Effects of fishing on the benthic biodiversity of seamounts of the "Graveyard" complex, northern Chatham Rise

Malcolm R. Clark
David A. Bowden
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David A. Bowden
Susan Jane Baird
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NIWA
Private Bag 14901
Wellington 6241

EXECUTIVE SUMMARY

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Small seamounts in the Graveyard complex, northern Chatham Rise, were surveyed in May–June 2006. This repeated a survey in 2001 to examine the effects of bottom trawling on seamount benthos, and to monitor changes over time. Eight seamounts (five fished, three unfished) were surveyed for fauna and substrate type using video and still camera equipment mounted in a towed sled, and physical sampling of the benthic fauna was carried out using a small epibenthic sled.

Over 5000 still camera images of the seafloor were examined, of which 3400 were suitable for descriptive and quantitative analyses. *K*-means partitioning of the images based on substrate composition defined six substrate classes. The occurrence of these classes varied in proportion between seamounts, and was related to the amount of bottom trawling. Substrate diversity was highest on unfished seamounts, which had higher levels of intact scleractinean coral matrix, and lower on fished seamounts where bedrock and coral rubble were predominant. Distributions of 12 major taxa were plotted, highlighting differences between seamounts in coral cover and several faunal groups. Multivariate analyses of faunal distributions by habitat type indicated a number of significant differences between unfished and fished seamounts. Signs of trawl impact (e.g., gouges, wires) were frequent on the fished seamounts, but scarce or absent on the three "unfished" ones. Several preliminary results from comparisons of 2001 and 2006 surveys are presented. Sled catches were examined by a number of taxonomic experts, and 317 taxa have been identified, most to at least genus level.

Multibeam data from previous surveys were analysed using habitat mapping software, and defined five "biologically meaningful" geomorphological classes based on depth and slope. Overlays with faunal distribution from the images indicated the method could be useful in using physical proxies to identify different faunal communities.

1.   INTRODUCTION

1.1   Overview

Seamounts, knolls, and pinnacles (underwater topographical features, UTFs) are common and widely distributed in the New Zealand region. There are over 800 such features associated with the tectonic plate boundary between the Australian and Pacific plates, as well as on offshore ridges and plateaux (Rowden et al. 2005). In this report we adopt the terminology of Pitcher et al. (2007) in using the term "seamount" to describe seamount-type features with an elevation of 100 m or greater.

Seamounts are often sites of high productivity, and the focus of important commercial fisheries based on fish species that form large aggregations in association with them (e.g., Sasaki 1986, Rogers 1994, Koslow 1997, Clark 1999). Around New Zealand, major deepwater fisheries occur on seamounts for orange roughy (*Hoplostethus atlanticus*), oreos (black oreo *Allocyttus niger*, and smooth oreo *Pseudocyttus maculatus*), black cardinalfish (*Epigonus telescopus*), and alfonsino (*Beryx splendens*) (Clark & O'Driscoll 2003). Although the fisheries for orange roughy and oreos also occur extensively on the gentle contours of the continental slope, over time they have become more focussed on seamounts. In the early 1980s less than 20% of the orange roughy catch was taken on seamount features, but this progressively increased to 60–70% in the mid 1990s (Clark & O'Driscoll 2003, O'Driscoll & Clark 2005). Such features were actively sought by the fishing industry, and the number being found and fished each year has also increased (Clark & O'Driscoll 2003).

However, in addition to being productive, seamounts are generally regarded as fragile habitat (e.g., Probert 1999). Benthic faunal communities are commonly based on extensive coral growths, which are fragile and readily impacted by heavy trawl gear (e.g., Hall-Spencer et al. 2002, Koslow et al. 2001). These corals are long-lived (the order of 100s of years) and slow growing, meaning their recovery from trawling will be slow (e.g., Gass & Roberts 2006, Tracey et al. 2007).

The environmental impact of fishing, especially bottom trawling, is the subject of growing public and political awareness. The effects of trawl gear have long been known – effects such as the scraping and ploughing of the seabed, the resuspension of sediments with a smothering impact, the destruction of non-target benthic animals, especially sessile and habitat-forming species like corals and sponges, and the dumping of processing wastes (see reviews by Hall 1999, Clark & Koslow 2007). Typically there is a reduction in species diversity, biomass, and number of species in extensively trawled ecosystems. The dominant benthic species can change, from large sessile types (e.g., corals, hydroids, sponges) to small opportunistic species, scavengers, and juveniles of many taxa. In some cases there can be a reduction in the age composition and size structure of species. The seafloor is generally smoothed by repeated trawling. Overall, there is typically a reduction in habitat complexity, both physical and faunal.

Most studies to investigate the effects of bottom trawling have been in shallow-water environments, but the effects are thought to be potentially more severe in deepwater communities. Here the animals are less adapted to natural disturbances (such as those caused by storms), the effects of gear may last longer, and recovery times can be longer because the animals are slower growing and less productive than their shallow-water and continental shelf equivalents (Rogers 1994, Koslow 1997). Koslow et al. (2001) investigated the benthic macrofauna of small seamounts off southern Tasmania, Australia, many of which were being trawled in the orange roughy fishery. They found strong differences in faunal composition and distribution on fished and unfished features, and despite confounding influences of depth concluded that trawling was responsible for stripping coral cover from the fished features. In 2001, a similar "compare and contrast" survey was carried out by NIWA on the Graveyard hills. This region has been heavily fished since the early 1990s, but effort has concentrated on a small number of features. This distribution enables study of seamounts that are in close proximity, have similar physical characteristics and have

been fished to varying degrees – a "natural" experimental situation. Results of the 2001 survey were given by Clark & O'Driscoll (2003) and Clark & Rowden (2009) which showed that the unfished seamounts had greater coral cover and some differences in species composition.

The Ministry of Fisheries (MFish) is required by the Fisheries Act 1996 to avoid, remedy, or mitigate any adverse effects of fishing on the aquatic environment. This requirement includes mandates that "associated or dependent species" should be maintained above a level that ensures their long-term viability, that biological diversity of the aquatic environment should be maintained, and that "habitat of particular significance for fisheries management" should be protected. Consequently, understanding the effects of trawling, and the type and nature of trawling impact, have become priorities for MFish. In the late 1990s seamounts were recognised as important fish habitat by MFish and 19 features were closed to fishing in 2001 (Brodie & Clark 2004). Research has continued in recent years to improve understanding of seamount biodiversity, and the likely effects of human activities on seamount communities. The work presented here builds on this previous research and progresses a study looking at the long-term effects of trawling, the resilience of deepwater faunal communities, and the effectiveness of management options.

This report describes results from the first objective (see below) relating to establishing a time series of measurements on seamounts. The main intention of the 2006 survey was to repeat coverage of the 2001 study, but cover the seamounts in greater detail, and expand the number of seamounts included in the survey.

1.2   OBJECTIVES

1.2.1   Overall objective

1. To improve understanding and knowledge about the effects of trawl fishing on underwater topographic features (UTFs) in New Zealand and to better determine what constitutes an 'adverse' effect of fishing.

1.2.2   Specific objectives

1. To monitor changes in fauna and habitats over time on selected UTFs in the Chatham Rise area that have a range of fishing histories.

2. To continue development of the risk assessment model to predict the effects of fishing, and provide options for the management of UTF ecosystems.

2. METHODS

2.1 Survey area

The study site (Figure 1) is located on the northern flank of the Chatham Rise, encompassing a group of small seamounts known as the "Graveyard seamount complex". The Graveyard seamounts consist of about 20 features ranging in depths at their peak from 750 m to 1250 m (Mackay et al. 2005) and at their base from 1050 m to 1600 m. The seamounts lie in close proximity to one another (distributed over 140 km^2 and between 1.5 and 12.6 km apart), limiting any likely geographical variations in faunal composition.
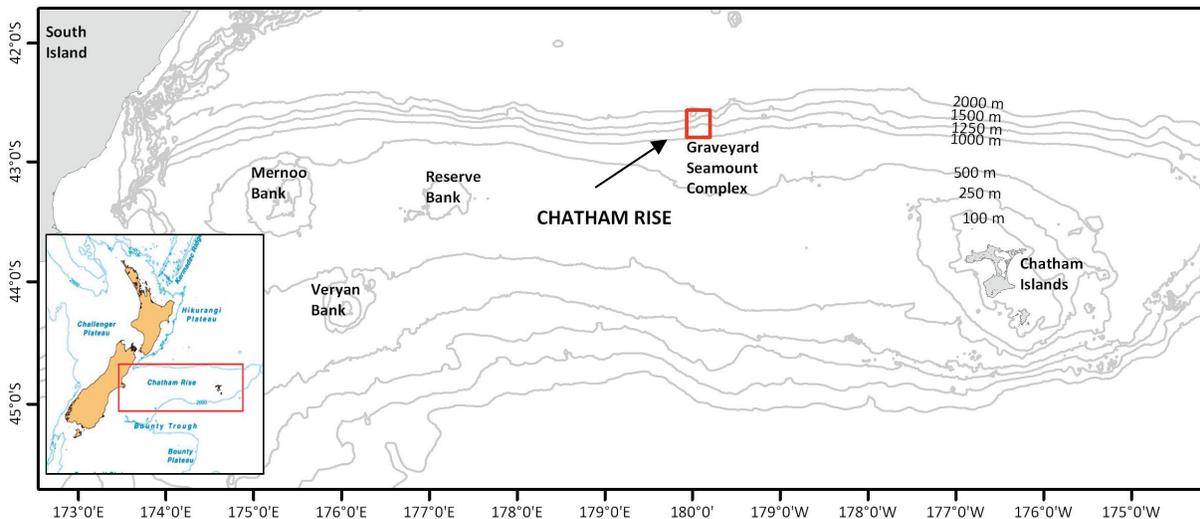
Figure 1: The Chatham Rise, showing the general location of the Graveyard seamounts (indicated by arrow).

2.2 Photographic data

2.2.1 Camera transects

Camera transects were run from the summit of the seamount feature down-slope to its base, where the gradient levelled out to surrounding sediments. On each seamount, a minimum of eight transects was run, radiating out from the summit and orientated approximately along the cardinal and principal intermediate points of the compass (N, NE, E, SE, S, SW, W, NW, N). On *Morgue*, where we are attempting to monitor "recovery" (or at least changes since cessation of fishing), more detailed coverage was applied, with 16 transects done.

The camera gear used was NIWAs Deep Towed Imaging System (DTIS) which incorporates both digital video and still cameras. In contrast to previous systems used by NIWA, the DTIS video has real-time video feed to the vessel through the CTD cable, enabling better control of the camera frame, and also providing immediate information to observers on the ship. An ultrashort baseline (USBL) acoustic tracking system transponder (Simrad HPR 410), CN22 net monitor unit, and Scanmar depth sensor were attached to the frame, to provide information on depth, altitude above the seafloor, and location relative to the vessel. The camera sled was maintained at a target altitude of 2–4 m above the seabed and photographs were taken automatically every 20 s.

About 5100 still images were initially examined for quality and screened for further detailed analysis. Over 1000 images were rejected because exposure or contrast were inadequate, or distance from the seafloor meant that faunal identification was impossible. A further 650 were suitable for determining substrate type, but were too distant for faunal examination. Images were also excluded from analyses if they were too dark, too light, or obscured (e.g., by disturbed sediment or fish swimming close to the camera lens). The final data set comprised 3405 images that could be used in full descriptive and quantitative analyses.

2.2.2   Photographic data analyses

Images were imported into ImageJ (free domain software at http://rsb.info.nih.gov/ij), colour-adjusted, and sized by reference to the scaling lasers in each image before further analysis. Transect length varied depending on the size of individual seamount features, and often extended beyond the base of the seamount on to surrounding sediment plains. For analysis, the horizontal extent of each seamount was defined by a basal polygon calculated as the largest contiguous isobath around the summit (with 50 m isobath spacing) and only images within this polygon were used in analyses. The conspicuous SW spur of *Morgue* is known from official trawl records not to have been fished, whereas the main cone of the seamount was heavily fished up to 2001. Therefore, in order to enable valid comparisons between fished and unfished features, the portion of the SW DTIS transect on *Morgue* that extended along the SW spur was excluded from quantitative analyses.

Because all transects were run from near the summit of the feature to its base, they each encompass the same range of seamount environments (summit, flank, base) at broadly similar depths. Transects can, therefore, be treated as replicate samples within features and are directly comparable between features if they are first standardised for differences in overall transect length (transects on large features are longer than those on small ones).

2.2.3   Substrate classification

In each image, seabed type was recorded as percent cover of 10 substratum categories: bedrock; boulders; cobbles; gravel; sand; sediment overlay; mud; shell hash; coral rubble; and intact scleractinian coral matrix. The percentage cover of each substrate type in each image was estimated by overlaying the image with a scaled grid. The accuracy of this method was tested by comparison with area measurements of detailed polygons using image analysis software (ImageJ) and proved to be a rapid and accurate method. Using the 10 substrate categories, images were then assigned to seabed habitat classes by means of non-hierarchical clustering using the *K*-means algorithm (Legendre 2001). This procedure assigns samples (from each image) to groups by calculating euclidean distances to initial group centroids then iteratively shifting centroids and reassigning samples until no further improvement is made. The number of groups is set by the user and in this case a range from 30 groups to 2 groups was specified. The algorithm was run over 99 starts for each number of groups, using random initial centroids. The optimum number of groups was then determined by calculation of the Calinski-Harabasz (C-H) statistic, which is a metric based on the least-squares distance between samples and group centroids; the highest C-H value indicating the best fit. The substratum classes defined by this process were used as habitat strata in all subsequent analyses to allow meaningful comparisons between seamounts. The similarity percentages routine (SIMPER) was then used to identify the proportions of each substrate type associated with each class. Having defined substratum classes and allocated each image to a class, it was possible to describe each transect in terms of (a) the set of *K*-means classes represented and (b) the proportion of seabed area represented by each class. These two components, membership and relative contribution, allowed calculation of diversity indices for each transect as a measure of substratum heterogeneity. Hill's N_2 ($1/1-\lambda$) (the reciprocal of Simpson's diversity index) was used here.

2.2.4 Fauna

Fauna were recorded as number of individuals per image and plots of their distribution and relative abundance were made. For multivariate analyses counts were made and then standardised to the number of individuals per 10 m^2. Taxa were recorded mostly at the level of class or phylum (unlike the more specific identifications from sled-caught samples). It was possible to discriminate by colour between patches of thicket-forming scleractinian corals (*Madrepora oculata* or *Solenosmilia variabilis*) with live extended polyps and background areas of intact but presumably dead coral matrix where polyps were not visible. Whereas overall coral cover was treated as a substrate and recorded as percent cover, the live patches were recorded as discrete counts as an estimate of the relative abundance of live coral.

To compare habitat-specific diversity between seamounts, data were initially explored by plotting taxon-accumulation curves for each *K*-means habitat class. These curves were constructed using individual images as sampling units. For comparisons of faunal assemblages between seamount features, however, transects rather than individual image frames were used. Individual image frames cover a relatively small area, which means that variance is very high and the mean number of taxa present in each image is low with many null values. Moreover, images are spatially autocorrelated with those closest to them and thus are not independent replicates. The logical unit of replication here is the transect. To be able to compare between transects it was necessary first to standardise for transect length. Because transects were linear and images were taken at equal intervals throughout, length can be expressed either as number of images or as the sum of areas recorded in each image. The sum of areas approach was used here. In order to retain the substratum class information derived from the analysis of seabed types, this standardisation also included a term for the proportion of the transect represented by each class. The approach used here was to calculate, for each transect, the average abundance per substratum class for each taxon and then multiply these values by the proportion of the transect represented by that class. The effect was to render two transects which are of different lengths but have identical average taxon abundances per substratum class equal in analyses. The resulting data matrix consists of 254 samples, each of which represents the standardised abundances of 32 taxa within a single *K*-means substratum class within a single transect.

Using the standardised transect data, Bray-Curtis similarities were calculated for all pairwise comparisons between samples. A non-metric multidimensional scaling (MDS) ordination was used to visualise differences in faunal assemblages between fished (FEI>0.1) and unfished (FEI<0.1) seamounts (see below). One-way ANOSIM was then used to test for differences in assemblage composition between fished and unfished seamounts within each of the six habitat classes defined by the *K*-means classification. Where significant differences were indicated, SIMPER was used to identify the taxa contributing most to the contrast.

2.3   Fishing intensity

Each seamount has a measured intensity of fishing which can be expressed as the Fishing Effects Index (FEI, O'Driscoll & Clark 2005). FEI was calculated up to the year 2006, using tow-by-tow data extracted from the NIWA database dw_cdb. The precision of these data is to the nearest nautical mile and does not allow automatic assignment to the nearest seamount because the Graveyard hills are small and close together. Informal discussions with the fishing industry (Rob Tilney, Deepwater Group, pers. comm.) have yielded some additional information to help resolve this. The eight seamounts were divided into two groups on the basis of fishing history, with *Ghoul*, *Pyre,* and *Gothic* into the unfished category with very low FEI (FEI<0.1, range 0–0.04) , and all other features (including *Diabolical*, which was regarded as largely unfished in 2001) in the fished category with a relatively high FEI (FEI>0.1, range 2.2–658).

2.4   Sled tows

Four tows with an epibenthic sled were carried out on each seamount to directly sample the benthos and verify camera observations. The sled (overall size: 155 cm long, 50 cm high and 130 cm wide) is a standard NIWA design, and has been used to sample the seamounts previously (Clark & Rowden 2009). Tows were positioned based on a random depth and random direction from the summit. The sled had a scanmar depth sensor which gave data on the depth, and therefore likely position of the sled, as well as when it was on the bottom (which backed up estimates of position from the amount of wire out, and bottom contact from tension sensors on the warps).

Biological material recovered in the sleds received initial onboard sorting and processing. Macro-invertebrates were identified to the lowest possible taxon, and data entered into an ACCESS database. Fresh specimens were photographed where possible, and then appropriately labelled and preserved for subsequent taxonomic identification by experts.

2.5   Habitat mapping

Substrate type was identified from the seafloor photographs for each of the eight seamounts (see section above). However, in areas which lack detailed sampling, habitats can potentially be inferred using geological characteristics important for biological communities. These include substrate, slope, aspect, relative bathymetric position (such as on a ridge or in a depression), and depth zone.

Terrain models have been used to develop GIS tools for marine habitat classification (Iampietro et al. 2005, Lundblad et al. 2006). An example is the Benthic Terrain Modeler (BTM) tool which is available in ArcGIS (Wright et al. 2005, Lundblad et al. 2006). The BTM develops a terrain model that builds on elevation data at fine and broad scales to create relative elevation indices that can be grouped by specific rules of neighbourhood, slope, and height to classify the terrain (Weiss 2001, Jenness 2002, 2006). Modifications for the marine environment allow the user to input a set of processed multibeam data, assign various parameters to define neighbourhoods, and classify according to appropriate algorithms. The BTM is based on a second-order derivative of slope. Bathymetric Position Indices (BPIs) are measures of a point of known depth with reference to the depth values in its neighbourhood. Thus, a cell with a positive value is higher than the neighbourhood cells, and one with a negative value is lower. Cells with values very close to, or at, zero are considered as flat seafloor. The algorithm takes into account the slope of each cell (derived from the input bathymetry data) and allows the user to define cell size and neighbourhood size, the latter to create broad-scale and fine-scale neighbourhoods. The resulting grids are standardised and then classified into structural (or habitat) classes by means of a classification dictionary which stipulates boundaries according to 1 standard deviation differences, in slope and depth. The result is a map showing the undersea landscape from flat areas to ridges.

The BTM approach was applied to the Graveyard features. For these data, 25 m x 25 m cells were used and fine-scale (3 x 3 cells) and broad-scale (5 x 5 cells) neighbourhood areas were used because of the resolution of the bathymetry data and the relatively small size of the underwater features. For example, *Morgue* is less than 400 m high, the central cone is less than 2000 m across (west to east), and there are several narrow features (such as lava flows).

The image data collected from the radial transects of each of the eight main features were overlaid on all the data layers derived from the swath mapping to extract the depth, aspect, slope, and structural habitat class of the cell in which the image was located. Thus, each image was assigned a value for these parameters, providing further data for the analysis of substrate and faunal group associations.

3.   RESULTS

3.1   Survey area

The survey covered eight seamount sites in the complex – *Graveyard*, *Morgue*, *Diabolical*, *Gothic*, *Pyre*, *Zombie*, *Scroll*, and *Ghoul* (Figure 2).The planned eight photographic transects per seamount were completed on all seamounts except *Scroll*, where poor weather and time constraints limited the work to four transects. On *Morgue*, 16 transects were carried out to give finer scale coverage to monitor detailed changes.
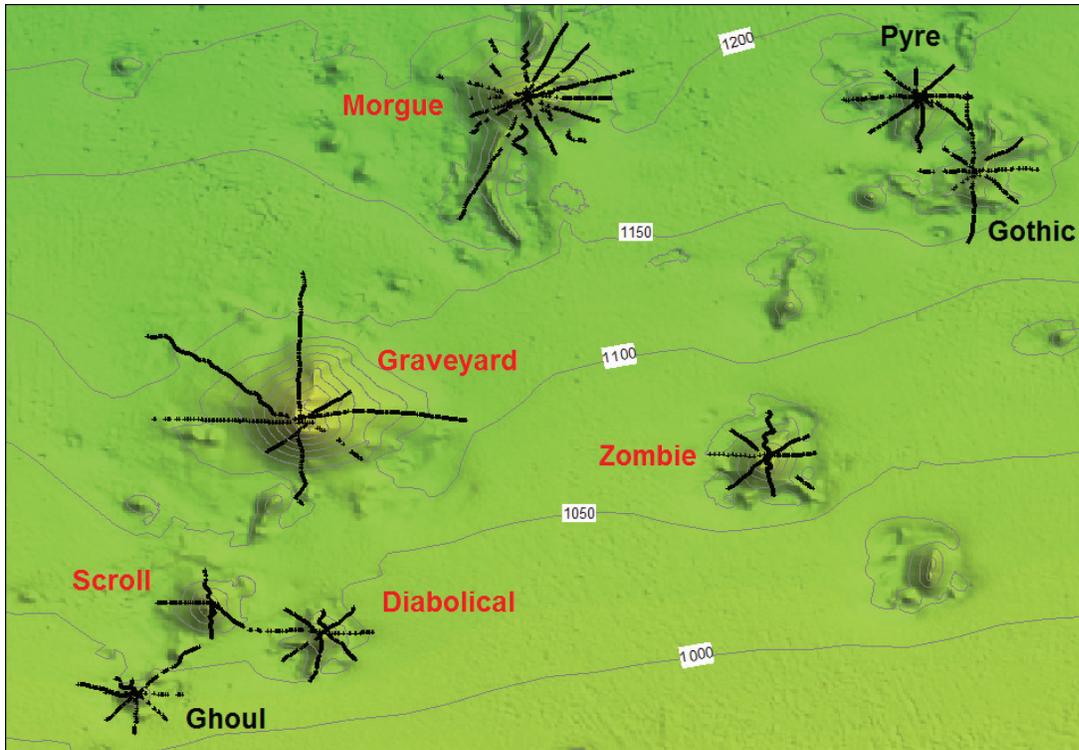

Figure 2: The Graveyard seamounts area, showing the 8 features surveyed, and position of camera transects (each cross is the location of a still photograph of quality suitable for detailed analysis). Seamount labels in red, fished; black, unfished.

The distribution of high quality images is detailed in Table 1.

Table 1: Number of images suitable for quantitative analysis per seamount.

Seamount	Fishing history	Number of images
Graveyard	Fished	710
Morgue	Fished (closed 2001)	796
Scroll	Fished	200
Zombie	Fished	465
Pyre	Unfished (closed 2001)	393
Gothic	Unfished (closed 2001)	273
Diabolical	Fished	294
Ghoul	Unfished	274
TOTAL		3 405

3.2   Substrate composition

K-means partitioning defined six substrate groups (Figure 3). Five of these were associated primarily with single substrate types (*K* classes 1–5: coral rubble, bedrock, intact coral, mud, and sand, respectively) with the sixth associated with a heterogeneous mix of coarse aggregates (SIMPER, Table 2).
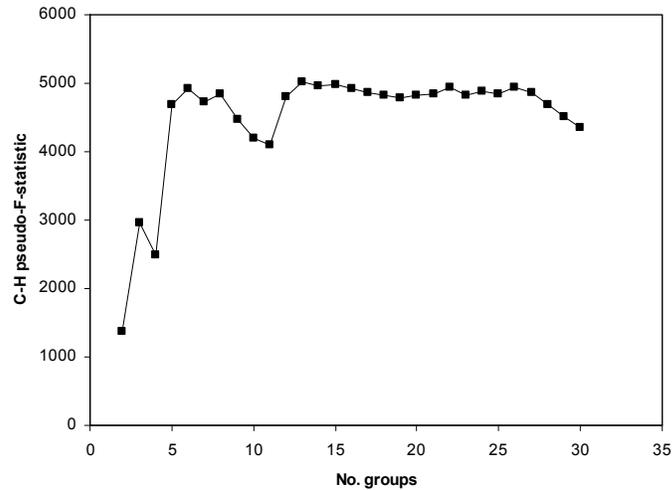

Figure 3: Calinski-Harabasz stopping statistic for *K*-means partitioning of substratum data. Highest values indicate optimal number of substrate groups. The first peak at six groups (C–H = 4926) was used here.

Table 2: Composition of the six substratum groups identified by *K*-means partitioning. SIMPER on untransformed percentage cover data. Dominant substrates in each class are shown in bold.

| *K*-means group	Substrate	Average cover (%)	Sq. dist/SD	Contribution (%)
1	**Coral rubble**	78.9	0.51	42.24
	Sand	15.8	0.46	35.39
	Bedrock	5.13	0.32	14.99
2	**Bedrock**	91.8	0.42	19.81
	Sediment overlay	9.34	0.31	59.04
	Sand	4.73	0.37	9.61
3	**Intact coral**	90.3	0.41	38.56
	Coral rubble	5.32	0.34	18.20
	Sand	4.17	0.37	7.36
4	**Mud**	99.2	0.12	57.66
	Bedrock	0.53	0.11	35.27
5	**Sand**	83.0	0.51	40.28
	Coral rubble	6.08	0.36	26.22
6	**Cobbles**	14.8	0.39	25.99
	Bedrock	30.1	0.50	19.36
	Sand	32.8	0.49	12.17
	Coral rubble	9.03	0.44	10.67
	Boulders	8.01	0.26	10.32

Substrate diversity (as Hill's N_2) was highest on the unfished seamounts and comparison with FEI values indicates lower substrate heterogeneity with increasing fishing intensity (Figure 4). When all transects were summed for each feature, it was clear that most of this effect is caused by the presence of intact

scleractinian coral matrix on the unfished features and a corresponding increase in exposed bedrock and coral rubble substrate on fished features (Figure 5). The percentage of coral rubble is highest on those seamounts with FEI values in the intermediate range (*Diabolical, Scroll, Zombie*; FEI~2-50) but is similar between unfished and heavily fished features.
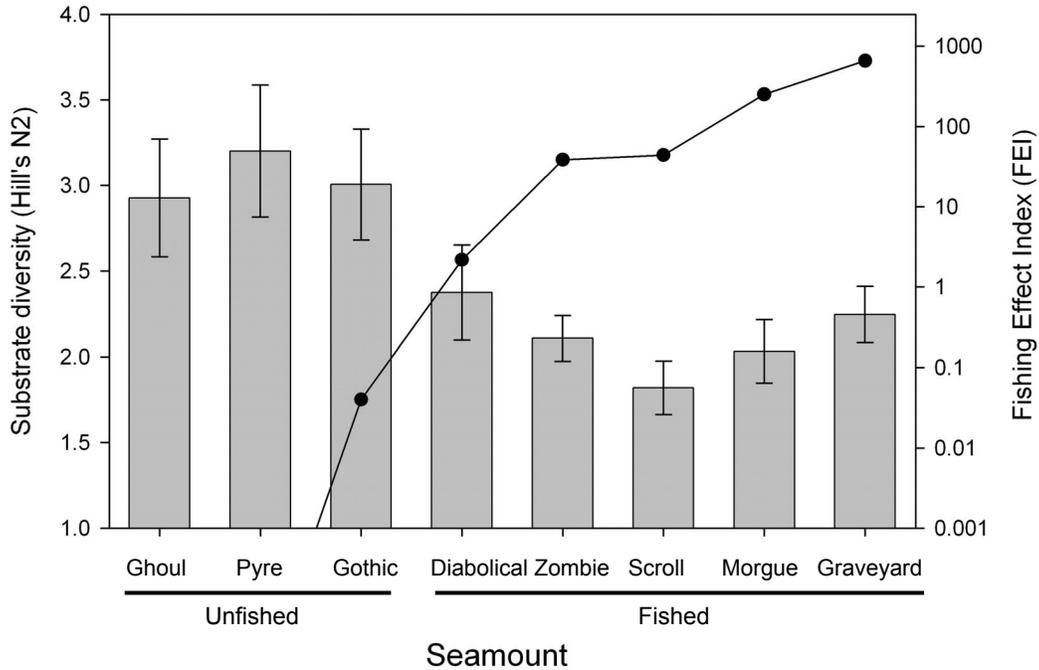
Figure 4: Substratum diversity (Hill's N_2, filled columns, means per transect + 1 se) and fishing intensity (Fishing Effects Index, solid line, note log scale on right-hand axis) for the eight seamount features in the study.
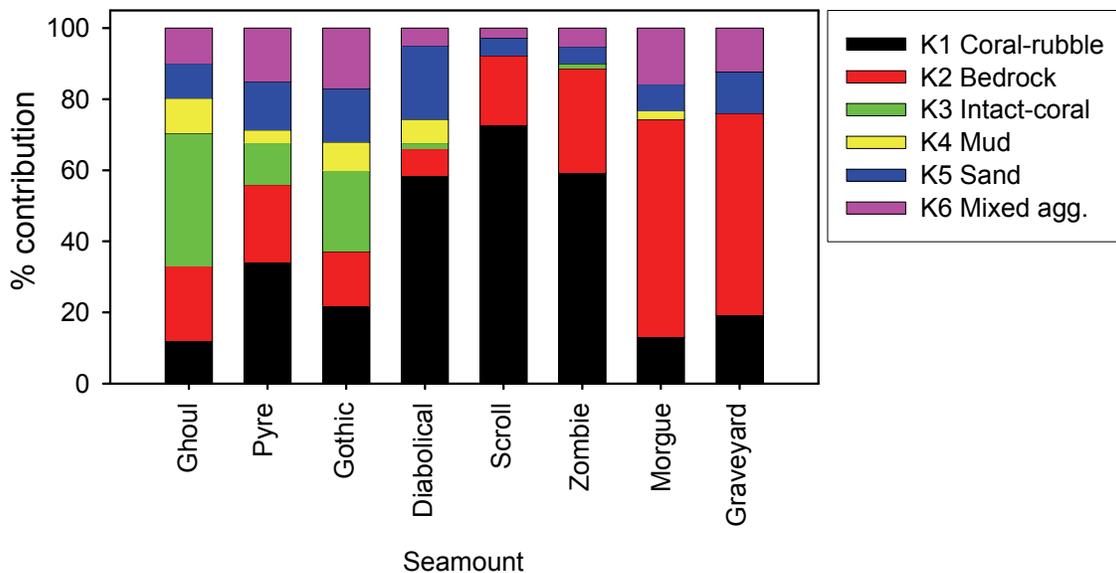
Figure 5: Percentage contribution of substratum classes derived from *K*-means clustering to each seamount feature. Values are calculated using all transects on each seamount.

The pronounced difference in intact coral cover between fishing levels is clearly illustrated in Figure 6. The expanding symbol plots show high coral cover on *Pyre*, *Gothic*, and *Ghoul*. On the fished seamounts, *Zombie* still had areas of intact coral, and a single transect on *Morgue* (the SW spur which has not been fished) also had extensive coral cover. Most of *Graveyard* was devoid of coral, except for a small patch beyond the base of the seamount, where there was a rocky outcrop on the slope. This pattern is also shown in the average percentage cover of intact coral per image on the features (Figure 7).
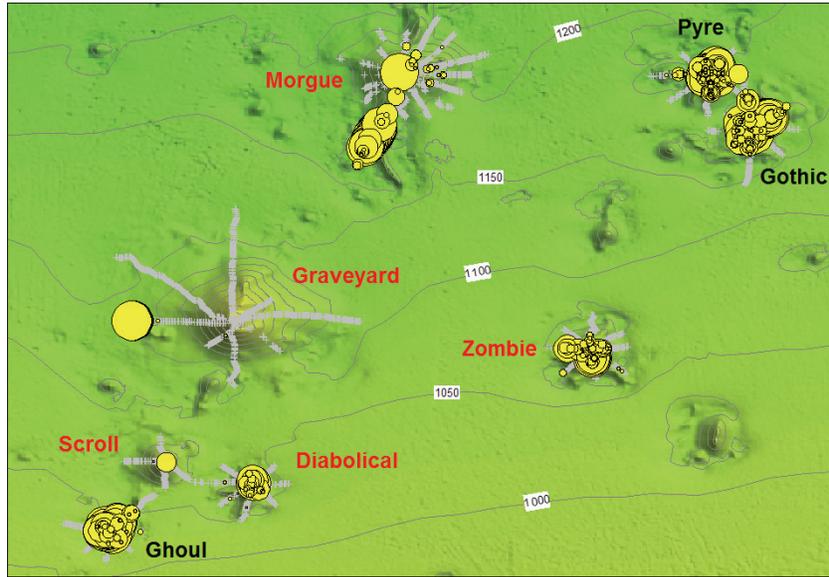

Figure 6: Distribution of intact coral. Symbol size is proportional to the percentage of each image covered by coral matrix. Seamount labels in red, fished; black, unfished.
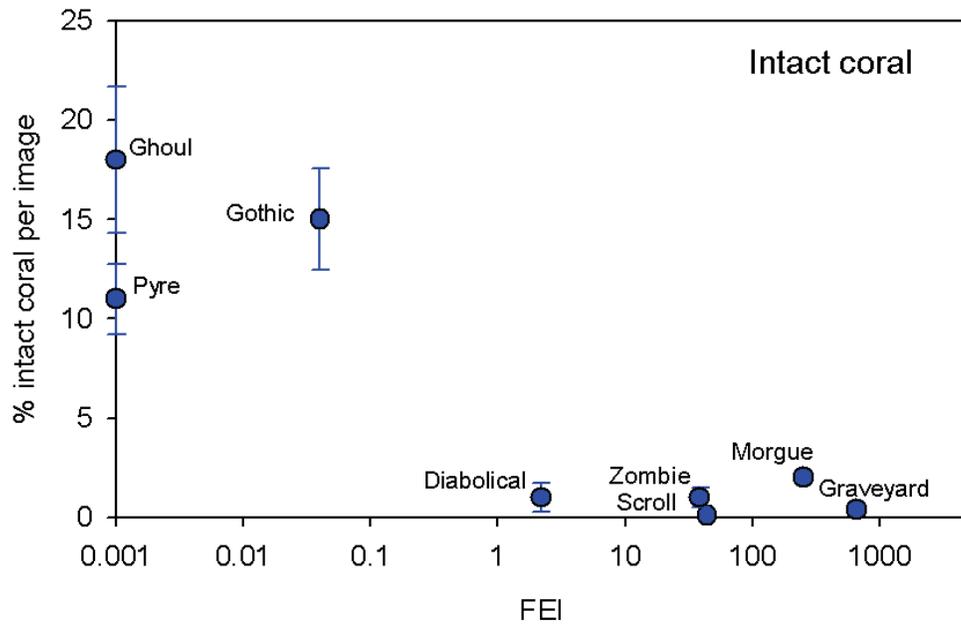

Figure 7: Intact scleractinean coral matrix: average percentage cover observed in seabed images in relation to fishing intensity expressed as Fishing Effects Index (FEI). Error bars ± 1 se.

This analysis suggests a step change in the amount of coral cover at FEI ~0.1 with negligible coral cover remaining at any fishing intensity above this level. Substratum type diversity is significantly lower for features with FEI>0.1 than for FEI<0.1 (ANOVA $F_{1,67}$ = 17.99, P <0.0001).

3.3   Benthic Terrain Modeler Habitat mapping

Multibeam swath bathymetry data (Mackay et al. 2005) at a resolution of 25 x 25 m cells were used to derive depth and slope using ArcGIS (Figures 8 and 9). The depth and slope derivatives were used as input data to the BTM algorithms with a classification dictionary that delineated the boundaries for area classifications.
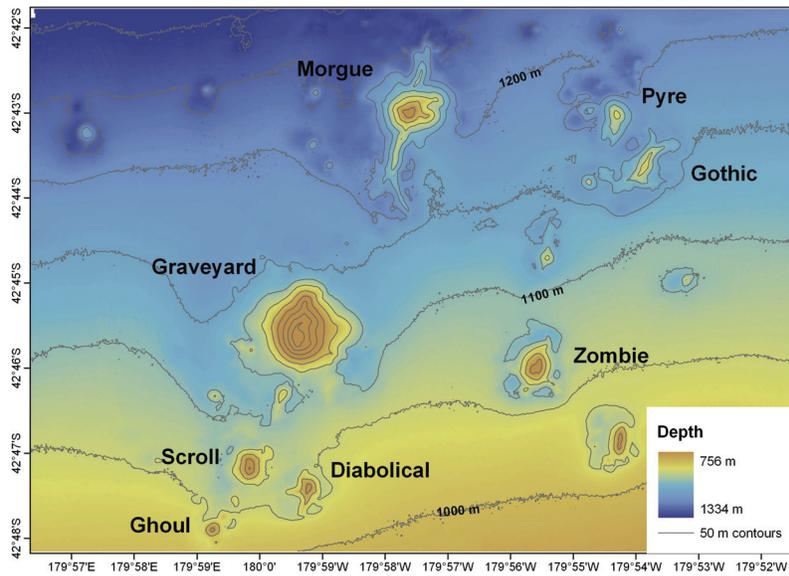

**Figure 8: Depth (m) and 50 m contours derived from swath multibeam data.**
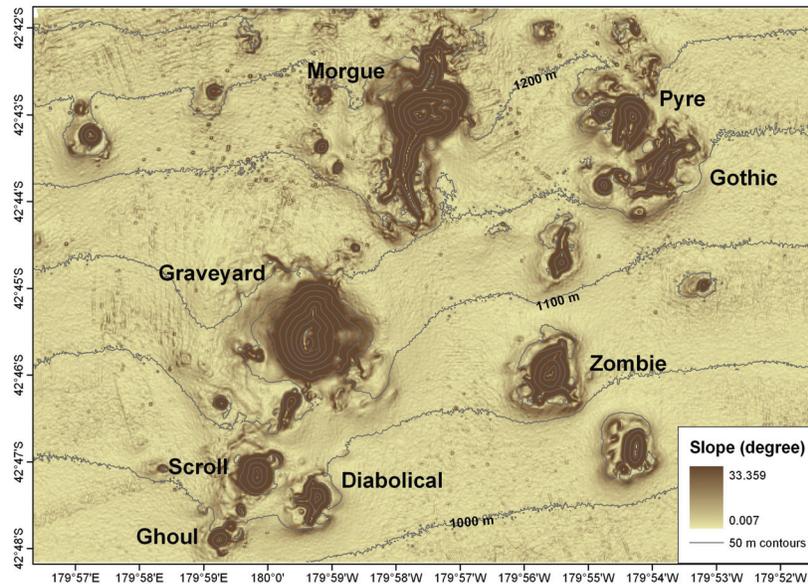
Figure 9: Slope (°) and 50 m contours derived from swath multibeam data.

Several classification dictionaries were tested for the best fit with the data. All were based on the original dictionary developed for the BTM which classifies structures on a macrohabitat scale (four classes) of crest-, slope-, valley-, and flat- (Lundblad et al. 2006). This appeared to delineate the data in a sensible manner, though it didn't provide any differentiation of the slope area, other than to define a 5° slope as a distinguishing feature for 'flat' and 'slope'. The slope derived from the bathymetry data, shown in Figure 8, does not show large difference on the flanks of the underwater features. However, closer scrutiny of the data of individual features indicated that there are some areas of steeper slope that may well limit the attachment or habitat of some biological groups relative to more gently sloping areas. Thus, we added a further level to the classification to define those slopes steeper than 24.5°.

The final BTM result is given in Figure 10 showing five derived geomorphological classes considered to be *biologically* relevant.

1) Ridges [hard, suitable for attaching organisms e.g., corals, sponges, crinoids]
2) Steep slope [also generally hard, similar to above, but potentially less water flow for filter feeders]
3) Slope [more gradual, potentially more mixed substrate types, less continuous hard cover, so patchier faunal distribution]
4) Gully [a depression in the bathymetry, likely more soft sediment, less coral, sponge]
5) Flat [generally surrounding the seamounts, soft muddy sediment].
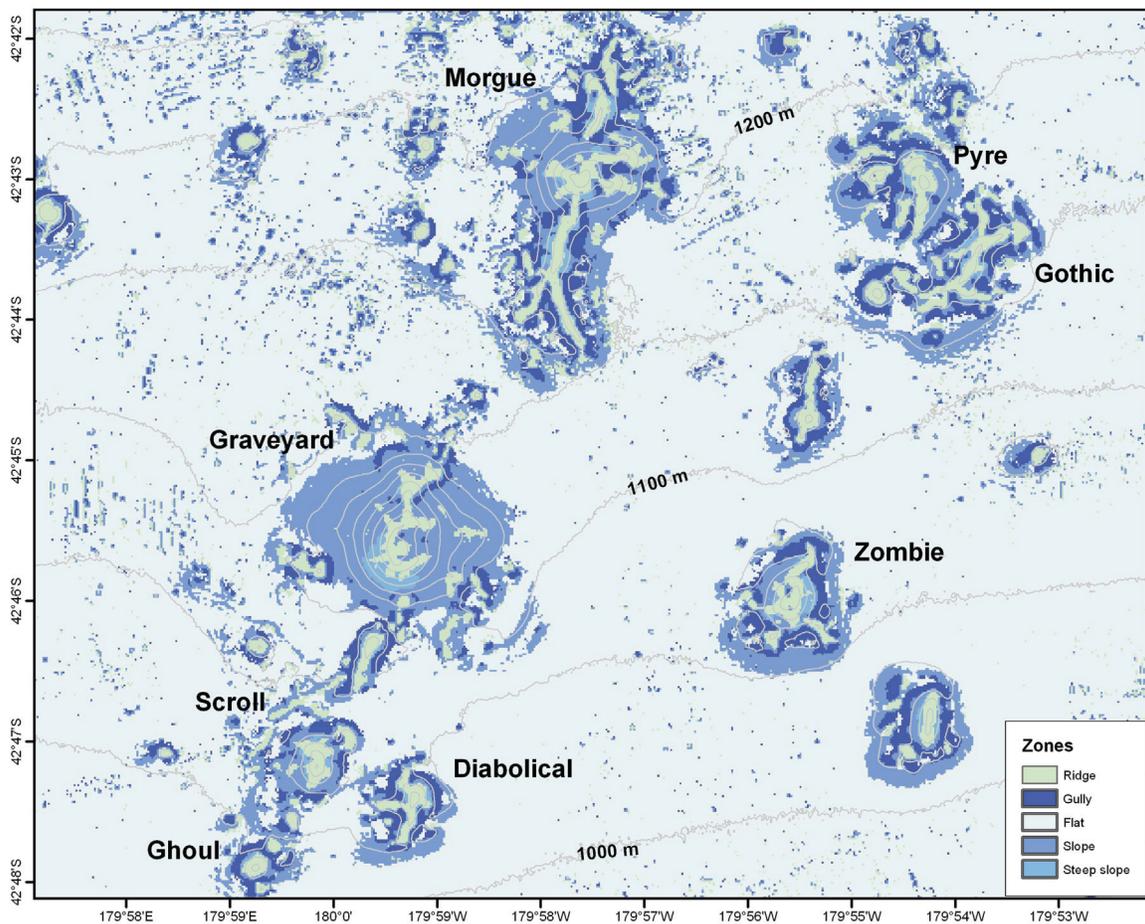
Figure 10: Geomorphologic zones derived from *Tangaroa* multibeam data using the Benthic Terrain Modeler.

Within GIS, overlays of the substrate (bedrock, sand, mud, etc) classes assigned to each image taken during the radial transects of the eight main features onto the structural classes produced from the BTM analysis indicate promising results (Figure 11). Bedrock and coral cover were largely on areas of higher relief (ridges), cobbles and boulders were generally in gullies, mud was in areas of lower relief and gullies, especially on the eastern lower flanks of *Morgue* (in the lee of the currents), and sand was generally on areas of low relief, gullies, and also the lower parts of some ridges, such as the southern end of *Morgue*, where currents may deposit sand from lower areas.
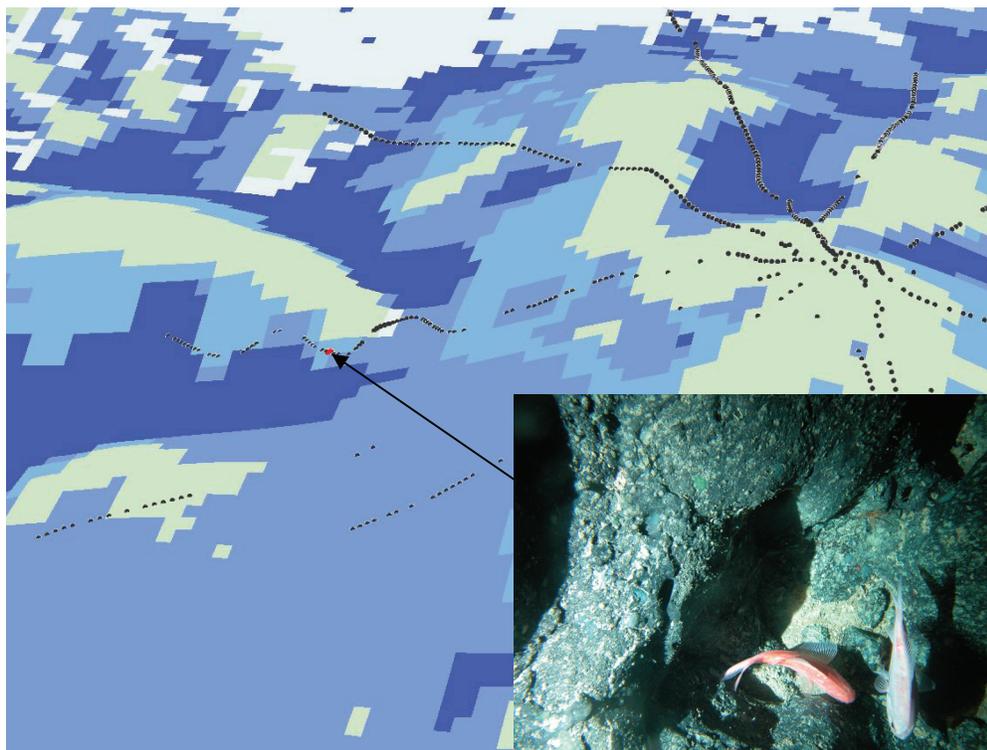
Figure 11: An example of the overlay of an image record on a transect to build up a picture of the structural environment and the associated biota. The arrow indicates the image location in an area of steep slope.

3.4   Faunal distribution

The composition and frequency of occurrence of faunal taxa varied between the seamounts (Table 3). The percentage of intact coral has been included as a substrate component, but counts were also made of "clumps" or "patches" of live coral, where pink polyps could clearly be seen. Live counts were high (over 50% of images in which intact coral was observed) on *Pyre, Gothic*, and *Ghoul*, and comparatively low on the others. Hence, although coral was seen in numerous images on *Morgue, Zombie*, and *Diabolical,* much of it was dead (see Figure 12).

Sponges, anemones, gastropods, asteroids, crinoids, and hydroids were relatively common on all seamounts. Other taxa showed considerable variation in their frequency in images between seamounts. Pagurids (hermit crabs) were common on the fished seamounts *Graveyard* and *Morgue*, but almost totally absent elsewhere. Brisingid asteroids were absent on *Zombie* and *Scroll*, and seen in only two images on *Diabolical*. Brittle stars were not found on *Scroll* and *Diabolical*, and echiuran worms were not seen on *Scroll, Gothic*, or *Ghoul*. Patterns of distribution and the relative proportion of major taxa on each feature are shown by the pie charts in Figure 13.

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Table 3: Number of images per seamount in which fauna were observed.

Taxon*	Graveyard	Morgue	Scroll	Zombie	Pyre	Gothic	Diabolical	Ghoul
COR (intact)	5	54	2	47	139	98	28	71
COR (live patches)	2	9	0	9	72	50	2	52
ONG	224	213	27	117	153	95	51	75
ANT	122	131	19	75	103	61	29	18
GAS	142	206	31	57	21	20	16	14
CRB	0	1	0	0	0	0	0	2
GAL	1	3	0	1	0	2	0	3
PAG	32	28	0	3	1	0	1	0
ASR	33	37	15	37	66	31	11	15
ASR(bris)	4	16	0	0	21	18	2	18
OPH	12	32	0	9	39	26	0	5
ECN	20	19	2	4	21	31	5	5
HTH	2	6	2	9	2	1	6	2
CRI	246	383	29	179	303	118	87	64
GOC	25	22	5	33	11	6	39	38
SOC	28	8	5	26	21	16	28	12
PTU	5	5	1	0	5	1	1	0
HDR	160	83	23	85	57	25	34	43
EHI	36	19	0	27	32	0	8	0
COZ	9	21	1	7	21	6	4	10
Images	710	796	200	465	393	273	294	274

*   Codes used are MFish 3-letter benthic invertebrate codes: ANT, Anthozoa (anemones); ASR, asteroids (sea stars); ASR(bris), brisingid sea stars; COE, coelenterate (unspecified); COR, coral; COR_recruits, stylasterid corals; COZ, Bryozoa; CRB, crabs; CRI, crinoids (large and small); ECN, echinoids (urchins); EHI, echiuran worms; GAL, galatheids (squat lobsters); GAS, gastropods; GOC, gorgonian coral; HDR, hydrocorals; HTH, holothurians; NAT, natant decapod (shrimps); ONG, sponge; OPH, ophiuroids (brittle stars); PAG, pagurids (hermit crabs); PTU, Pennatulacea (sea lilies); SIA, stony coral; SOC, soft corals; WRM, polychaete worm.
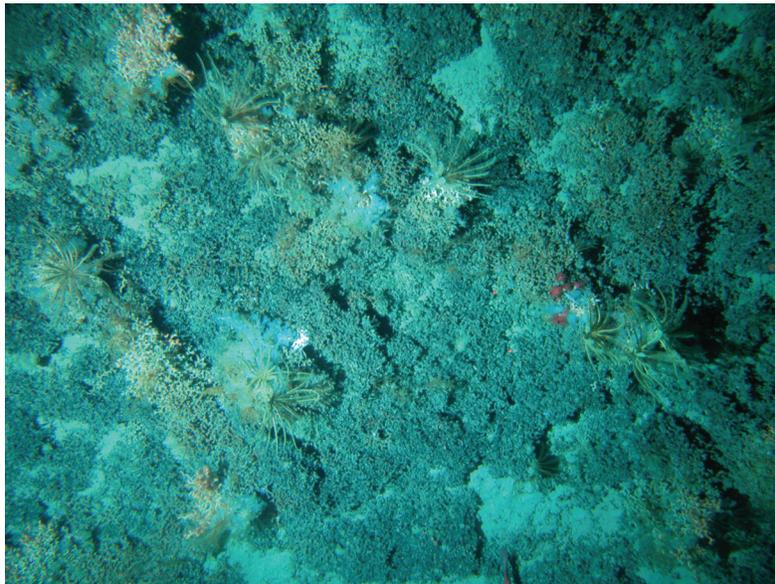
Figure 12: Image of the seafloor (approximately 2 m x 1 m) taken at a height of 2 m, showing intact stony coral. Four live "clumps" are visible by their orange polyps, but most of the matrix is dead (grey coloration).
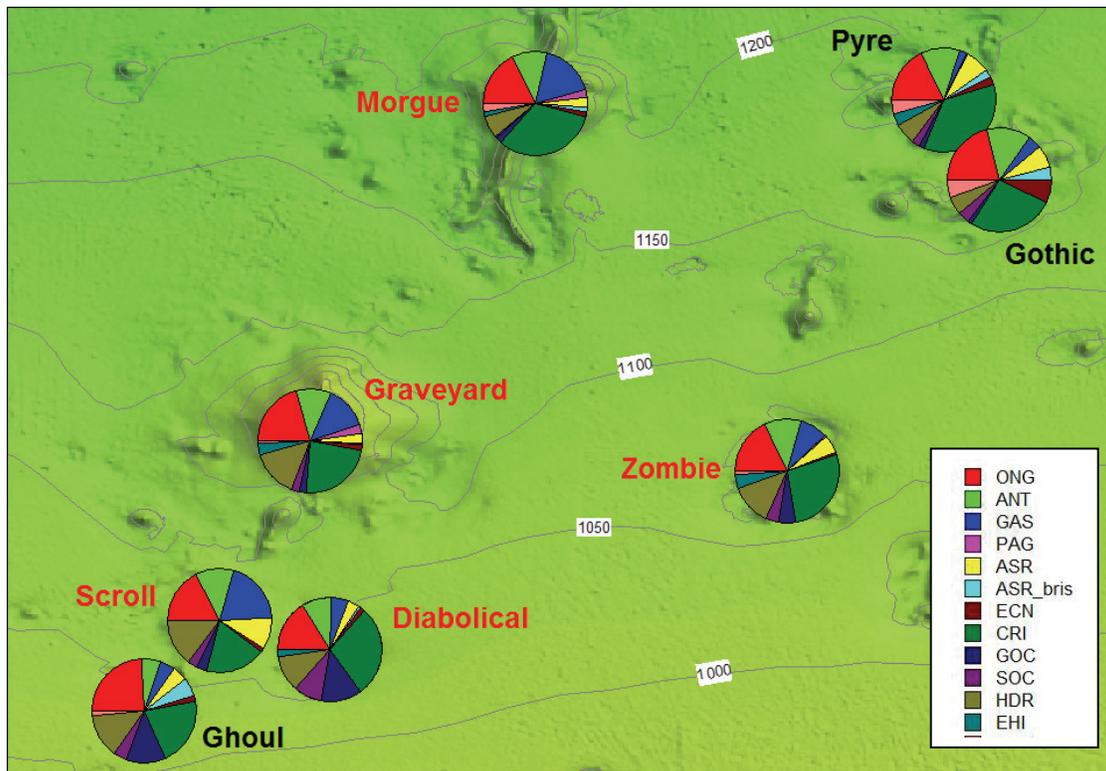
Figure 13: Relative composition of higher taxa from the Graveyard seamounts. (See Table 3 for key.)

Distribution plots of the 12 major taxa are given in Figure 14, and show a high variability in distribution and relative abundance between seamounts for many taxa. Anemones were widespread on all features, but only abundant in a few "patches". Similarly sponges were frequently recorded, with high abundance in only one image on *Pyre*. Soft corals (mainly *Anthomastus* sp.) were common on *Diabolical* but not elsewhere, and gorgonian corals were also relatively abundant on *Diabolical* and *Ghoul*. Stylasterids, which are regarded as an early colonising group (e.g., Clark & Rowden 2009, Clark et al. 2009), were abundant on *Graveyard*, especially on the exposed rocky surfaces near the summit. They were also relatively widespread on *Morgue* and *Zombie*. Their abundance on fished seamounts may also be due to their small size, making them less susceptible to damage by trawl ground gear. However, in contrast to stylasterids, the distribution of live coral was largely restricted to the unfished seamounts of *Pyre, Gothic,* and *Ghoul*. There was one patch observed at the base of *Graveyard* where there is a small area of rough seafloor. This provides a different impression of overall coral abundance when compared with the more widespread distribution of intact (live and dead) coral in Figure 6.

Gastropods occurred frequently on the fished seamounts of *Morgue* and *Graveyard*, which is likely to reflect an ecological response to trawling disturbance by these scavenging and predatory taxa. Hermit crabs (pagurids) were also common on these seamounts. Brisingid asteroids were commonly observed in association with intact coral, which was also habitat for brittle stars on *Pyre* and *Gothic*. Brittle stars were also common at the base of several features, as soft sediment became more prevalent (e.g., *Morgue*). Crinoids and urchins were widespread, but particularly abundant on *Pyre* and *Gothic*. Overall distributions, although variable, indicate that some taxa are more common on fished, or unfished, seamounts. Fishing will therefore have different impacts on various components of the benthic invertebrate assemblage.

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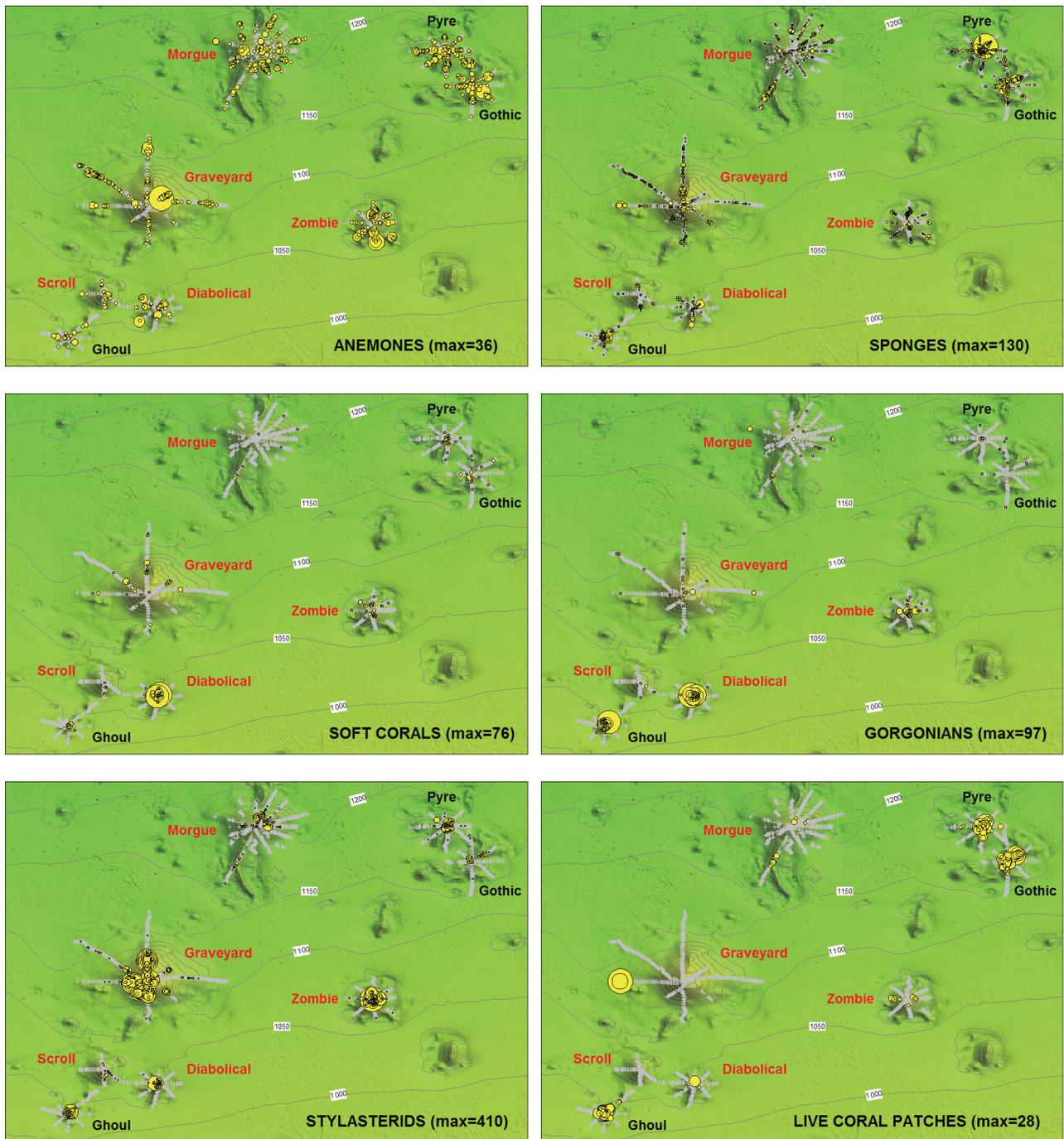
Figure 14: Distribution of major taxonomic groups in photographic images between seamounts (red, fished; black, unfished). The size of the expanding symbols is proportional to the number of individuals (maximum given in parentheses). Counts are not standardised by image area.

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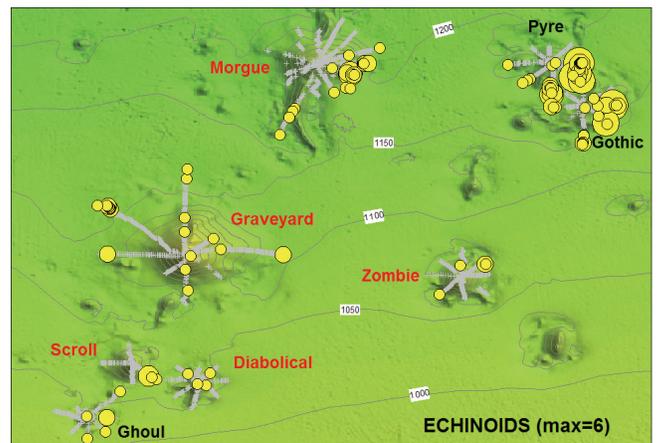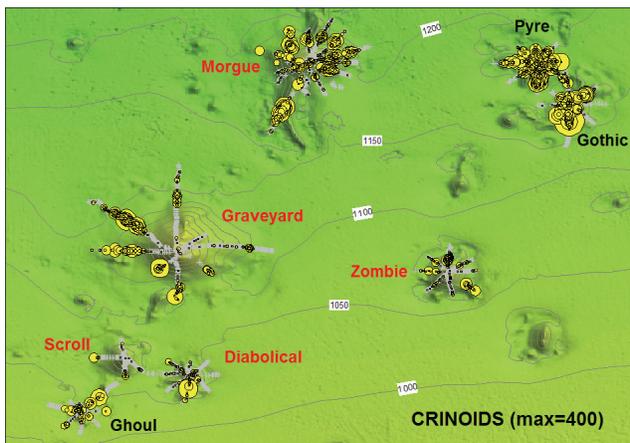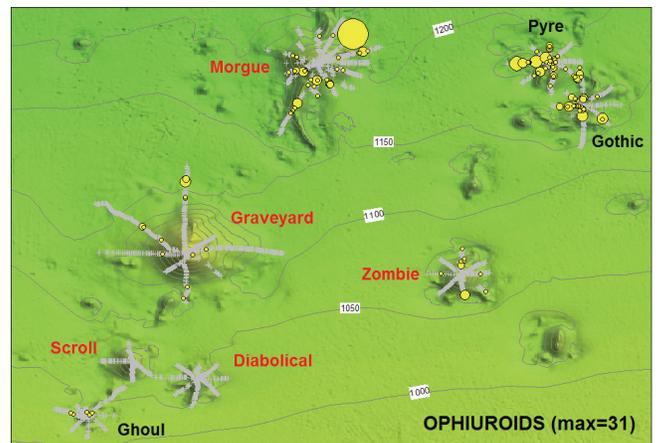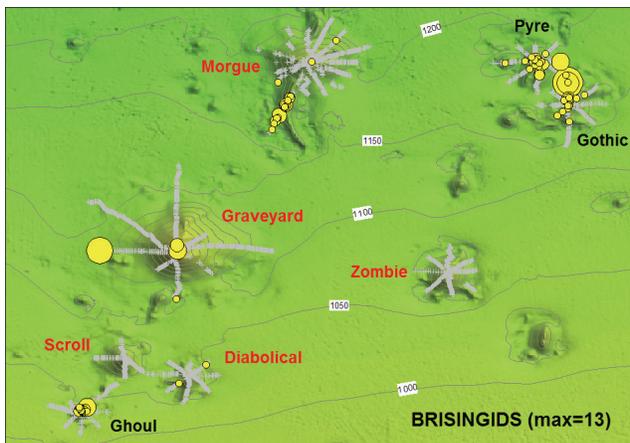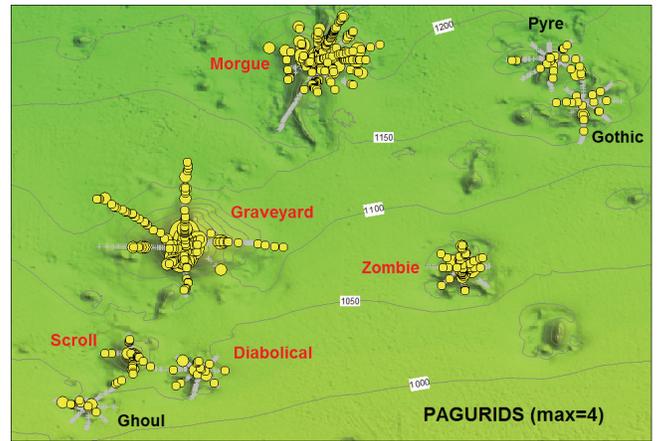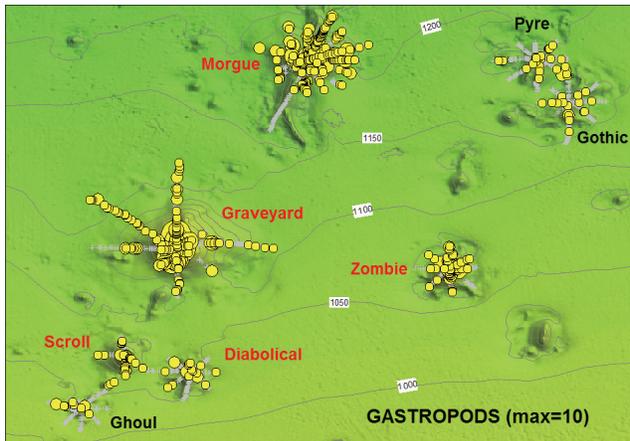
Figure 14 (cont): Distribution of major taxonomic groups in photographic images between seamounts (red, fished; black, unfished). The size of the expanding symbols is proportional to the number of individuals (maximum given in parentheses). Counts are not standardised by image area.

The distributions of a number of these taxa are correlated with substrate type. Brisingid asteroids were commonly seen in association with intact coral (Figure 15), which enable the starfish to position themselves and their raised arms for suspension feeding clear of the substrate (Figure 16). Conversely, gastropods were seen primarily on exposed areas of seafloor away from the coral matrix (see Figure 15).
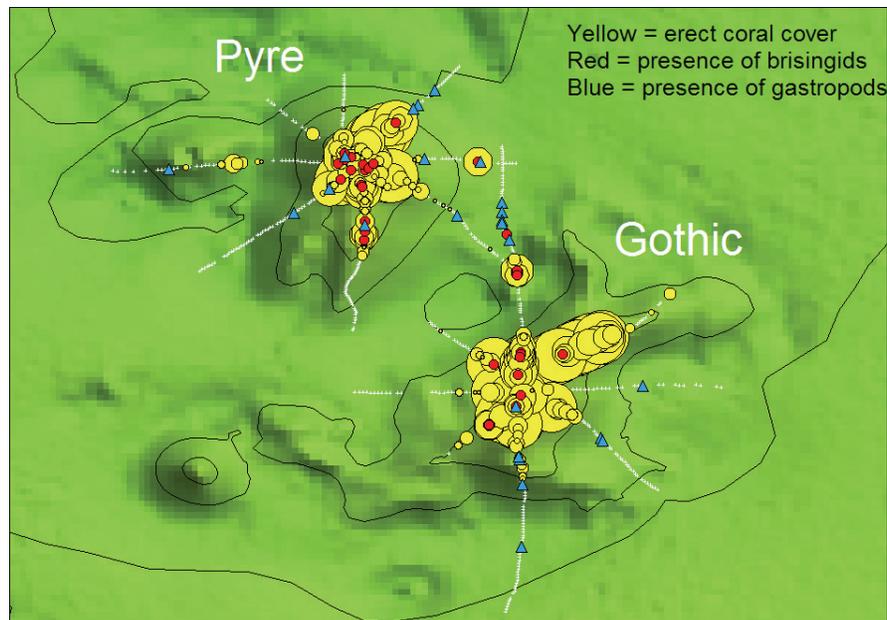
Figure 15: The distribution of intact coral (yellow expanding symbols), brisingid starfish (red dots), and gastropods (blue triangles) on the unfished seamounts *Gothic* and *Pyre*.

Figure 16: Brisingid starfish situated on the top of intact coral matrix (image area approximately 2 m by 1 m, taken from a height of 2 m).

3.5 Faunal assemblage analyses

Taxon accumulation curves for unfished seamounts had a steeper gradient, and thus higher within-habitat diversity, on all K-means substratum classes except $K4$ (mud) than did those from fished seamounts (Figure 17). However, this pattern was not consistent. On substratum classes $K1$, $K3$, $K5$, and $K6$, the unfished seamounts *Gothic*, *Ghoul*, and *Pyre* showed the highest rates of taxon accumulation. However, on class $K2$ ('bedrock') *Ghoul* was indistinguishable from the fished features *Graveyard* and *Morgue* whereas *Zombie* matched the rates seen on the unfished *Gothic* and *Pyre*. Similarly, on $K6$ ('mixed aggregates') and $K3$ ('intact coral') *Zombie* matched *Ghoul*, and on class 5 ('sand') *Scroll* matched *Pyre* and *Gothic*.
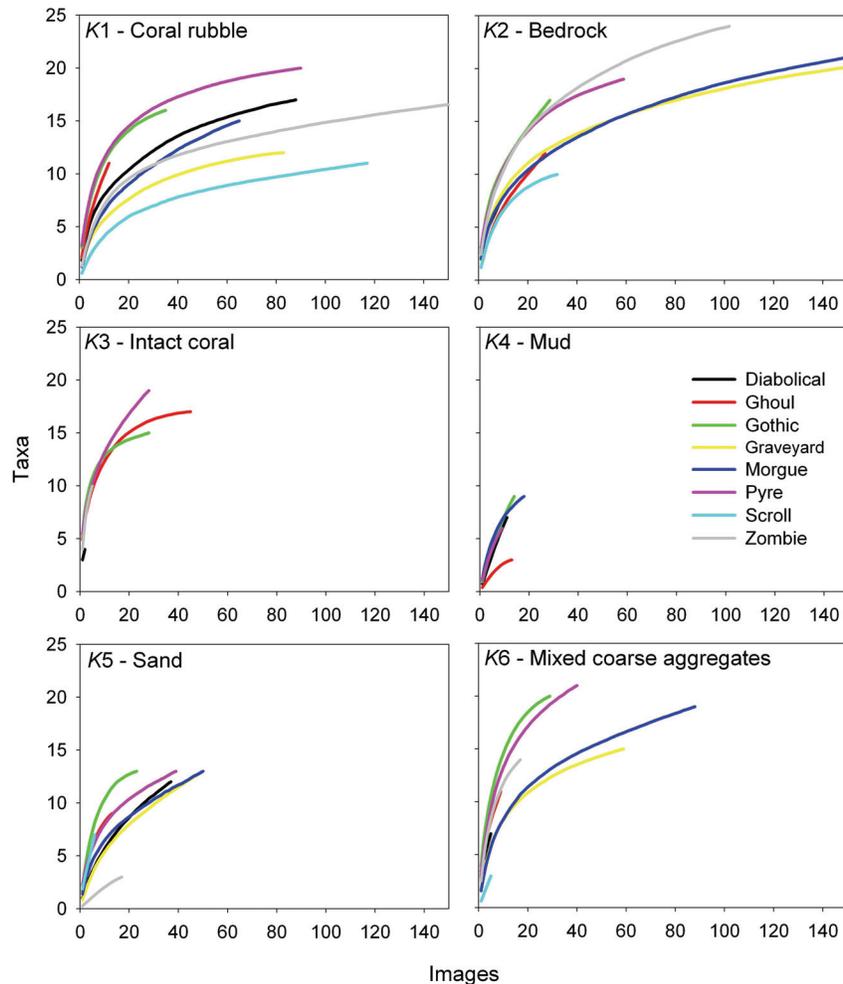
Figure 17: Taxon accumulation curves for each K-means substratum class on each seamount.

3.5.1 Multivariate analyses

ANOSIM indicated that the faunal assemblages associated with three of the six K-means habitat classes ($K1$ coral rubble, $K2$ bedrock, and $K3$ intact coral) differed significantly between fished and unfished seamounts (Table 4). This separation is clear in the MDS ordination of the full dataset (Figure 18). SIMPER analysis showed that the taxa contributing most to the observed faunal differences between fished and unfished seamounts varied with substrate class (Table 5). Dissimilarity/SD is a relative

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measure of the consistency of contribution of each taxon to overall dissimilarity and here we take values over 1.0 to indicate the taxa discriminating most between assemblages on fished and unfished seamounts. On coral rubble substrate (class $K1$), scleractinean corals and comatulid crinoids were more common on unfished seamounts. On bedrock substrate (class $K2$) gastropods were more common on fished seamounts. On intact coral substrate (class $K3$) live coral heads, comatulid crinoids, brisingid starfish, hydroids and natant decapods were all more common on unfished seamounts.

Table 4: One-way ANOSIM on 4th root transformed data for differences between faunal assemblages on unfished (FEI<0.1) and fished (FEI>0.1) features across each *K*-means substratum class. Significant differences are shown in bold. Global R = 0.081, *P* = 0.001 for all FEI<0.1 vs all FEI>0.1.

K-means substratum class	R	*P*	Permutations	Number > R
$K1$ coral rubble	0.379	**0.001**	999	0
$K2$ bedrock	0.157	**0.009**	999	8
$K3$ intact coral	0.766	**0.001**	999	0
$K4$ mud	-0.109	0.883	462	408
$K5$ sand	-0.003	0.422	999	421
$K6$ mixed aggregates	0.006	0.427	999	426
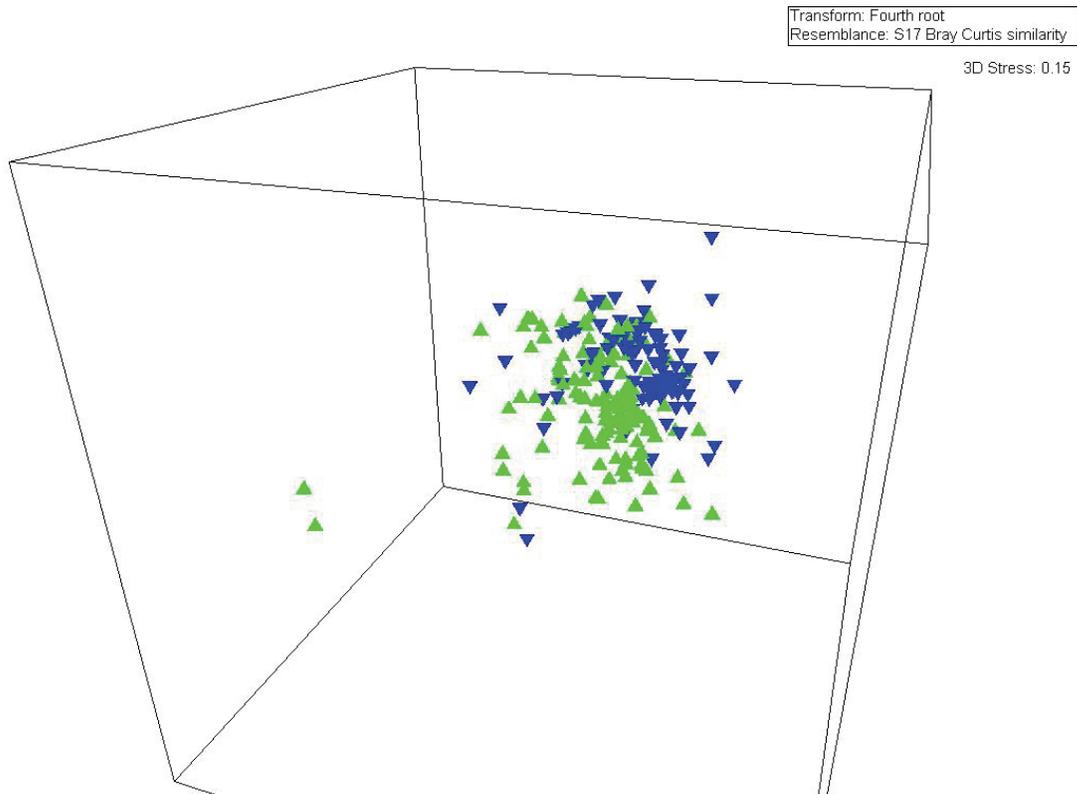
Figure 18: MDS of Bray-Curtis similarities calculated from fourth root transformed abundance data for all benthic fauna recorded in images. Individual plots represent faunal assemblages in each *K*-means habitat class in each transect and are coloured to distinguish between those from fished features (FEI>0.1 (green)) and unfished features (FEI<0.1 (blue)).

Table 5: SIMPER analyses on presence/absence data for assemblage differences between fished and unfished seamount features on *K*-means substratum classes *K*1, *K*2, and *K*3. Codes are given in Table 3.

K-means substratum class *K*1 ('coral rubble')

Taxon*	Average abundance (Inds m^{-2})		Av.Diss	Diss/SD	Contrib%	Cum.%
	FEI>0. 1	FEI<0. 1				
GAS	0.86	0.30	6.13	0.86	9.42	9.42
COR_recruits	0.78	0.40	5.01	0.87	7.70	17.12
SIA coral	0.16	0.70	4.45	1.17	6.83	23.95
ASR	0.41	0.50	4.35	0.74	6.69	30.64
CRI (small)	0.62	0.95	4.15	0.56	6.37	37.01
ANT	0.54	0.55	4.14	0.84	6.36	43.37
ONG	0.68	0.75	4.02	0.71	6.18	49.56
CRI (large)	0.03	0.60	3.81	1.10	5.86	55.42
HDR	0.16	0.55	3.66	0.96	5.62	61.04
SOC	0.41	0.45	3.63	0.87	5.57	66.61
NAT	0.38	0.40	3.59	0.81	5.52	72.13
OPH	0.03	0.50	3.26	0.87	5.01	77.15
GOC (yellow)	0.38	0.00	2.69	0.68	4.13	81.28
ASR (Bris)	0.03	0.35	2.23	0.67	3.43	84.71
SIA	0.19	0.10	1.62	0.49	2.49	87.20
COE	0.11	0.15	1.43	0.48	2.19	89.39
GOC (other)	0.08	0.15	1.26	0.48	1.94	91.33

K-means substratum class *K*2 ('bedrock')

Taxon*	Average abundance (Inds m^{-2})		Av.Diss	Diss/SD	Contrib%	Cum.%
	FEI>0. 1	FEI<0. 1				
GAS	0.68	0.16	4.62	1.08	8.02	8.02
COR_recruits	0.61	0.26	4.07	0.96	7.07	15.08
ASR	0.59	0.53	4.06	0.82	7.05	22.13
ANT	0.80	0.63	4.06	0.74	7.04	29.17
EHI	0.27	0.53	3.95	0.81	6.86	36.03
NAT	0.56	0.32	3.73	0.91	6.48	42.52
ONG	0.83	0.89	2.92	0.45	5.07	47.59
OPH	0.32	0.26	2.70	0.77	4.68	52.27
CRI (small)	0.95	0.84	2.33	0.38	4.05	56.32
SIA	0.22	0.26	2.29	0.71	3.98	60.31
CRI (large)	0.15	0.32	2.24	0.71	3.89	64.20
SOC	0.20	0.26	2.16	0.68	3.76	67.95
COE	0.24	0.11	1.97	0.60	3.42	71.37
PAG	0.34	0.00	1.97	0.67	3.42	74.79
GOC (yellow)	0.22	0.11	1.89	0.54	3.29	78.08
HDR	0.22	0.16	1.88	0.61	3.26	81.34
COR_live	0.02	0.26	1.68	0.57	2.92	84.26
COZ	0.12	0.21	1.58	0.60	2.75	87.01
WRM	0.12	0.11	1.30	0.47	2.25	89.26
GOC (other)	0.17	0.00	0.90	0.44	1.57	90.83

Table 5: *continued*

K-means substratum class *K*3 ('intact coral')

Taxon*	Average abundance (Inds m^{-2})		Av.Diss	Diss/SD	Contrib%	Cum.%
	FEI>0. 1	FEI<0. 1				
COR_live	0.33	1.00	5.88	1.05	9.82	9.82
CRI (small)	0.17	0.78	5.44	1.27	9.10	18.91
ASR_bris	0.00	0.72	5.07	1.47	8.46	27.38
CRI (large)	0.00	0.56	4.32	0.98	7.21	34.59
HDR	0.00	0.61	4.18	1.18	6.98	41.57
NAT	0.17	0.61	4.15	1.08	6.93	48.50
ANT	0.50	0.61	4.10	0.91	6.86	55.36
GOC (yellow)	0.33	0.50	3.95	0.91	6.60	61.96
SOC	0.17	0.50	3.45	0.96	5.77	67.72
ONG	0.67	1.00	3.32	0.59	5.55	73.28
GAS	0.33	0.28	3.14	0.78	5.25	78.52
OPH	0.00	0.44	2.87	0.87	4.80	83.32
ASR	0.00	0.33	2.04	0.69	3.42	86.74
COR_recruits	1.00	0.89	1.54	0.30	2.58	89.32

3.6   Impacts of trawling

The analyses presented above show clear differences in faunal assemblage composition and distribution between fished and unfished seamounts. Direct evidence of trawl impact was observed frequently in the form of trawl wires, deep gouges and regular parallel grooves that were most likely caused by trawl doors and ground gear respectively (Figure 19). The number of images with trawling signs was highest on *Zombie* (53 images), then *Scroll* (40), *Graveyard* (20), *Morgue* (7), *Diabolical* (6), *Gothic* (2), *Ghoul* (1), and *Pyre* (1) (Figure 20).
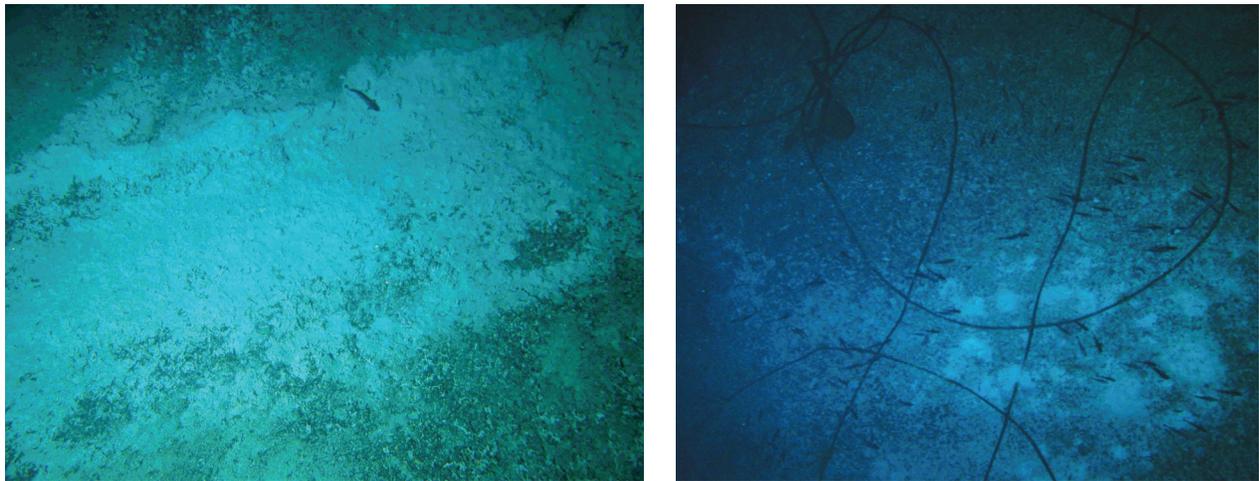
Figure 19: Examples of images showing a deep door gouge on *Scroll* (left), and tangled trawl wires from *Zombie* (right).
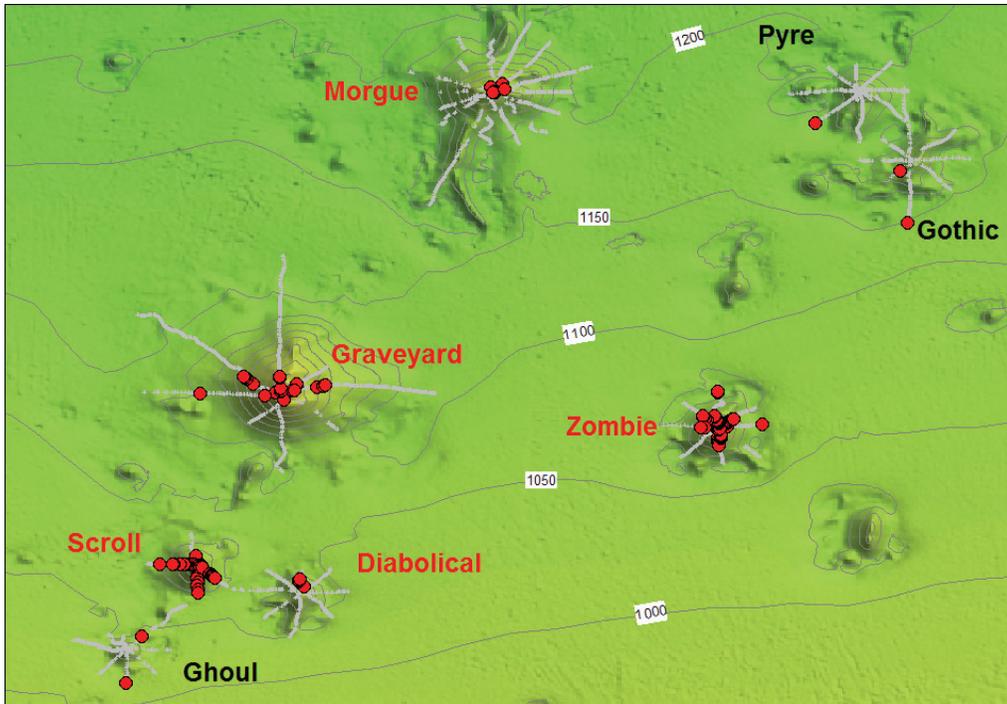
Figure 20: Distribution of trawl signs (red dots representing obvious door gouges, bobbin scours, pieces of netting or wire) observed in seabed images from the Graveyard seamounts (seamount labels red, fished; black, unfished).

The likely impacts of trawling are also evident on *Morgue* where the SSW photographic transect ran down the spur that has not been fished. Directional tow data from commercial records is often poor when tows are short, but analysis of individual tow data up to 2001 showed a striking lack of any tows in that direction (Figure 21). The photographic transect covered over 0.5 km where intact coral occurred as the main substrate type (Figure 22). Thus, this spur appears to be a section of the seamount where the original coral matrix has been unfished, and the rugged lava tongue has provided a "refuge" for the coral community.
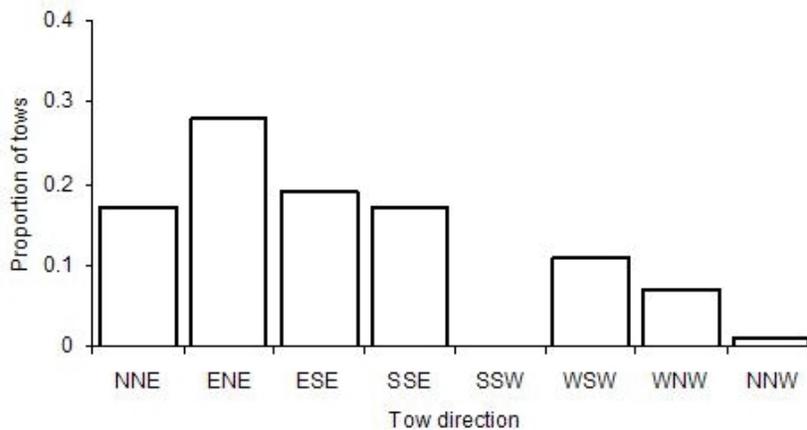
Figure 21: Directional frequency of trawls on *Morgue*. Tows are binned into 45° sectors.
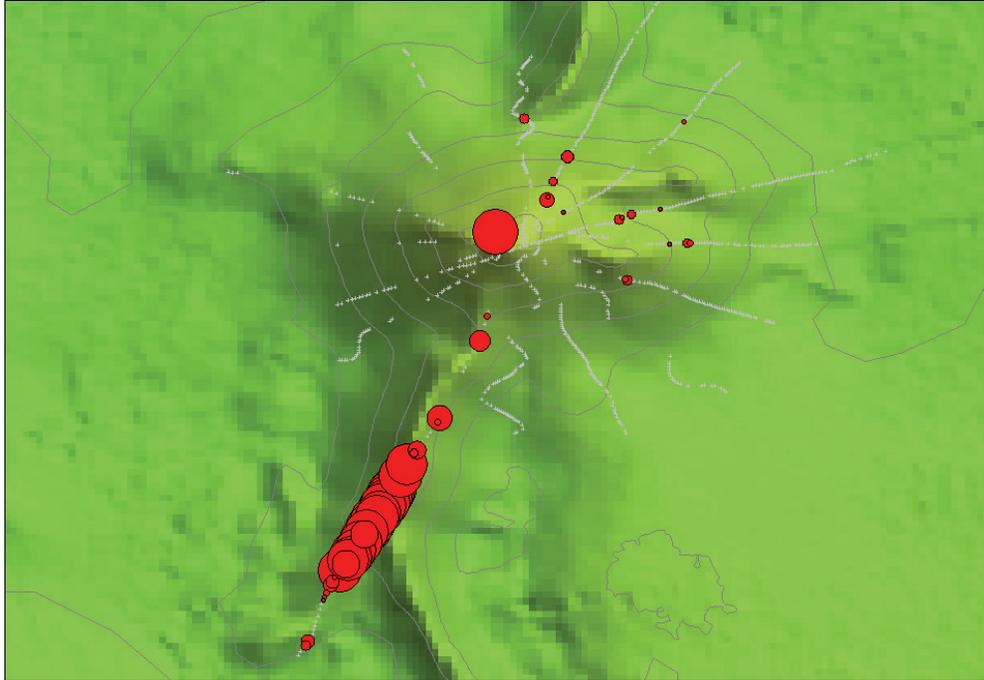
Figure 22: Distribution of intact coral on *Morgue*. The abundance of coral on the unfished SSW lava flow is clear.

3.7   Changes 2001–2006

The improved technology available for the survey in 2006 has provided some challenges in ensuring comparability with the baseline survey in 2001. NIWA has developed processing protocols during and since the 2006 survey, and this led to several re-examinations of the image data from the 2006 survey to ensure its consistency with other NIWA surveys (e.g., Macquarie Ridge, IPY-CAML) and also alignment with image processing carried out at CSIRO in Tasmania. The 2001 data are currently being re-examined under the FRST seamounts programme, and so it is not possible to present detailed comparison of 2001 and 2006 surveys here. However, some analyses can be compared even though the re-examination is incomplete. Comparisons of the percentage of images showing trawl marks, and intact coral, are given in Table 6. This shows that the observed frequency of trawling signs decreased appreciably on *Morgue*, as expected, but also on *Graveyard*. The proportion of images with intact coral was consistently low on *Morgue* and *Graveyard*, and higher on *Diabolical*, and especially *Gothic*. There was a substantial decrease in frequency of coral observations, and mean percentage cover per image on *Gothic* between 2001 and 2006.

Table 6: Comparison between 2001 and 2006 surveys of percentage of images with trawl gear sign, percentage of images with intact coral, and mean percentage cover of coral in all images.

Seamount	Trawl sign		Intact coral frequency		Mean percent cover of intact coral	
	2001	2006	2001	2006	2001	2006
Morgue	14.5	0.5	0	1.9	0	0.3
Graveyard	27.3	2.8	0	0.7	0	0.4
Diabolical	10.3	2.0	10.3	9.5	4.1	1.3
Gothic	0	4.9	78.0	35.9	23.4	12.3

3.8   Sled catch composition

The focus in this project has been on analysis of the extensive photographic image data. However, most epibenthic sled samples have been identified, and a full species list is given in Appendix 1. A total of 317 taxa have been resolved, most to genus level at least. Of note is the finding of a new genus and species of Bryozoa (*Kenovidoma singularis*) and potentially a further five new bryozoan species (D. Gordon, NIWA, pers. comm.).

4.   DISCUSSION

The analyses have emphasised a number of differences between fished and unfished seamounts. An important assumption in this is that there was no difference between the seamounts before fishing and hence that any differences in substrate type or faunal assemblage are the result of bottom-contact fishing gear. The close proximity of all the seamounts to each other, and overlapping depth ranges, suggest that the faunal communities are likely to have been inherently similar and to have differed only in scale (Clark & Rowden 2009). The confirmation during the survey of extensive areas of intact *Solenosmilia variabilis* on an unfished region of *Morgue* provides strong support for this original similarity. Subsequent observations have been made of intact coral in some other scattered areas of *Morgue* and *Graveyard* during a survey in June 2009 (NIWA unpublished data). However, substrate type is a well known environmental factor governing faunal composition (see review by Howell in press), and it differs between the seamounts. Hence it has been important in this study to compare faunal assemblages between seamounts by habitat type to avoid confounded results.

Generally, the comparison of fished and unfished seamounts presented here, using more detailed photographic data than in 2001, support the findings of Clark & Rowden (2009). They found significant differences in the benthic faunal assemblages of the fished (*Graveyard, Morgue, Scroll, Zombie*) and unfished (*Pyre, Gothic, Diabolical, Ghoul*) seamounts based on sled and photographic data. Clark & Rowden (2009) discussed possible causes of difference due to depth, size, elevation, and substrate type. They felt these factors were sufficiently similar between the seamounts to make the most likely explanation for the differences being that bottom trawling had removed much of the coral cover from the fished seamounts. This was also reported from Tasmanian seamounts by Koslow et al. (2001), although in that study depth differences between fished and unfished seamounts was a confounding factor.

The role of stony coral matrix as biogenic habitat on seamounts is well recognised (e.g., Rogers et al. 2007). A large number of species are reported to be associated with such habitat, and on the Graveyard seamounts several invertebrate taxa have frequently been observed in the coral matrix (e.g., polychaete worms, brittle stars) or on its surface (e.g., sponges, echinoids, brisingid starfish) (authors' unpublished data). Hence a wider benthic community than just the coral may be affected by a reduction in the amount of coral cover available (Probert et al. 1997).

Based on the strong assumption that coral cover may have been similar between all the seamounts before fishing began, trawling has caused a reduction in the overall matrix from 10–20% to 1–2%. Little is known about how much coral is required to maintain the population, but we suggest there is little doubt that a 90% reduction in its extent is a substantial, and adverse, impact (see discussion further below). Many coral species are slow-growing and long-lived (see review by Rogers et al. 2007), including the main species on the Graveyard seamounts, *Solenosmilia variabilis* (NIWA unpublished data). There is also evidence recruitment of stony corals may be affected by changing substrate composition, and sediment resuspension from trawling (Rogers 1999) and hence removal by trawling may have long-lasting consequences for the seamount benthic community (Althaus et al. 2009).

The relationship between the proportion of intact coral and fishing intensity suggests that trawling has an adverse impact on the coral matrix after a relatively low number of trawls. All the fished seamounts had low proportions of intact coral per image, even though the number of trawls ranged between 11 (Diabolical, total distance towed 3.9 km) and over 2000 (Graveyard, total distance towed 2,700 km). Of the "unfished" seamounts, Gothic is known to have had four trawls, yet had a relatively high coral cover. Because coral has a patchy distribution on a seamount, we would not expect a clear linear relationship between number of trawls and coral cover. The impact will depend upon the overlap of trawl lines with coral distribution. Nevertheless, it appears likely that by the time tens of trawls are carried out (e.g., on *Diabolical, Scroll, Zombie*) the impact is potentially as high as hundreds of trawls (*Morgue, Graveyard*) and this has a clear adverse effect on the coral and associated communities.

There has been recent work on ecosystem indicators for New Zealand fisheries, which covers aspects of species and community structure (e.g., Tuck et al. 2009), and defined harvest level criteria for commercial fisheries (Ministry of Fisheries 2008) but there are no established biological reference points for habitats in New Zealand. The draft Strategy for Managing the Environmental Effects of Fishing (SMEEF) (Ministry of Fisheries 2005) noted two aspects that are relevant in considering whether the strong difference in coral cover observed in this study constitutes an "adverse effect". The first is the clause in the Fisheries Act 1996 (section 9(b)) that states "…biological diversity of the aquatic environment should be maintained". The second is the suggestion that in the absence of relevant biological reference points "the reversibility of an effect of fishing should be used as the primary determinant of the point at which an effect of fishing on a habitat type becomes adverse". Species diversity is often cited as an "ecological indicator" of human disturbance, but simple measures such as species richness do not capture changes in faunal composition. Hence in the scientific literature there is increasing reference to indicators based on "functional components" of habitats (e.g., de Juan et al. 2009), and reviews with extensive lists of ecological indicators usually include biogenic habitats such as corals, and specifically the percentage cover (e.g., Fulton et al 2004, Mangi et al 2007). However, most studies do not address the question of "how much is enough". Viehman et al (2009) review a policy in the United States which involves carrying out a natural resource damage assessment when shallow coral reefs are impacted. This policy has an objective of complete restoration to the pre-damage state, and that is almost certainly not reasonable in deep-sea environments. However, Link (2005) does suggest some limits for area of live, hard, coral. He suggests a warning threshold of 30% below the maximum area coverage, and a limit reference point of 50% below the maximum (which is when management action would be invoked). The derivation of these percentages is not specified, but the 50% level was stated based on theoretical considerations. If the criteria of Link (2005) were to be applied, then the reduction of coral cover on the fished seamounts of the Graveyard complex would require action to mitigate the cause of the coral decline.

The proportion of coral rubble habitat varied between the seamounts. The percentage was low on the unfished features, but also on the two most heavily fished (*Graveyard, Morgue*). It was highest on those with intermediate fishing levels, *Diabolical, Scroll,* and *Zombie*, where it constituted 55-70 % of the substrate. Reasons for this pattern are unknown. If rubble is formed largely by trawling impact, and coral was previously abundant on *Graveyard* and *Morgue*, then the amount of rubble on those two seamounts should be high. However, rubble may get more broken up and moved away from the seamount summit by repeated contact with trawl ground gear, and the smaller fragments are dispersed by currents around the seamounts.

Catch-effort data as well as information from commercial fishing skippers indicate that *Graveyard* has been the most heavily trawled of the Graveyard hills. This initially seems at variance with the observations of trawl marks during this study, which were highest on *Zombie* and *Scroll*. However, a likely explanation for this is that definite signs of trawl impact are mainly left in soft sediment. Scroll and Zombie have more soft substrate than Graveyard and Morgue, where bedrock dominates much of the seamounts (see Figure 5). Furthermore, trawl marks were only scored in the seabed images where the

evidence was unequivocal, with strong parallel marks being visible. Where the seabed has been repeatedly trawled, multiple tracks may cross, resulting in disturbance patterns that are not readily interpreted at the scale of individual DTIS seabed images.

Stylasterids (hydrocorals) were widely distributed (see Figure 14), but were more frequently observed on fished seamounts (especially *Graveyard*). The stylasterids *Calyptopora reticulata* and *Lepidotheca fascicularis* were reported by Clark & Rowden (2009) as discriminatory species distinguishing between fished and unfished features, being more abundant on fished seamounts. They suggested these species were "early colonisers" that could take advantage of substrate that has been cleared of coral matrix by trawling. The results of the 2006 survey, especially the large numbers observed on *Graveyard*, imply that, as well as colonising bare surfaces, the taxa may also be resilient to trawling. Stylasterids were also frequently observed on fished seamounts off Tasmania (Althaus et al 2009), and the small size of the corals (generally less than 20 mm) could offer protection by not being affected in the spaces between bobbins or rollers on the groundrope, or where bottom contact is light or intermittent if the trawl is bouncing over rough seafloor (Clark et al. 2009).

Pagurids and gastropods were also frequently observed in photographic transects on *Graveyard* and *Morgue*. These are primarily predatory or scavenging taxa, which may benefit from lower coral cover (which could restrict their mobility) and more frequent disturbance of the substrate making burrowing species vulnerable as well as fauna directly killed by the passing trawl (Hall 1999).

BTM appears to be a promising tool for prediction of faunal composition, although more detailed ground-truthing against the photographic data set is needed. Recent studies have used similar habitat mapping techniques to predict the likely occurrence of hard-bottom habitat off the east coast of the USA (Dunn & Halpin 2009) and cold-water coral cover west of Ireland (Guinan et al 2009). The latter study is of particular relevance to New Zealand seamounts, as cold-water corals are a major biogenic habitat on untrawled features (e.g., Clark & Rowden 2009), and a major concern for marine conservation (Probert 1999). Hence, BTM analyses could be applied to seamounts off New Zealand where multibeam data are available, but where biological sampling has not been carried out, to provide a "first-cut" assessment of potential faunal composition.

Comparative analyses between 2001 and 2006 surveys have at this stage been limited to simple trawl mark and intact coral summaries (Table 6). These show some major differences, but are affected to an extent by sampling effort: the higher density, and more continuous along-transect coverage, of photographic images taken in 2006 compared to 2001 can affect the estimates of coral cover, which is typically patchy. The more widespread use of DTIS in a number of seamount and other seabed projects since its first deployment in 2006 has lead to the development of image processing protocols for consistency throughout NIWA. The data from 2001 are being re-examined and sized, and plans are to undertake more extensive comparisons when that task is completed, and when new data from the 2009 survey are available. Given that growth rates for many deep-sea invertebrates are believed to be slow (see references in Rogers et al. 2007, Samadi et al. 2007) and that in shallow-water environments communities associated with biogenic structures are the slowest to recover (Collie et al. 2000; Kaiser et al. 2006), the three surveys together will enable a more powerful comparison over 8 years rather than 5.

The time series continued under this project, and the further survey in 2009 is providing valuable ecological information on rarely-studied longer-term changes in undisturbed and disturbed systems, and represents an important contribution to evaluating the efficacy of seamount management measures established under the draft Seamount Management Strategy and Benthic Protected Areas declaration.

5.   ACKNOWLEDGMENTS

6.   REFERENCES

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Appendix 1: Species caught in epibenthic sled sampling during the 2006 Graveyard survey. Note: an operational taxon unit is a discrete known, unknown, or undescribed species.

Phylum	Class/Subclass	Order	Family	Taxon (operational taxon unit)
Porifera	Demospongiae	Astrophorida	Pachastrellidae	*Poecillastra laminaris*
				Pachastrella
				Vulcanella (Vulcanella) orthotriaena
				Thenea novaezealandiae
				Characella
				Poecillastra
				Poecillastra schulzii
			Ancorinidae	*Stelletta*
				Tethyopsis
			Geodiidae	*Geodia*
				Geodia regina
				Geodia vestigifera
		Hadromerida	Polymastiidae	*Spinularia australis*
				Radiella
				Tentorium semisuberites
				Ridleia
			Suberitidae	*Plicatellopsis*
				Rhizaxinella
				Suberites
		Poecilosclerida	Cladorhizidae	*Chondrocladia meliiderma turbiformis*
				Abyssocladia
				Asbestopluma
				Asbestopluma Helophloeina
			Coelosphaeridae	*Inflatella spherica*
				Lissodendoryx bifacialis
				Lissodendoryx (Ectyodoryx)
			Dendoricellidae	*Pyloderma demonstrans*
				Dendoricella
				Pyloderma latrunculioides
			Phellodermidae	*Echinostylinos*
			Hymedesmiidae	*Hymedesmia*
				Hymedesmia microstrongyla
			Myxillidae	*Myxilla (Ectyomyxilla)*
				Iophon
			Anchinoidae	*Phorbas*
			Microcionidae	*Ophlitaspongia*
			Esperiopsidae	*Esperiopsis*
		Lithistid Demospongiae	Phymatellidae	*Neoaulaxinia persicum*
			Corallistidae	*Awhiowhio sepulchrum*
		Spirophorida	Tetillidae	*Tetilla australe*
				Craniella microsigma

Phylum	Class/Subclass	Order	Family	Taxon (O.T.U.)
		Haplosclerida	Phloeodictyidae	*Calyx*
			Callyspongiidae	*Callyspongia (Euplacella)*
			Petrosiidae	*Neopetrosia*
			Chalinidae	*Cladocroce*
				Haliclona (Gellius) regia
		Dictyoceratida	Irciniidae	*Ircinia turrita*
			Dysideidae	*Euryspongia arenaria*
	Hexactinellida	Lyssacinosida	Rossellidae	*Crateromorpha (Crateromorpha)*
			Euplectellidae	*Euplectellidae*
				Bolosominae
		Hexactinosida	Tretodictyidae	*Tretodictyidae*
				Psilocalyx
			Farreidae	*Farrea*
				Farrea occa ssp. *similaris*
			Aphrocallistidae	*Aphrocallistes beatrix* ssp. *beatrix*
			Euretidae	*Euretinae*
				Periphragella elisae
				Periphragella
			Dactylocalycidae	Dactylocalycidae
		Amphidiscosida	Hyalonematidae	*Hyalonema (Cyliconema)*
			Pheronematidae	*Semperella*
		Aulocalycoida	Aulocalycidae	*Euryplegma auriculare*
				Aulocalycidae
	Calcarea	Clathrinida	Leucaltidae	*Leucettusa*
Cnidaria	Anthozoa	Actiniaria	Actiniidae	*Actinia*
				Urticinopsis
			Actinostolidae	*Actinostolidae*
			Halcampoididae	*Halcampella*
			Halcuriidae	*Halcurias endocoelactis*
				Actiniaria
		Alcyonacea	Alcyoniidae	*Anthomastus*
				Paraminabea
			Clavulariidae	Clavulariidae
				Alcyonacea
		Antipatharia	Schizopathidae	*Parantipathes*
				Antipatharia
		Ceriantharia		*Ceriantharia*
		Gorgonacea	Acanthogorgiidae	*Acanthogorgia*
			Chrysogorgiidae	*Chrysogorgia*
			Isididae	*Acanella*
				Keratoisis
				Minuisis
				Mopseinae
				Peltastisis
			Plexauridae	*Muriceides*
				Plexauridae
			Primnoidae	*Calyptrophora*

Phylum	Class/Subclass	Order	Family	Taxon (O.T.U.)
				Narella
				Primnoella
				Thouarella
				Thouarella (Euthouarella)
				Tokoprymno maia
				Gorgonacea
		Pennatulacea	Funiculinidae	*Funiculina*
			Stachyptilidae	*Stachyptilum*
		Scleractinia	Caryophylliidae	*Caryophyllia*
				Desmophyllum dianthus
				Solenosmilia variabilis
			Dendrophylliidae	*Enallopsammia rostrata*
			Flabellidae	*Flabellum*
			Oculinidae	*Madrepora oculata*
			Poritidae	*Goniopora*
				Scleractinia
		Telestacea	Telestidae	*Telestula*
		Zoanthidea	Epizoanthidae	*Epizoanthus paguriphilus*
				Octocorallia
	Hydrozoa	Anthoathecata	Eudendriidae	*Eudendrium*
			Stylasteridae	*Calyptopora reticulata*
				Lepidopora
				Lepidotheca
				Lepidotheca fascicularis
				Stenohelia
				Stylaster
				Stylasteridae
				Anthoathecata
		Hydroida		*Hydroida*
		Leptothecata	Aglaopheniidae	*Aglaophenia*
			Campanulariidae	Campanulariidae
			Haleciidae	*Halecium*
			Lafoeidae	*Acryptolaria*
				Lafoea
				Lafoeidae
				Zygophylax
			Plumulariidae	*Plumularia*
			Sertulariidae	*Sertularella*
			Tiarannidae	*Tiarannidae*
				Leptothecata
				Hydrozoa
				Siphonophora
	Scyphozoa			Scyphozoa
Mollusca	Bivalvia	Limoida	Limidae	*Acesta saginata*
				Escalima regularis
				Limatula
		Myoida	Cuspidariidae	*Cuspidaria fairchildi*
		Ostreoida	Pectinidae	*Delectopecten fosterianus*
		Veneroida	Montacutidae	*Benthoquetia integra*

Phylum	Class/Subclass	Order	Family	Taxon (O.T.U.)
	Gastropoda			Gastropoda
	Gastropoda/Opisthobranchia	Thecosomata	Cavoliniidae	*Cavolinia tridentata*
	Gastropoda/Prosobranchia	Archaeogastropoda	Fissurellidae	*Emarginula*
			Trochidae	*Antimargarita maoria*
				Calliostoma
		Mesogastropoda	Naticidae	*Falsilunatia*
				Falsilunatia powelli
		Neogastropoda	Volutomitridae	*Volutomitra banksi*
		Neotaenioglossa	Ranellidae	*Fusitriton laudandus*
		Stenoglossa	Buccinidae	*Eosipho*
				Oamaruia
				Penion benthicolus
			Marginellidae	Marginellidae
			Muricidae	*Pagodula*
			Nassariidae	*Nassarius ephamillus*
			Olividae	*Amalda benthicola*
			Volutidae	*Alcithoe flemingi*
		Vetigastropoda	Trochidae	*Archiminolia meridiana*
	Polyplacophora/Neoloricata	Ischnochitonida	Mopaliidae	*Placiphorella*
			Schizochitonidae	*Loricella profundior*
	Scaphopoda	Dentaliida	Laevidentaliidae	*Laevidentalium*
Brachiopoda	Articulata	Terebratulida	Kingenidae	*Ecnomiosa inexpectata*
			Terebratulidae	*Liothyrella*
				Brachiopoda
Bryozoa	Gymnolaemata	Cheilostomata	Arachnopusiidae	*Arachnopusia*
				Arachnopusia sp. 2
			Bitectiporidae	*Bitectipora ozalea*
			Buffonellodidae	*Ipsibuffonella*
				Ipsibuffonella sp
			Bugulidae	*Nordgaardia*
			Calloporidae	*Kenovidoma singularis* n. gen., n. sp.
				Kenovidoma singularis n. gen, n. sp.
				Pyriporoides precocialis
				Ramphonotus
				Retevirgula
			Cellariidae	*Euginoma* n. sp.
			Celleporidae	*Galeopsis*
				Lagenipora
				Lagenipora sp.
			Chaperiidae	*Chaperiopsis*
				Chaperiopsis splendida
			Cribrilinidae	*Figularia*
				Figularia pelmatifera
				Figularia sp.
				Figularis
			Farciminariidae	*Columnella magna*
			Hippothoidae	*Hippothoa*
			Lekythoporidae	*Harpago*

Phylum	Class/Subclass	Order	Family	Taxon (O.T.U.)
				Peocilopora n. sp ("nova")
			Microporidae	*Micropora*
				Micropora sp.
			Phidoloporidae	*Reteporella*
			Porinidae	*Semihaswellia umbrella*
			Romancheinidae	*Escharella*
				Escharella spinosissima
			Schizoporellidae	*Chiastosella exuberans*
			Smittinidae	*Smittina*
				Smittina n. sp.
	Stenolaemata	Cyclostomata	Annectocymidae	*Entalophoroecia*
				Entalophoroecia sp.
			Crisiidae	*Crisia*
			Cytididae	*Supercytis recens* n. sp.
			Diaperoeciidae	*Annectocyma*
			Horneridae	*Homeohornera*
				Pseudidmonea
			Lichenoporidae	*Disporella* n. sp. *("flabellata")*
				Disporella sp.
				Disporella sp. 1
			Oncousoeciidae	*Stomatopora*
			Pseudidmoneidae	*Pseudidmonea*
			Stomatoporidae	*Stomatopora* sp.m
			Tubuliporidae	*Tubulipora*
Arthropoda	Pycnogonida	Pycnogonida	Pycnogonida	*Pycnogonida*
	Malacostraca	Amphipoda	Epimeriidae	*Epimeria horsti*
		Decapoda	Atelecyclidae	*Trichopeltarion janetae*
			Axiidae	*Eiconaxius*
			Chirostylidae	*Gastroptychus rogeri*
				Uroptychus cardus
				Uroptychus raymondi
			Cymonomidae	*Cymonomus soela*
			Galatheidae	*Munida isos*
				Munidopsis tasmaniae
				Phylladiorhynchus pusillus
			Goneplacidae	*Neopilumnoplax nieli*
			Hippolytidae	*Hippolytidae*
			Lithodidae	*Neolithodes*
				Paralomis
			Nematocarcinidae	*Nematocarcinus*
				Nematocarcinus gracilis
				Nematocarcinus hiatus
			Oplophoridae	*Oplophorus novaezealandiae*
			Paguridae	*Bythiopagurus macrocolus*
				Goreopagurus poorei
				Propagurus deprofundis
			Pandalidae	*Plesionika*
			Parapaguridae	*Parapagurus latimanus*
				Sympagurus dimorphus

Phylum	Class/Subclass	Order	Family	Taxon (O.T.U.)
			Polychelidae	*Pentacheles laevis*
				Stereomastis sculpta
			Pylochelidae	*Trizocheles brachyops*
			Sergestidae	*Sergestes arcticus*
				Leontocaris yarramundi
		Isopoda	Aegidae	*Aega gordoni*
				Aega kakai
				Aega semicarinata
				Rocinela resima
			Serolidae	*Acutiserolis*
		Mysidacea		Mysidacea
	Maxillopoda	Sessilia	Balanidae	*Ecnomiosa inexpectata*
	Ostracoda			Ostracoda
Echinodermata	Asteroidea	Brisingida	Brisingidae	*Asterostephane moluccana*
			Freyellidae	*Freyella echinata*
			Novodiniidae	*Novodinia novaezelandiae*
				Brisingida
		Forcipulatida	Asteriidae	*Allostichaster farquhari*
				Cosmasterias dyscrita
				Sclerasterias mollis
				Smilasterias
				Smilasterias actinata
			Zoroasteridae	*Zoroaster*
				Forcipulatida
		Notomyotida	Benthopectinidae	*Cheiraster (C.) otagoensis*
		Spinulosida	Echinasteridae	*Echinaster farquhari*
				Henricia aucklandiae
				Henricia compacta
		Valvatida	Goniasteridae	*Ceramaster patagonicus patagonicus*
				Ceramaster sp. B
			Podosphaerasteridae	*Podosphaeraster somnambulator*
			Poraniidae	*Marginaster patriciae*
		Velatida	Korethrasteridae	*Peribolaster lictor*
			Pterasteridae	*Pteraster robertsoni*
			Solasteridae	*Crossaster multispinus*
				Paralophaster
	Crinoidea	Articulata	Antedonidae	Antedonidae
				Thaumatometra alternata
				Tonrometra multicirra
				Tonrometra spinulifera
			Charitometridae	Charitometridae
		Bourgueticrinida	Phrynocrinidae	*Phrynocrinus nudus*
		Comatulida		Comatulida
				Crinoidea
	Echinoidea	Echinoida	Echinidae	*Gracilechinus multidentatus*
		Echinothurioida	Echinothuriidae	*Araeosoma*
				Sperosoma
		Pedinoida	Pedinidae	*Caenopedina otagoensis*

Phylum	Class/Subclass	Order	Family	Taxon (O.T.U.)
	Holothuroidea	Spatangoida	Spatangidae	*Spatangus mathesoni*
		Aspidochirotida	Stichopodidae	*Pseudostichopus mollis*
			Synallactidae	*Bathyplotes*
		Elasipodida	Pelagothuriidae	*Enypniastes eximia*
		Molpadiida	Molpadiidae	*Molpadia*
	Ophiuroidea	Euryalinida	Asteroschematidae	*Ophiocreas oedipus*
		Ophiurida	Amphilepididae	*Amphilepis*
			Amphiuridae	*Amphioplus*
				Amphioplus (Unioplus) cipus
				Amphiura
			Ophiacanthidae	*Ophiacantha*
				Ophiacantha brachygnatha
				Ophiacantha rosea
				Ophiacantha spectabilis
				Ophiacantha vepratica
				Ophiacantha vivipara
				Ophiacantha yaldwyni
				Ophiocamax applicatus
				Ophiologimus prolifer
				Ophiophthalmus relictus
				Ophioplinthaca plicata
			Ophiactidae	*Ophiactis abyssicola*
				Ophiactis hirta
				Ophiactis profundi
			Ophiomyxidae	*Ophiomyxa*
				Ophioscolex
			Ophionereididae	*Ophiochiton fastigatus*
			Ophiuridae	*Ophiocten cryptum*
				Ophiomisidium irene
				Ophiomusium lymani
				Ophiozonella stellata
				Ophiura (Ophiuroglypha) rugosa
				Ophiura irrorata
				Ophiurida
Chordata Urochordata	Ascidiacea			Ascidiacea [Tunicates]