Chatham–Challenger Ocean Survey 20/20 Post-Voyage Analyses: Objective 10 – Biotic habitats and their sensitivity to physical disturbance

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EXECUTIVE SUMMARY

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During 2006 and 2007, an ambitious project to quantify and characterise seabed habitats to depths of 1500 m on the Chatham Rise and the Challenger Plateau was carried out through a series of voyages, and subsequent analyses under the auspices of Ocean Survey 20/20, a long-term government programme to map the Exclusive Economic Zone. This report details the findings of Objective 10 which aimed to determine the biotic habitats on the seabed across the Challenger Plateau and Chatham Rise, and assess their importance to ecosystem function, production, and sensitivity to disturbance. Available methods for determining the sensitivity of biotic habitats, biodiversity and benthic communities to physical disturbance of the seafloor were assessed, and overall patterns of sensitivity across the two locations described using 3 methods.

Biotic habitats represent groups of taxa that occur at one or more sites. A number of taxa or a single taxon can define a biotic habitat. Sites within a biotic habitat may have faunal communities that are very similar to one another, or they may be quite different, making variable community composition a diagnostic of that biotic habitat.

The 19 biological groups identified across sampling transects in the Chatham-Challenger project were confirmed as spatially contiguous biotic habitats, associated with specific environmental factors or found in specific locations. Of the 19 groups, nine formed major biotic habitats; one of which was unique to the Challenger Plateau and four unique to the Chatham Rise. The remaining ten groups formed minor biotic habitats, six of which were also unique to the Chatham Rise and one was unique to the Challenger Plateau.

Biotic habitats are often associated with certain environmental characteristics (e.g., depth, slope) that make extended mapping possible through the use of these as surrogate variables. Here we were able to use depth, roughness, tidal currents and sea surface productivity as surrogate variables to produce maps of the biotic habitats across both the Challenger Plateau and Chatham Rise. Importantly, habitats are defined as covering scales of interest to a particular study or management objective, and in this case are broad-scale biotic habitats covering tens to hundreds of kilometres.

The three methods used to define the sensitivity of benthic communities and biotic habitats differed in the way sensitivity was calculated: (1) the characterising and dominant taxa of a biotic habitat; (2) the abundance of all taxa at a site; or (3) the richness of all taxa at a site. The first of these methods is not recommended for use as it exhibited a low range of values. Methods 2 and 3 both showed wide ranges of values across both the Challenger Plateau and the Chatham Rise. They also produced low values where fishing intensity was high, as would be expected if sensitive species had been removed. Both these methods are likely to be useful as management tools for human-mediated physical disturbances such as bottom fishing.

1. OBJECTIVES

Overall project 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.

2. SPECIFIC OBJECTIVE 10:

To define habitats (biotic) encountered during the survey and assess their relative sensitivity to modification by physical disturbance, their recoverability and their importance to ecosystem function / production.

3. INTRODUCTION

The benthos of the New Zealand EEZ beyond the coastal and shallow shelf zones is known largely from commercial and scientific fisheries bycatch records and from limited numbers of research voyages. Much of the designed sampling campaigns have been targeted at specific commercial fish species or habitats such as seamounts, canyons, vent and seep sites, with adhoc sampling, conducted over many years, producing sparse information over a wide area (Rowden et al. in press, Leathwick et al 2010, Beaumont et al 2008 & 2010). The Oceans Survey 20/20 voyages to the Chatham Rise and Challenger Plateau represent the most comprehensive sampling initiative (Figure 1), aimed at describing patterns of benthic biotic habitat and biological diversity across extensive areas of the EEZ to date. A central goal of the OS 20/20 programme is to generate quantitative descriptions of biodiversity across the EEZ. In Objective 9 of the current project (ZBD2007-01) the relationships, patterns and contrasts in species composition, assemblages, habitats, biodiversity and biomass (abundance) both within and between stations, strata and areas were elucidated (see Floerl & Hewitt 2010). The role of Objective 10 reported here was to scale up the biological groups determined under Objective 9 to spatially contiguous biotic habitats, assess their importance in ecosystem function, and evaluate their likely sensitivity to physical disturbance.

Extensive areas of the Chatham Rise and parts of the Challenger Plateau are commercial fishing areas. Evaluating the potential influence of bottom fishing and mining activities on benthic marine habitats has been the subject of intensive research efforts in recent years (reviewed in Jewett et al. 1999; Collie et al. 2000; Thrush & Dayton 2002; Boyd et al. 2005; Kaiser et al. 2006; Thrush & Dayton 2010). Sustainable management of these benthic habitats in the face of continuing commercial activity is reliant on appropriate and interpretable measures of the responses of these habitats to different disturbance regimes (type, frequency, extent and intensity).

Disturbance through bottom fishing activities such as dredging and trawling impacts not only on commercially targeted species but also has indirect effects on the benthic habitats, the resident biota and key ecosystem functions (Thrush & Dayton 2002). These effects include the modification of sedimentary characteristics through sediment removal and turnover (e.g., increases in coarse material, and decreases in organic content (Guerra-García et al. 2003)), and damage or destruction of many species, particularly large, habitat-forming epibenthic species. These changes to habitats can cause ongoing modification of ecosystem functioning (e.g. de Grave and Whitaker 1999; de Juan et al. 2009).

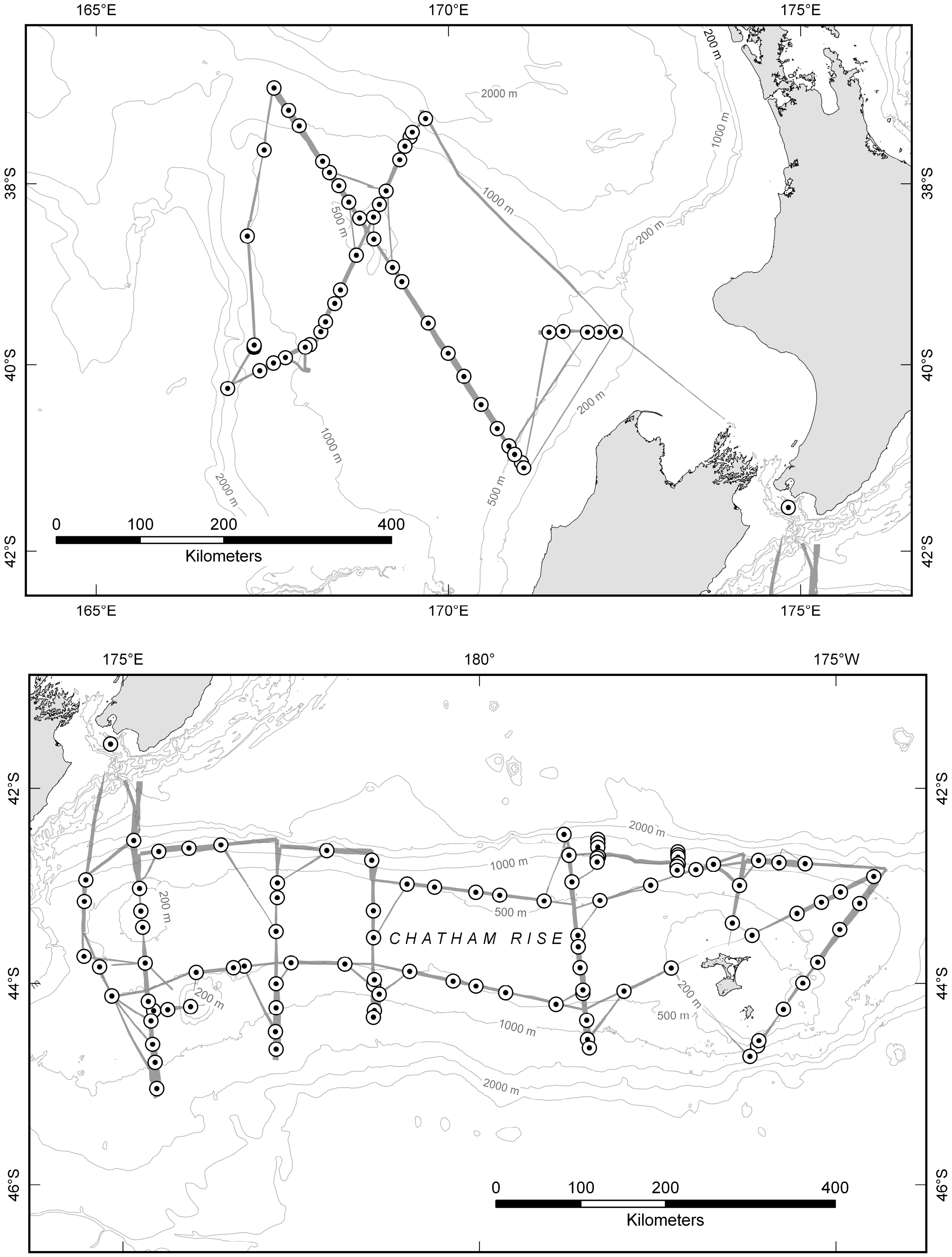

Figure 1. Chatham Rise (top) and Challenger Plateau (bottom) Oceans 20/20 surveys, showing acoustic multibeam transects and sampling sites at which benthic invertebrates and sediments were collected (circles).

This report covers a number of aspects important to the description of biotic habitats, their functionality and sensitivity, including:

- the spatial scale at which they are defined
- the description of the biotic habitats, including dominant species, biodiversity, ecological function and environmental characteristics
- the relative sensitivity of present biological communities and biotic habitats to modification by physical disturbance.

Further research funded under Ministry of Fisheries contract #ZBD2009-25 (Predicting impacts of increasing rates of disturbance on functional diversity in marine benthic ecosystems) is planned to expand on the results reported here.

METHODS

Datasets

Data used to determine biotic habitats came from video transects (DTIS), photo quadrats (STILL), and direct sampling of the seabed using a seamount sled (SEL), and beam trawl (TB) sampling. Data used to determine sensitivity and recoverability were derived from DTIS only, owing to the more complete spatial coverage provided by this method (Ministry of Fisheries project ZBD2007/01 Objective 6 Hewitt et al in review).

Data on environmental variables potentially associated with the biotic habitats came from a number of sources: sediment grain size from Objective 5 (Ministry of Fisheries project ZBD2007/01 Objectives 1-5 Bowden 2011) and 7 (Ministry of Fisheries project ZBD2007/01 Objective 7 Nodder et al. in review); depth and roughness from the acoustic data (Nodder 2008); and salinity, current speed, sea-surface temperature gradient and productivity from the Marine Environmental Classification (MEC) dataset (Snelder et al 2006).

Definitions

Marine habitats are often described based solely on environmental characteristics, e.g., mud or a specific depth range 7 – 24 m (Ministry of Fisheries and Department of Conservation 2008). Such habitats generally contain a large variety of biological communities, exhibiting a variety of functional characteristics and sensitivities to anthropogenic impacts. Even environmental classifications frequently produce environmental classes containing many biological communities and, sometimes, individual biological communities are found in more than one class. This within-class biological variability, driven by biological interactions, ecological connectivity, historical patterns and variation over time constrains the usefulness of environmentally based habitats for sustainable management of biodiversity (Menge et al. 2002, Genin 2004, Leathwick et al. 2006, Sharp et al. 2007, Bowden et al. 2011). Conversely, ***biotic habitats*** are groupings of taxa that occur at one or more sites, defined either by a number of characterising taxa (e.g., sponge gardens) or by a single taxon (e.g., oyster beds) that determines the distribution of other taxa. Sites occurring within a biotic habitat may have biological communities that are very similar to one another, or they may be quite different, making variable community composition a diagnostic of that biotic habitat. Different biotic habitats frequently provide different **ecological services** (e.g., refugia from predation, living space, nutrients), even when the number of species is similar. Sustainable management of biodiversity relies on the preservation of ecological functioning, through the maintenance of services, thus, biotic habitats provide a useful management concept for an ecosystem based approach to management of marine resources. Biotic habitats are sometimes associated with a specific mix of environmental characteristics (e.g., depth, slope, sediment type), thus creating the opportunity to more easily map them.

If a biotic habitat has been determined statistically using clustering techniques, the next step is to determine the taxa that characterise the biotic habitat. ***Characterising taxa*** are those that are always found at very similar densities throughout the biotic habitat, but do not have to be highly abundant. ***Dominant taxa*** are those that have the highest (here defined as the ten highest) average abundances across all sampled sites in that biotic habitat. Dominant taxa are usually characterising taxa, but may not be if their densities are highly variable.

Sensitivity is generally defined as the likelihood of impairment, death or extinction of individuals, populations, ecosystem functions, communities or habitats in response to one or many stressors. Here we confine the definition to the likelihood of death to an individual.

Determining and mapping the biotic habitats

Defining the biotic habitats occupying the Challenger Plateau and Chatham Rise was dependent on results from ZBD2007/01 objectives 9, 12, and 14 and the scale required by a technical working group comprised of NIWA, MFish and DoC personnel. The biotic habitats were required both for broad-scale mapping purposes and as the basis for descriptions of differences in ecosystem functions that could be used to assess potential sensitivity/resistance of biotic habitats to physical disturbance in the survey areas.

Assessment of the utility of the biological groupings identified under Objective 9 as biotic habitats required three steps:

- Assessment of whether Objective 9 biological groups demonstrated spatial continuity; i.e. were adjacent sites representative of the same groupings? For all biological groups defined in Objective 9 containing more than one site (i.e. major groups B1–B9 and minor groups m10–m12), we calculated the number of sites where the nearest site was in the same group.
- Where adjacent sites were from different biological groups, we evaluated whether strong environmental differences occurred between them. Stepwise discriminant analysis was used to select a subset of the environmental variables for use in discriminating among the groups. A non-parametric method based on k-nearest-neighbour (Rosenblatt 1956; Parzen 1962) with a uniform kernel was used to discriminate between variables, and variables were entered and removed from the model based on their contribution to the discriminatory power of the model as measured by Wilks' lambda. Note that minor groups 13, 14, 18 & 19 could not be included in this analysis, as sediment data (normally a strong driver of benthic communities) were not available. Once a subset of significant discriminatory variables had been determined, their performance was evaluated as probabilities of misclassification. If a subset of environmental variables produced low misclassification rates (misclassification < 25% average), then the biological groups developed in Objective 9 were confirmed as the final biotic habitats.
- Where adjacent sites were from different biological groups and strong environmental differences did not occur, the data on species composition was investigated to determine whether the sample could be better allocated to a different biological group (by comparing within and between group similarities before and after reallocation) or whether the set of sites should form a new biotic habitat.

Assessing sensitivity to physical disturbance

While manipulative experiments provide the most direct examination of sensitivity of areas to disturbances, such studies are difficult to conduct in meaningful ways for large-scale or repetitive disturbances. Recently, ecologists have focussed on linking biological traits of species to characteristics of specific disturbances as a method of assessing sensitivity. Such methods are applicable across a wide range of habitats and regions where detailed species-specific knowledge or experimental data are not available (de Juan et al. 2009; Tyler-Walters et al. 2009). In the marine environment, many of these assessments have focused on the effects of commercial fishing disturbance on the benthic communities, but the techniques are applicable to other types of physical disturbance of the seafloor, including channel dredging (e.g. Guerra-García et al. 2003) and mining (e.g. Boyd et al. 2005).

Soft-sediment habitats (such as comprised the majority of the sites sampled in this study (Ministry of Fisheries project ZBD200701, Objective 1 – 5 data, Bowden 2011) are sometimes naively considered homogeneous plains of sand or mud. However, the habitat engineering activities of the resident organisms often make these systems highly heterogeneous and species rich. Many of the habitat-forming species, as well as others that serve important functional roles in seafloor ecosystems, are sensitive to physical disturbance because of biological traits associated with their morphology, life style and ability to recolonise disturbed areas. Experimental manipulations and large-scale surveys have demonstrated that soft-sediment invertebrates are more physically affected by disturbance if they are sedentary, or have low mobility, and have fragile body structures such as shells or branches (e.g. Thrush et al. 1998, 2002 and references therein). Species that are large-bodied, sessile and protrude from the sediment are frequently easily fragmented or crushed by bottom fishing gears, so corals, large bryozoans and sponges, for example, are particularly sensitive (Sainsbury et al 1997, Burridge et al. 2003). Compounding these impacts, large sessile species are also habitat-forming, providing settlement space for other sessile species, or refugia for mobile species (e.g. Thrush et al. 2001), and often alter the composition of the surrounding sediments (e.g. Widdows et al. 2002; Schwindt et al. 2004). Removal of these species may therefore have important ecosystem effects on the surrounding areas (Thrush & Dayton 2010 and references therein).

Biotic habitats will also respond differently to fishing disturbance depending on the stability and complexity of the sediments, on the strength and direction of prevailing currents and tides, and the incidence of natural disturbance (Jewett et al. 1999; Collie et al. 2000; Boyd et al. 2005). For example, fine-grained sediments can be resuspended by the passage of trawls and dredges and have detrimental effects on filter-feeding organisms (e.g. Thrush and Dayton 2002; Rabeni et al. 2005). Biotic habitat stability in the face of high wave and tidal flow stress that is generated in bryozoan reefs can be lost due to fishing impacts resulting in potentially permanent change due to the mobilisation of fine sediments (Cranfield et al 2003).

Although fragile and large-bodied species with limited movement can be vulnerable to these impacts, some species might be favoured by the action of trawling or dredging. For instance, if the scale of the fishing activity is less than the distance mobile predators and scavengers can readily move, these species can move into the disturbed area and take advantage in the short term increase in food resources provided by damaged organisms. A change in the availability of organic matter within disturbed sediments may improve conditions for deposit feeders. For example, Collie et al. (1997) found an increase in scavenging crabs and echinoderms at sites disturbed by bottom fishing activities, greater species evenness, and a concomitant decrease in the abundance of rare species. De Grave and Whitaker (1999) found clear differences in faunal composition in areas with different disturbance histories, from filter-feeding bivalves in areas recovering from dredging, to omnivorous crustaceans in areas subject to continuing dredging. While faunal composition may be expected to respond to changes in the disturbance regime, where regimes are constant (e.g., De Grave and Whitaker 1999), the community will tend to remain in a certain state.

Thus characteristics of the disturbance that are important to determining sensitivity of organisms are:

- Spatial extent of the area disturbed and the speed with which the disturbance occurs determines which types of organisms can move out of the disturbance path, or utilise new food resources in the disturbed area;
- Depth of sediment disturbance determines which types and the overall proportion of organisms affected;
- Whether sediment is turned over, resuspended or removed, determines the extent of changes in sediment type and whether a larger area is affected by redistribution of fine particles;
- Whether all, some or no organisms are removed;
- Frequency of the disturbance will drive the probability of organisms being able to either repair themselves or recover to previous population densities before being disturbed again.

Given these factors, assessment of sensitivity of locations will often need to be done separately for different types of disturbances.

Calculation of sensitivity

Taxa were assigned to a set of biological traits (Table 1), reflecting current knowledge of the response of benthic fauna to physical disturbance (de Juan et al. 2009). The traits used are an abbreviated list, not including many functionally important attributes such as size, age, rarity and density. Important attributes were not included for a number of reasons: (a) information on these attributes was very limited; (b) the information would need to be spatially explicit and thus not fit into a general framework; or (c) they were more related to recoverability than sensitivity.

Table 1: List of biological traits that define sensitivity to physical disturbance.

ATTRIBUTE	TRAITS	RESPONSE TO DISTURBANCE & RATIONALE
Feeding	Scavengers & predators	Positive; Provision of additional food source
	Suspension, deposit, grazers	Neutral; this is a conservative interpretation as variability in the magnitude of positive or negative effects is likely to be dependent on location, disturbance regime and individual traits
Habit	Erect	Negative; Liable to breakage
	All others	Neutral; other habits are encompassed in the analysis by attributes related to living position
Mobility	Sedentary	Strongly negative; Unable to move away from approaching disturbance
	Limited	Negative; May be able to move away
	High	Neutral; Able to move away from (or bury below) approaching disturbance
Living position	Sediment surface	Strongly negative; Will be disturbed
	In top 2cm of sediment	Negative or neutral dependent on depth of disturbance;
	Deeper than 2 cm in sediment	Negative or neutral dependent on depth of disturbance;
Fragility	Very fragile	Strongly negative; Will be damaged/killed if disturbed
	Fragile	Negative; Will be damaged if disturbed
	Robust or not known	Neutral

Note that the trait analysis used in this study is focused on sensitivity at the scale of an individual or colony rather than a population level. Transferring sensitivity from an individual up to a population requires detailed information on reproduction (ability, type, influence of density and sex ratios), density-dependent effects on recruitment and survival and generation time and time to adulthood. The shortened list of traits, the emphasis on death rather than impairment and the focus on individual organisms rather than effects on population dynamics act to make the calculations conservative, i.e., likely to under-estimate rather than over-estimate sensitivity. Finally, allocation of a taxon to a trait was also conservative. For example, if degree of fragility was unknown, the taxon was allotted to the more robust category. If the mobility was unknown, the taxon was equally allotted to limited and high mobility categories (see Hewitt et al 2008). If feeding mechanism or habit was unknown, the taxon was equally allotted to all possible traits (Hewitt et al 2008). The traits used are amongst the more well-known (sedentary, fragility) and most easily determined from the video data (e.g., erect habitat), however, the effect of lack of knowledge was assessed (see section "Assessing uncertainty" below).

These traits were then grouped into varying degrees of sensitivity to the immediate effects of a physical disturbance, similar to bottom trawling, (*sensu* Hiscock and Tyler-Walters 2006, Tyler-Walters et al. 2009; Table 2).

The characteristics of the type of disturbance represented in Table 2 are that the disturbance primarily propagates across the surface of the seafloor and is most likely to disturb organisms protruding from the surface of the seafloor. The area disturbed at any one time is small enough to allow mobile predators to migrate into the area to utilise a new food resource and the rate of disturbance propagation across the surface of the seafloor is slow enough to allow highly mobile fauna to escape. Again we consider this conservative as it does not consider disturbances which plough through the sediment or any far-field effects associated with the production of sediment plumes that affect the feeding activity of organisms beyond the immediate area of impact. This is the disturbance assessed throughout the rest of the report and referred to as "light surface disturbance".

Table 2: Categories of sensitivity, modified from Tyler-Walters et al. (2009), for individuals to physical disturbance that primarily travels across the surface of the seafloor, derived from biological traits.

SENSITIVITY CATEGORY	SENSITIVITY RANK	EXPECTED RESPONSE	BIOLOGICAL TRAITS
High	3	Individuals in disturbed areas die	Sedentary, erect life forms that are very fragile
Intermediate	2	Some individuals in disturbed areas die	Fragile life forms that either form erect structures or are surface dwellers with limited mobility
Low	1	A few individuals may die	Non-sedentary erect, or fragile life forms that live on surface or in the top 2 cm of the sediment and have Limited Mobility
Tolerant	0	No response	Live mainly subsurface with High Mobility (burrowing capacity)
Favoured	-1	Individuals may move into disturbed area	Scavengers & predators which are highly mobile

Three methods were used to calculate sensitivity at each site within this study.

Method 1: Sensitivity based on biotic habitats

Tyler-Walters et al. (2009) explored a number of ways of accumulating sensitivities from individual species sensitivity rankings to a community response at a site and concluded that the best results were obtained based on considering the top 5 taxa that characterised specific biotic habitats (as defined by SIMPER analysis) and the top 10 dominant taxa. The sensitivity of a site then depended upon the most sensitive of those taxa (called the “worst-case scenario”). To calculate this for our data, the characterising taxa from the 19 biotic habitats were assessed for sensitivity. If one of them had high sensitivity then that biotic habitat was declared highly sensitive and all sites described as belonging to that biotic habitat were classified as highly sensitive. If none of the characterising taxa had high sensitivity, then the ten most dominant taxa were investigated, and the highest sensitivity level represented in these used as the overall sensitivity rating for the biotic habitat.

Method 2: Sensitivity incorporating abundance

Ranks of sensitivity were aggregated from taxon to site level by multiplying the rank sensitivity value of a taxon (Table 2) by the abundance of each taxon at a given site and summing these values over all taxa at the site (e.g. Stark and Maxted 2007). A weighted average for that site was then calculated by dividing that sum by the number of taxa found at that site. High overall site scores are characteristic of a community with biological traits that are mainly sensitive to that disturbance (de Juan et al. 2009).

Method 3: Sensitivity incorporating taxa

For each site, the number of taxa in each of the sensitivity categories (i.e., high, intermediate, low, tolerant and positive) were calculated. These were not standardised by the number of taxa observed at each site as various relationships between disturbance and species richness have been observed or postulated depending on the disturbance regime and the nature of impacted community or habitat disturbed (Connell 1977, Ellis et al 2000, Hewitt et al. 2009 & 2010 Thrush and Dayton 2002).

Assessment of methods against fishing disturbance

To determine which of the methods was most likely to be useful in assessing the sensitivity of biotic habitats to a fishing disturbance, the relationship between site sensitivities and the distribution of bottom fishing was assessed. Fine-scale position data from commercial trawlers using gear on or near the seafloor were used to measure the intensity and frequency of bottom trawling over 16 years, from 1989–90 to 2004–05, in depths down to 1600 m (Ministry of Fisheries project BEN200601, Baird et al. in review). This trawl effort was expressed by individual tow polygons representing the estimated swept area of each trawl and summarised by 25 km^2 cells for spatial and temporal analysis.

There are a number of factors that are likely to influence which taxa occur at a site and how abundant they are, especially over the large environmental and spatial gradients occurring in this study. Because there are a number of potentially influential factors, we would not expect a clear relationship between mean sensitivity and fishing intensity. Rather we would expect fishing intensity to exert a control on how many sensitive taxa could occur, and how abundant these could be. That is, we expect to see a factor ceiling response (Figure 2, after Thomsen et al. 1996, Cade et al. 1999).

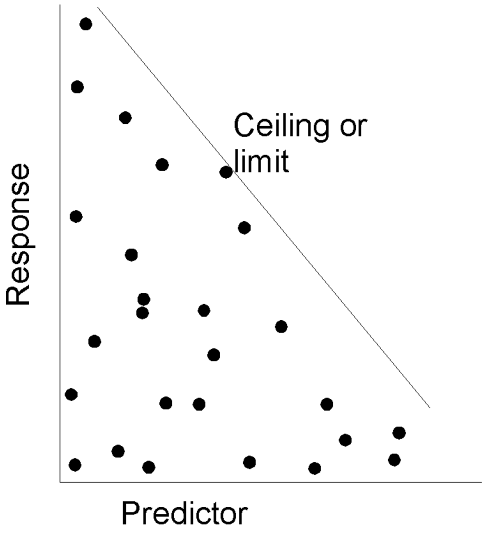

Figure 2. Conceptual scatter plot showing a potential biological response to a predictor confined beneath a limit or ceiling controlled by that predictor factor.

There are three theoretical community responses to physical disturbance (Figure 3). Firstly, there may be a linear decrease in ecological response variables (e.g., number of species, biomass, nutrient cycling). Secondly, there may be a rapid initial decrease, which then slows as the more sensitive species disappear. Thirdly, communities may initially be resilient to the disturbance with no change occurring until a threshold is passed, after which there is a rapid change. In the results section we compare scatter plots of the site sensitivities against the derived fishing intensity to see whether factor ceiling responses are observed and, if they are, what type of response is indicated.

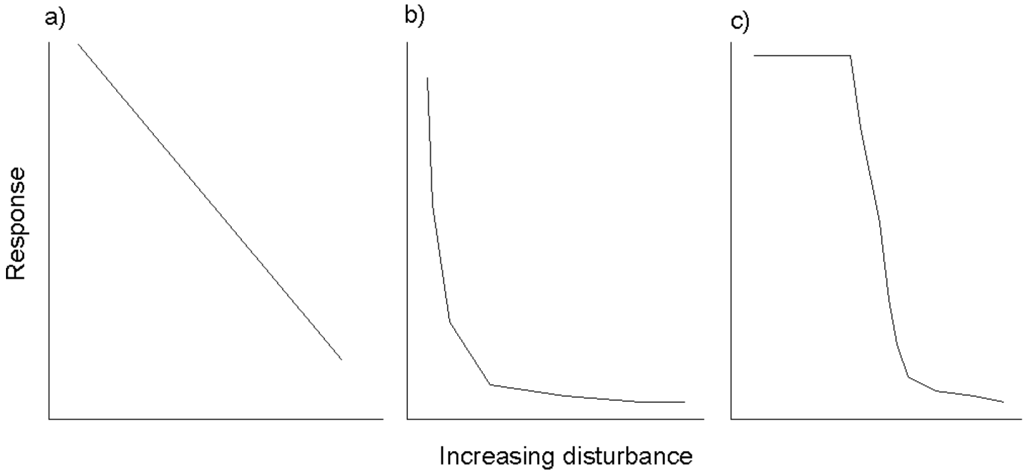

Figure 3. Theoretical factor ceiling responses to a physical disturbance, a) linear decrease, b) log decrease, and c) a threshold response.

Assessments of uncertainty

Potential effects of uncertainties related to assigning taxa to biological traits and then in the assignment of sensitivity to that trait were assessed. Assigning taxa to biological traits can be difficult for two reasons: (i) we know little of the biological traits of many taxa, especially those that are rare and (ii) many taxa are plastic in their traits, e.g., a species may be both a deposit feeder and a predator/scavenger. To minimise errors associated with poorly known biological traits, we have used traits that are amongst the more well-known (sedentary, fragility) and most easily determined from the video data (e.g., erect habitat). We assessed the effect of lack of knowledge of traits by changing the assignment of the taxa to that trait and calculating the average percent change that occurred as a result for methods 2 and 3. As an example, for a predator/deposit-feeder, we first assigned the taxon as a predator (potentially overestimating sensitivity), then as a deposit-feeder (potentially underestimating sensitivity).

We assessed uncertainty associated with assigning traits to sensitivity from traits by making a random selection of 105 taxa and changing their sensitivity category by one level. That is, a taxon ranked as intermediate would be changed to low or high. The direction of change was also determined randomly. The average percent change in sensitivity score estimated by methods 2 and 3 was then calculated.

RESULTS

Final biotic habitats

The biological groupings determined under ZBD200701 Objective 9 were generally spatially contiguous and therefore are confirmed for use as biotic habitats occurring across the two areas (Challenger Plateau and Chatham Rise). On the Chatham Rise, 65% of sites closest to each other were in the same biotic habitat despite being separated on average by 21 km. Very similar results were observed for the Challenger Plateau where 63% of sites had an average separation distance of 20 km.

Three sites were reallocated as follows. Site A009 on the Challenger Plateau was initially grouped into B1, but was bracketed by sites grouped into B9 (sites C112 and B115). Site A009 contained many of the same species as these two other sites and placing it into group B9 did not decrease the within group dissimilarity. Site C082 on the Chatham Rise was initially grouped into m12 with site DD1 on the Challenger. Community composition varied considerably between sites C082 and DD1 and as a result group m12 had a very low within-group similarity. Site C082 was removed from this group and placed into the biotic habitat closest in taxonomic similarity (m13). Site C011 on the Chatham Rise was initially placed into group B7, however, its community composition was very similar to that at nearby sites (C012 and B011, group B5) and its environmental characteristics were different to those in the rest of group B7, being deeper and having lower salinity. For these reasons, this site was placed into biotic habitat B5.

Stepwise discriminant analysis selected 11 variables as useful in classifying the biotic habitats (Table 3).

The misclassification rate of this subset of 11 variables for classifying the biotic habitats was then assessed. Misclassification was generally low with rates of misclassification less than 10% in most biotic habitats, even for those containing very few sites (Table 4).

Table 3: Significant environmental variables, selected by discriminant analysis, that describe biotic habitats. SSTgrad is the spatial gradient of annual mean sea surface temperature and VGPM is the sea surface productivity (see Snelder et al. 2006). Roughness is the standard deviation of slope values calculated over surrounding 1 km^2 cells.

ENVIRONMENTAL VARIABLES	F-VALUE	P-VALUE
Derived from acoustic data		
Depth	24.02	<.0001
Derived from MEC data		
Roughness of seafloor	1.67	0.0968
Salinity	10.11	<.0001
SSTgrad	3.94	0.0001
VGPM	2.69	0.0055
Sediment type (% cover) from Objective 5 & 7		
Mud	5.76	<.0001
Sand	4.76	<.0001
Boulders	83.44	<.0001
Bedrock	5.72	<.0001
Cobbles	3.6	0.0004
Gravel	3.19	0.0012

Table 4: Misclassification rate (%) based on the subset of variables described in Table 1 for all biotic habitats containing more than 1 sampled site.

BIOTIC HABITAT	NO. SITES SAMPLED	MISCLASSIFICATION RATE (%)
B1	6	0
B2	12	22
B3	17	12
B4	12	0
B5	24	18
B6	6	0
B7	14	9
B8	15	9
B9	17	36
m11	2	0
m10	3	0

Depth was a significant contributor to biotic habitat classification, splitting the biotic habitats into 4 groups (Table 5): very shallow (<250) containing minor biotic habitat m15 and m18; shallow (250–500m) containing minor biotic habitats m17 and m19 and major biotic habitat B7; moderate depths (500–800m) containing minor biotic habitat m11 and major biotic habitats B2 and 3; and deep (>800m) containing minor biotic habitats m12, m14 and m16 and major biotic habitats B1, B4, B8 and B9. Minor biotic habitats m10 and m13 occurred over a very wide range of depths and major biotic habitats B5 and B6 were also variable in depth.

These four subgroups were separated further based on the other environmental variables (Table 5).

Descriptions of all the biotic habitats (Table 6, Figure 4) were based on characterising taxa and their functional attributes, diversity and environmental drivers. The latter includes the variables given in Table 5 and other variables available only for selected sites collected under Objective 5 (Table 7).

Table 5. Means and standard deviations of the environmental variables for biotic habitats (BH). Rough = roughness, Sal = Salinity, Prodn = sea surface productivity, Curr = depth averaged maximum tidal current, SSTgrad = sea surface temperature gradient.

BH	DEPTH m	ROUGH	SAL ppb	PRODN mgC m^{-2} d	CURR m/s	SSTGRAD °C/km	SAND %	MUD %
B1	1080±212	5.4±4.1	34.45 ±0.03	471±68	0.13±0.03	0.007±0.003	0	100
B2	569±78	7.0±4.1	34.50 ±0.02	616±64	0.20±0.04	0.029±0.013	7±27	93±27
B3	601±111	3.3±2.6	34.67 ±0.10	515±55	0.20±0.02	0.006±0.004	0	100
B4	1039±265	18.8±7.3	34.43 ±0.06	627±117	0.14±0.04	0.021±0.007	4±13	90
B5	466±114	4.1±2.0	34.47 ±0.09	639±80	0.25±0.09	0.034±0.009	4±20	96±20
B6	461±255	10.4±4.4	34.59 ±0.20	615±98	0.25±0.07	0.023±0.010	14±37	86±37
B7	370±120	5.8±5.2	34.83 ±0.24	669±73	0.24±0.06	0.016±0.010	7±26	92±26
B8	1189±139	17.9±16.5	34.49 ±0.03	536±53	0.12±0.03	0.019±0.006	0	100
B9	927±139	15.0±9.3	34.46 ±0.04	617±66	0.16±0.02	0.021±0.012	12±30	86
m10	815±674	10.3±12.0	34.61 ±0.22	653±23	0.45±0.05	0.018±0.014	57±50	7±13
m11	565±47	17.8±18.1	34.2 ±0.06	595±104	0.13±0.07	0.021±0.019	33±33	13±18
m12	1728	17.4	34.63	499	0.08	0.011	0	99
m13	550±642	7.1±4.1	34.46 ±0.17	557±132	0.25±0.20	0.020±0.015	22±32	49±44
m14	1218	23.4	34.41	495	0.03	0.018	0	100
m15	40	4.1	34.80	672	0.74	0.011	7	0
m16	1844	40.1	34.62	838	0.09	0.013	0	100
m17	261	8.8	35.11	659	0.22	0.018	94	6
m18	165	38.8	34.85	537	0.56	0.007	46	0
m19	253	3.9	34.61	696	0.32	0.029	90	7

Table 6: Final biotic habitat (BH) descriptions, including depth range and environmental characteristics that differ from other biotic habitats. Figure 4 shows their spatial distributions. TOM = Total Organic Matter

BH	CHARACTERISING TAXA, FUNCTIONAL ATTRIBUTES AND BIODIVERSITY	DEPTH m	ENVIRONMENTAL CHARACTERISTICS	LOCATION
B1	Dominated by high densities of *Ophiomusium lymani* with low beta diversity, evenness and Simpson's diversity and a high proportion of infaunal species rare in abundance	760 - 1241	Low roughness, very muddy, high TOM	Chatham: southwest Challenger: one site only
B2	Variable communities of sedentary epifauna (the Anthozoa *Radicipes* & *Anthioptilum* and the Sponge Cladhorizidae) providing habitat structure, mobile bioturbating decapods (*Pycnoplax victoriensis, Campylonotus rathbue*) and small infauna.	548 - 746	Shallow, muddy, moderate phytodetritus	Chatham: north and northeast
B3	Variable communities containing suspension-feeding Hydroids, mobile bioturbators (Holothurians, Decapods (Galatheidae & Crangonidae), Sipunculids and an Onuphid.	481 -815	Shallow, very muddy, low TOM and phytodetritus	Challenger: extensive
B4	Dominated by mobile deposit feeders (the echinoid, *Gracilechinus multidentatus*, with some Ophiuroids and a Holothurian), low epifaunal Simpson's index and evenness.	686 - 1239	Low calcium carbonate, high phytodetritus	Chatham: south
B5	Variable communities of surface bioturbators (Parapaguridae, Onuphids and Gastropods), *NB*, beam trawl samples very variable	210 - 682	Shallow, low roughness, muddy	Chatham: south and ridge
B6	Dominated by bioturbators (Parapaguridae and Spatangidae, Shrimps and 2 infaunal Gastropods).	150 - 824	High phytodetritus	Chatham
B7	Dominated by bioturbators (Decapods *Munida gracilis* & *Notopandalus magnoculus*) with some habitat structure (Chaetopterids, sled data only), high epifaunal beta diversity.	249 - 587		Chatham: northern ridge Challenger: south east
B8	Variable communities containing a Caridea decapod and a Holothurian with Parapaguridae, Gastropods, and an infaunal Sipunculid. Dominated by mobile bioturbators	1002 - 1824	Very muddy, moderate roughness and phytodetritus	Chatham: northeast Challenger: north
B9	Variable community of deposit feeders, scavengers and burrowers, with high epifaunal species richness	740 - 1370	Sandy mud, low phytodetritus	Chatham: northern Challenger: southeast
M10	Dominated by Anemones,	100 - 1270	High currents, sandy, low TOM, high calcium carbonate	Chatham: ridge
M11	Dominated mainly by mobile epifauna (Asteroids & Decapods) with some anemones	531 - 600	Very rough, low currents, moderately sandy and calcium carbonate, high phytodetritus	Chatham: south

BH	CHARACTERISING TAXA, FUNCTIONAL ATTRIBUTES AND BIODIVERSITY	DEPTH m	ENVIRONMENTAL CHARACTERISTICS	LOCATION
M12	Dominated by mobile epifauna and bioturbators (Holothurians & Shrimps)	1728		Challenger: northeast
M13	Variable community (Polychaetes, Encrusting Sponges, Bryozoans and Anemones) with high habitat structure	96 - 1004		Chatham: southeast
M14	Mobile epifauna (Holothurians & Ophiuroids)	1217		Chatham: south, mid
M15	Sponges, high habitat structure	41		Chatham: ridge
M16	Surface bioturbator (*Spatangus* sp.)	1844		Chatham: northwest
M17	Mobile predator (*Astropecten*/*Lithosoma*)	293		Challenger: southeast
M18	Decapod (*Teratomaia richardsoni*) with habitat structure (Halichondrid)	166		Chatham: southeast
M19	Anthozoa and Scaphapoda	253		Chatham: ridge

Table 7. Additional sedimentary information available for some sites from Objective 5 as means and standard deviations. (TOM = total organic matter, $CaCO_3$ = calcium carbonate, Chlorophyll *a*, and its degradation product, Phaeophytin).

BIOTIC HABITAT	TOM (% dry wt)	$CaCO_3$ (% dry wt)	CHLOROPHYLL ($\mu g.g^{-1}$)	PHAEOPHYTIN ($\mu g.g^{-1}$)
B1	3.11±1.46	54.3±21.3	0.011±0.006	1.02±0.79
B2	2.74±0.54	53.0±18.3	0.055±0.042	2.87±1.37
B3	1.96±0.65	80.6±16.1	0.004±0.005	0.44±0.40
B4	2.41±0.23	27.6±18.7	0.072±0.064	3.81±2.44
B5	2.98±1.07	29.3±24.8	0.059±0.038	3.87±1.87
B6	2.33±0.57	46.9±31.1	0.033±0.048	3.54±1.81
B7	2.39±1.38	40.2±26.9	0.041±0.035	2.74±2.12
B8	2.16±0.41	74.4±16.8	0.004±0.010	0.54±0.60
B9	2.73±1.05	62.6±20.9	0.011±0.011	0.98±0.97
m10	1.88±0.20	80.3±5.0	0.017±0.013	1.10±0.46
m11	2.39		65.0	

However, producing a continuous biotic habitat map is only realistic if environmental variables that were available from the MEC could be used to separate the biotic habitats. Minor biotic habitat 10 made this difficult, and the lack of continuous information on sediment grain size meant that major biotic habitats B4, B8 and B9 could not be separated. Major biotic habitats B5 and B6 needed not only grain size information but information on phytodetritus to be separated. A biotic habitat map has been produced (Figure 4), using rules based on ranges of depth, seasurface productivity, roughness and tidal currents exhibited by the sites within the biotic habitats and spatial congruity (Box 1), however, it is important to realise that outside of the sampled positions there is considerable uncertainty.

Box 1: Rules used to derive biotic habitat map. Depth ranges derived from the sites representing the habitats are used as an initial category. This is followed by any other useful environmental variables and spatial patterns. The cutoff points used to separate habitats are either the actual maxima/minima or, where a category is not separated from another category by more than 15%, the average of the two categories. For example, if B9 in deep waters has a maximum tidal current of 0.1244, while m10 has a minimum of 0.1268, then the cutoff point is defined as the average between these 2 (0.1256). Many of the minor habitats with only a single site are plotted only at the site at which they occur.

Challenger

Depth > 1500m = m12

Depth 1000 – 1500 m = B8

Depth 730 – 800 m with spatial kriging = B9

Depth <500 m with spatial kriging = B7

Otherwise if Depth 450 – 820 m habitat = B3

Chatham

Depth < = 200m and tidal current =

- 0.28 – 0.31 B6
- 0.75 – 0.77 m10

Depth >200 and ≤500 m

- tidal current <0.2 or VPGM <545 or VPGM >750 = B6
- otherwise = B5
- B7 overlaid these other habitats and was derived by spatial kriging around the sampled sites

Depth >500 and <=750 m

- salinity > 34.55 = B6
- salinity ≤34.55 and >34.47 and VPGM>740 = B7
- salinity ≤34.55 and >34.47 and VPGM≤740 = B2
- salinity ≤ 34.47 and VPGM > 583 = B5
- salinity ≤ 34.47 and VPGM ≤ 583 = B4

Depth >750 and ≤1000 m

- roughness < 1.00008035 and tidal current is < 0.1320 = B6
- otherwise B9
- spatial kriging B4

Depth >1000 and ≤1250 m

- roughness is ≤ 1.000064 and >1.000005 = B1
- tidal current <0.045 = m14
- roughness > 1.000442 = B9
- roughness ≤1.000442 and > 1.000064 and tidal current ≤ 0.12297 = B8
- roughness ≤1.000442 and > 1.000064 and tidal current > 0.12297 and <0.130 = m10
- spatial kriging B4

Depth >1250 and ≤2000 m

- roughness > 1.00065082 = B8
- else if tidal current > 0.1256 = m10
- else if roughness ≤ 1.00065082 and tidal current ≤ 0.1256 = B9

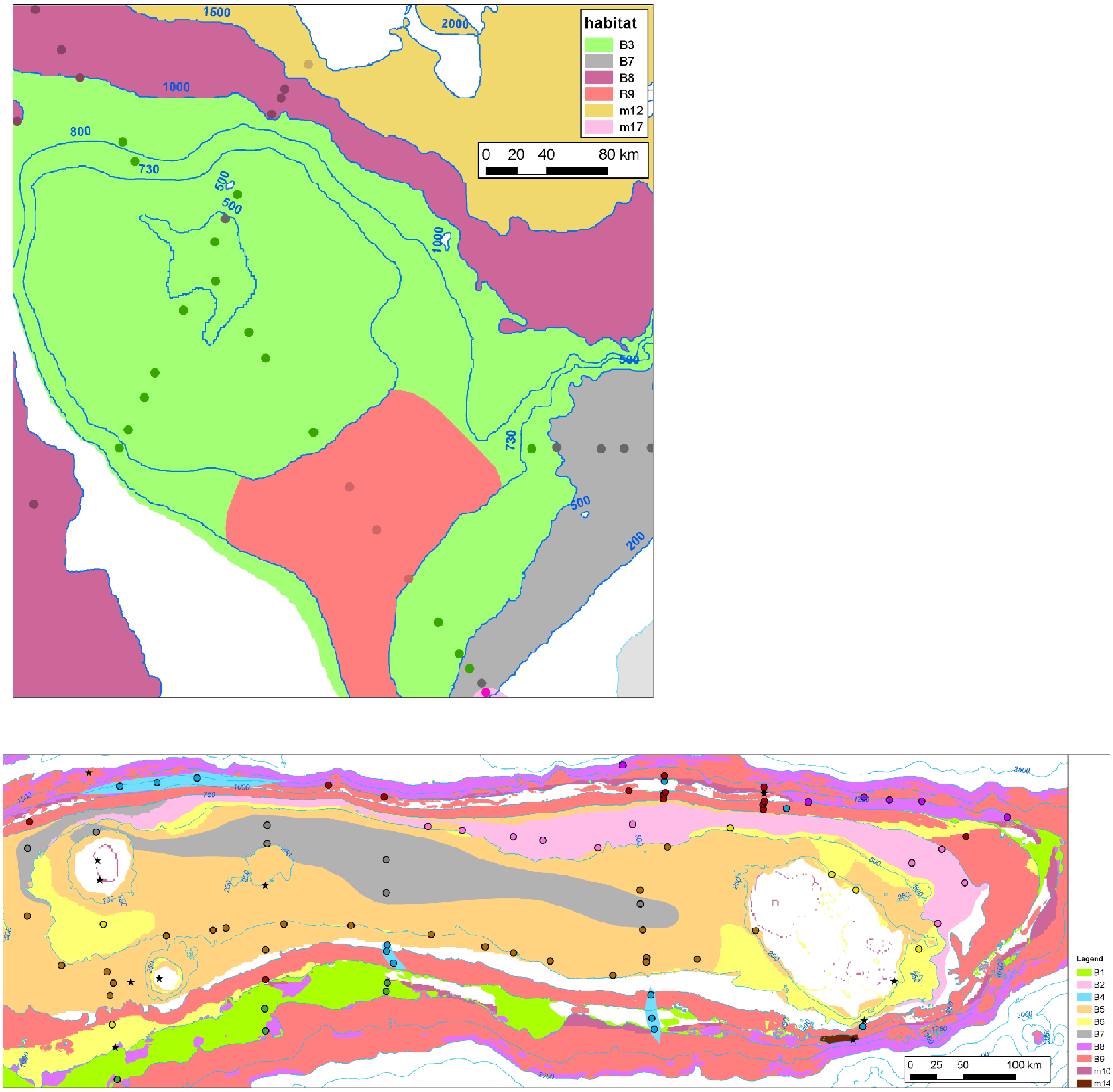

Figure 4. Spatial pattern of biotic habitats across the Challenger Plateau (upper) and the Chatham Rise (lower). Intensity of colours is used to indicate 3 levels of certainty: DTIS sampled positions (filled circles) are shown in intense colours indicating highest certainty; areas interpolated based on distinctive environmental characteristics related to specific biotic habitats or spatial kriging (as described above in Box 1) are shown in faded colours indicating lower certainty, and white areas are those for which we do not have enough information to predict biotic habitats. Stars represent sites designated as minor habitats.

Sensitivity to a Light Surface Disturbance

Method 1: Sensitivity based on biotic habitats

Using Method 1 (habitat method), all of the biotic habitats except B4, B6, B7, m12, m16, and m17, were rated "high sensitivity". Across the Challenger Plateau, 28 sites were classified as having high sensitivity to a light surface disturbance, and 8 sites were classified as having low sensitivity. Across the Chatham Rise, 81 sites were classified as high sensitivity and 15 as having low sensitivity to a Table 2 disturbance.

Across the Challenger Plateau region, most sites were classified as having high sensitivity to a light surface disturbance. Two sites in the shallow regions to the far south-east were classified as having low sensitivity, as were four sites along the eastern transect, one site in shallow regions in the centre of the plateau, and another in deeper waters in the far north-east (Figure 5).

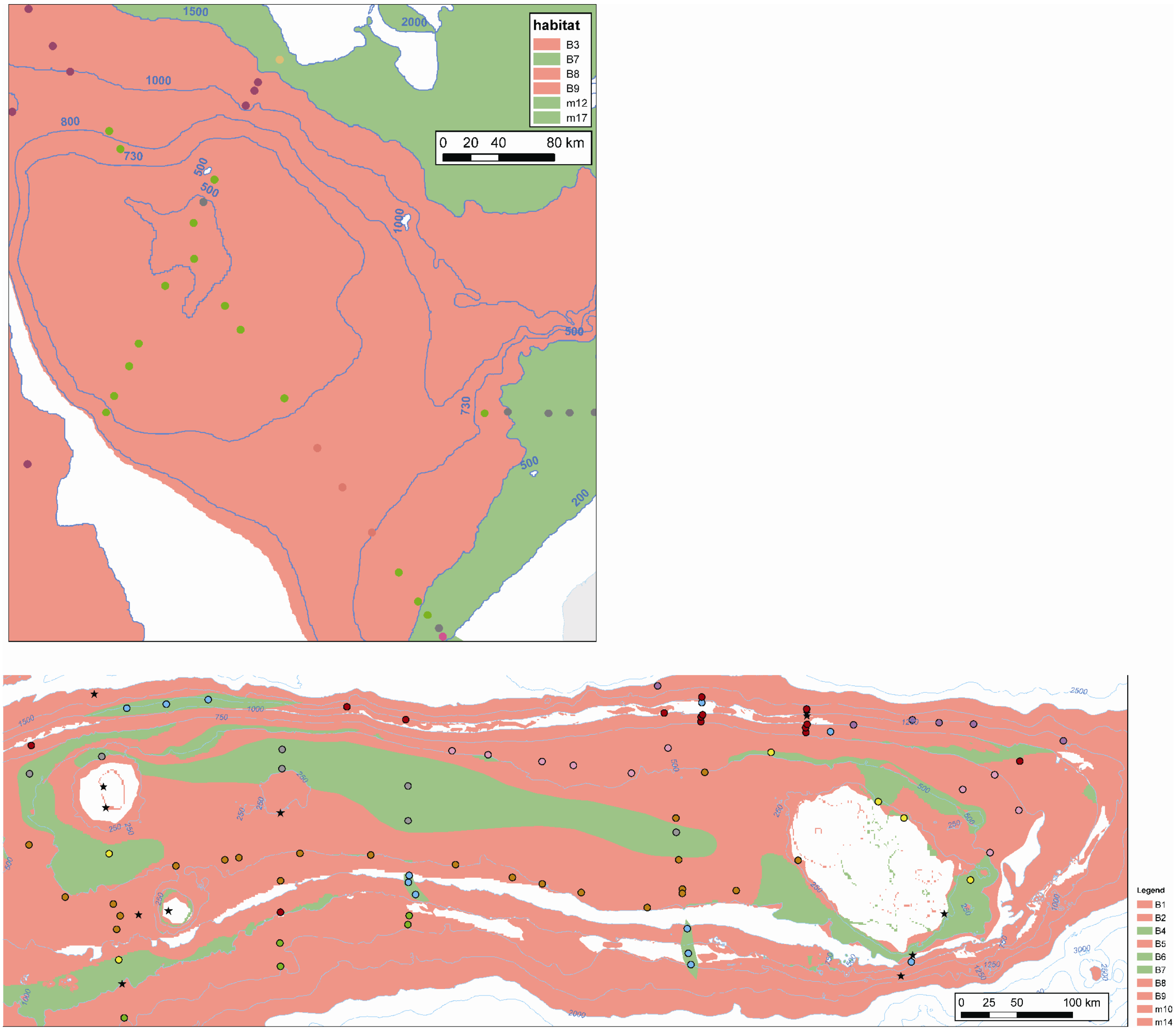

Figure 5. Habitat sensitivity categories (orange is high sensitivity, green is low sensitivity) to a light surface disturbance across the Challenger Plateau (upper) and Chatham Rise (lower), as determined using the habitat method. Site locations are shown by a dot, the colour of which indicates the biotic habitat type as per Figure 4.

Across the Chatham Rise region, most sites were also classified as high sensitivity, but there were more sites classified as having low sensitivity to disturbance, and these were distributed over a large part of the region (Figure 5).

Method 2: Sensitivity incorporating abundance

Using method 2 (abundance method), across the Challenger Plateau region, sensitivity to a light surface disturbance was generally higher in the southwest corner in 500 – 1000 m water depth (Figure 6 upper panel). Across the Chatham Rise region, sites with higher sensitivity were generally located in deeper waters (> 1000 m), particularly those along the southwest side of the Rise (Figure 6 lower panel).

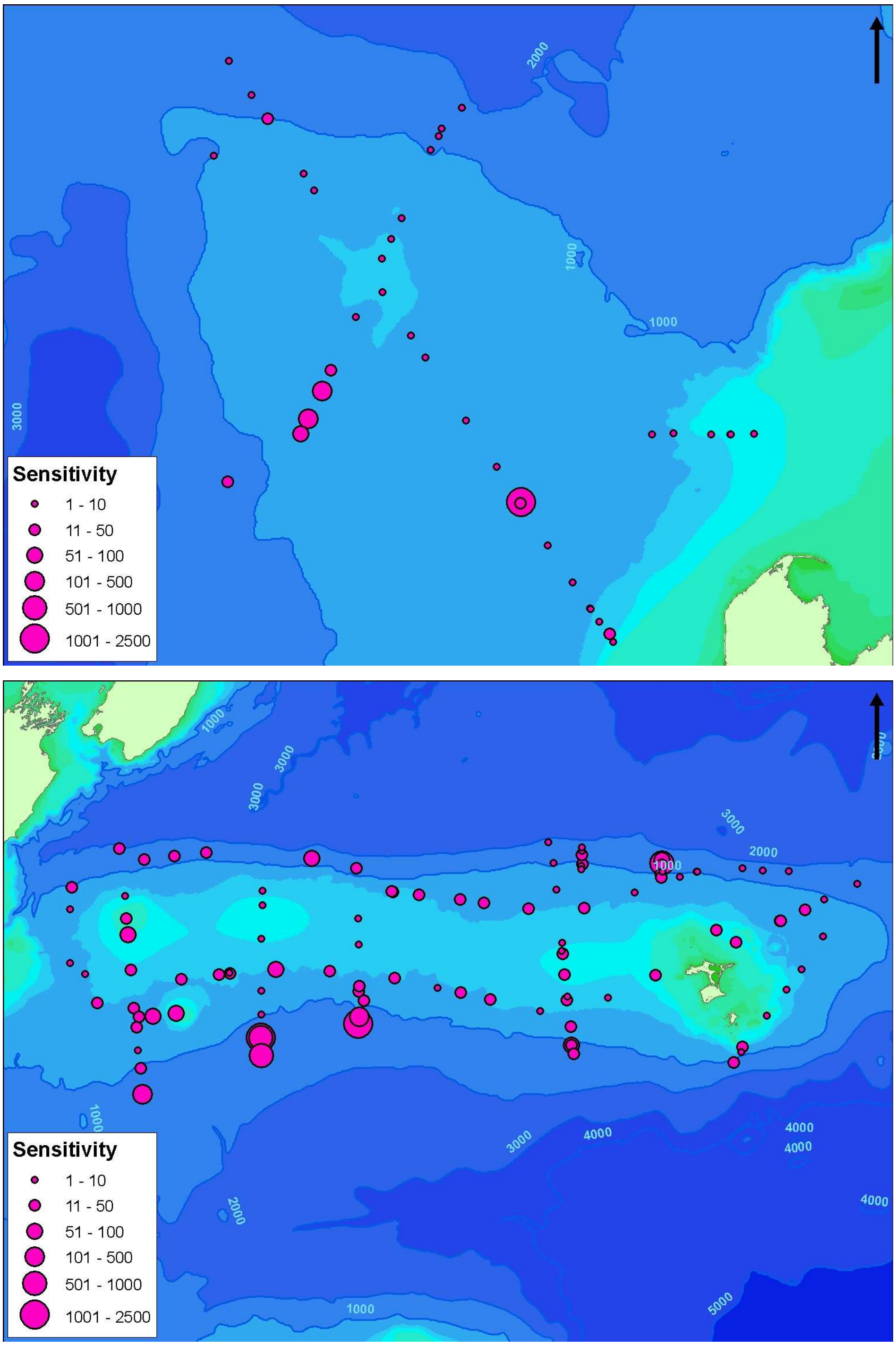

Figure 6. Site sensitivity to a light surface disturbance across the Challenger Plateau (upper) and Chatham Rise (lower), as determined using abundance method.

Using the abundance method, there were no significant differences (*t*=0.01, *P* =0.99) between sensitivity of the Challenger Plateau (mean sensitivity = 74.6) and Chatham Rise (mean sensitivity = 74.2).

Major biotic habitat B1 was assessed as by far the most sensitive habitat type, to a light surface disturbance (Figure 7). However, this biotic habitat type was found at relatively few sites; only one site in the Challenger region, and six sites in the Chatham region (southwest deep).

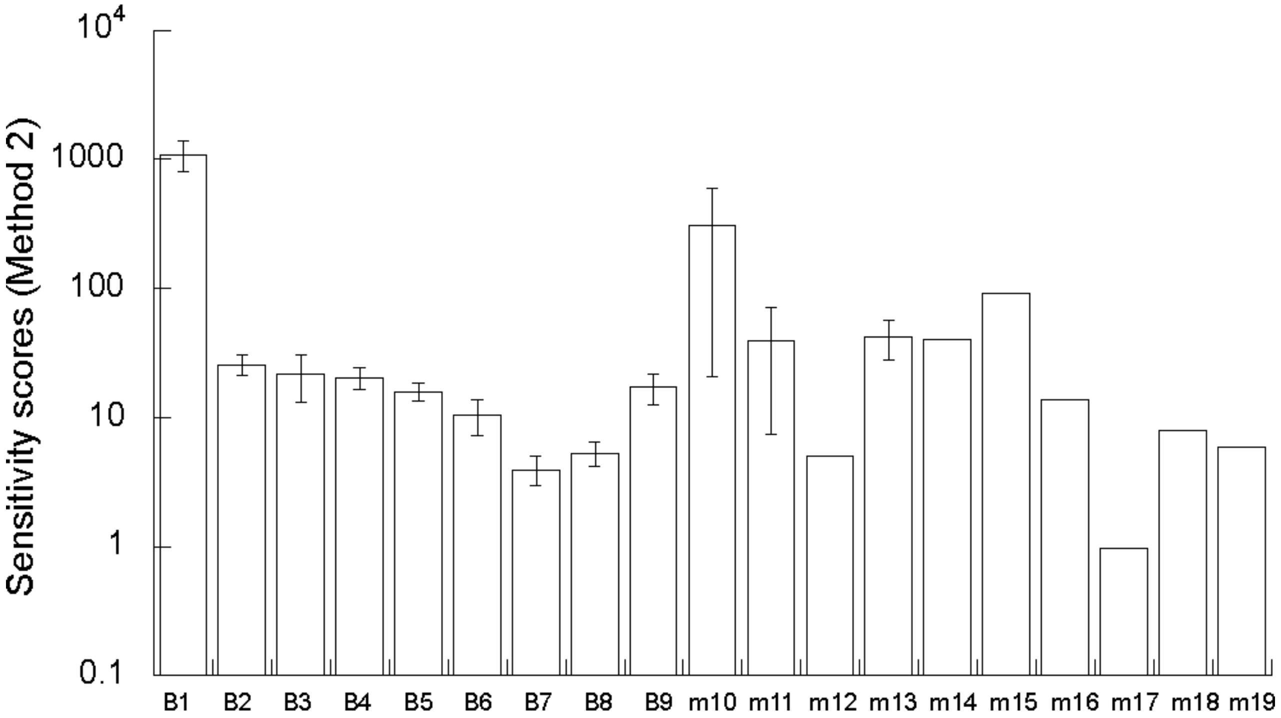

Figure 7. Mean and standard error of sensitivity values for the abundance method to a light surface disturbance for all biotic habitats.

Average sensitivity, based on the abundance method, to a light surface disturbance, in biotic habitats designated as high by habitat method was much higher than average values in biotic habitats designated as low by habitat method (97.7 *cf.* 11.5 ± 1.9).

Site sensitivity assessed using the abundance method showed a negative relationship with fishing intensity. Sites subjected to lower levels of fishing displayed a much larger range of sensitivities to light surface disturbance (Figure 8) while at higher fishing intensities, sensitivity values were consistently low. This overall pattern did not change when the Chatham Rise and Challenger Plateau data were plotted separately, but the analysis would be improved if there were more sites available in the areas of higher fishing intensity. It is also important to note that no sites were located in areas of highest fishing intensity (the maximum intensity index being 370.7).

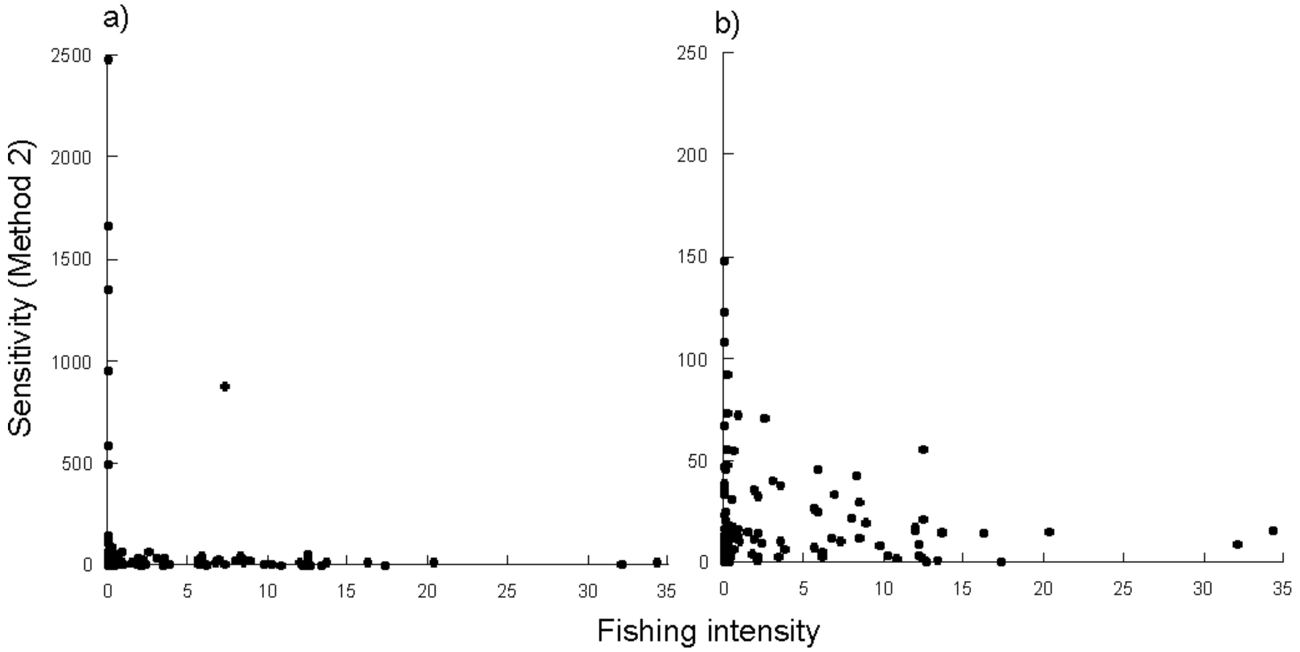

Figure 8. Relationship between fishing intensity (proportion of 25 km^2 cell trawled over 16 years) and site sensitivity to a light surface disturbance using the abundance method: a) full dataset, b) lower section of graph expanded to demonstrate that relationship holds even when extremely high values are removed.

Method 3: Relative sensitivity based on number of taxa (taxa method)

The proportions of taxa in each site that were categorised as being of high, intermediate, low, tolerant and favoured sensitivity to a light surface disturbance were very similar across both the Challenger Plateau and Chatham Rise regions ($p < 0.05$, Figure 9), with species in the low sensitivity category being the most abundant, and tolerant taxa being the least abundant.

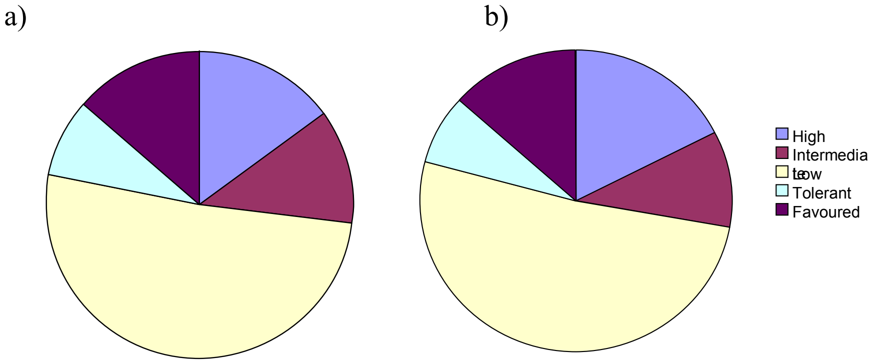

Figure 9. Mean proportions of taxa within each site categorised as being of high, intermediate, low, tolerant and favoured sensitivity to a light surface disturbance within the Challenger Plateau (a) and Chatham Rise (b) regions.

Percentages of taxa with high sensitivity to a light surface disturbance at each site differed according to biotic habitat, with around 30% of taxa in biotic habitat B1 and m18 assessed as highly sensitive (Figure 10). M15 had the highest percentage of taxa defined as high and intermediate sensitivity. B2, m10, m11 and m13 all had assemblages comprising around one-quarter highly sensitive taxa, whereas B6 and B7 had relatively low percentages of highly sensitive taxa (5–10%). Across all biotic habitats, the percentages of taxa with intermediate sensitivity to disturbance were relatively low (less than 20%) and more even (Figure 10).

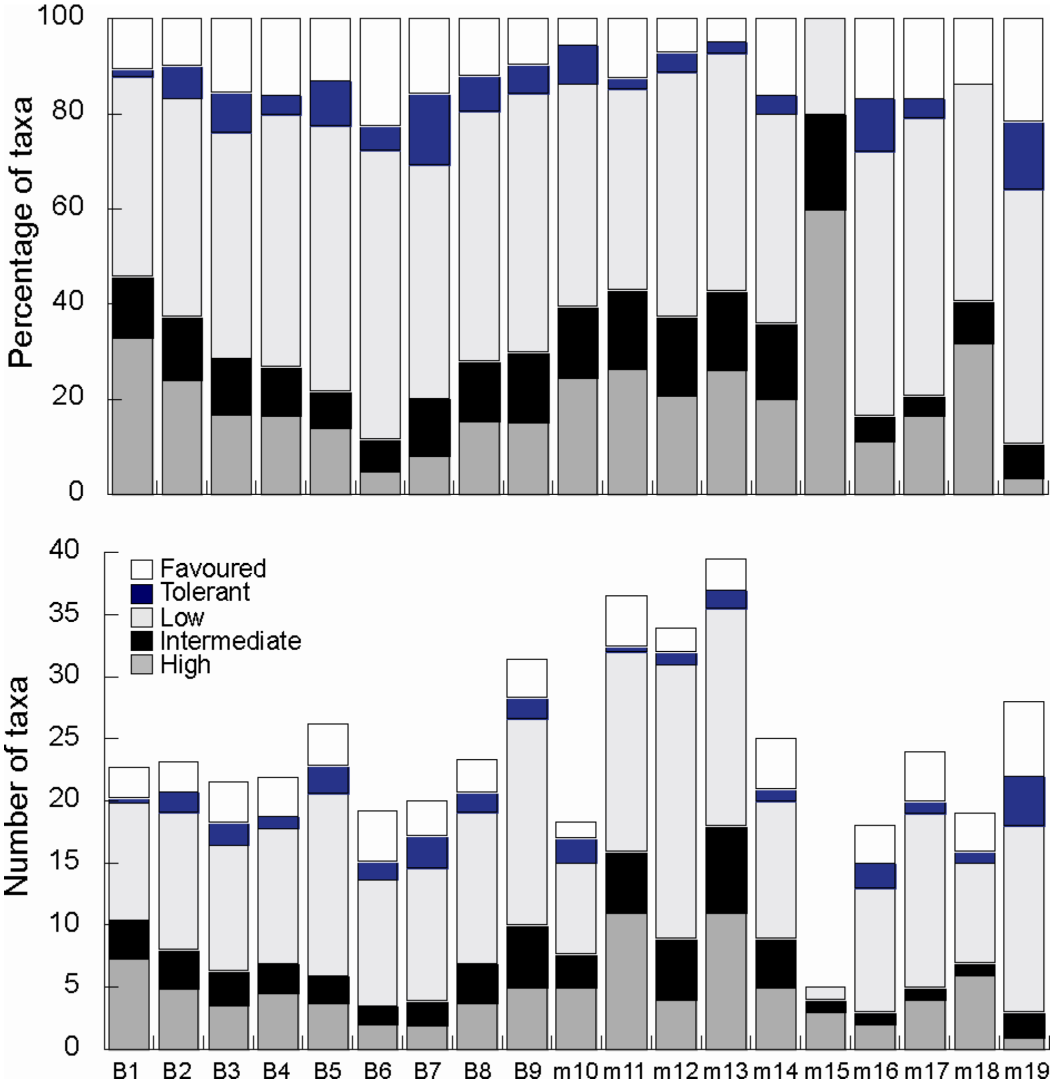

Figure 10. Mean percentage and numbers of taxa within each biotic habitat categorised as being of high, intermediate, low, tolerant and favoured sensitivity to a light surface disturbance across sites within the Challenger Plateau and Chatham Rise regions.

There were differences between the biotic habitats that had the greatest absolute number of compared to the highest percentage of taxa categorised as high sensitivity to a light surface disturbance (Figure 10). Whereas M15 had the highest on a percentage basis, m11 and m13 had the highest actual numbers of "high sensitivity" taxa. The biotic habitat with the lowest percentage of "high sensitivity" taxa was B6, which was one of the biotic habitats with the lowest numbers of "high sensitivity" taxa (along with B7, m16 and m19).

The average number of high sensitivity taxa in biotic habitats designated as being of high sensitivity to a light surface disturbance by the habitat method was higher than the average values in biotic habitats designated as low by the habitat method (4.5 *cf.* 3.3).

On both the Challenger Plateau and the Chatham Rise, sites with the highest numbers of high sensitivity taxa were scattered across the location (Figure 11). On the Challenger high numbers of high sensitivity taxa were less likely to be found in the shallow central ridge (< 500 m water depth), while on the Chatham Rise, they were less likely to be found on the southern side around the 1000 m contour (Figure 11).

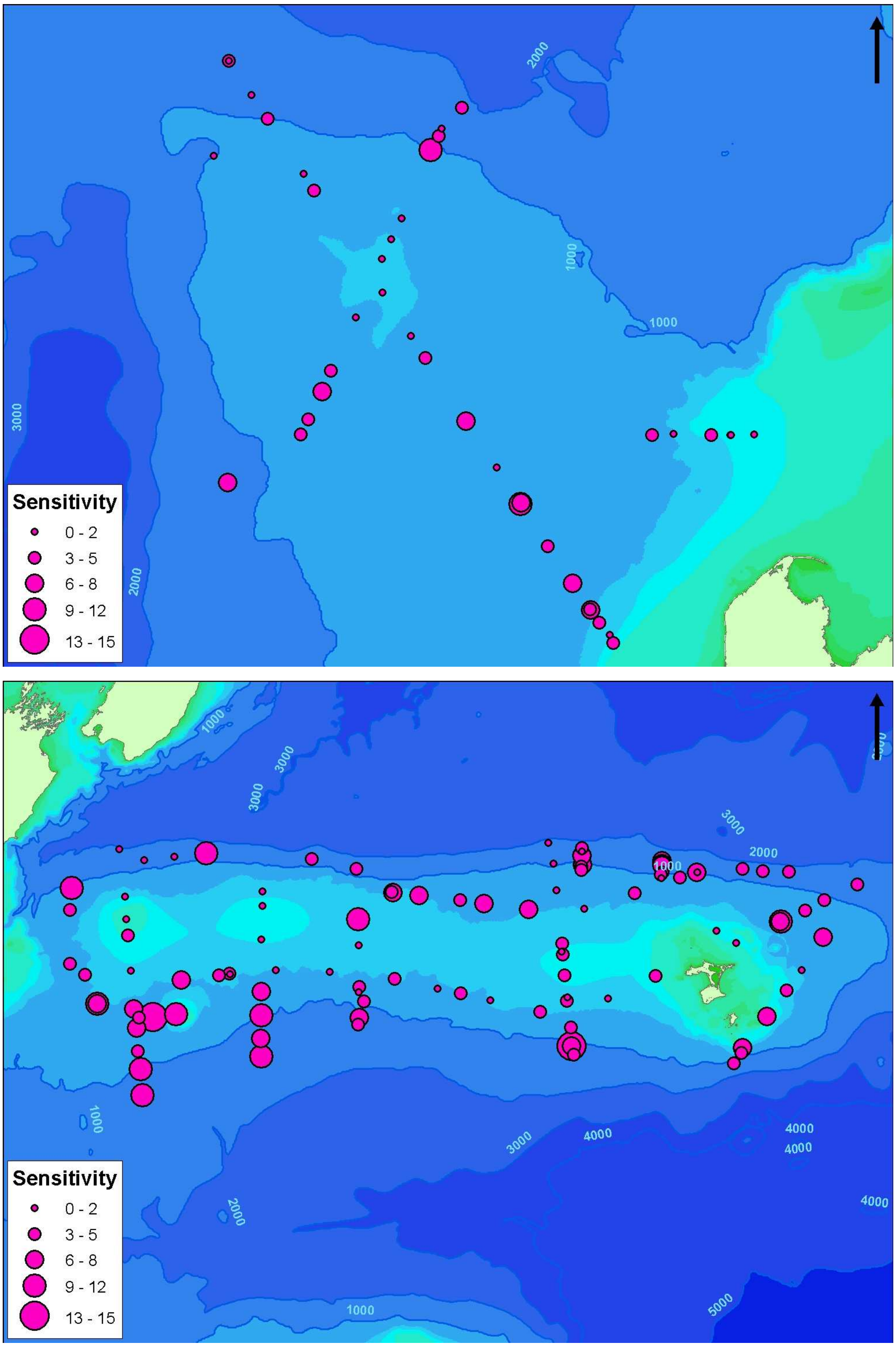

Figure 11. Number of taxa categorised as having a high sensitivity to a light surface disturbance at each of the sampled sites across the Challenger Plateau (upper) and Chatham Rise (lower) regions.

For taxa assessed as being intermediate in sensitivity to a light surface disturbance, highest densities on the Challenger Plateau were found at intermediate water depths (500 – 1000 m; Figure 12upper panel. Across the Chatham Rise, highest densities were found across the depth range, but similar to the pattern observed for numbers of highly sensitive taxa, high densities were infrequently found on the southern side around 1000 m (Figure 12).

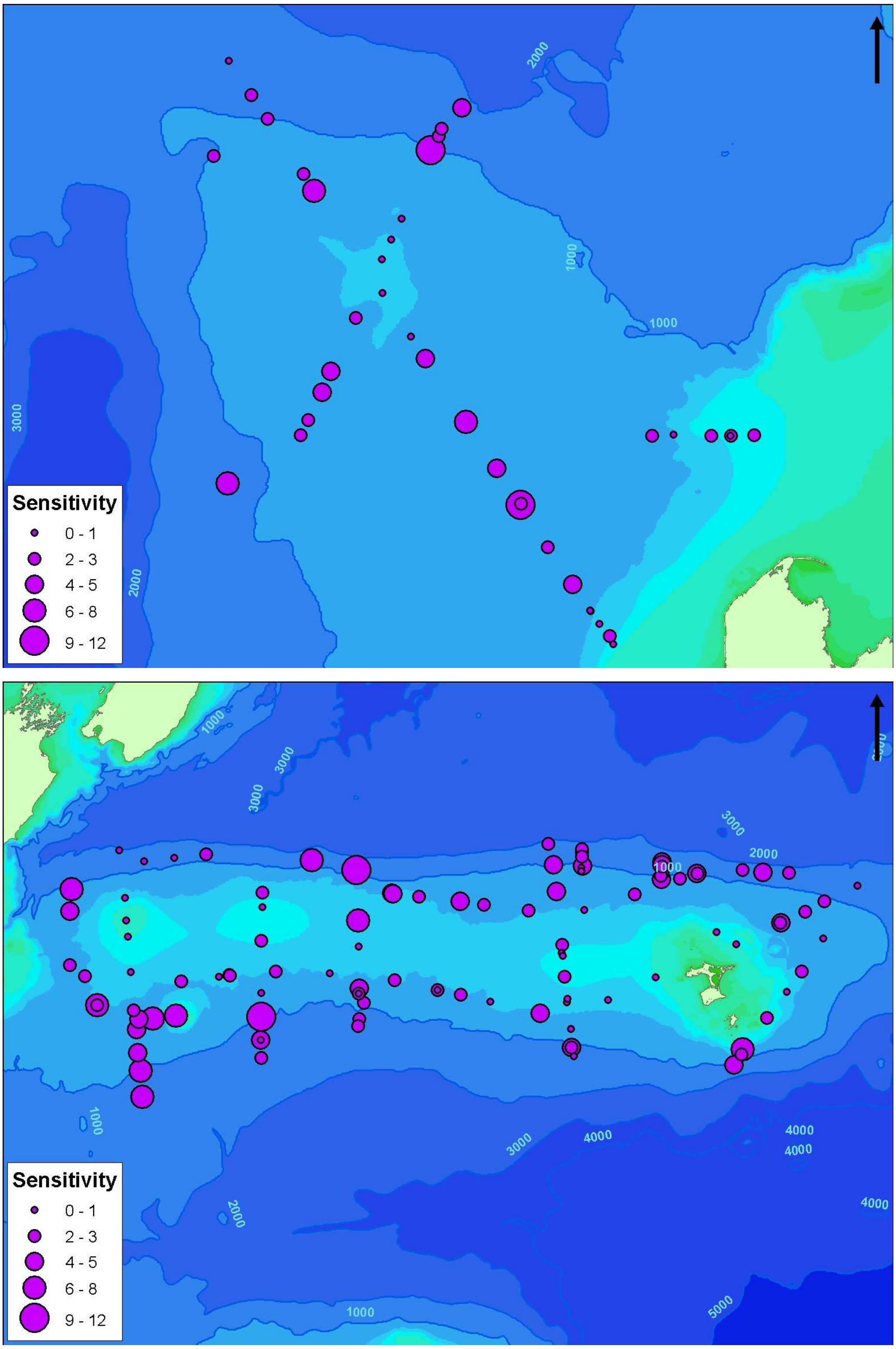

Figure 12. Number of taxa assessed as having an intermediate sensitivity to a light surface disturbance at each of the sampled sites across the Challenger Plateau (upper) and Chatham Rise (lower) regions.

The number of taxa at each site categorised as being of high sensitivity to a light surface disturbance, using the taxa method, declined with increasing fishing intensity (Figure 13a), and this pattern remained when the numbers were converted into percentages (Figure 13b), suggesting that the decrease was not being driven simply by decreased species richness. Numbers (Figure 13c) and percentage of taxa assessed as intermediate in sensitivity showed a similar pattern. In contrast, both the number and the percentages of favoured species at each site, showed no relationship with increasing fishing intensity (see Figure 13d for the relationship for number of taxa).

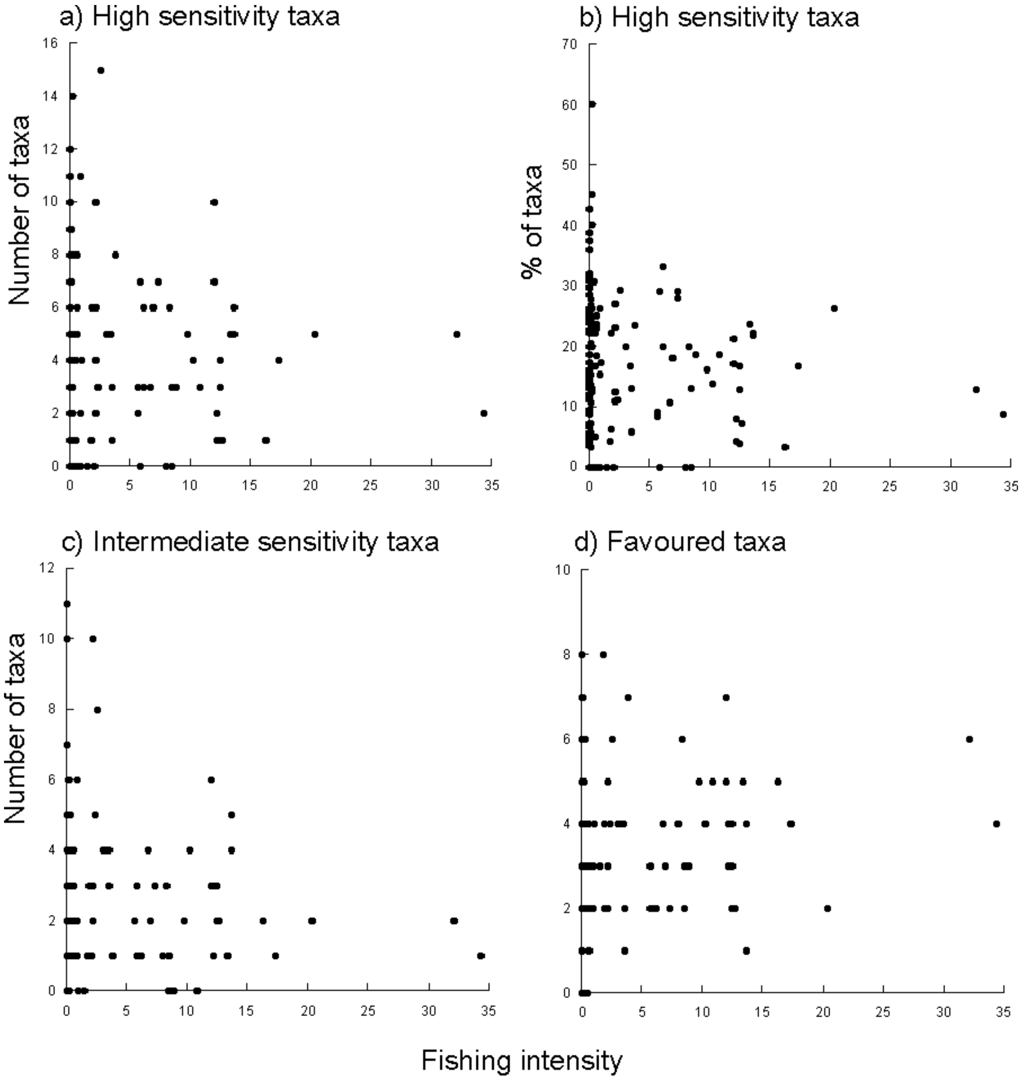

Figure 13. Relationship between fishing intensity (proportion of 25 km^2 cells trawled over 16 years) and site sensitivity to a light surface disturbance using the taxa method, a) number of taxa with high sensitivities, b) percentage of taxa with high sensitivities, c) number of intermediate sensitivity taxa, (d) number of taxa that may be favoured by disturbance.

DISCUSSION

This report covers a number of aspects relevant to the definition and utility of biotic habitat classification as applied to the Chatham Rise and Challenger Plateau Ocean Survey 20/20 surveys in 2006-2007. Key issues include: the spatial scale at which the biotic habitats are defined; the patterns in biotic habitat type observed; how they reflect dominant taxa, biodiversity, ecological function and environmental characteristics; and their relative sensitivity to physical disturbance.

Biotic habitats

Biotic habitats were defined at the scale of the sampling (average distance between sites 20 km), with many biotic habitats spatially consistent across a 75 km scale on the Challenger Plateau. On the Chatham Rise many biotic habitats were spatially consistent at a 100 km scale along depth contours and 50 km across depth contours.

The Challenger Plateau had fewer biotic habitats than the Chatham Rise and these biotic habitats were more functionally similar to each other than those observed on the Chatham Rise (Table 6). The three main biotic habitats of the Challenger Plateau (B3, B7 and B8) were characterised by mobile bioturbators, although B3, which was found extensively across the centre of the Plateau, also contained suspension-feeding hydroids and, closer towards the coast, biotic habitat B7 contained a moderate amount of biotic habitat structure in the form of polychaete tubes.

Different areas of the Chatham Rise generally had different biotic habitats, e.g., the northern versus the southern side of the Rise, the shallower central area versus the deeper areas, and the east versus the west. Chatham Rise biotic habitats exhibited a more diverse suite of biological traits (and thus potentially ecosystem functions) than the Challenger Plateau, with biotic habitats often dominated by suspension feeding and arborescent sessile species, including sponges, anemones and bryozoans (Table 6).

In deep soft-sediment marine ecosystems, important functions delivered by the benthic organisms include biodiversity, habitat engineering, sediment stability/transport, nutrient fluxes at the water-sediment interface, secondary production and carbon sequestration. All of these underpin the delivery of important ecosystem services. This range of functions occurs as a result of a full range of biological traits. Suspension-feeders play an important role in benthic-pelagic coupling, enhancing fluxes of nutrients, oxygen and carbon between the water and the seafloor. Bioturbating organisms increase sediment permeability and water and oxygen content, destabilising chemical gradients in pore water, and influencing rates of remineralization and inorganic nutrient efflux. Both bioturbating and suspension-feeding organisms strongly affect productivity of the benthic system. Finally, species that provide habitat structure on the seafloor (e.g., tube worms, sponges, bryzoans) increase productivity by providing both a surface for other individuals to grow on, and, if densities are sufficient, a refuge for other species from predators, often acting as nursery areas for juveniles. Many of the biotic habitats observed on both the Challenger Plateau and the Chatham Rise, thus, provide important ecosystem functions.

Comparison of methods for assessing sensitivity

1. Certainty in estimates of sensitivity

The three methods, based on either habitats, abundance or number of taxa, evaluated within this study provide different levels of accuracy and uncertainty for different aspects of assessment of sensitivity (Table 8).

Table 8: Relative levels of certainty (L, low; M, medium; H, high) in evaluating site and biotic habitat vulnerability to disturbance based on the three methods used in the present study, for each of the tasks required by each method. Blank cells appear where the method does not require that task.

TASK	LEVEL OF CERTAINTY		
	HABITAT METHOD	ABUNDANCE METHOD	TAXA METHOD
Estimate number of taxa	H	M	L
Estimate abundance	M	M	
Determine taxon traits	H	M	L
Determine sensitivity from traits	H	H	H
Assign sites to biotic habitats	M		
Determine characterising taxa	H		
Determine dominant taxa	H		

Gear type used to sample the benthos will have a big influence on estimates of sensitivity because of differences in gear selectivity. In this study, we focussed on using the DTIS video data for two reasons: (1) DTIS samples were the most spatially comprehensive, and (2) the sampling provided the highest possible sample area per site, which should result in higher accuracy in estimating the number of taxa at a site, as well as more certainty in estimating their abundance. In contrast to other sampling gear such as the sediment corer and epibenthic sled, however, DTIS video sampling provides data on fewer taxa than other methods because detection of organisms is generally limited to larger taxa, and taxonomic identification is more challenging.

Estimating the number of taxa. Sensitivity based on taxa is the only method affected by lack of certainty around whether we adequately sampled taxa richness. A relative quantification of the uncertainty for this method could be gained by using the difference between proportions of rare taxa observed here and those found in other deep sea soft-sediments. However, this would require the assumption that the number of rare taxa is not affected by disturbance, which is certainly not the case in shallower waters (Ellis et al 2000, Hewitt et al 2009).

Estimating abundance. Lack of accuracy in estimates of abundance is usually driven by the patchy spatial distributions that species frequently demonstrate. Certainty is however increased through the sampling of large areas by the DTIS video system.

Defining the biological traits for taxa. We have limited knowledge of the biological traits of many taxa, especially those that rare. The traits we have used are amongst the most well-known (sedentary, predator/scavenger, fragility) and most easily determined from the video data (e.g., erect habitat). However, we assessed the effect of lack of knowledge of traits by changing the assignment of the taxa to either a more sensitive or a less sensitive trait. This analysis suggests that uncertainty associated with determining traits is generally low for sensitivity based on the taxa method (Table 9). Uncertainty is higher for sensivity based on the abundance method, driven mainly by the very high numbers of *Ophiomusium lymani* in some samples. Interestingly, however, the general relationship to fishing intensity did not change with the changes in trait assignment.

Table 9: Average (±standard error) percent change in sensitivity ranking (Abundance method) and number of taxa in the high and intermediate sensitivity categories (Taxa Method). Overestimate = uncertain trait is changed to a more sensitive rank, Underestimate = uncertain trait is changed to a less sensitive rank

	ABUNDANCE METHOD	TAXA METHOD , NUMBER WITH HIGH SENSITIVITY	TAXA METHOD , NUMBER WITH INTERMEDIATE SENSITIVITY
Overestimate	15.5±3.8	0	13.3±1.7
Underestimate	51.6±4.6	0	5.5±1.2

Determining sensitivity from traits. Published information on the effects of different types of physical disturbances on certain biological traits were used, nevertheless we assessed this source of uncertainty. Low levels of uncertainty were associated with the Abundance method (13.1±3.5) and the high sensitivity category of the Taxa method (14.3±1.8). However, the number of taxa with intermediate sensitivity (Taxa method) exhibited higher levels of uncertainty (~26%).

Assigning sites to biotic habitats. An assessment of how well this was achieved can be gained from both the relative degree of dissimilarity within and between biotic habitats and the percentage of times a replicate sample from the same site was assigned to a different DTIS group (Objective 9; Floerl & Hewitt 2010). While the relative degree of dissimilarity was high (~0.7 for most biotic habitats), assignment to different groups was low (~0.2).

Determining characterising taxa. The statistical method developed for this (SIMPER, Clarke 1993) is robust to determining how consistent the presence or abundance of a taxon is across a set of sites and gives the percentage contribution of the taxa to the similarities in community composition within and between groups of sites. Within Objective 9 any uncertainty related to defining the characterising taxa was reduced to a low level by ensuring that the characterising taxa had to contribute at least 5% to overall similarity. Note that characterising taxa are not necessarily abundant.

Determining dominant taxa. This is a standard technique and uncertainty is largely related to the degree of within- and between-site heterogeneity.

2. Overall assessment of utility of methods for defining sensitivity

Defining sensitivity based on biological traits that render individual organisms sensitive to a particular type of physical disturbance should prove to be a powerful tool in the future. At present, it is in a developmental stage around the world. Here, we have tested three different methods of compiling information from the taxon level to a community/area level, using a physical disturbance, such as a trawl, that drags over the surface of the sediment but is not focussed on removing sediment or organisms, or digging deeply into the sediment.

Method 1, based on biotic habitats, is classified as the 'worst-case' scenario (using terminology from Tyler-Walters et al. 2009), appeared the least useful method. It is most likely to be insensitive to assessing impacts because, as long as a single individual of a highly sensitive species characterises the biotic habitat, the biotic habitat (and thus the site) is designated as highly sensitive. Thus, monitoring of a site over time is unlikely to pick up a change, even though the abundance of sensitive organisms may have declined markedly. The compression of the assessment towards the high end of the sensitivity spectra will also provide managers with little scope by which to make decisions about priority areas for protection. If all areas are classified as sensitive, how is prioritisation to be carried out? However, the method may be useful to indicate that the area does contain sensitive taxa and thus may benefit from protection with an aim to restoration.

Method 2, relative sensitivity based on abundances, demonstrated a broad range of values across all sites in response to the Table 2 disturbance. Although abundant species might be over-represented in the final scores, with the effect of potentially under-estimating the relative sensitivity of a site, this method showed a surprisingly strong negative relationship with fishing intensity. If this method is used, it should be kept in mind that it is likely to provide a conservative estimate of the effects of disturbance, as rare species will have a limited influence on the overall ranking of a given site.

Method 3, sensitivity based on the number of taxa in different sensitivity categories, also demonstrated a broad range of values across all sites in response to the light surface disturbance. It does incorporate rare species, and both the number and proportion of taxa in the high and intermediate sensitivity categories showed a reasonably strong negative response to fishing intensity.

Our recommendation is that the relative sensitivity based on abundances and the number of taxa in the high and intermediate categories from the method based on number of taxa provide the most useful assessment of sensitivity of sites and biotic habitats, despite the associated uncertainties. If they are both used in future, observing consistent patterns with both methods will increase confidence in the results. We have applied the approach in a conservative fashion and also recommend that further refinement of the approach is needed (through improved understanding of biological trails and sensitivities) to derive a less biased analysis.

Sensitivity of the Challenger Plateau and Chatham Rise

1. Patterns related to a light surface disturbance

Regardless of the method used to determine sensitivity to the light surface disturbance, no real differences were observed between the Challenger Plateau and Chatham Rise, with both locations showing a full range of values.

However, within each location, slightly different patterns of sensitivities to the light surface disturbance were apparent depending on which methods were used. While methods based on both abundance and taxa suggested that the southwest corner of the Challenger Plateau was sensitive, the taxa method suggested the deeper areas to the northwest and the < 500 m central ridge were the least sensitive. On the Chatham Rise both methods identified the southern side around 1000 m as being least sensitive, but the taxa method again identified more areas as having higher sensitivity than did the abundance method. It is interesting to note that the area in the Chatham Rise identified by both methods as lacking high sensitivity taxa correspond to the area characterised by demersal fish communities including hoki and ling (Leathwick et al. 2006), with much of the area subjected to bottom fishing (Figure 14; Ministry of Fisheries project BEN200601, Baird et al. in review).

Importantly, comparisons of taxa sensitivities with available information on known distribution of fishing effort over a 16 year period suggest that the Chatham Rise, despite its biological diversity, is being affected by fishing. Fishing appears to constrain the variability of richness and abundance of sensitive taxa such that maximum richness and abundance decreases with recorded fishing effort (see Figure 8 and 13). The loss of traits and trait diversity in turn implies constraints on the functionality of the ecosystem, as sensitive taxa generally are those that provide erect habitat structure on the seafloor, are large and long-lived and frequently are suspension-feeders.

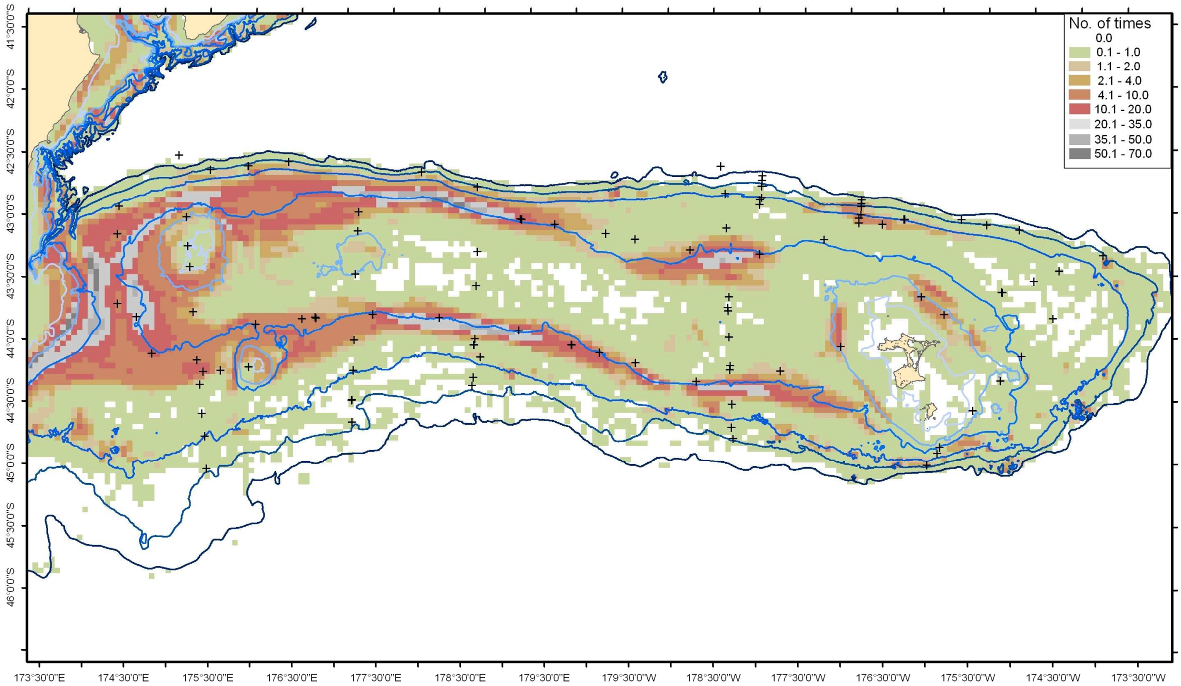

Figure 14. Distribution of fishing intensity as a proportion of 25 km^2 cell trawled over 16 years (Ministry of Fisheries project BEN200601, Baird et al. in review) on the Chatham Rise. Sampled sites are overlaid as crosses.

2. Other factors affecting sensitivity

The present study evaluated the efficacy of three different methods for assessing the sensitivity of benthic biotic habitats to physical disturbance. The size of area disturbed (by a single tow) is assumed to be sufficiently small that the mobility of some taxa will allow them to move back into the area post-disturbance to utilise new food resources. The depth to which sediment is disturbed is also assumed to be only of the order of 0–2 cm, such that deeper-dwelling individuals are unaffected and tube dwellers or fast burrowers could withdraw to safe depths. Many more taxa will be sensitive to activities that disturb deeper into the sediment.

However, assessing sensitivity, especially sensitivity based on individual traits, is only part of any assessment of potential impacts. Impacts on population dynamics and meta-communities are also important and their magnitude will be affected by the history and current areal extent and frequency of the disturbance, and potential recovery rates of the impacted benthic community. Frequently occurring disturbances of the surface of the sea floor over large areas (such as may occur with bottom trawling) may result in the inability of fragile, long-lived species to maintain population levels, changing communities to those dominated by opportunistic species (Thrush et al 2005). In disturbed systems, recovery rates are also frequently controlled by how isolated the disturbed area is from potential sources of colonists, and whether environmental characteristics such as sediment type and chemical makeup have changed.

Future research

The data collected by this Ocean Survey 20/20 project offer an unparalleled opportunity to increase our knowledge of many of the biological traits needed to assess sensitivities to different disturbances. For example, analysis of the different types of taxa (and their abundances) collected across environmental and anthropogenic gradients will improve our ability to determine environmental drivers and predict how taxa and diversity will be impacted by anthropogenic disturbance. The DTIS imagery (both video and still cameras) can be analysed to increase our knowledge of species behaviour (feeding, mobility, small scale patchiness and living position) all of which will increase our ability to predict impacts and assess ecosystem function. For any management use of these techniques at the scale of the Chatham Rise and Challenger Plateau, it is important to note that despite the broad coverage of the 2007 OS 20/20 surveys, there are likely to be some significant benthic biotic habitats are not represented and there others that we do not yet know of (Levin and Dayton 2009). Comparable data from surveys other than the OS 20/20 voyages already exist and could be incorporated in analyses to provide representation of biotic habitats not covered by the 2007 surveys. Examples include biotic habitats on the Westpac hills on Challenger Plateau, for which DTIS and epibenthic sled data are available.

Moreover, analysing the data across the very broad scales utilised in these projects will allow us to assess the relative importance of regional species pools and spatial connectivity, and environmental gradients, on the maintenance of marine biodiversity in New Zealand.

Finally, further research funded under Ministry of Fisheries contract #ZBD2009-25 (Predicting impacts of increasing rates of disturbance on functional diversity in marine benthic ecosystems) is planned to expand on the results reported here, and place the relationships between functional traits and fishing effort within the context of a conceptual model of disturbance and recovery dynamics. The data from the Oceans Survey 20/20 Challenger/Chatham series of reports will be used in this new project to quantify rare species abundance, biomass, functional diversity, relative importance of habitat structure, and ecosystem productivity of the different biotic assemblages to parameterise recovery dynamics within the disturbance/recovery model.

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PUBLICATIONS

NA

DATA STORAGE

Data generated by this objective is currently held in the ZBD200701A database (MS Access) and consists of the biotic habitat identifier for each site, taxon information, and the site sensitivities based on the three methods. On completion of the review process, these data will be submitted to the Ministry of Fisheries data manager at NIWA for loading in to the BIODS database.