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Assessing the potential of multibeam echosounder data for predicting benthic invertebrate assemblages across Chatham Rise and Challenger Plateau

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Multibeam sonar has great potential for remote characterisation of seafloor habitats and fauna but interpretation is highly scale dependent. Under the Ocean Survey 20/20 programme (OS 20/20) New Zealand is collecting multibeam data combined with physical seabed samples across large areas of its Exclusive Economic Zone (EEZ). We used multibeam echosounder (MBES) transects from the Chatham Rise and Challenger Plateau together with nested biological sample data to explore the potential of vessel-mounted MBES for remote characterisation of seabed biological assemblages and habitats in the deep-sea. The MBES transects extend over thousands of kilometres laterally and from about 250 to 1800 m depth. At 150 sites nested within these transects, seabed biological assemblages and substrates were sampled, primarily by video transect and epibenthic sled.

For analysis, two alternative methods for defining acoustic polygons at each site were trialled (1) a buffered convex hull encompassing all samples at a site, and (2) a full swath-width rectangle centred on the site centroid and scaled by depth in the along-swath dimension such that polygon proportions, but not size, were consistent across all sites. Summary MBES statistics were generated for each site, for each method, based on (1) backscatter intensity, (2) bathymetry, and (3) class membership of a benthic terrain model generated from the bathymetry. Relationships between these acoustic classes and biological assemblages observed in seabed video transects (DTIS video) and epibenthic sled samples (SEL) were then explored. First, BIOENV was used to assess the degree of correlation between a matrix of similarities between sites generated from the remote-sensed MBES data and matching similarity matrices generated from the directly observed faunal datasets (DTIS and SEL). These analyses used the full, unclassified, data in each case. Second, the acoustic parameters found to have the strongest correlations with fauna distributions in the BIOENV analysis were used to classify sites into self-similar MBES classes using both hierarchical (group average) and non-hierarchical (*K*-means) clustering. The relative similarity of faunal assemblages at sites within each of these MBES classes, and the dissimilarity of faunal assemblages between MBES classes, were quantified using the ANOSIM R statistic and the fauna associated with different MBES classes were evaluated using SIMPER. Finally, the MBES classes were compared with a parallel classification of the same sites developed using the faunal samples from the DTIS video under Specific Objective 9 of this project.

Correlation between unclassified MBES and faunal data sets across the entire study area was low (BIOENV max. $\rho = 0.491$). This value increased in all comparisons when Chatham Rise and Challenger Plateau data were analysed separately (maximum $\rho = 0.636$). Clustering of sites based on MBES data resulted in 9 to 14 acoustic classes, depending on clustering method and acoustic patch method, whereas 20 classes were generated by the faunal data. Dissimilarity of faunal assemblages within MBES classes was high for all classifications (SIMPER, greater than 70%) but in most comparisons was significantly lower than dissimilarity between classes, indicating some correspondence between MBES and fauna. Comparisons between the site classifications generated from MBES data and those from DTIS fauna data showed more than 50% matching of four DTIS faunal classes with MBES classes. The strongest matching was associated with high population densities of the brittle star *Ophiomusium lymani* at sites in 1200 m depth on the southern flank of Chatham Rise, suggesting that small body-size benthic fauna might, indeed, influence MBES signatures. However, on the Challenger Plateau, this same MBES class was associated with another faunal class and across all faunal classes there were more discrepancies than agreements between the MBES and faunal classifications. We conclude that there is potential for at least coarse-level prediction of benthic faunal assemblages from MBES data but the spatial scales across which sites are compared should be matched to broad scale ecological patterns.

1 INTRODUCTION

1.1 Overview

Acoustic data from sonar systems consist of two distinct components: a measure of the time taken for the reflected sound pulse to return to the transducer, and a measure of the strength of the returning pulse. The former gives the distance from transducer to target and thus, by calculation, the depth of water, while the latter, the 'backscatter', is related to the physical characteristics of the target surface: a hard, smooth surface will return strong backscatter, while a soft, porous, surface will return weak backscatter. In multibeam echosounder (MBES) systems, another variable can be collected; the angular range characteristic of individual sonar beams in the multibeam fan. Because the distance the acoustic beams travel to the seabed increases with increasing angle away from the vertical in MBES systems, and the angle of incidence at the seabed decreases at the same time, across-swath backscatter profiles have a distinctive form in which there is a band of very high backscatter response directly under the ship (the 'nadir'), a region of relatively consistent response in the middle of the angular range, and a pronounced drop off in response towards the edges of the swath.

Considerable research effort has been invested in methods for interpreting ship-borne sonar data in terms of the physical and biological characteristics of the seabed (Kostylev et al. 2001, Legendre et al. 2002, Hewitt et al. 2004, Fonseca and Mayer 2007, Anderson et al. 2008), with most effort being concentrated on interpretation of backscatter data (Kloser et al. 2001, Le Gonidec et al. 2005, Durand et al. 2006). At a coarse level, backscatter is intuitively interpretable: areas of strong backscatter are clearly discernible from those with low backscatter and this allows us to differentiate between hard and soft substrate (rock versus sand, for instance). Finer scale interpretation of sediment grain size, however, has been less successful and differentiation between benthic biological assemblages has met with very limited success. Where acoustically conspicuous substrates are also strongly associated with characteristic fauna, acoustic data can be effective for predicting the distribution of benthic fauna. Examples of this include cold water corals (Roberts et al. 2005, Dolan et al. 2008) and the chemosynthetic fauna of cold seeps (Jones et al. 2010, Klaucke et al. 2010). On more homogeneous substrates associated with deep sea environments and coastal soft sediments, however, attempts to predict faunal distributions from acoustic signatures have been less successful (Hewitt et al. 2004).

The principal reason for this lack of discrimination is the mis-match between the spatial resolution of the sonar data and the scales over which benthic faunal assemblages influence the acoustic properties of the seabed. Individual beams of the EM300 multibeam sonar have apex angles of 1° (lateral) and 2° (fore and aft). Thus, at 50 m depth each beam insonifies a patch of seabed at least 2 m^2 in area (and considerably more than this with increasing angle away from the nadir), increasing to more than 200 m^2 at 500 m and more than 600 m^2 at 1000 m depth. Given that benthic invertebrate fauna do not scale similarly with depth (i.e. organisms are not ten times larger at 1000 m than at 50 m), it is clear that any direct response of MBES to benthic assemblages or to physical properties of the seabed at the scale of these fauna is likely to be highly depth dependent. This effect is exacerbated by the usual practice of gridding MBES data at uniform grid size over all depth ranges, regardless of the potential for increased spatial resolution at shallower depths.

For instance, in the present study, all MBES bathymetry data were gridded at 25 m × 25 m and backscatter data at 10 m × 10 m across all depths from 50 m to 1800 m. In consequence, a grid cell at 500 m depth represents fewer acoustic beam returns than does a cell at 50 m.

Despite these factors weighing against finding a consistent relationship between acoustic data and fauna distributions, it is still possible either that some aspects of seabed morphology and sediments detectable in acoustic data might be correlated with faunal distributions, or that larger scale characteristics of assemblages (e.g. high population densities over areas of tens of square metres) can affect sonar responses. Given the potential advantages to be gained if a clear correlation between acoustic properties of the seabed and fauna distributions were to exist at the scale of the present study, it is certainly a worthwhile exercise to assess the strength of correlations between MBES data and benthic faunal data across the Chatham Rise and Challenger Plateau study regions. Here we used MBES and benthic biological data collected over three voyages (TAN0610, TAN0705, TAN0707) during the Ocean Survey 20/20 Chatham–Challenger Hydrographic, Biodiversity and Seabed Habitats Project to explore the potential utility of MBES data for predicting benthic habitats and fauna.

1.2 Objectives

1.2.1 Overall objectives

1. To quantify in an ecological manner, the biological composition and function of the seabed at varying scales of resolution on the Chatham Rise and Challenger Plateau.
2. To elucidate the relative importance of environmental drivers, including fishing, in determining seabed community composition and structure.
3. To determine if remote-sensed data (e.g. acoustic) and environmentally derived classification schemes (e.g. Marine Environment Classification system) can be utilized to predict bottom community composition, function, and diversity.

1.2.2 Specific Objective:

To assess the extent to which acoustic, environmental, or other remote-sensed data can provide cost-effective, reliable means of assessing biodiversity at the scale of the Ocean Survey 20/20 surveys.

[Note: here, we consider only acoustic data; the use of other environmental data layers for prediction of biota is included in later analyses in this project]

2 METHODS

2.1 Acoustic data

Data were available from the 2006 Ocean Survey 20/20 voyage TAN0610, collected using the R/V Tangaroa’s Kongsberg EM300 multibeam system. For the most part, these data are narrow transects each of which is built up from two passes of the ship in opposite directions, such that the resulting acoustic swaths overlap to give a wider insonified transect (Figure 1) but some sections were single swath. Bathymetric data from the transects had been processed to remove artefacts (using C & C HydroMAP software) and stored as a uniform 25 × 25 m gridded raster layer across all depths. Backscatter data had been processed using Sonarscope software (www.ifremer.fr) and was available as a 10 × 10 m gridded raster layer with backscatter values in decibels (dB). Sonarscope processing compensates for systematic variations in across-swath backscatter intensity by applying algorithms that reduce the backscatter gain around the nadir and increase it towards the edges. An alternative approach to dealing with across-swath variations in backscatter strength is to work with the unmodified signal and analyse the angular range response profile directly ("Angular Range Analysis" Fonseca and Mayer 2007, Fonseca et al. 2009). Unfortunately, because the data for this study had already been processed in *Sonarscope*, it was impractical to re-process the data to extract the angular response characteristics required for ARA.

In addition to the bathymetry and backscatter data, a benthic terrain model (BTM) was derived from the bathymetry raster. BTM classifies each cell in a multibeam bathymetric raster in terms of its depth relationship to surrounding cells. For instance, if surrounding cells on two sides are deeper, the cell in question is a crest; if they are shallower, it is a depression; if they are shallower on one side and deeper on the other, it is on a slope. Four BTM classes were defined here: *crests*; *depressions*; *flats*; *slopes*.

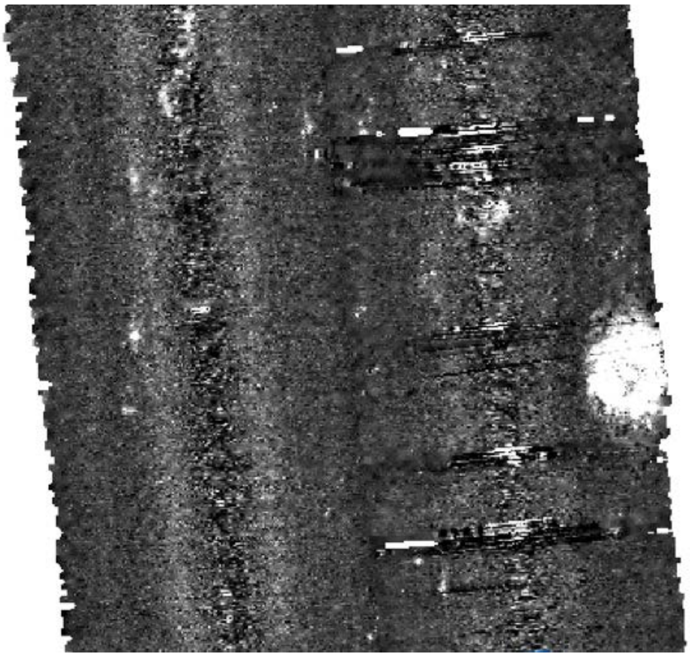


Figure 1: Backscatter image of a section of MBES transect from Chatham Rise. The transect consists of two swaths (left and right in image). The data have been processed in *Sonarscope* but the central nadir is clearly visible in each swath. High backscatter shows as lighter pixels, low as darker, but processing has modified the response in the central nadir, which would otherwise be of high backscatter.

2.2 Faunal data

The fauna samples available for ground-truthing the acoustic data were collected at a number of sites distributed across Chatham Rise and Challenger Plateau during the Ocean Survey, all sampling sites being nested within the acoustic transects (Nodder 2007a, b, 2008, Bowden 2011). The sampling gears used most consistently across all sites were the Deep Towed Imaging System (DTIS) video camera and the ‘seamounts’ epibenthic sled (SEL). These data sets are, therefore, used here for comparison with the acoustic data. In Specific Objectives 1 and 5 of the present project, benthic fauna from these samples were identified to the finest achievable taxonomic level (Bowden 2011) and in specific Objective 9 classes of faunal assemblages were developed using a hierarchical group average clustering method based on these data (Floerl et al. 2012). Here, we use both the full species-level data and the assemblage classes for comparisons with the acoustic data.

2.3 Definition of acoustic patches

Because faunal samples were taken at specific *a priori* sites, an initial task for the acoustic comparison was to define the shape and size of acoustic patches at each site. Two principal methods for achieving this were considered (Figure 2):

(1) a convex hull polygon encompassing the seabed tracks of all sampling gear used at that site, with an added buffer zone (10 m);

(2) a rectangle covering the full width of the acoustic transect at the sampling site and scaled by depth in the along-swath dimension such that patch proportions, but not size, are the same for all sites, regardless of depth.

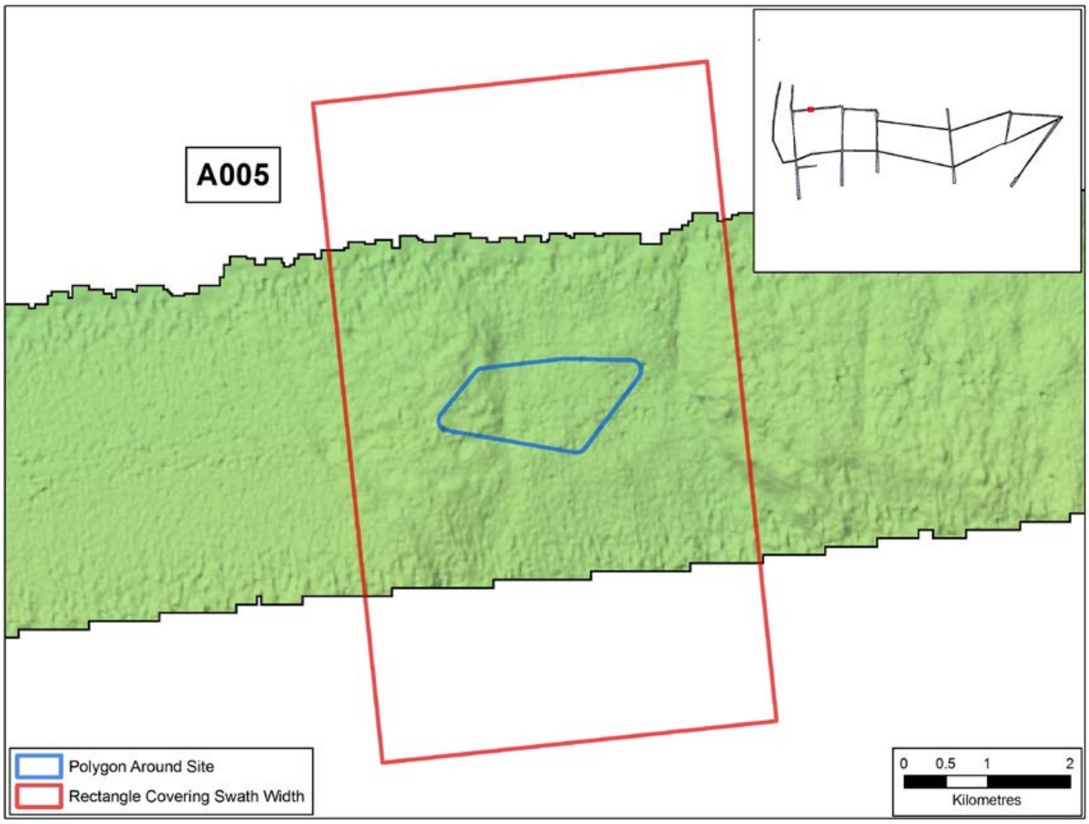


Figure 2: Delineation of regions for acoustic characterisation of sampling sites, showing two alternative methods: a buffered convex hull polygon encompassing all seabed sampling conducted at the site (blue polygon), and a full swath-width rectangle centred on the sampling gear centroid and scaled with depth in the along-swath dimension such that rectangles at all sites have the same relative proportions. Example shows MBES bathymetry layer for site A005 on the north-eastern Chatham Rise (inset).

Each of these approaches has theoretical advantages and drawbacks. The convex hull method has the advantage that it only uses acoustic data from the physical sample locations and their immediate environs. Thus, any correlation between faunal and acoustic datasets might be expected to be clearer. The inherent across-swath variation in acoustic transects, however, introduces potential confounding factors with this method. For instance, if two sites have identical acoustic signatures but at one site the sampling polygon is centred on the nadir line of the swath while at the other it is centred towards the swath edge, the measured backscatter characteristics will be different. The principal advantage of the rectangle method is that, by using the entire width of the acoustic transect, it standardises for across-swath artefacts (i.e. these artefacts are incorporated in the same way at all sites and thus should not influence comparisons between sites). The drawback to this method is that the area of seabed that has been sampled for fauna now constitutes a relatively small proportion of the acoustic patch and thus any correlation between fauna and acoustic response at small scales may be swamped by variability of acoustic response across regions of the patch that were not directly sampled for fauna.

We reasoned that the rectangle method for acoustic patch definition would be more appropriate here because it overcomes the generic problems associated with swath profiles and because averaging acoustic response over larger seabed areas might be more appropriate to the large spatial scales (kilometres to hundreds of kilometres) and depth range (50 – 1800 m) at which the OS 20/20 study was conducted. However, the arguments were not conclusive and in order to compare results from the two methods, analyses using both methods (polygons and rectangles) were run in parallel.

For the acoustic patches defined at each sampling site, summary statistics characterising the variability of cell values within the patch were derived from the three MBES data sets (bathymetry, backscatter, and BTM, Table 1). Inevitably, some of these statistics are strongly correlated with each other but as there was no prior knowledge as to which ones might be important in the context of this study, all were included in initial analyses.

Table 1: Multibeam echosounder (MBES) data: descriptive statistics used to characterise acoustic sites

MBES data	Statistic	Code
Bathymetry	Minimum	Bathy_Min
	Maximum	Bathy_Max
	Range	Bathy_Range
	Mean	Bathy_Mean
	Standard deviation	Bathy_Std
Backscatter	Minimum	BS_Min
	Maximum	BS_Max
	Mean	BS_Mean
	Median	BS_Median
	Standard deviation	BS_Std
	Variance	BS_Var
	Skewness	BS_Skew
	Kurtosis	BS_Kurt
BTM	Minimum	BTM_Min
	Maximum	BTM_Max
	Mean	BTM_Mean
	Standard deviation	BTM_Std
	Variety	BTM_Variety
	Majority	BTM_Majority
	Minority	BTM_Minority

2.4 Analyses

2.4.1 Data audit

MBES data were first checked for outliers using PCA ordination. Any extreme outliers were investigated by examination of the raw data and of the relevant images (Bathy, BS, and BTM rasters). Where there were problems with the raw data, sites were excluded from further analysis. At other sites, MBES polygon data were not computed because sampling at these sites consisted of only one gear type and thus the resultant ‘polygon’ would be a line or point. Across all four data sets (MBES rectangles, MBES polygons, DTIS video fauna, and SEL fauna), full data were available at 110 sites from the total of 148 core sites sampled during the Chatham-Challenger OS 20/20 voyages. This subset of 110 sites is used in all analyses that follow.

2.4.2 BIOENV

Following the ‘bottom-up’ analysis approach described by Hewitt et al. (2004), relationships between the full (unclassified) MBES and faunal data were explored using BIOENV (Clarke and Ainsworth 1993). This technique identifies which combinations of environmental variables (MBES data) best match variations in faunal assemblage composition between sites. For every combination of environmental variables, it calculates the Spearman rank correlation between two matched similarity matrices: one matrix representing rank similarity between sampling sites based on faunal assemblages, the other based on acoustic parameters. Because this approach does not involve prior classification or clustering of either data set, it involves no preconceptions as to which is the ‘correct’ pattern describing the study sites. It does, however, incorporate the full variability of the data and thus any patterns may be masked to some extent by statistical noise. The BIOENV procedure also enables a significance statistic for the correlation to be generated by comparison of the measured ρ value against a distribution generated by random permutation of sample labels in each matrix. For analysis, acoustic data were first normalised to enable simultaneous use of variables measured on different absolute scales and similarities between sites were then calculated as Euclidian Distance. Fauna data from the DTIS video are fully quantitative but were square root transformed to down weight the influence of highly abundant taxa. Fauna data from the seamounts epibenthic sled are at best semi-quantitative and therefore were fourth-root transformed, with the expectation that the more severe transformation would compensate for any variations in sampling efficiency between sites. Site similarities based on faunal data were calculated as Bray-Curtis distances.

2.4.3 Clustering

Two principal approaches to statistical clustering of multivariate data are available: hierarchical, in which the sample population is divided sequentially into groups of similar sites, and non-hierarchical in which sites are re-assigned to classes iteratively until optimal class membership is achieved (i.e. within-class similarity and between-class dissimilarity are both maximised). To ensure that the clustering method was not influencing results, both approaches were used to generate classifications of the study sites based on MBES acoustic data. In both approaches, classifications were run in parallel for MBES rectangles and polygons data sets, and the MBES variables used throughout were those identified as being most strongly correlated with the faunal data in the BIOENV analyses.

Hierarchical clustering of MBES data was done using the group average CLUSTER routine in PRIMER v 6.1 (www.primer-e.com). Data were first normalised and a matrix of similarities between sites was calculated using the Euclidian Distance metric. The resulting dendrogram was assessed for clusters by two methods: first, at a fixed Euclidian distance chosen visually with the criteria of maximising the number of clusters overall while minimising the number of clusters containing fewer than four sites; and second, using the SIMPROF method for defining the significance of clusters (Clarke et al. 2008). SIMPROF was run at significance levels of 5% and 10%.

Non-hierarchical clustering was run using *K*-means (Program *K*-means, Legendre 2001). Prior to clustering, a ranging transformation was applied to MBES data (option 3, ranging for variables with arbitrary zero in *Program K-means*) to place all variables on the same measurement scale. Classifications from 2 to 30 groups were run, with random starting seeds and no weightings applied to the variables. The Calinski-Harabasz (C-H) statistic was used to determine the optimum number of resulting classes. C-H is a measure of how distinct clusters are from each other in the resulting classification; higher C-H values indicating less overlap between clusters.

For both clustering methods and all variations within each, the relative degree of overlap between clusters was quantified by means of the ANOSIM R statistic. R increases with increasing dissimilarity between clusters and thus can be used as a relative measure of which clustering method most effectively assigns the sites to distinct groups. All groups with membership of fewer than four sites were excluded from ANOSIM analyses. For each clustering technique (hierarchical and non-hierarchical), the approach that yielded the highest ANOSIM R value was taken to be the best representation of the data and was used in subsequent comparisons with the faunal data.

2.4.4 Comparison with fauna

The acoustic groups resulting from the MBES classifications were analysed for similarities in their faunal assemblages using SIMPER analysis (Clarke 1993) on both the DTIS video fauna and the epibenthic sled fauna data sets. This procedure identifies the taxa contributing most to faunal similarity within sites and yields values for within-group similarity and between-group dissimilarity (i.e. the inverse of similarity) and for each taxon calculates percentage contribution to within-group and between-groups similarity. Finally, a parallel classification of the 110 sample sites generated from DTIS video fauna data (Specific Objective 9) was compared with the classifications based on MBES data. Comparisons were made by visual assessment of maps and by contingency tables which show the frequency of occurrence of each faunal class in each MBES class and vice versa. Where faunal classes were most strongly associated with particular MBES classes, the fauna characterising each class were compared using the SIMPER outputs calculated earlier.

3 RESULTS

3.1 Acoustic data

PCA ordination of the MBES data showed eight extreme outlier sites, seven on Challenger Plateau and one on Chatham Rise. At each of these sites, one of the two swaths that make up the transect was badly degraded, presumably because of rough sea-state during data acquisition (Figure 3). These sites were excluded from analyses. MBES data were also examined for a number of other sites which were moderate outliers but as there were no obvious problems with the raw data these sites were retained.

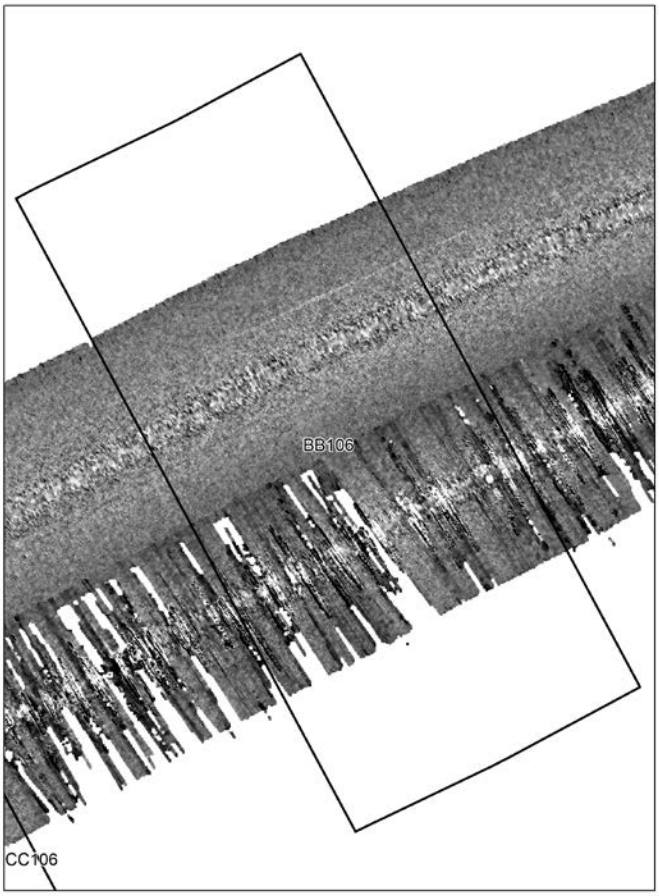


Figure 3: Backscatter image from site BB106 on Challenger Plateau, showing degraded acoustic data in the lower swath caused by rough sea-state during data acquisition. The upper swath was run on a downwind course and the lower swath into the weather. This and six other sites with similar artefacts were excluded from analyses.

3.2 BIOENV

Rank correlation between similarity matrices based on either of the two fauna datasets (DTIS and SEL) and all combinations of MBES variables was relatively low (Spearman $\rho<0.65$, Table 2) but significant ($P < 0.05$ for all tests). When all sites were included in the analysis, maximum correlation was 0.491 for the comparison between the DTIS video fauna data set and the polygon method of MBES patch delineation. Correlation values increased when the two study locations were analysed separately but did not exceed 0.603 for any combination of data sets. For Chatham Rise, the DTIS video fauna provided stronger correlation with MBES data than did the SEL samples, but on Challenger Plateau this pattern was reversed.

The set of MBES variables that best matched fauna distributions varied depending on the faunal dataset used and the method of MBES patch delineation (Table 2). Across all analyses, the number of MBES variables providing the best correlation ranged from 1 to 5 and the most frequently recurring variables were those related to bathymetry (Table 3). Although some of these variables were strongly correlated with each other (e.g. the standard deviation and variance of backscatter), all 13 variables in Table 3 were included in the subsequent classifications of sites using MBES data.

Table 2: Summary of highest Spearman rank correlation (BIOENV, ρ) between MBES variables and faunal assemblages. Values are shown for two methods of defining acoustic patches at study sites (rectangles and polygons), two faunal data sets (DTIS video and seamounts epibenthic sled – SEL), and for all study sites combined (Chat+Chall) and each location separately (Chatham, Challenger). See appendix for expanded BIOENV results.

		Faunal dataset	
MBES patch definition	Location	DTIS	SEL
Rectangles	Chat+Chall	0.488	0.362
	Chatham	0.516	0.372
	Challenger	0.573	0.577
Polygons	Chat+Chall	0.491	0.384
	Chatham	0.525	0.422
	Challenger	0.567	0.603

Table 3: MBES variables providing best matches with faunal data and the number of times each occurred in the set of best-matching variables across all BIOENV comparisons (see Appendix Table A1 for full data).

MBES variable	No. of occurrences
Bathy_Mean	9
Bathy_Std	5
Bathy_Max	4
Bathy_Min	4
BS_Mean	3
BS_Min	3
BTM_Majority	3
BS_Kurt	2
BS_Var	2
BS_Std	1
BTM_Min	1
BTM_sum	1
BTM_Variety	1

3.3 Clustering

3.3.1 Hierarchical

As is usual with hierarchical clustering of ecological data, the group average dendrograms yielded multiple classes separating off across a range of distances. For the MBES rectangles dendrogram, a cut-off at a Euclidian Distance of 2.6 (ED 2.6) was chosen by eye as representing the best balance between minimising the number of singleton sites while retaining the maximum number of groups overall. For the MBES polygons dendrogram a distance of 3.0 (ED 3.0) was chosen using the same criteria. For the MBES rectangles this resulted in 26 classes of which 8 had more than three members. For the MBES polygons these values were 23 and 7, respectively. Classifications from SIMPROF tests produced somewhat greater numbers of classes overall than ED 2.6 or ED 3.0 but the number with more than three members was similar, at 9 classes for rectangles and 11 or 12 for polygons.

3.3.2 Non-hierarchical

K-means classification resulted in 9 and 12 acoustic classes from the rectangle and polygon MBES data sets respectively. C-H values were higher for the rectangle classification, indicating more clearly defined clustering than for the polygon data but neither peak was pronounced (Figure 4). For the rectangles classification, there were 7 classes with more than three members, and for the polygons classification there were 8.

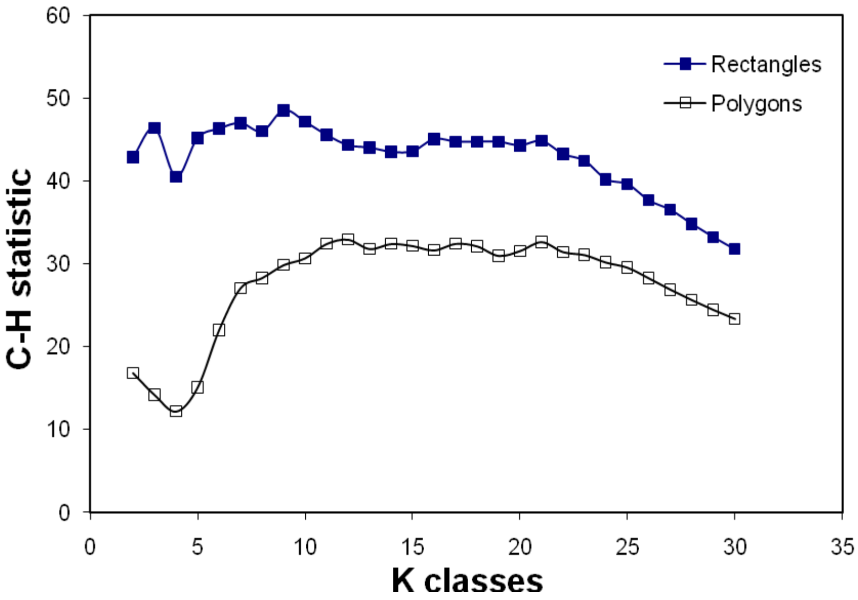


Figure 4: *K*-means clustering of Chatham Rise and Challenger Plateau sites based on MBES variables delineated either by full swath-width rectangular patches or by polygons drawn around the sampling sites: higher C-H statistic values indicate less overlap between clusters.

3.3.3 Evaluation of clustering

The number of classes identified by the different clustering approaches ranged from 6 to 12 once those with membership of fewer than three sites were excluded (Table 4) but ED and *K*-means generated fewer classes with fewer than three members than did SIMPROF. For both MBES rectangles and polygons, the ANOSIM Global R statistic was highest for group average clustering using the SIMPROF 10% significance criterion to define groups. Contrary to indications from the C-H values, ANOSIM Global R values were also higher for *K*-means classification based on MBES polygon data than on rectangle data but both *K*-means classifications resulted in considerably lower R values than for the hierarchical approaches. For the hierarchical methods, R increased in the order: ED < SIMPROF 5% < SIMPROF 10% but this improvement in cluster definition was accompanied by an increase in the number of sites excluded from the ANOSIM analysis because of low class membership. Thus, for MBES rectangles, ED 2.6 classification excluded 12.7% of sites and resulted in R = 0.869 whereas use of the SIMPROF 10% criterion resulted in an increase to R = 0.908 but with the exclusion of 21.8% of sites (Table 4). Because the SIMPROF 10% classifications result in a high number of excluded sites, only the SIMPROF 5% classifications are shown in subsequent analyses. For each hierarchical clustering method, Global R was higher for rectangles than for polygons but for non-hierarchical *K*-means clustering, this was reversed.

Table 4: Comparison of three clustering methods/criteria for MBES acoustic patches defined either as rectangles or polygons. ANOSIM Global R was calculated using only classes with site membership more than three.

MBES patch definition	Cluster method	Total number classes	Number singleton classes	Number doubleton classes	% sites in single or doubleton classes	Number classes with >3 members	Global ANOSIM R
Rectangles	ED 2.6	26	10	2	12.7	8	0.869
	SIMPROF 5%	28	9	6	19.1	9	0.899
	SIMPROF 10%	33	12	6	21.8	9	0.908
	K-means	9	0	1	1.8	7	0.516
Polygons	ED 3.0	23	11	4	17.3	7	0.844
	SIMPROF 5%	28	7	8	20.9	12	0.821
	SIMPROF 10%	36	9	13	31.8	11	0.896
	K-means	12	0	5	9.1	6	0.680

3.4 Comparisons with fauna

3.4.1 SIMPER

MBES classes derived from rectangle data yielded more distinct faunal assemblages than did those derived from polygon data; differences between within-class and between-class faunal dissimilarity being greater for all classification methods (Figure 5). For most MBES classes, in all classifications, within-class dissimilarity of DTIS video fauna data was high (more than 70%), the lowest within-class dissimilarity being 66.76% (rectangles, SIMPROF 5% class *h*), which translates to maximum within-class faunal similarity values of less than 30%, and for most classes less than 25% (Figure 5, Table A2). Despite this, within-site dissimilarity was consistently lower than between-site dissimilarity for all classification methods except for *K*-means on MBES polygon data. The hierarchical classifications of MBES rectangles data (ED 2.6 and SIMPROF 5%), which showed the greatest separation between clusters in ANOSIM comparisons, also showed the most distinct faunal assemblages. Average within-class faunal dissimilarities for these classifications were 73.0 ± 1.9 (se)% and 71.1 ± 2.8%, respectively, compared to average between-class dissimilarities of 85.2 ± 0.8% and 85.6 ± 0.8 (SIMPER on square-root transformed DTIS video fauna data). In comparisons using SEL faunal data, within-class dissimilarities were higher than for DTIS data in all cases and these data are not shown.

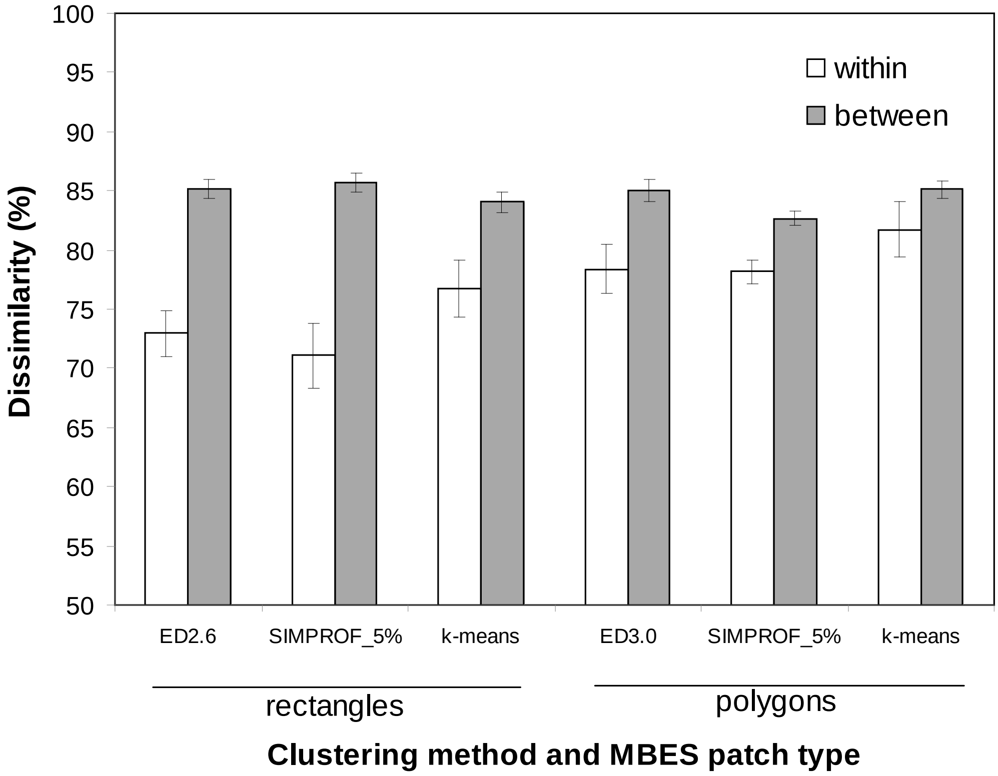


Figure 5. Mean dissimilarities (± se) of benthic fauna (SIMPER using the Bray-Curtis dissimilarity metric on square-root transformed DTIS video data) within and between MBES acoustic classes generated using three clustering methods: hierarchical group average delimited by fixed Euclidean distance (ED 2.6 and ED 3.0); group average delimited by SIMPROF procedure at 5% significance; and *K*-means, and two methods for delineating acoustic patches: polygons and rectangles. See Methods for details. All comparisons except for *K*-means on polygon data are statistically significant (ANOVA P<0.05, see Table A3).

3.4.2 MBES classes versus DTIS fauna classes

Visual comparisons between classes generated from MBES data and those generated from faunal data (Figures 6–8) suggested stronger correspondence between the classifications than is indicated by the preceding analyses based on the unclassified fauna data. In all classifications (MBES and DTIS fauna) there is a distinction between Chatham Rise and Challenger Plateau and on Chatham Rise between the northern and southern flanks of the rise and between eastern and western regions. Challenger Plateau classifications are less well differentiated but all show some separation by depth and along the southeast-northwest axis.

However, on closer inspection, matches between MBES and faunal classes are inconsistent both within and between classifications. This is apparent when the contingency tables associated with these comparisons are considered (Table 5). For each classification method, those based on MBES rectangles showed stronger matching with fauna classes than did those based on MBES polygons. The strongest overall matching between MBES classes and DTIS faunal classes was for the *K*-means rectangle classification (Figure 8, Table 5) for which 6 faunal classes showed more than 50% correspondence with MBES classes. The ED2.6 rectangle classification showed matches of more than 50% with 5 faunal classes but 2 of these faunal classes were associated with the same MBES class and there were 8 sites in singleton or doubleton MBES classes compared to just one in the *K*-means classification.

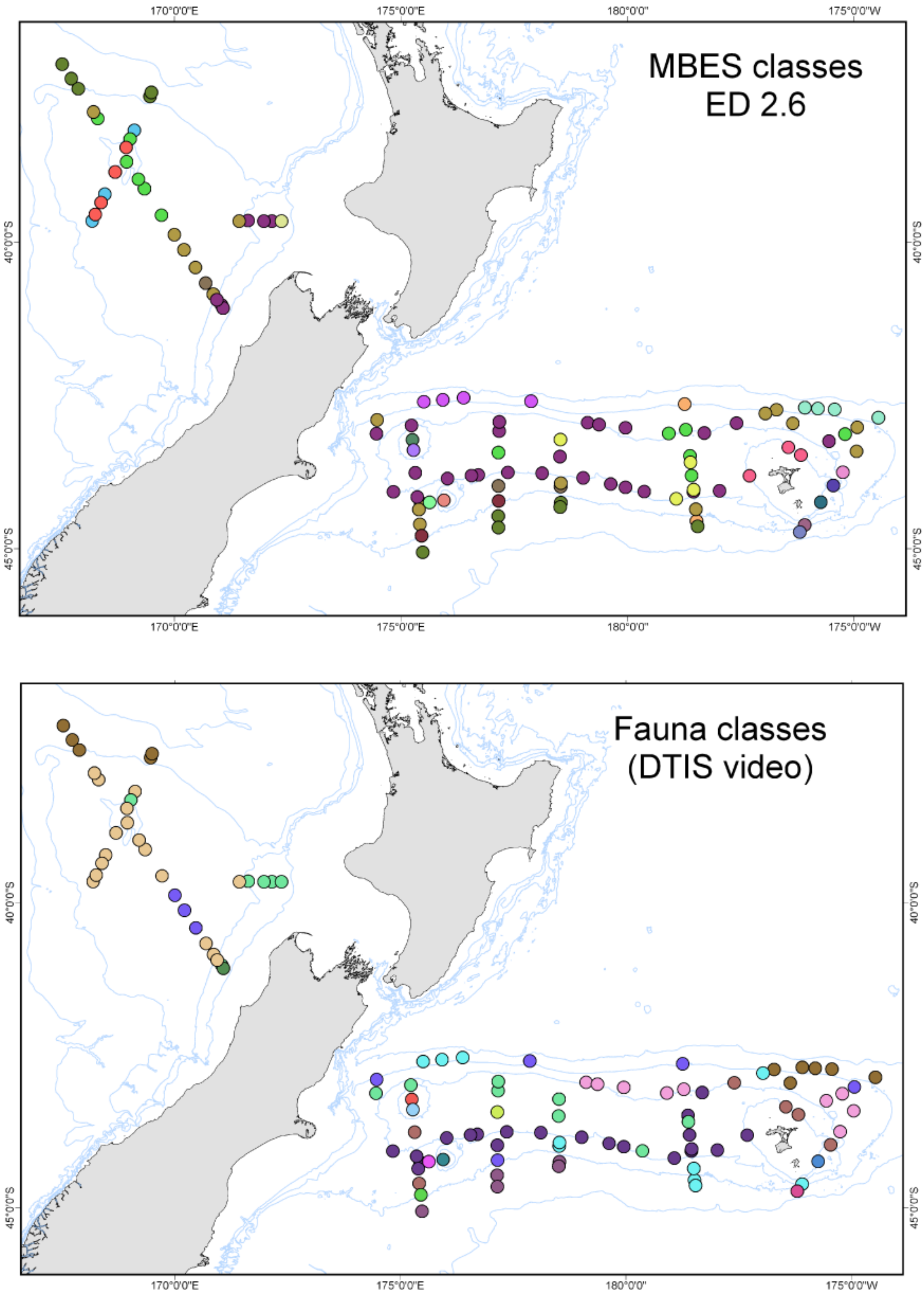


Figure 6: Comparison between MBES classes from group average clustering of acoustic rectangles with groups delimited at Euclidian Distance 2.6 (top panel) and faunal assemblage classes from DTIS video (bottom panel - group mean average clustering at Modified Gower distance 2.0). Note, because each panel represents a different classification, class colours are not matched between classifications: it is matching of patterns, rather than colours, that indicates similarity between classifications.

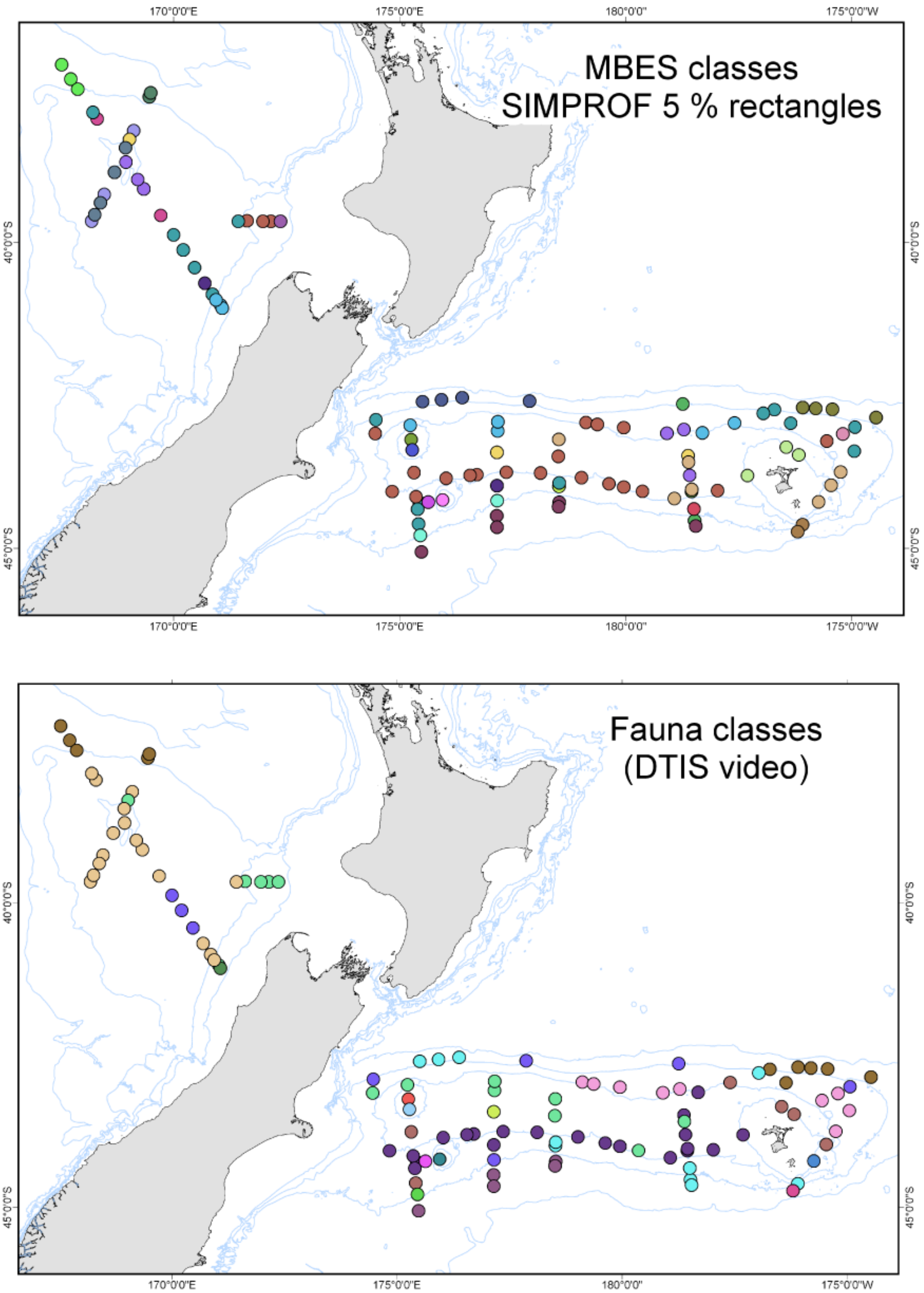
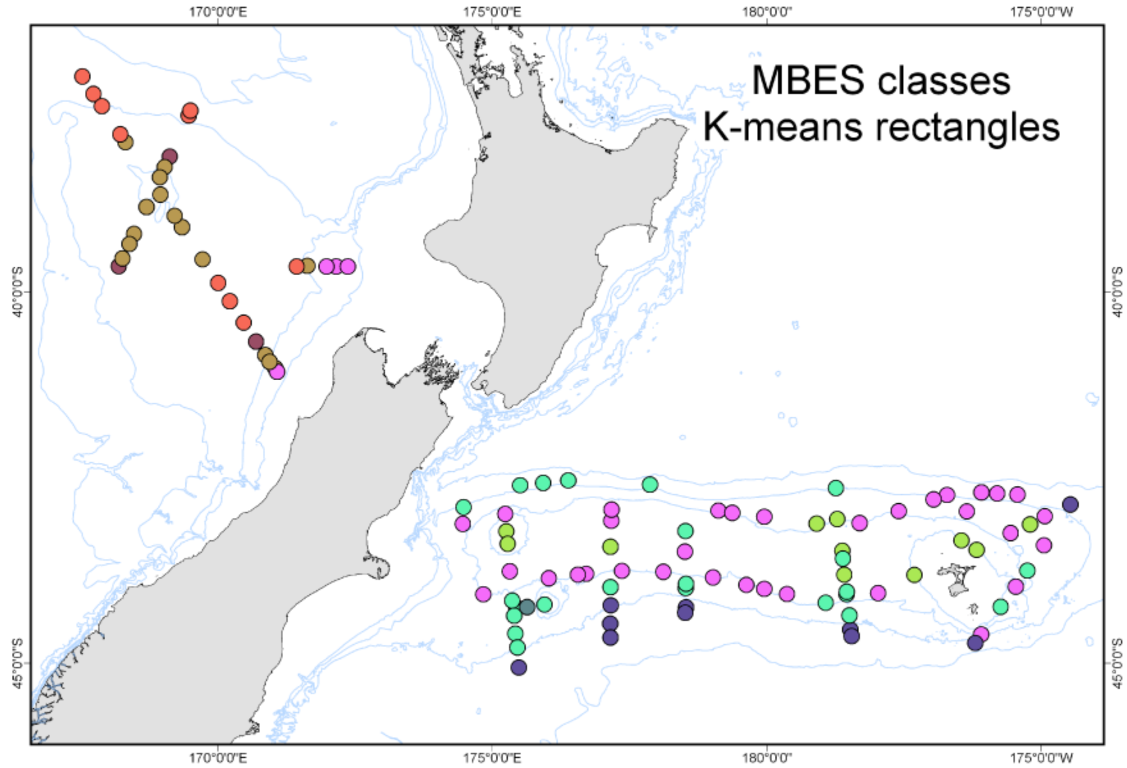


Figure 7. Comparison between MBES classes from group average clustering of acoustic rectangles with groups delimited by SIMPROF 5% criterion (top panel) and faunal assemblage classes from DTIS video (bottom panel - group mean average clustering at Modified Gower distance 2.0).



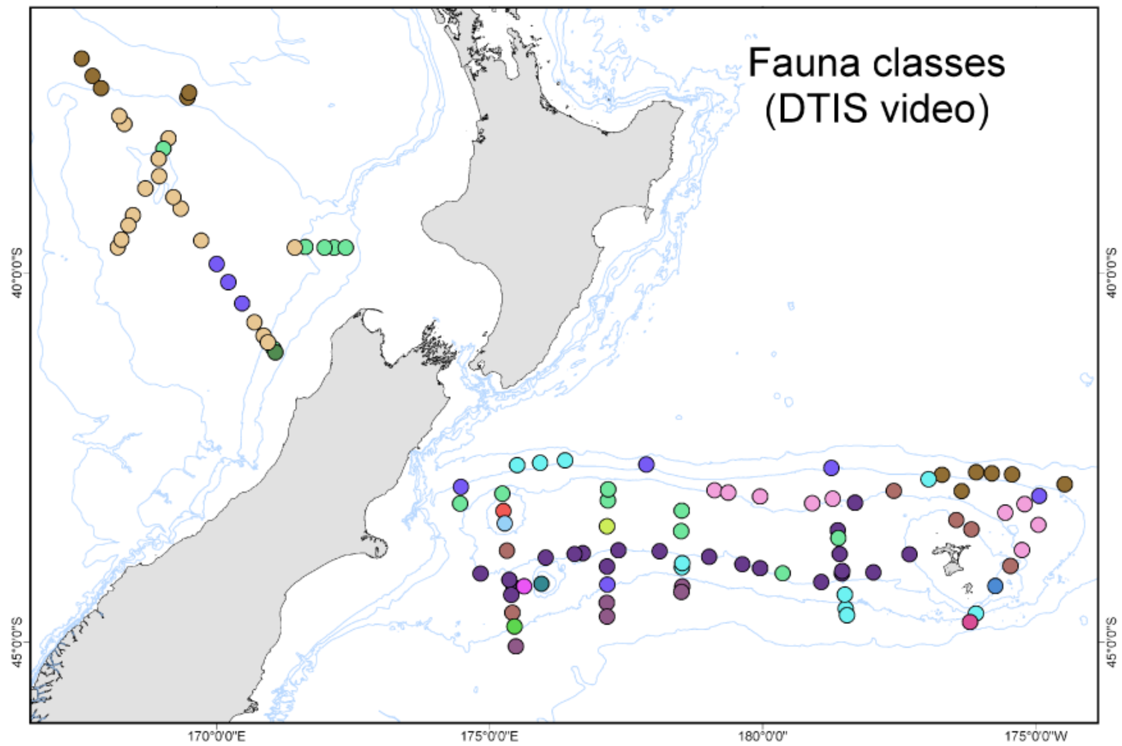


Figure 8: Comparison between MBES classes from *K*-means clustering of acoustic rectangles (top panel) and faunal assemblage classes from DTIS video (bottom panel - group mean average clustering at Modified Gower distance 2.0).

Table 5: Summary of contingency table comparisons (full data in Table A4) for relationships between fauna classes generated by group average clustering of DTIS fauna data, and MBES classes generated using three clustering methods (ED, SIMPROF 5%, *K*-means) and two MBES patch delineation methods (rectangles and polygons). Values are the highest percentage occurrence of DTIS video fauna groups (a-t, left) in any one MBES group e.g. if all sites belonging to one fauna class occurred in only one MBES class, the max. value would be 100%. Max. values were calculated only for DTIS fauna classes containing more than two sites.

	MBES rectangles			MBES polygons		
Fauna class	ED 2.6	SIMPROF 5	*K*-means	ED 3.0	SIMPROF 5	*K*-means
c	100	100	100	60	60	60
l	44	44	56	67	44	67
m	29	24	71	59	29	76
n	30	30	60	40	50	60
o	62	51	52	43	29	48
p	33	33	50	33	33	33
r	71	43	64	29	21	36
s	45	36	45	27	36	73
t	63	63	38	38	38	38
Mean ± se	53±7.8	47±7.7	60±6.0	44±4.8	38±4.0	54±5.5

The DTIS video faunal class *c* showed the strongest matching with MBES classes, at 100% matching for faunal classes within acoustic class for all of the MBES rectangle classifications. The majority of comparisons were less than 50% however, and while sites within faunal class *c* were consistent in their allocation to a single acoustic class, the reverse was not true: the acoustic class with which a particular fauna class was associated was often also associated with other faunal classes. When the two survey regions were considered separately, it was clear that some faunal classes were restricted to either Chatham Rise or Challenger Plateau (Table 6) and in the case of faunal class *c*, while there was 100% matching between five sites on Chatham Rise and MBES class *k* (ED 2.6 rectangles classification), on Challenger Plateau this same MBES class *k* was 100% matched with faunal class *s*.

Table 6: Summary of contingency table comparisons between classifications based on DTIS video fauna and MBES data, as described in Table 5 but split here by survey area: Chatham Rise and Challenger Plateau (MBES rectangle classifications only are shown). Values are the highest percentage occurrence of DTIS video fauna groups (a-t, left) in any one MBES group.

	Chatham Rise			Challenger Plateau		
Fauna class	ED 2.6	SIMPROF 5	*K*-means	ED 2.6	SIMPROF 5	*K*-means
c	100	100	100			
l	44	44	56			
m				29	24	71
n	30	30	60			
o	62	51	52			
p	33	33	50			
r	75	25	75	67	50	50
s	67	50	83	100	60	100
t	40	40	60	100	100	100
Mean ± se	56±8.5	51±8.2	67±6.2	74±16.8	58±15.9	80±12.2

The individual taxa associated with each faunal and acoustic class for which contingency tables showed more than 50% matching are shown in Table 7 (acoustic class data are from SIMPER analyses in this report, faunal class data are from DTIS video classes calculated in Objective 9 of project ZBD200701). It is striking that faunal class *c* is strongly defined in all classifications by the presence of the ophiuroid *Ophiomusium lymani*. Similarly, faunal class *o* is characterised in all classifications by the presence of pagurid crabs and the polychaete ‘quill’ worm *Hyalinoecia longibranchia*. Other classes are less well in agreement but faunal class *t* is characterised in two of the three MBES classifications by a consistent set of fauna dominated by gastropod molluscs and shrimps.

Table 7: Fauna contributing most to within-class similarity for classes which show more than 50% coincidence between faunal (DTIS video fauna) and acoustic (ED 2.6, SIMPROF 5%, *K*-means) classifications, as summarised in Table 5. Data are shown only for classifications using MBES rectangles because these have stronger within-class similarities and matching with faunal classes. Percent contributions to within-class similarity (SIMPER) are shown in parentheses for each taxon. Class labels for each classification are shown in bold type.

							Classification method
	DTIS fauna (obj9)		ED 2.6		SIMPROF 5%		*K*-means
c	*Ophiomusium lymani* (94%)	k	*Ophiomusium lymani* (41%) *Enypniastes eximia* (7%)	j	*Ophiomusium lymani* (76%)	7	Ophiomusium lymani (72%)
l	*Radicipes sp.* (35%) *Anthoptilum* sp. (30%)					4	Pagurid crab (19%) *Hyalinoecia longibranchia* (9%) Shrimp (7%) Munida gracilis (6%) Gastropod mollusc (6%) Hydroids (5%)
m	Hydroids (79%)					8	Hydroids (34%) Ceriantharia spp (8%) *Hyalinoecia longibranchia* (8%)
n	*Gracilechinus multidentatus* (83%)					1	*Gracilechinus multidentatus* (28%) Pagurid crab (16%) Gatropod mollusc (8%)
o	*Pagurid crab (41%)* *Hyalinoecia longibranchia (11%)*	v	*Pagurid crab (14%)* *Hyalinoecia longibranchia (9%)* *Munida gracilis* (9%) Gastropod mollusc (6%) Asteroid (5%) Hydroids (5%)	w	*Pagurid crab (15%)* *Hyalinoecia longibranchia (10%)* Munida gracilis (6%) Hydroids (5%) Anemones (5%) Ceriantharia spp (5%) Gastropod mollusc (4%)	4	Pagurid crab (19%) *Hyalinoecia longibranchia* (9%) Shrimp (7%) Munida gracilis (6%) Gastropod mollusc (6%) Hydroids (5%)
r	*Munida gracilis*(76%)	v	*Pagurid crab (14%)* *Hyalinoecia longibranchia (9%)* *Munida gracilis* (9%) Gastropod mollusc (6%)			4	Pagurid crab (19%) *Hyalinoecia longibranchia* (9%) Shrimp (7%) Munida gracilis (6%)

						Classification method	
DTIS fauna (obj9)		ED 2.6		SIMPROF 5%		*K*-means	
			Asteroid (5%)				Gastropod mollusc (6%)
			Hydroids (5%)				Hydroids (5%)
t	Gastropod mollusc (21%)	u	Gastropod mollusc (9%)	u	Gastropod mollusc (10%)		
	Shrimp (17%)		Shrimp (9%)		Shrimp (9%)		
	Ophiura sp. (12%)		*Pagurid crab (8%)*		Hydroids (8%)		
			Anemones (7%)		*Pagurid crab (8%)*		
			Hydroids (7%)		*Hyalinoecia longibranchia (7%)*		
			Hyalinoecia longibranchia (6%)		Anemones (7%)		

4 DISCUSSION

Given the disparities in spatial scale of remote-sensed MBES data and observational benthic invertebrate fauna in the deep sea, particularly for primarily soft-sediment environments, we considered it unlikely that any consistent relationship between the two would exist such that faunal assemblage composition could be predicted from the characteristics of the MBES signal alone. This expectation is reinforced by published studies, almost exclusively from shallow water, which have demonstrated only weak relationships between acoustic signatures and benthic fauna in soft sediment environments (Hewitt et al. 2004, Holmes et al. 2008). The present study also spans larger spatial scales and a much greater range of depths than any other studies we are aware of. Because variations in faunal assemblages at regional scales can be influenced by factors other than the local scale environment characterised by MBES data (e.g. long-term differences in productivity and tectonic history) and because the spatial resolution of MBES data decreases strongly with increasing depth, these factors further decreased the likelihood of finding any consistent relationship with fauna. The analyses presented here largely reinforce this view and the primary conclusion is that there is apparently no clear relationship between the MBES acoustic data and distributions of benthic faunal assemblages that would enable us routinely to predict their occurrence with any degree of certainty at the scale of the OS 20/20 Chatham-Challenger data. Rank correlations between sample sites in terms of acoustic and faunal data are low (BIOENV ρ less than about 0.6 for all comparisons) and although MBES classifications by themselves were relatively robust in terms of having significantly lower faunal dissimilarity within classes than between classes, within-class faunal similarity was always low and did not correspond strongly with classes generated from the faunal data. However, there are some unexpected and intriguing correspondences between the faunal and acoustic classifications that merit further investigation and prompt questions about the spatial scales at which we should attempt ecological interpretation of MBES acoustic data.

Across the entire study area, only four out of the twenty DTIS faunal classes (*c*, *o*, *r*, and *t*) showed more than 50% matching to MBES acoustic classes. For three of these classes, the percentage of sites matching was no more than 71% but for each class the lists of characteristic fauna derived from MBES groupings were remarkably similar to those derived from the DTIS video samples (Table 7). Given that all the benthic taxa involved here are of relatively small body size (generally less than 15 cm) and most were not present in high densities, these matches were unexpected. The strong matching of DTIS faunal class *c* within a single MBES acoustic class in all classifications is particularly striking. Faunal class *c* occurred only at five sites, all of which were on muddy sediment substrates in 1150–1250 m depth on the western half of the southern flank of Chatham Rise, and benthic assemblages at these sites were characterised in all classifications (DTIS and MBES) by the brittlestar *Ophiomusium lymani*. Adult *O. lymani* have an arm spread of up to about 20 cm and body disc diameter of up to about 40 mm, and seabed images from these sites show consistently high population densities (often more than 20 individuals per square metre) throughout DTIS transects, with many individuals in a posture which raises their central disc above the sediment surface (Figure 9). It is conceivable that high population densities of these hard-bodied organisms over extensive areas could affect MBES signatures sufficiently to be detectable in our acoustic analyses. Neighbouring sites in the same depth range show similar muddy sediment substrates and share some of the same fauna as the *c* sites but do not have the dense *O. lymani* populations and are allocated to different classes in all analyses, suggesting that the brittlestars might indeed be having a direct effect on MBES signatures. However, these are among the deepest sites sampled during the Chatham-Challenger OS 20/20 voyages and thus have the coarsest acoustic resolution, each MBES beam insonifying a seabed area more than 600 m^2 at this depth. This makes a consistent quantifiable MBES response to the brittle star populations unlikely but perhaps not impossible.

An alternative explanation for such matching between fauna and MBES is that both are responding independently to physical characteristics of the seabed. Thus substrate characteristics that have a certain MBES profile may also be those that are most suitable as habitat for a particular set of benthic organisms. This, of course, is how we intuitively interpret MBES images in practice. For instance, hard substrates generate MBES profiles with high backscatter and rugosity components and we know that sessile suspension-feeding fauna are more likely to be found in such areas. However, such obvious distinctions are rare across the mainly sedimentary environments of Chatham Rise and Challenger Plateau and the question that remains unanswered here is whether or not the differences we have quantified in MBES profiles are also ecologically significant for the distributions of benthic organisms. If correspondence between MBES profiles and faunal distributions is a consequence of both factors responding independently to physical aspects of the seabed (as opposed to MBES being directly affected by acoustic reflectivity of the organisms themselves, as postulated for *O. lymani* above), it is also important to be aware that these characteristics of the seabed are themselves a consequence of physical oceanographic and geological processes operating across a broad range of spatial and temporal scales. Thus, currents, rates of sedimentation, proximity to regions of high water-column productivity, geology, tectonics, and temperature all influence the acoustic characteristics of the seabed. Given this, there is a strong argument that we should interpret acoustic data in the context of these broader scale factors. That is, in much the same way that the MBES transects in the present study enable us to view our point- or transect-sampled biological data in a wider spatial context, we need to evaluate MBES data in the context of the broader-scale oceanographic, geologic, and evolutionary factors that are likely to dictate the spatial scales over which faunal interpretations derived from MBES data are meaningful.

Figure 9: High population density of the brittle star *Ophiomusium lymani* at 1200 m depth on the southern flank of Chatham Rise (DTIS transect; station TAN0705_044, site A008). Seabed area in the image is 1.49 m^2 and 23 individuals are visible. Mean population density throughout the 1.7 km long transect was more than 15 individuals per square metre.

The potential importance of factors acting at larger spatial scales is highlighted here by the observation that a single MBES acoustic class could be strongly associated with different faunal classes in each of the two survey regions. For instance, in the ED 2.6 rectangles classification, MBES class *k* was associated with faunal class *c* on Chatham Rise but with class *s* on Challenger Plateau. The five faunal class *c* sites were all on the southern flank of Chatham Rise and comparisons between them and neighbouring sites in that part of the study area showed clear and consistent differentiation of the sites in both faunal and MBES data sets, faunal differences being driven almost entirely by the presence or absence of *O. lymani*. When the comparison was extended to include Challenger Plateau, sites with the same class of acoustic signature were, again, strongly associated with a particular faunal class but this assemblage was not the same as that on Chatham Rise. Thus, although the acoustic signatures of all these sites were similar to each other and distinct from others in the MBES classifications, faunal comparisons generated from them were valid only at local scale within the overall survey: i.e. either within Chatham Rise or within Challenger Plateau but not between areas. If the arguments in the preceding paragraph are accepted, this lack of comparability can be interpreted as being a consequence of differences in regional scale environmental factors between the two study areas. We know that Challenger Plateau and Chatham Rise differ at least in terms of primary production, water mass characteristics, proximity to frontal mixing zones, and temperature gradients (Snelder et al. 2006, Nodder et al. 2007a, Nodder et al. 2007b). Therefore, we might expect there to be differences in the overall species-abundance composition of benthic assemblages in each region and, consequently, for physically similar habitats in the two regions to be occupied by somewhat different sets of organisms.

Because the oceanographic parameters that influence both substrate characteristics and benthic assemblage structure are precisely those that form the basis of the Marine Environment Classification (Snelder et al. 2006, Snelder et al. 2007) and its subsequent variants, a logical next step in the ecological interpretation of MBES data in the New Zealand region would be to constrain comparisons to be within individual MEC classes. Thus, MBES sites would only be compared with other sites that occur within the same MEC class. Obviously, this would generate another layer of questions in that an MEC classification level appropriate to the expected scales of acoustic and faunal variation would have to be selected, but it would have the advantage of constraining comparisons to environmentally similar sets of sites based on objective classification of spatially consistent, broad-scale, environmental parameters. At the very least, because depth has a strong influence on the MEC, this would go some way to addressing the inherent problem with MBES data of decreasing resolution with depth.

5 ACKNOWLEDGEMENTS

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6 DATA MANAGEMENT

Data from the analyses presented here have been lodged with the Ministry for Primary Industries Data Manager at NIWA for loading into the Marine Biodiversity and Biosecurity Database (BIODS) where they will be referenced to the raw data from which they are derived.

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8 APPENDICES

Table A1: BIOENV analysis: MBES variables best matching patterns of faunal distribution across Chatham Rise and Challenger Plateau. Values are shown for two methods of defining acoustic patches at study sites (rectangles and polygons), two faunal data sets (DTIS video and seamounts epibenthic sled – SEL), and for all study sites combined (A, B) and each location separately (Chatham, C, D; Challenger, E, F). The best ten combinations of MBES variables were calculated in each case. Of these, only the combinations with highest Spearman rank correlation values (ρ) are shown for each number of combined variables; this illustrates the influence of adding extra variables in the analysis. Highest ρ values are shown in bold (these correspond to values in Table 2).

A. Chatham Rise and Challenger Plateau combined – acoustic rectangle method.

Faunal data set	No. of variables	Best variable combination (ρ)
DTIS video	1	Bathy_Mean (0.459)
	2	BS_Min, Bathy_Mean (**0.488**)
	3	BS_Min, BS_Kurt, Bathy_Mean (0.487)
	4	BS_Min, BS_Kurt, BTM_Majority, Bathy_Mean (0.480)
Epibenthic sled (SEL)	1	Bathy_Mean (0.348)
	2	BTM_Majority, Bathy_Mean (0.361)
	3	BS_Kurt, BTM_Majority, Bathy_Mean (**0.362**)
	4	BS_Min, BS_Kurt, BTM_Majority, 31 Bathy_Mean (0.348)

B. Chatham Rise and Challenger Plateau combined – acoustic polygon method.

Faunal data set	No. of variables	Best variable combination
DTIS video	4	BS_Min, BS_Var, Bathy_Min, Bathy_Mean (0.490)
	5	BS_Min, BS_Var, Bathy_Min, Bathy_MAX, Bathy_Mean (**0.491**)
Epibenthic sled (SEL)	2	Bathy_Mean, Bathy_STD (**0.384**)
	3	Bathy_Min, Bathy_Mean, Bathy_STD (0.383)
	4	BTM_Majority, Bathy_Min, Bathy_Max, Bathy_Mean, Bathy_STD (0.382)

C. Chatham Rise – acoustic rectangle method.

Faunal data set	No. of variables	Best variable combination
DTIS video	1	Bathy_Mean (0.509)
	2	BTM_Majority, Bathy_Mean (**0.516**)
	3	BTM_Variety, BTM_Majority, Bathy_Mean (0.487)
	4	BS_Max, BS_Avg, BTM_Variety, Bathy_Mean (0.489)
	5	BS_Max, BS_Avg, BTM_Std, BTM_Variety, Bathy_Mean (0.488)
Epibenthic sled (SEL)	1	Bathy_Mean (0.346)
	2	BTM_Variety, Bathy_Mean (**0.372**)
	3	BTM_Variety, BTM_Majority, Bathy_Mean (0.372)
	4	BTM_Variety, BTM_Majority, Bathy_Mean (0.355)
	5	BS_Avg, BTM_Std, BTM_Variety, BTM_Majority, Bathy_Mean (0.343)

D. Chatham Rise – acoustic polygon method.

Faunal data set	No. of variables	Best variable combination
DTIS video	4	BS_Avg, Bathy_Min, Bathy_Max, Bathy_Std (**0.525**)
	5	BS_Mean, BS_Kurt, Bathy_Min, Bathy_Max, Bathy_Std (0.522)
Epibenthic sled (SEL)	3	BTM_Min, Bathy_Max, Bathy_Std (**0.422**)
	4	BTM_Min, Bathy_Min, Bathy_Max, Bathy_Std (0.420)
	5	BTM_Min, Bathy_Min, Bathy_Max, Bathy_Mean, Bathy_Std (0.418)

E. Challenger Plateau – acoustic rectangle method.

Faunal data set	No. of variables	Best variable combination
DTIS video	2	BS_Min, Bathy_Min (**0.573**)
	3	BS_Min, BS_Kurt, Bathy_Min (0.573)
	4	BS_Min, BS_Kurt, Bathy_Min, Bathy_Mean (0.565)
	5	BS_Min, BS_Var, BS_Kurt, Bathy_Min, Bathy_Mean (0.557)
Epibenthic sled (SEL)	4	BS_Avg, BS_Var, Bathy_Mean, Bathy_Std (0.575)
	5	BS_Avg, BS_Var, BTM_Majority, Bathy_Mean, Bathy_Std (**0.577**)

F. Challenger Plateau – acoustic polygon method.

Faunal data set	No. of variables	Best variable combination
DTIS video	4	BS_Std, BTM_sum, Bathy_Min, Bathy_Mean (0.553)
	5	BS_Std, BTM_sum, Bathy_Min, Bathy_Max, Bathy_Mean (**0.567**)
Epibenthic sled (SEL)	4	BS_Mean, BS_Kurt, Bathy_Mean, Bathy_Std (**0.603**)
	5	BS_Mean, BS_Kurt, bathy_Max, Bathy_Mean, Bathy_Std (0.603)

Table A2: SIMPER analyses. Dissimilarity (%) between benthic fauna (DTIS video, unclassified data) in acoustic classes derived from MBES variables using; A, group average clustering of acoustic polygons with classes defined at a Euclidian distance of 3.0 (ED 3.0); B, group average clustering of acoustic polygons with classes defined by SIMPROF (5% significance level); C, group average clustering of acoustic rectangles with classes defined at a Euclidian distance of 2.6 (ED 2.6); D, group average clustering of acoustic rectangles with classes defined by SIMPROF (5% significance level); *K*-means clustering of acoustic polygons; and E, *K*-means clustering of acoustic rectangles. (classes are labelled on both axes, only classes containing more than three sites are included). Bold values show within-class dissimilarity.

A. ED 3.0 Polygons versus DTIS fauna.

	j	l	m	n	i	h	q
j	**76.81**						
l	84.40	**85.66**					
m	79.43	85.22	**78.02**				
n	83.78	90.45	84.93	**77.94**			
i	79.29	86.74	77.63	85.62	**67.86**		
h	84.00	88.61	79.99	88.23	78.41	**80.29**	
q	86.65	93.21	88.71	81.55	87.67	91.66	**82.02**

B. SIMPROF 5% Polygons v DTIS fauna.

	j	n	z	w	i	aa	y	v	k	r	p	e
j	**75.17**											
n	74.00	**74.61**										
z	84.62	87.36	**82.93**									
w	78.50	80.16	86.91	**76.05**								
i	76.84	74.45	86.33	78.10	**74.96**							
aa	86.41	88.20	80.35	85.84	85.74	**78.37**						
y	82.11	84.17	81.82	81.49	84.97	77.94	**80.49**					
v	77.84	72.74	88.12	79.48	75.65	89.21	86.00	**76.51**				
k	74.47	77.77	82.99	80.2	80.03	85.46	79.66	81.00	**76.81**			
r	80.68	79.78	88.11	77.48	75.61	87.61	86.45	77.9	83.62	**77.99**		
p	84.21	84.69	92.46	86.27	86.16	92.09	90.31	86.56	86.51	84.28	**85.87**	
e	80.83	79.10	89.58	79.49	74.53	89.86	88.59	78.76	83.94	76.86	85.18	**78.26**

C. ED 2.6 Rectangles versus DTIS fauna.

	h	i	k	l	t	u	v	w
h	**73.89**							
i	86.7	**66.76**						
k	85.06	85.72	**74.74**					
l	86.63	87.48	89.08	**63.85**				
t	91.89	92.27	90.72	85.63	**70.61**			
u	82.06	82.48	84.59	80.09	84.35	**77.29**		
v	87.7	87.9	90.13	75.03	85.69	81.32	**76.94**	
w	88.18	87.51	88.62	79.02	76.72	81.62	80.54	**79.54**

D. SIMPROF 5% Rectangles versus DTIS fauna.

w	**74.65**								
u	80.13	**76.79**							
j	91.49	86.41	**50.56**						
m	77.27	80.35	90.75	**74.92**					
h	87.19	82.34	91.69	86.78	**66.76**				
x	80.59	83.16	93.65	80.18	89.59	**76.71**			
aa	78.78	81.59	91.35	79.34	87.50	80.91	**74.89**		
g	87.29	82.64	88.75	87.63	86.71	88.86	87.37	**73.89**	
s	86.29	83.63	94.67	85.87	92.27	85.23	74.08	91.89	**70.61**
	w	**u**	**j**	**m**	**h**	**x**	**aa**	**g**	**s**

E. *K*-means Polygons versus DTIS fauna.

k1	**79.31**									
k2	79.85	**72.98**								
k3	86.86	86.77	**81.85**							
k4	88.16	86.57	82.29	**79.29**						
k5	83.04	78.57	81.48	78.23	**69.87**					
k7	79.51	76.89	85.60	85.44	79.61	**77.14**				
k8	86.01	84.70	91.12	91.38	88.07	85.24	**88.06**			
k9	90.13	84.00	91.36	89.47	85.17	88.26	89.42	**88.76**		
k10	84.51	78.69	83.69	85.74	78.27	82.27	86.44	79.31	**89.24**	
k12	81.17	82.58	98.76	90.24	85.27	80.80	87.52	92.67	88.44	**90.73**
	k1	**k2**	**k3**	**k4**	**k5**	**k7**	**k8**	**k9**	**k10**	**k12**

F. *K*-means Rectangles versus DTIS fauna.

k1	**79.21**							
k2	83.75	**73.70**						
k3	84.64	83.30	**84.63**					
k4	81.47	83.41	86.89	**79.72**				
k5	84.64	77.49	81.59	84.68	**74.29**			
k6	84.81	86.53	88.58	83.98	89.49	**86.68**		
k7	85.67	89.13	86.48	88.02	84.17	90.63	**78.09**	
k8	84.99	70.62	86.96	83.12	80.52	87.70	90.63	**71.01**
k9	87.20	73.62	80.77	85.77	70.26	90.21	87.76	75.83
	k1	**k2**	**k3**	**k4**	**k5**	**k6**	**k7**	**k8**

Table A3. One-way ANOVA comparisons of within-class and between-class faunal similarity of MBES classes (SIMPER analyses) for three classification methods and two acoustic patch definitions; details as for Figure 6. All comparisons are unbalanced. Consequently, significance levels are not reliable but P values indicate relative degree of distinction between classification methods.

Classification		DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
ED3.0 poly	Comparison	1	234.602	234.602	10.580	.0032	10.580	.896
	Residual	26	576.521	22.174				
ED2.6 rect	Comparison	1	928.611	928.611	43.211	<.0001	43.211	1.000
	Residual	34	730.661	21.490				
K-means poly	Comparison	1	93.392	93.392	3.470	0.0681	3.470	0.433
	Residual	53	1426.631	26.918				
K-means rect	Comparison	1	388.345	388.345	12.507	0.0010	12.507	0.950
	Residual	43	1335.200	31.051				
SIMPROF 5% poly	Comparison	1	203.296	203.296	9.254	.0032	9.254	.869
	Residual	76	1669.682	21.969				
SIMPROF 5% rect	Comparison	1	1531.833	1531.833	45.736	<.0001	45.736	1.000
	Residual	43	1440.196	33.493				

Table A 4 (A–F). Chatham Rise and Challenger Plateau OS 20/20 sample sites: contingency tables showing frequency of occurrence of sampling sites in DTIS video fauna classes (at left) in relation to MBES classes (at top) and vice versa. Maximum values show the highest percentage of sites occurring in one class, e.g. if all sites belonging to one fauna class occurred in only one MBES class, the max. value would be 100. Max. values are calculated only for classes containing at least three sites.

A. DTIS versus MBES rectangles ED2.6.

	MBES classes																								
Fauna classes	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	Totals	Max
a	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
b	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
c	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	5	100
d	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	
h	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
i	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
j	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	
k	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	
l	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	4	3	9	44
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	4	3	1	5	17	29
n	0	0	0	0	1	0	1	3	0	0	1	0	0	0	0	1	0	0	0	0	3	0	0	10	30
o	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	1	0	0	2	13	2	21	62
p	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	1	2	0	6	33
q	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
r	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	10	1	14	71
s	0	0	0	0	0	0	0	0	4	0	5	0	0	0	0	0	0	0	0	0	2	0	0	11	45
t	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	5	0	0	8	63
Totals	1	1	1	1	1	1	2	4	4	2	11	4	1	1	1	3	3	3	1	4	17	31	12	110	4
Max								75	100		45	50				33	100	66		100	12	42	17		

B. DTIS versus MBES rectangles SIMPROF 5%.

Fauna classes	MBES classes																													
	a	aa	ab	b	c	d	e	f	G	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	Totals	Max
a	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
b	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
c	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	100
d	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
g	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	
h	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
i	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
j	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
k	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
l	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	4	0	0	1	9	44
m	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	4	0	3	0	0	1	2	0	17	24
n	0	0	0	0	0	0	1	1	3	0	0	1	0	0	0	1	0	0	0	0	0	1	2	0	0	0	0	0	10	30
o	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	1	0	0	0	2	1	11	1	0	0	21	52
p	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	1	0	1	1	0	0	6	33
q	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
r	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	6	4	0	0	14	43
s	0	0	0	0	0	0	0	0	0	4	0	0	3	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	11	36
t	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	8	63
Totals	1	6	3	1	1	1	2	2	4	4	2	6	3	2	7	1	2	3	3	1	4	1	16	1	22	8	2	1	110	
Max		50	33						75	100		83	100		28.6			100	66		100		31		50	50				

C. DTI versus MBES rectangles *K*-means.

Fauna classes		MBES classes									
		1	2	3	4	5	6	7	8	Totals	Max
	a	1	0	0	0	0	0	0	0	1	
	b	0	0	0	0	0	0	1	0	1	
	c	0	0	0	0	0	0	5	0	5	100
	d	0	0	0	0	0	1	0	0	1	
	g	0	0	0	1	0	0	0	0	1	
	h	0	0	1	0	0	0	0	0	1	
	i	0	0	0	0	0	1	0	0	1	
	j	1	0	0	0	0	0	0	0	1	
	k	0	0	0	0	0	1	0	0	1	
	l	1	0	0	5	0	3	0	0	9	56
	m	0	3	0	0	2	0	0	12	17	71
	n	6	0	0	2	0	0	2	0	10	60
	o	7	0	0	11	0	3	0	0	21	52
	p	1	0	0	3	0	2	0	0	6	50
	q	1	0	0	0	0	0	0	0	1	
	r	2	0	0	9	0	0	0	3	14	64
	s	0	0	0	5	5	0	1	0	11	45
	t	3	0	0	1	3	0	1	0	8	38
	Totals	23	3	1	37	10	11	10	15	110	
	Max	30	100		30	50	27	50	80		

D. DTIS versus MBES polygons ED 3.0.

MBES classes

Fauna classes

	a	b	c	d	e	f	G	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	Totals	Max
a	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	
c	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	0	0	1	0	0	5	60.0
d	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	
g	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
h	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
i	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	
j	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
k	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	
l	0	0	0	0	0	0	1	0	1	1	0	0	6	0	0	0	0	0	0	0	0	0	0	9	66.7
m	1	0	0	0	0	0	0	5	1	0	0	0	10	0	0	0	0	0	0	0	0	0	0	17	58.8
n	0	0	0	0	0	0	0	0	0	4	0	0	0	1	2	0	3	0	0	0	0	0	0	10	40.0
o	0	0	0	0	0	0	0	1	1	9	1	1	8	0	0	0	0	0	0	0	0	0	0	21	42.9
p	0	0	0	0	0	0	0	0	0	2	0	2	2	0	0	0	0	0	0	0	0	0	0	6	33.3
q	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
r	0	0	0	0	0	0	1	2	2	2	1	2	4	0	0	0	0	0	0	0	0	0	0	14	28.6
s	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	3	1	0	2	1	0	0	0	11	27.3
t	0	0	0	0	1	0	0	0	0	3	0	0	0	2	0	0	1	1	0	0	0	0	0	8	37.5
Totals	1	1	1	1	1	1	2	8	5	22	2	6	31	7	2	3	9	1	2	1	1	1	1	110	
Max								62.5	40	40.9		33.3	32.3	42.9		100	33.3								

E. DTIS versus MBES polygons SIMPROF 5%.

Fauna classes	MBES classes																													
	a	aa	ab	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	Totals	Max
a	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	
c	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	5	60
d	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
g	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
h	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
i	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
j	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
k	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	
l	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	4	0	0	0	1	1	0	0	0	9	44
m	1	0	0	0	0	0	2	1	2	0	1	0	0	0	0	0	0	0	0	5	1	0	0	1	3	0	0	0	17	29
n	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	10	50
o	0	0	0	0	0	0	1	0	0	0	1	2	1	0	0	6	1	1	0	1	0	0	3	4	0	0	0	0	21	29
p	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	1	0	0	0	0	1	0	0	0	6	33
q	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
r	0	0	0	0	0	1	2	0	0	1	1	1	0	0	0	1	1	2	1	3	0	0	0	0	0	0	0	0	14	21
s	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	4	11	36
t	0	1	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	8	38
Totals	2	5	2	2	2	2	5	1	2	1	4	4	7	1	1	9	2	6	1	14	1	1	3	6	5	2	5	14	110	
Max		60					40				25	50	42.9			66.7		33.3		35.7			100	66.7	60	0	40	35.7		

F. DTIS versus MBES polygons *K*-means.

Fauna classes		MBES classes									Totals	Max
		1	2	3	4	5	7	8	9	12		
	a	0	1	0	0	0	0	0	0	0	1	
	b	0	0	1	0	0	0	0	0	0	1	
	c	0	0	3	2	0	0	0	0	0	5	60
	d	0	0	0	0	0	0	1	0	0	1	
	g	1	0	0	0	0	0	0	0	0	1	
	h	0	0	0	0	0	0	0	1	0	1	
	i	0	0	0	0	0	0	1	0	0	1	
	j	0	0	0	0	0	0	0	1	0	1	
	k	0	0	0	0	0	0	1	0	0	1	
	l	6	0	0	0	0	3	0	0	0	9	67
	m	13	0	0	0	0	2	1	0	1	17	76
	n	1	0	1	6	0	2	0	0	0	10	60
	o	6	3	0	0	0	10	1	0	1	21	48
	p	2	0	0	0	0	2	2	0	0	6	33
	q	0	0	0	0	1	0	0	0	0	1	
	r	4	2	0	0	0	5	2	0	1	14	36
	s	1	0	8	2	0	0	0	0	0	11	73
	t	0	0	3	2	1	2	0	0	0	8	38
	Totals	34	6	16	12	2	26	9	2	3	110	
	Max	38	50	50	50	50	38	22	50	33		