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Are changes in orange roughy density detectable in acoustic backscatter from a mixed species fish assemblage?

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7. **Executive Summary:**

Trawl catches and target strength - length relationships were combined to estimate the species-specific area backscattering coefficients from a mixture of species on the flat areas around the North West Hills on the Chatham Rise. Although orange roughy constituted a large proportion ($\bar{x} = 48$ %) by weight in the samples, their contribution to the area backscattering coefficient was very low (< 1 %). Robust cardinalfish (30.1 %), 3 species of rattails (White rattail = 17.4 %, Notable rattail = 13.8% and Serrulate rattail = 9.7 %) and Johnson's cod (10.8 %) made the largest contributions to the area backscattering coefficient (*values in brackets*) despite their relatively low catch rates (totaling an average of 7.6 % of the catch by weight). Varying the mean orange roughy catch rates by a factor of $0.1 - 10$ times illustrated that increasing the density of orange roughy by a factor of 10 times would only increase the area backscattering coefficient from the mixture by 3 %. We conclude that changes in orange roughy density of this order are not likely to be detectable in acoustic backscatter using echo integration data. This does not mean that orange roughy cannot be separated from mixtures, but to detect them it will be necessary to use echo discrimination techniques such as the phase difference-<TS> and chirp methods.

8. Objectives:

To investigate the effects of widely differing target strengths on the abundance estimates of mixed species by simulation.

9. Introduction

Acoustic biomass estimation of orange roughy has been used to support fisheries stock assessments since 1986 in New Zealand. Surveys are spatially focussed on the spawning plumes that are often associated with seamounts, although the plumes also occur over relatively flat bathymetry in some areas. Although the spawning plumes themselves are almost ($> 95\%$) pure orange roughy, there is considerable biomass of roughy over the "flat" areas around the plumes. These areas support a mixed assemblage of fish species. To estimate the biomass of orange roughy acoustically it is necessary to develop acoustic techniques that can be applied to the "flat" areas as well as to the spawning plumes.

To estimate orange roughy biomass where a mixture of species occur, one must determine what fraction of the acoustic returns are due to roughy, as opposed to the other species in the mixture. The proportions of orange roughy and bycatch species are determined by trawling. Target strength-size relations for many of the more abundant bycatch species are now known from swimbladder modelling (Macaulay and Grimes, 2000; Macaulay, 2001; Macaulay et al., 2001, 2002). Total acoustic backscatter is partitioned to species using the species $< TS_i > -length$ regressions and the species-specific size distributions weighted by the proportions of each species in the trawl catches in that area ($< TS_i >$ is tilt-averaged target strength for a given sized fish of species i). This approach requires a lot of trawling that is both time consuming and expensive. It is important to test the underlying assumptions of the method and to evaluate whether the procedures are useful for estimating the biomass of orange roughy in mixtures of species. One of the assumptions is that a change in the biomass of orange roughy will result in a detectable change in the integrated acoustic backscatter.

Orange roughy is a particularly problematic species to separate from a mixture of species because it has an unusually low $< TS >$. Kloser et al. (1997) reported that a single 8.2 *cm* myctophid has approximately same $< TS >$ as a 35 *cm* orange roughy (cited as -50 *dB*). By their calculation, a 33 *cm* rattail had a $< TS >$ equivalent to 4 orange roughy, and a single morid cod was equivalent to 79 orange roughy. The effect of this disparity in $< TS >$ is that backscatter from orange roughy can be lost in the backscatter from associated bycatch species in the same area. This is because the proportion of the total backscatter due to orange roughy is far smaller than the proportion of the trawl catch weight due to orange roughy (by as much as a factor of 28, according to Kloser et al. (2000)) .

In this paper we test whether the acoustic backscatter due to changes in the proportions of orange roughy can be detected amongst the much larger signal from bycatch species in a mixed species assemblage. The broader question of whether changes in the mix of species in trawl catches is reflected in the integrated acoustic backscatter is of fundamental interest in fisheries surveys. The underlying multispecies model is an extension of the linearity of fisheries acoustics model. Essentially, given the densities of a known number of fish of species having measured size distributions and representative tilt angle distributions, then the total integrated acoustic backscatter is predictable if the $< TS > -length$

relationship for each species is also known. When the density of a species in the assemblage changes, the change may be reflected in the total integrated backscatter, but the magnitude of change will be greatly influenced by the $< TS >$ of the species. The concern is that for orange roughy with low $< TS >$, no change will be detectable. The multispecies model is seldom tested despite the application of acoustics to biomass estimation of mixed assemblages in the tropics and at locations where there are more than two easily identifiable species present. It is particularly important to test the assumptions where the mixtures of species include those with markedly differing $< TS >$. This is the case for orange roughy acoustic surveys in Australia, Namibia, Chile and the North Atlantic, as well as in New Zealand. Investigation of this problem is therefore of wider relevance than its application to the New Zealand orange roughy surveys.

The problem might be approached in three ways. First, one could attempt to correlate acoustic backscatter with associated targeted trawl catches. If this were done over a range of contrasts in species composition, one could test whether differences in orange roughy catch rates were detectable as differences in echo integrals. A second approach might be theoretical, using an artificial fish community and known $TS - length$ relationships to calculate the relative contributions of orange roughy *versus* other species to the echo integrals. The last approach would be to use the real fish community and known $TS - length$ relationships derived from scattering models for all species to solve the "inverse problem", as attempted by Greene et al. (1998) for mixtures of zooplankton. We have used this last approach with certain caveats. We do not have scattering models for all of the species in the fish community, nor are we likely to have them in the future. Perhaps the most important ommisions at present are the abundant non-swimbladdered elasmobranchs, such as deep-water dogfish. Consequently we are working in this paper with a real community, but it is a subset of the total community because our $TS - length$ relationships are largely based on swimbladder models.

10. Methods

We proceed by making simple calculations based on fish densities and $< TS > -length$ relationships. This approach was considered more likely to yield a useful result than correlating acoustic backscatter with trawl catches because the acoustic and trawl targets are necessarily separated by both space and time (because of the need to retrieve the towbody before deploying a trawl to fish acoustic marks). We simulated the area backscattering coefficients (s_a, see MacLennan et al. (2002)) that would be produced by a representive subset of the mixed fish species assemblage containing orange roughy. We then varied the proportion of orange roughy in the assemblage and calculated the change in the total areal backscattering from the mixture. By simulating species change in the fish assemblage, just by varying orange roughy density in the first instance, we could predict the magnitude of change in the proportion of orange roughy that would be necessary to produce a detectable change in s_a.

To simulate s_a from a mixed species assemblage we first had to define what a representative mixture of species was. Trawl catch data from a survey of the Northwest Hills, Chatham Rise during June/ July 2002 using the RV *Tangaroa* (voyage TAN0208) and the commercial vessel *Ocean Ranger* (ORA0201) were extracted from a database for this purpose. Trawl gear used in this survey was a six panel rough bottom trawl with no lower wings and codend mesh size of 100 *mm*. Length of sweeps and bridles was 50 *m* on TAN0208, but 45 *m* on ORA0201. We included all trawls on 'flat' areas away from hills that met a satisfactory trawl performance criteria (specifically, that the spread of sweeps and bridles were within normal parameters, the net was undamaged on retrieval and the catch appeared normal). Catch rates ($kg\ km^{-1}$) for each species were calculated by dividing catch weight by distance towed. Since we did not have $< TS > -length$ regressions for all species, the species assemblage was simplified to include only those species for which we have reasonable regressions (Table 1), with the additional criterion that the species occurred in more than one trawl catch. Trawl catches were averaged by species over all trawl tows to produce a representative and usable species composition for the simulations.

$< TS > -length$ regressions used in our calculations apply to individual fish rather than to fish weight, so it was necessary to estimate the numbers of fish at a given size comprising the weighed catch for each trawl. Length distributions were extracted from each tow for the selected species and corrected by the proportion of the catch that was sub-sampled, ss, wherever the whole catch of a species was not measured. Backscattering cross-sections ($\sigma_{bs} = 10^{<TS>/10}$, see MacLennan et al. (2002)) for each fish species and individual size were calculated and summed over all species and sizes to give s_a (for the purpose of this analysis, the equivalent beam angle, time varied gain correction and calibration factor (see MacLennan and Simmonds (1992)) were treated as constants, and dropped from the calculation). The relative contribution of species i to the area backscattering coefficient, s_a, was calculated as $\sum_{i=1}^{j} \sigma_{bs_i} / \sum \sigma_{bs}$ where j = number of species. The next step was to manipulate the abundance of key species to observe the effect on s_a. This was done by increasing or decreasing $\sum \sigma_{bs_i}$ for orange roughy by a factor of 0.1 to 10 times to simulate changes in catch rate of orange roughy. $\sum \sigma_{bs_i}$ for bycatch species was unaltered initially, because it was uncertain how best to vary the realtive proportions of species in a realistic manner.

11. Results

Orange roughy were a relatively high percentage (mean = 48 % by weight) of the catch on 'flat' areas away from the hills. Bycatch species were classed into more abundant and less abundant groups. Basketwork eels (BEE), 4 species of rattails (CSE, CSU, MCA and WHX), hake (HAK), Johnson's cod (HJO), hoki (HOK), javelinfish (JAV) and ribaldo (RIB) were the numerically more abundant bycatch species. Black javelinfish (BJA), oreos (BOE and SSO), a rattail (CIN) and robust cardinalfish (EPR) were the less abundant bycatch species (Figure 1).

$< TS >$ among bycatch species showed a different pattern to their densities. Robust cardinal fish (EPR) and ribaldo (RIB) had notably higher <TS> than other species (partly because they are large fish, but also because they have large swimbladders)(Figure 2). Orange roughy stood out by their lower <TS>. The relative contributions of species to total acoustic backscattering ($\sum \sigma_{bs_i} / \sum \sigma_{bs}$) showed that robust cardinalfish (EPR) made a disproportionate contribution (30.1 %) to $\sum \sigma_{bs}$. Three rattails (WHX = 17.4 %, CIN = 13.8 % and CSE = 9.7 %) and Johnson's cod (HJO = 10.8 %) also made large contributions to $\sum \sigma_{bs}$ (Figure 3). Comparison with the proportional mean catch rates shows that none of these were especially abundant in the trawl catches (Figure 3). In addition to the orange roughy, these five bycatch species (totaling an average of 7.6 % of the catch by weight) would be the important species to vary when examining species specific effects on s_a. Varying species other

Table 1: Current $< TS > -length$ regressions for bycatch species. Data for all species except hoki and orange roughy are derived from swimbladder modelling (Macaulay and Grimes, 2000; Macaulay et al., 2001, 2002). The hoki $< TS > -length$ regression was calculated from a combination of *in situ* and swimbladder data (Macaulay, 2001). The slope for the orange roughy $< TS > -length$ regression was derived from experiments with live fish (McClatchie et al., 1999), with a slope adjusted using results from (Barr, 2001)

Code	Species	Intercept (*dB*)	Slope (*dB*)	n
BEE	Basketwork eel (*Diastobranchus capensis*)	-70.1	20.1	30
BJA	Black javelinfish (*Mesobius antipodum*)	-84.5	25.9	16
JAV	Javelinfish (*Lepidorhynchus denticulatus*)	-73.5	20.0	10
BOE	Black oreo (*Allocyttus niger*)	-62.1	14.9	27
SSO	Smooth oreo (*Pseudocyttus maculatus*)	-87.7	27.6	44
CIN	Notable rattail (*Caelorinchus innotabilis*)	-93.9	35.8	15
CSE	Serrulate rattail (*Coryphaenoides serrulatus*)	-93.8	34.6	20
CSU	Four rayed rattail (*Coryphaenoides subserrulatus*)	-84.6	26.3	32
MCA	Ridge scaled rattail (*Macrourus carinatus*)	-80.8	27.9	53
WHX	White rattail (*Trachyrincus aphyodes*)	-80.2	28.8	25
EPR	Robust cardinalfish (*Epigonus robustus*)	-83.6	34.4	36
EPT	Deepsea cardinal fish (*Epigonus telescopus*)	-86.6	34.6	8
HJO	Johnson's cod (*Halargyreus johnsoni*)	-70.3	22.5	28
RIB	Ribaldo (*Mora moro*)	-66.7	21.7	30
HAK	Hake (*Merluccius australis*)	-83.5	27.1	12
HOK	Hoki (*Macruronus novaezelandiae*)	-74.0	18.0	27
ORH	Orange roughy (*Hoplostethus atlanticus*)	-74.3	16.2	16

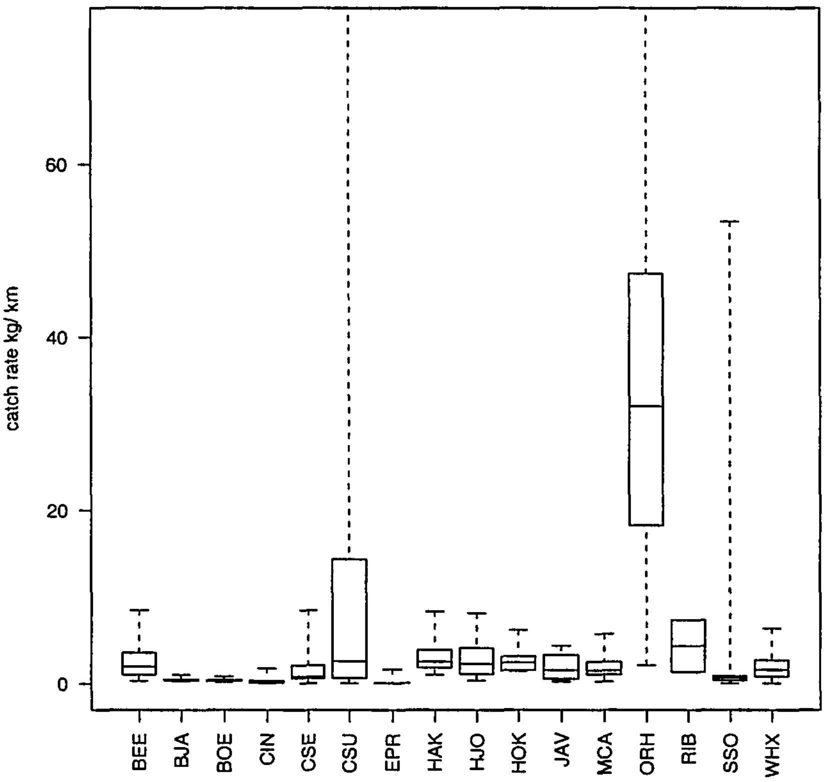

Figure 1: Density of selected species (from Table 1) in the fish assemblage using catch rate ($kg\ km^{-1}$) as an approximation for fish density (neglecting variable capture efficiencies). Box plot centre line = median, box limits are 25^{th} and 75^{th} percentiles, whiskers represent the full range of the data.

than orange roughy could be included in future analyses.

Varying the catch rate (i.e. the density) of orange roughy had a small effect on the area scattering coefficient, s_a. Even a factor of 10 increase in the density of orange roughy produced only a 3 % change in s_a (Figure 4).

12. Discussion

Whether or not the small change in s_a due to changes in orange roughy density would be detectable will depend upon the accuracy of the acoustic echo amplitude measurements. Accuracies will be a function of the measurement precision, variability due to noise and variability in the amplitude ensembles due to the the mixtures of scatterers. While measurement precision is high, and variability due to noise will generally be low, the variability from scatterers is likley to be high. Each of these sources of variability can be quantified (and might be

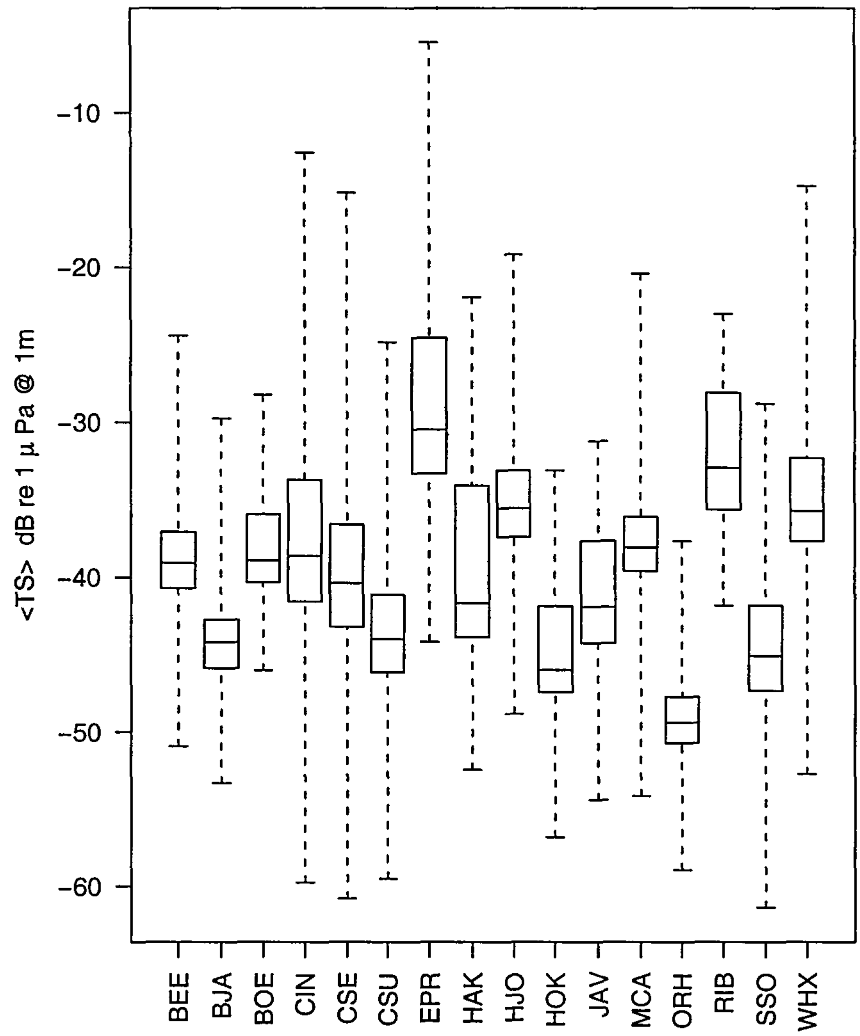

Figure 2: Tilt-averaged target strength, <TS>, of species from Figure 1 estimated from lengths using the regressions in Table 1. Boxplots are explained in Figure 1.

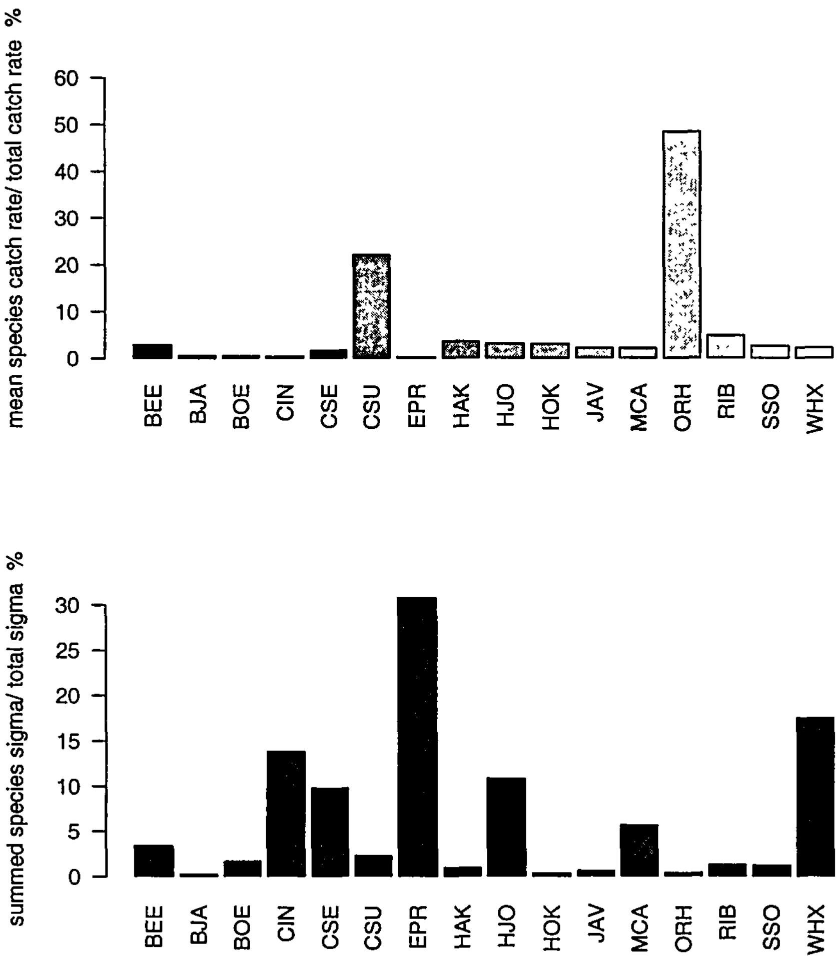

Figure 3: Top panel: Mean relative densities of selected bycatch species for which we have $< TS > -length$ regressions. Lower panel: Relative backscattering contributions of bycatch species $(\sum \sigma_{bs_i}/\sum \sigma_{bs})$ to the area backscattering coefficient, s_a. Species names are listed in Table 1.

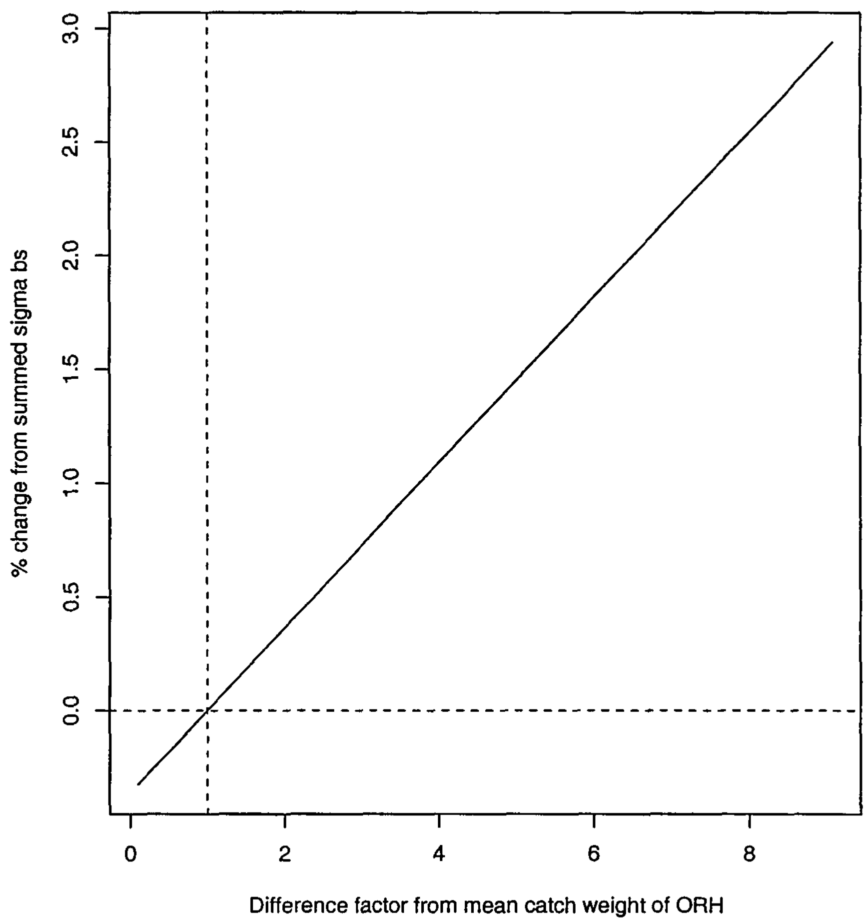

Figure 4: Change in the area scattering coefficient, s_a, resulting from a change in orange roughy density by a factor of $0.1 - 10$ times the mean roughy catch rate in trawls away from the NW Hills on the Chatham Rise. Dotted lines show the starting point for comparisons (i.e., at the mean orange roughy catch rate the difference factor = 1).

the subject of future work). An appropriate distribution could be fitted to the echo ensembles from scatterers (Clay and Heist, 1984), and the distribution parameters used to estimate the variability. The small change in s_a due to changes in orange roughy density could then be compared to the variability expected in the acoustic measurements, but would most likley to be found to be too small to be detectable. This does not mean that orange roughy are not detectable in mixtures of species. It does mean that they are not likely to be detectable in mixtures based on echo integration data. To detect the roughy it will be necessary to use echo discrimination techniques, such as those advanced by Barr et al. (2000).

It is important to note that the fish community used for the calculations was operationally defined as the assemblage of species captured by the orange roughy bottom trawl used on orange roughy surveys. The trawl catch does not represent with 100% accuracy the species assemblage insonified. The difference between the actual fish assemblage that is insonified and the assemblage captured in the trawl arises from species-specific differences in catchability. We cannot quantify the species-specific catchability at present, but the effect of this factor is unlikely to substantially alter the conclusions of this study.

13. Acknowledgements

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