYING THE ACOUSTIC PACKING DENSITY OF FISH SCHOOLS WITH A MULTI-BEAM SONAR

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Multi-beam (swath) sonar systems provide the capability to ensonify an entire aggregation of fish in a single pass. However, estimation of abundance and discrimination between species via the use of target strength are considerably more complex than using traditional echosounders, because they ensonify targets at a much wider range of incidence angles. The beam pattern and along beam resolution of multi-beam swaths can produce individual sample volumes that are of similar magnitude to an individual fish (particularly for large fish, say >1m in length). If individual fish can be resolved, (either as a single fish within a sample, or as multiple contiguous samples that delineate a single fish), and if one assumes that this situation applies to the whole school, acoustic packing density can be determined by dividing the volume of the school by the number of detected acoustic targets. This estimate is proportional to the actual packing density of the fish, defined as the number of fish per unit volume of water. Acoustic backscatter of fish from a number of schools comprising different species were collected off Perth, in 2005 and 2007, using a Reson Seabat 8125 and 7125 respectively. Nearest neighbour distances of between 1 and 3 body lengths were observed and packing density of acoustic targets showed distinct variation between some species. However, schools of the same species also displayed different acoustic packing densities at different stages of their growth and development. Such differences were more difficult to observe in schools of fewer fish because the variations in packing density had less impact on the overall volume of the smaller schools associated with fewer fish. Therefore discrimination between species was only deemed possible when surveying two species of different sized fish at the same time. Video ground truth data is recommended to confirm species composition whatever the type of school observed.

INTRODUCTION

Multi-beam sonar (MBS) systems have been traditionally used to acquire bathymetric data for mapping purposes. As such, they were developed to produce a swath of wide angle perpendicular to the vessel track (typically upwards of 120°), narrow angle in the alongtrack direction (typically in the order of 0.5-1.5°), and to store only the data from depths near to the seafloor. The MBS beam geometry results in sampling of a very wide, but thin slice of the water column (Figure 1), providing fine-scale information of the seafloor.

Over the last twenty or so years MBS systems have been increasingly employed to map mid-water schools of fish in deeper and deeper waters [1-7]. The capability of MBS to ensonify an entire aggregation or school in a single pass saves considerable time and money, and improves reliability of data by reducing the possible movement of the school [8-10]. These aggregations can be visualised in three dimensions (Figure 1, red and yellow objects, representing schools of two different fish species) and the volume (or area) occupied by the fish can be compared if successive transects are conducted (Figure 2). However, the considerable increase in the amount of data to be stored from the seafloor only to include that for the entire water column, required data processing speeds which have only been achievable with recent advances in data processing and storage techniques. The time taken for the sonar to process the water-column backscatter is one of the limiting factors for the maximum ping rate a system can provide. If the pings are too far apart then the system may not detect in-water targets that are present between two consecutive pings (Figure 1) [7-10]. Recent MBS systems have improved such that even in waters of >100 m depth a ping rate may be achieved which can significantly reduce the unsampled space between pings [11].

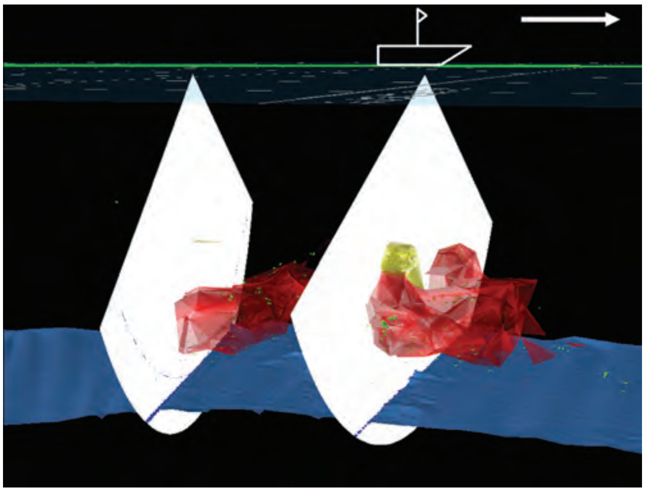

Figure 1. A visualisation of multi-beam sonar ‘pings’ 7 and 36 (white wedges) from an acoustic transect (green line) over a sandy seafloor (blue surface) and two schools of fish (represented by the yellow and red objects), conducted with a Reson 8125. Note that if consecutive pings are far apart then a target sitting between them may not be ensonified and therefore not detected

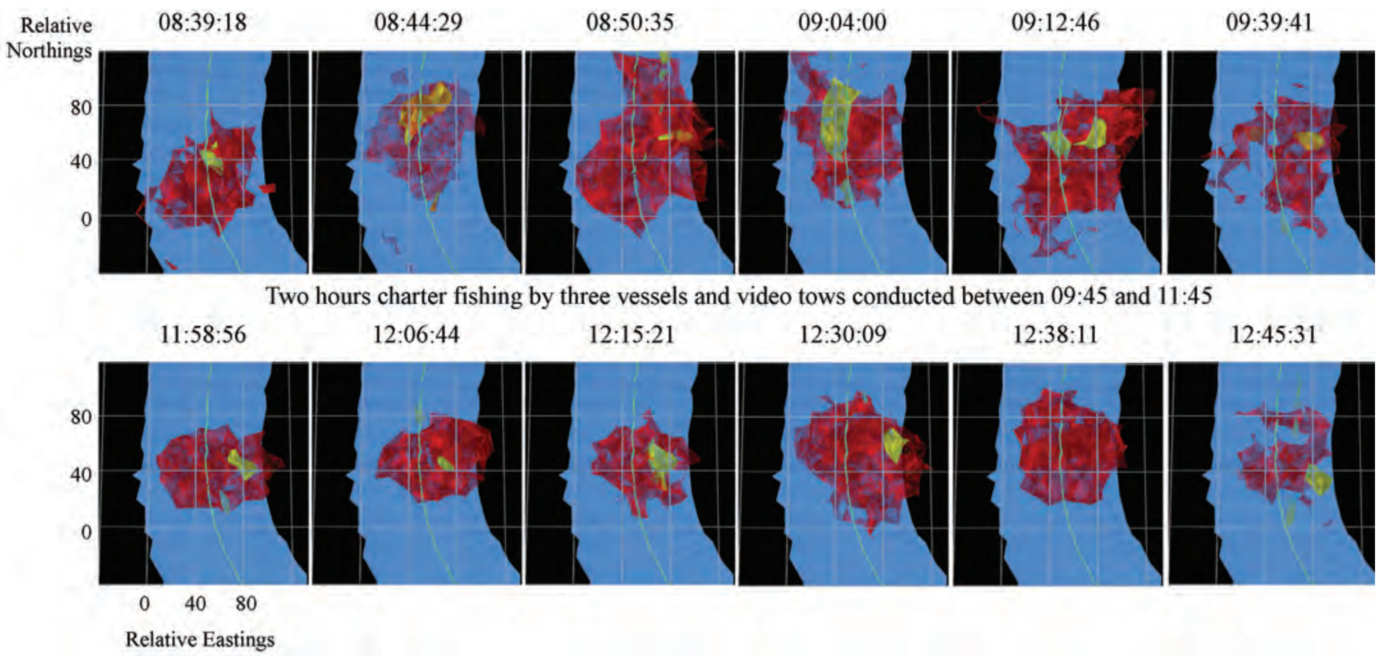

Figure 2. Plan views of two sets of six transects over a school of *S. hippos* (red object) and *P. dentex* (yellow object) above the seafloor (blue surface), separated by two hours of fishing and video tows

As acoustic targets are detected across the MBS swath the variation in angle of incidence between sonar and target is considerably greater than that within a single- or split-beam sonar. Combined with the anisotropic nature of acoustic reflectance by a swimbladder this means the relationship between fish length and target strength is considerably more complex than that used for echo-integration and species discrimination in typical echosounder surveys [12,13]. Therefore alternative methods of discriminating between species and estimating abundance are being investigated [10].

This study acquired backscatter from 6 different schools of fish (5 different species) in waters off Western Australia to look at the acoustic packing density detected by Reson 8125 and 7125 multi-beam sonar systems. The species ensonified in this study were as follows:

1. Samsonfish (*Seriola hippos*) - a pelagic member of the Carangidae family endemic to Australia, Norfolk Island and New Zealand [14]. The species is distributed around the temperate waters of Australia in depths up to 100 m [15]. As a strong, pelagic fish the species has become renowned as a catch and release sports fish and length distributions from a recent study revealed a range of 55 to 160 cm fork length with a median of 107 cm during 2004/5 and 2005/6 summer seasons, off the Perth coast [16].
2. Skipjack trevally (*Pseudocaranx dentex*) - The skipjack trevally are widely distributed around warm temperate waters. It is a streamlined, fast-swimming, schooling Carangid species that grows to a maximum length of 94 cm. Adults tend to occur in large schools near the sea floor in coastal waters in depths of up to 120 m with pelagic schools formed by batch spawners which aggregate in the summer [15, 17].
3. Bight redfish (*Centroberyx Gerrardi*) - This species mainly inhabit deep waters along the edge of the continental shelf and can live to at least 64 years and 66 cm [9]. Inshore migration has been reported in *C. gerrardi* around the Cape Naturaliste region to form spawning aggregations numbering in the thousands between February and April [9].
4. West Australian dhufish (*Glaucosoma hebraicum*) - Endemic to coastal waters of western and south western Australia *G. hebraicum* is a slow growing, sedentary, demersal species inhabiting reefs and caves to depths of 200 m, with the maximum reported *G. hebraicum* being 1.22 m long (total length) and weighing approximately 26 kg [9, 18-20]. Although 100 by 10 m deep "ghost patches" of thousands of *G. hebraicum* have been historically reported in the Capes region of Western Australia, the species is now typically found in groups of three and, to a lesser extent, up to ten [9]. Occasionally groups numbering in the tens of G. hebraicum have been observed along the West Coast Bio-region.
5. Unidentified baitfish - While video evidence could not identify the species of the fish these fish were estimated to be approximately 10 cm in length.

METHODS

Multi-beam sonar surveys of numerous schools of fish were conducted aboard *RV Naturaliste*, a 21.6 m Fisheries vessel, in October 2005 and February 2007. The 2005 survey employed a RESON Seabat 8125 (operating at 455 kHz) and the 2007 survey a RESON Seabat 7125 (400 kHz). Each system was mounted on the port side of the vessel, 2.77 m below the water surface and 3.95 m from the vessel centreline. During surveys the vessel speed was kept to between 4 and 5 knots. The maximum operating rates were approximately 4.5 s between pings for the

2005 survey and 1.2 s for the 2007 survey, translating to horizontal inter-ping distances of 5.4 to 7.2 m and 2.3 to 2.9 m in 2005 and 2007, respectively. Accounting for the fore-aft beam angles, but excluding the effects of pitch and yaw, at 80 m depth the distances between the edges of the acoustic swaths of two consecutive pings was 4.1 to 5.9 m in the 2005 survey and 0.8 to 1.3 m for the 2007 survey. Individual acoustic samples represented an along-beam sample depth of 10 cm and a width that varied with range, e.g. ~60cm at 70 m range. Comparison of acoustic packing densities of fish targets required standardising the number of pings in a given along-track distance. This is particularly important if the distance between pings is such that the likelihood of missing targets between pings is high. The number of detected targets in the 8125 study was therefore artificially increased by the ratio in inter-ping distance between the two surveys (2.53 times) to be comparable with the number of targets detected in the 7125 survey.

Ships positions were recorded using a Furuno Differential GPS system. Octopus F180 and Applanix POSMV motion sensors supplied pitch, roll and yaw data, which were logged in PDS2000 software together with sound velocity profile (SVP) data (Seabird). Towed underwater video transects were conducted before and after acoustic surveys to verify site species presence and confirm school structure. Settings of each system can be found in [10].

Noise was evident in each survey and was removed as per Parsons et al. [21], using Echoview v4.1. In each survey acoustic targets were detected using the "multi-beam target detection", using height, width and length dimensions of more than 0.02 m (i.e. the size of an individual sample). After school detection algorithms had been applied each ping was visually scrutinised to identify any remaining noise samples which were manually identified. In many cases individual fish reflected backscatter in a number of acoustic samples [21], which made up an acoustic target. The locations of these targets within the swath were exported from Echoview and into Matlab, along with the GPS and motion sensor data. Here roll and heading adjustments were made to each swath and the target positions geo-referenced in Cartesian coordinates accordingly. Each acoustic target was linked to its three nearest neighbours to form a tetrahedron. These tetrahedrons were linked together to form an object which reflected the overall volume of the aggregation of fish. To standardise the method of determining which targets were considered part of the school and maximum linking distance was applied to exclude fish not considered part of the aggregation, based on how far they were from their nearest neighbours. Various threshold distances were applied (1 m intervals) until 85% of all detected targets were included in the object. The volume of the object was then calculated in Matlab to represent the volume of the aggregation.

RESULTS

During the February 2007 surveys, numerous small schools of fish were observed, however, only one aggregation of *G. hebraicum* and one of *C. gerrardi* were encountered where video tows could ground truth species composition. At a suspected *G. hebraicum* spawning site in Geographe Bay a school numbering in the tens of *G. hebraicum* was observed on towed video. The video GPS stamp confirmed the location of the tight *G. hebraicum* school in an area of high coverage of seagrass and small limestone lumps, with five larger *G. hebraicum* separated to the north and a school of baitfish to its southwest (Figure 3). A MBS acoustic transect was conducted five minutes after the video tow and acoustic backscatter suggested two schools of fish, one at each of the locations identified by the video tow. Data from the two acoustically derived groups revealed differences in aggregation features that suggested *G. hebraicum*, sparsely populating an area to the north west of a seabed lump, and a school of baitfish hovering above the seabed lump. Target counting and aggregation volume calculation of the *G. hebraicum* revealed 129 acoustic targets encompassed by a volume of 2,381 m^3 based on a threshold 9 m nearest neighbour linking distance. This produced an estimate of 18.5 m^3 per acoustic target

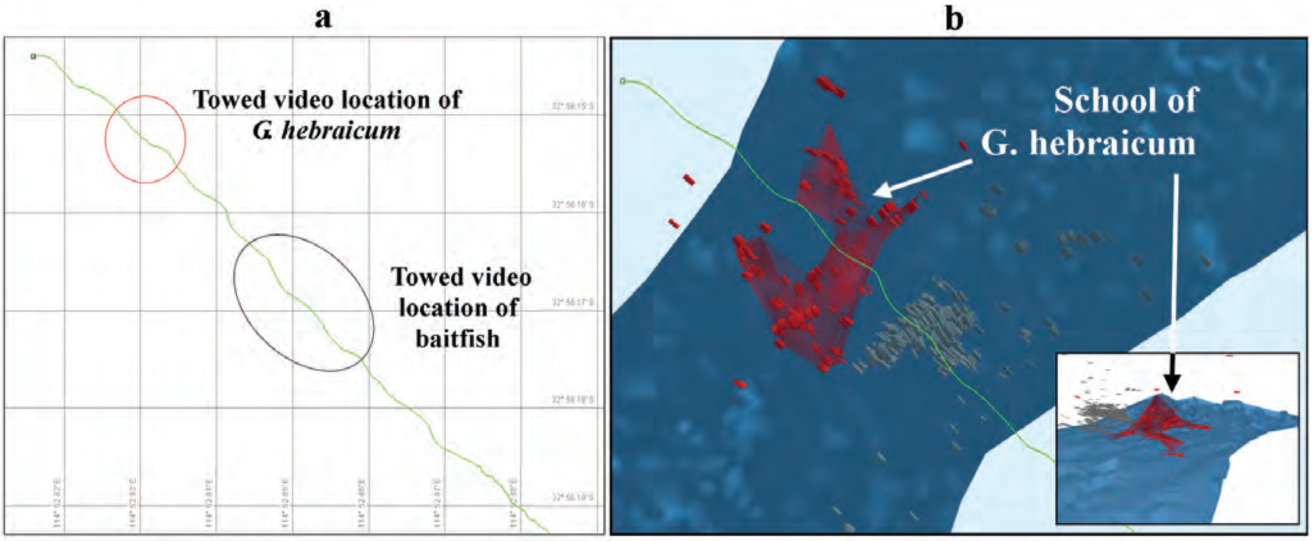

Figure 3. Map outlining locations of *G. hebraicum* and baitfish confirmed by towed video (a). Plan and aerial view (inset) of 3-D visualisation of targets in the areas where *G. hebraicum* (red) and baitfish (grey) were detected on camera (b)

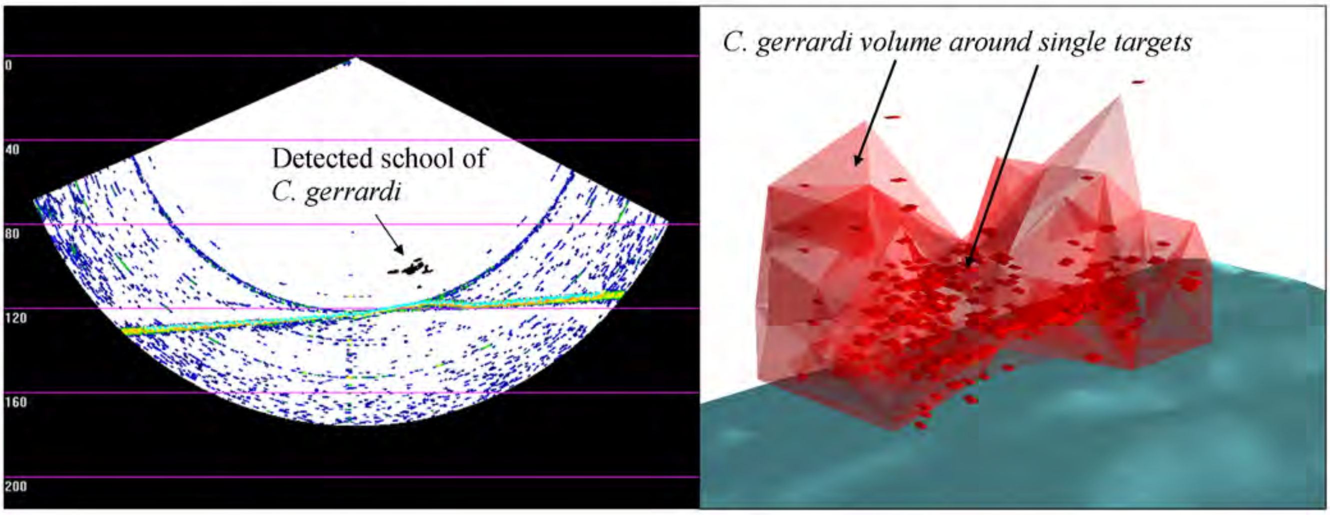

Figure 4. Acoustic multi-beam swath of a predominantly *C. gerrardi* school (left) and 3-D visualisation (right)

(mean nearest neighbour distance based on body length was not calculated due to lack of biological sampling and therefore no accurate known mean length). Video data displayed tens of *G. hebraicum* (a minimum of 18), and while it was certain that not all fish were observed by the towed video, this was far less than the number of acoustic targets detected. The school of small fish numbered 237 acoustic targets in 1,529 m^3 (9 m nearest neighbour linking distance) at 6.5 m^3 per target (body lengths unknown).

The surveys of *C. gerrardi* at sites close to Cape Naturaliste recommended by local fishermen revealed several small multi-species aggregations which included *C. gerrardi*. This survey highlighted the need to ground truth using video data, since the aggregations were initially thought to predominantly comprise *C. gerrardi* based on line fished biological sampling. By contrast, video evidence displayed not only *C. gerrardi* , but individuals from at least two other, similar sized species. An example of a RESON 7125 acoustic swath over a speculated *C. gerrardi* aggregation acquired in February, 2007 and the subsequent 3-D visualisation are shown in Figure 4. The detected targets displayed visible school structure and backscatter differences from aggregations of *S. hippos* surveyed with the same system and settings. Target counting and aggregation volume revealed 262 individual acoustic targets in a volume of 10,739 m^3 based on a threshold 9 m nearest neighbour linking distance (41 m^3 per target). At the centre of the aggregation *C. gerrardi* acoustic targets were more closely linked than those of *S. hippos* and comprised fewer individual samples with each target.

Adjusted acoustic target density for dense areas of *P. dentex* from the 8125 survey produced an acoustic packing density of 1.3 ±0.4m^3 per target with least squares regression correlation of $R^2 = 0.87$ (Figure 5). By comparison the sparse area of *S. hippos* produced 23.8 ±5.1 m^3 ($R^2 = 0.91$) and 13.9 ±4.1 m^3 ($R^2 = 0.97$) for the October Reson 8125 and February Reson 7125 surveys respectively. These acoustic target densities equated to approximately 3 (*P. dentex*), 2 (*S. hippos*, 8125 survey) and 1.6 (*S. hippos*, 7125 survey) body lengths as nearest neighbour distances.

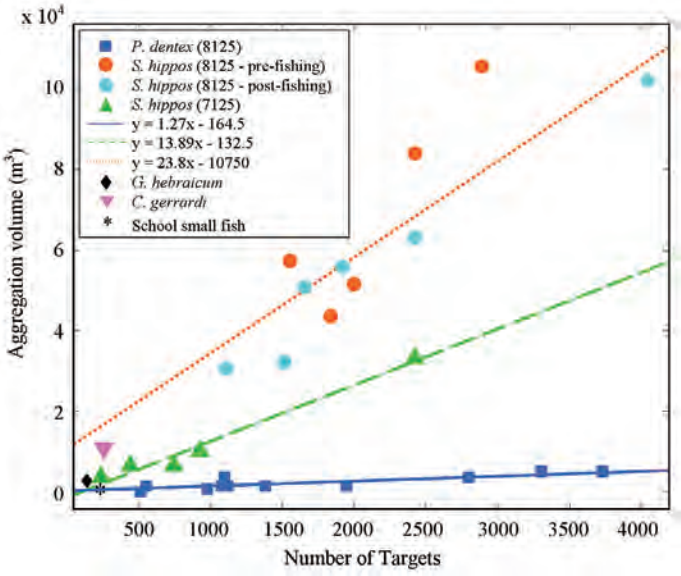

Figure 5. Detected acoustic target to aggregation volume relationships for a dense volume of *P. dentex* (■), *S. hippos* (● pre-fishing, ● post-fishing) (as detected by the RESON 8125 – not all points are shown) and *S. hippos* (▲) as detected by the RESON 7125). Calculated single transect values for *G. hebraicum* (♦), *C. gerrardi* (▼) and small fish school (*) are also shown

DISCUSSION

Though based on a small sample this study has illustrated several considerations associated with abundance estimates and discrimination of fish species via multi-beam sonar. All nearest neighbour distances of acoustic targets observed in this survey were of a similar order to nearest neighbour distances of fish in previous reports [22, 23]. Packing density is reportedly related primarily to body length and behaviour [23, 24], and to a smaller extent species [22]. Parsons [10] illustrated that it is possible to discriminate between two schools comprising fish of significantly different body lengths, surveyed at the same time, by the packing density of acoustic targets. However, comparison of packing density of schools of the same species in different stages of their life cycle also showed significant differences (compare the 8125 and 7125 survey packing densities). This highlights the need for ground truth data in MBS surveys before species composition can be confidently determined.

Despite the difference in body size between fish such as *G. hebraicum* and *C. gerrardi*, the acoustic packing densities of small schools were similar. This suggests that there is a minimum number of fish and school size required before differences in packing density can be observed and that species discrimination via acoustic packing density will increase with school size. In the schools reported here, visual ground truthing of species was a necessity.

The discrepancy between the number of *G. hebraicum* discerned on the towed video was notable. Part of this disparity could be explained by fish hiding in habitat as the towed video passed, the narrow field of vision on a towed camera not detecting some of the school, or the difficulty in counting mobile fish using video techniques. There is also the possibility of multiple acoustic detections of the same fish, similar to that observed in *S. hippos* surveys [21] and the *P. dentex* and baitfish schools shown here. However, the fact remains that around five times as many acoustic targets were detected than fish observed on the video. These points reiterate the need for multiple transects of a school to minimise bias and the necessity to understand avoidance behaviour of each species. The need to accurately normalise for sampling effort in acoustic and video techniques is as important as it is in traditional methods, such as catch per unit effort. It also suggests that target counting is currently most useful for large fish with large nearest neighbour distances.

The shortening and elongation of an aggregation's volume in successive transects, combined with decrease and increase of acoustic targets (i.e. a change in volume and targets numbers, but a constant packing density) may be indicative of avoidance behaviour and that the larger volumes and target numbers are due to fish swimming along with the direction of the survey vessel [21]. The towed video data on *G. hebraicum*, compared with the number of acoustic targets detected in that school adds credence to the argument. This suggests that when estimating abundance via multi-beam sonar detected target counting and/or school volumes multiple transects are required and the lower target numbers and/or smaller volumes are more representative of the number of fish that are present. The comparison of acoustic packing densities between the original Reson 8125 survey [25] and that described here, highlights the need to ensure that the number of targets missed between acoustic pings is minimised.

It is the authors' opinion that while acoustic packing density, as detected by MBS, may identify two different schools of different sized fish, the smaller the number of fish, the less chance of correctly discriminating species. The maximum available ping rate must be sufficient to limit the number of missed targets and the effects of avoidance behaviour must be accounted for. In multiple transects of the same school, where across track avoidance is not observed, it is the transect which detects the least number of targets that is most likely to be an accurate representation of the number of fish present.

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Inter-Noise 2014

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The Australian Acoustical Society will be hosting Inter-Noise 2014 in Melbourne, from 16-19 November 2014. The congress venue is the Melbourne Convention and Exhibition Centre which is superbly located on the banks of the Yarra River, just a short stroll from the central business district. Papers will cover all aspects of noise control, with additional workshops and an extensive equipment exhibition to support the technical program. The congress theme is *Improving the world through noise control*.

Key Dates

The dates for Inter-Noise 2014 are:
Abstract submission deadline: 10 May 2014
Paper submission deadline: 25 July 2014
Early Bird Registration by: 25 July 2014

Registration Fees

The registration fees have been set as:

Delegate	$840	$720 (early bird)
Student	$320	$255 (early bird)
Accompanying person	$140	

The registration fee will cover entrance to the opening and closing ceremonies, distinguished lectures, all technical sessions and the exhibition, as well as a book of abstracts and a CD containing the full papers.

The Congress organisers have included a light lunch as well as morning and afternoon tea or coffee as part of the registration fee. These refreshments will be provided in the vicinity of the technical exhibition which will be held in the Main Foyer.

The Congress Banquet is not included in the registration fee.

Technical Program

After the welcome and opening ceremony on Sunday 16 November, the following three days will involve up to 12 parallel sessions covering all fields of noise control. Major areas will include Community and Environmental Noise, Building Acoustics, Transport Noise and Vibration, Human Response to Noise, Effects of Low Frequencies and Underwater Noise.

A series of distinguished lectures will cover topics such as:

- Acoustic virtual sources
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