



Monitoring change in benthic communities in Spirits Bay

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EXECUTIVE SUMMARY

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Spirits Bay, at the northern-most tip of the North Island of New Zealand, is an area of cultural significance to Maori and also supports important commercial fisheries. Voluntary (applying only to the scallop fishery) and then regulated (applying to all mobile bottom fishing) closures were introduced in 1997 and 1999, respectively, in response to concerns over the effects of fishing on the highly unusual, sponge, bryozoan and hydroid dominated epifaunal community observed in the area.

Following a broad-scale survey of the area between North Cape and Cape Reinga in 1999, surveys focussing on a more limited area have been conducted in 2006 and 2010. These surveys have collected infaunal community samples through grab sampling, and data on epifaunal communities through seabed photography. The survey in 2006 also included acoustic mapping components, and the 2010 survey was stratified on the basis of this.

Fishing effort data for the study area were compiled from Ministry of Fisheries records and information provided by the scallop fishing industry, and the benthic communities were examined in relation to environmental variables and fishing terms, using multivariate approaches (DISTLM and CCA).

The analysis of both epifaunal and infaunal community data consistently identified year, habitat and depth effects, but the fishing terms were also found to explain a significant component of the overall variance. The models for the epifaunal communities explained more of the variance than those for the infaunal data. The combined fishing terms typically explained 15–30% of total variance (median 20%) and roughly half of the explained variance, comparable with previous studies conducted in New Zealand.

The community data were examined with CCA to differentiate between the various significant effects, allowing species responses to individual fishing terms to be identified. For both data sets, different species were found to be sensitive to the different fishing effort terms, which is predicted to reflect the different types of disturbance associated with the gears. Comparison with previous epifaunal work on sensitivity to fishing disturbance demonstrated that species identified as most sensitive to fishing in the present analyses had previously been categorised as either sensitive to dredging disturbance, or moderately sensitive to dredging but growing to a medium or large individual size. Most of these species were also considered to have a poor probability of recovery following disturbance.

OBJECTIVES

OVERALL OBJECTIVES:

1. To survey Spirits Bay and Tom Bowling Bay benthic invertebrate communities according to the monitoring programme designed in ENV2005-23.

SPECIFIC OBJECTIVES:

1. To survey Spirits Bay and Tom Bowling Bay benthic invertebrate communities according to the monitoring programme designed in ENV2005/23.
2. To assess changes in benthic communities inside and outside the closed area since 1997.

1. INTRODUCTION

Spirits Bay (Piwhane) is at the northern-most tip of the North Island of New Zealand (Figure 1), between North Cape and Cape Reinga. Ngati Kuri have been the kaitiaki of these waters for at least the last 700 years, but the area is of great cultural and spiritual significance to all Maori, as the pathway to the spiritual world of their ancestors. The area also supports several commercial fisheries including (but not restricted to) an important part of the Northland scallop fishery and some bottom trawling for snapper and trevally, and recreational fishing interests.

The scallop grounds in the area have been occasionally surveyed since 1996 to estimate abundance and population size frequency of scallops, and to estimate potential yield on the basis of these data (Williams et al. 2007). During the 1996 northern scallop stock survey carried out by NIWA (for the Ministry of Fisheries), very unusual dredge bycatch was observed in the 40–50 m depth range in Spirits Bay. This bycatch was taken mostly in the area specified by fishers as the area where most scallops had been caught during 1995 (stratum 93). Specimens were later identified by NIWA specialists. The fauna was so unusual (including a high proportion of local endemic species) within stratum 93 (Figure 1) that the Ministry was alerted to the issue, and further samples were taken during the 1997 scallop stock survey. The additional samples seemed to confirm that the community was highly unusual, dominated by sponges, bryozoans, and hydroids, and had a very high proportion of new or endemic species. Given the limited sampling, it was thought unlikely that the full diversity of this unusual community had been determined. The restriction of sampling to strata designed for scallop surveys constrained our knowledge of the geographical extent of the community. Other samples in NIWA collections of macrofauna from similar depths around Northland were found to be quite different, suggesting that the community found in Spirits Bay and Tom Bowling Bay was uncommon around the mainland. Some of the rare taxa had been recorded in other areas of high current flow such as the Three King Islands, Ranfurly Bank, and Cook Strait, but many were apparently local endemics.

In response to the levels of bycatch, a voluntary closure to dredging was established by fishers in 1997 (north of a line at 34° 22' S, Figure 1). The foliose nature and large size of much of the colonial, filter-feeding fauna in Spirits Bay suggested that, not only was the community unique, but it was also likely to be susceptible to damage through suffocation and burial during the course of bottom dredging for scallops (O'Shea 1996). Moreover, there was also good reason to suppose that the physically highly structured nature of the community was beneficial for spat settlement and survival (Walters & Wethey 1996, Talman et al. 2004). Similar benefits for scallops have also been identified for areas of biogenic maerl habitat (Kamenos et al. 2004). Serious curtailment of recruitment in a commercial fishery for bay scallops has been described (Peterson et al. 1987) following degradation of a seagrass community by mechanical clam harvesting. Destruction of the colonial, filter-feeding fauna of Spirits Bay may, therefore, lead to recruitment problems in the scallop fishery as well as the loss of an important ecological archetype.

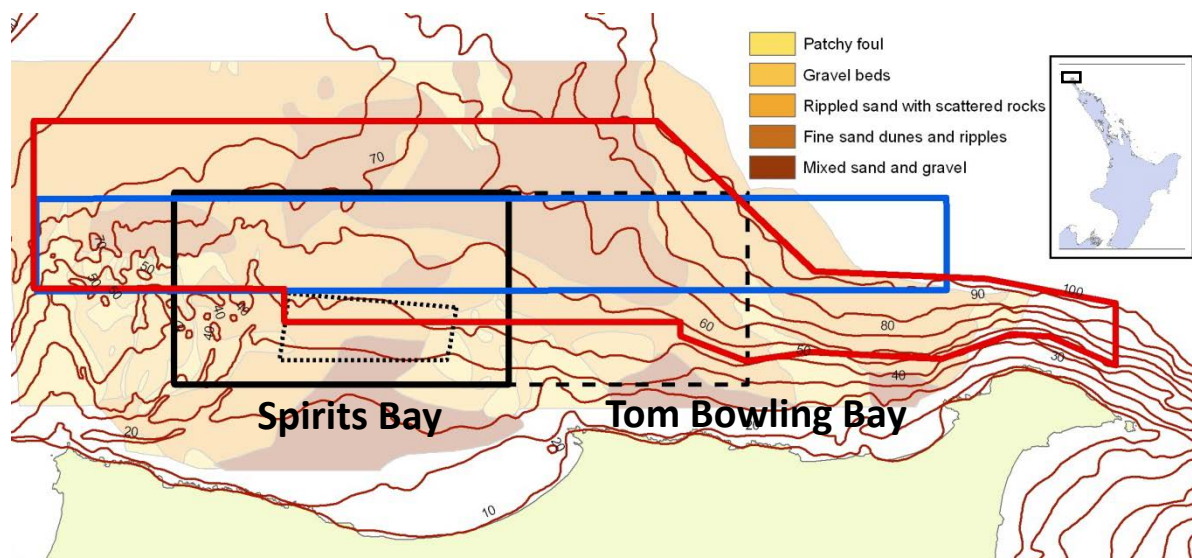


Figure 1: Map showing area surveyed during ENV9805 (colours from habitat map generated from side-scan sonar in 1999), the areas closed to fishing in the region, and the primary (solid black line) and secondary (dashed black line) survey areas surveyed in ENV2005-23. Black dotted line represents scallop survey stratum 93. Depths in metres. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997). Small box in inset map indicates region of study.

Because of concerns over the effects of fishing on benthic communities in the area, the Ministry of Fisheries commissioned research to examine the nature and extent of the sponge- and bryozoan-dominated community between North Cape and Cape Reinga (ENV9805, conducted between October 1998 and September 2000). This project conducted a broad scale survey across the whole area (Figure 1), and was seen as a first step in assessing the extent to which mobile bottom fishing gear affected benthic community structure in the area. The project (Cryer et al. 2000) identified a probable link between dredge fishing for scallops and a decline in the unique and highly diverse fauna in part of Spirits Bay. It was inferred that associated species, especially large, fragile, or long-lived forms, were likely to be adversely affected by fishing, that biological diversity was likely to be reduced, and that habitat of particular significance for fisheries management (e.g., that containing much “spat catching” foliose colonial fauna) was likely to be affected. On the basis of these inferences, the Ministry of Fisheries introduced a regulated closure (covering the voluntary closed area and also extending further south towards the eastern extent of the area) to mobile bottom fishing methods (trawling for finfish as well as dredging for scallops) in 1999. As a second step, the Ministry funded project ENV2005-23 to design a more focussed programme to monitor the changes in the benthic communities in the specific area around stratum 93 (Figure 1). ENV2005-23 (Tuck et al. 2010) provided the second focussed survey in a time series to monitor changes in benthic communities in the area. Significant differences were identified between the “voluntary”, “regulated” and “open to fishing” areas, and species contributing to differences in communities included those previously identified as being most vulnerable to the effects of fishing. However, the community differences could not be attributed specifically to fishing, owing to environmental gradients and uncertainty over the history of fishing impacts in the area. No significant differences were identified within areas between the 1999 and 2006 surveys. Additional information is also available from the wider area survey conducted under ENV9805 but direct comparisons with that study are complicated by differences in sampling approaches and scale.

The current project (BEN2009-02) provides the third survey of the benthic communities in the area, and the second focussed particularly on the area around stratum 93.

2. METHODS

2.1 Study area

During the study in 2006 (Tuck et al. 2010), sidescan and multibeam sonar surveys were conducted to provide data on broader scale habitat patterns. These data were used to generate an acoustic habitat map for the area (on the basis of expert interpretation of the multibeam bathymetry and backscatter, and sidescan mosaic), which was then ground truthed with video and still images from the 2006 survey stations (Simon Bardsley, NIWA, pers. com.). A similar approach has previously been used for habitat classification within the Bay of Islands OS20/20 studies (Mitchell et al. 2010). The resulting map with allocated habitat types is shown in Figure 2 and Figure 3, and was quite similar to the habitat maps generated within ENV2005-23 using the NOAA Benthic Terrain Modeller software (BTM) (Lundblad et al. 2006) and interpretation of the sidescan mosaic (Tuck et al. 2010).

The most distinctive features identified were the large sand waves to the west of the study area. To the southeast there is an area of coarser sediment and rocky outcrops, with much of the remainder of the area classified as sandy. Areas of sandwaves were identified within different regions of the map, although the BTM analysis suggested that sandwaves were present throughout the area, but were less obvious in some areas, depending on their wavelength and amplitude (Tuck et al. 2010). A patch of distinct habitat in the centre of the northern edge of stratum 93 was also identified (described as shell/sand), coinciding with the area previously identified as having particularly high sponge biodiversity (Tuck et al. 2010).

2.2 Fishing pressure

Data on the spatial pattern and intensity of scallop dredging are available from the Ministry of Fisheries Catch and Effort Landings Return (CELR) data. The CELR data records hours dredged for each day by vessel and scallop fishery statistical area. Unfortunately, while these data provide a useful source of information on the overall levels of effort and catches in the area, the entire area between North Cape and Cape Reigna is covered by a single scallop statistical area (9A), and therefore the spatial pattern of effort and disturbance within the study area cannot be examined from these data alone. Scallop fishing effort (hours fished per annum) in area 9A is presented in Figure 4. Both hours fished and number of tows are reported in the CELR system, and show very similar patterns. Reported scallop fishing effort in area 9A increased rapidly from a few exploratory tows in 1993 to over 6000 hours fishing in 1997, declined to about 1000 hours by 2000, and then declined at a slower rate, with no scallop fishing reported in 2005 or 2006. Low levels of effort (300–400 hours) were reported in 2007 and 2008, with only 1 hour of scallop fishing reported in 2009.

In the previous analysis of the patterns in benthic communities in relation to fishing pressure in this area (Tuck et al. 2010), in the absence of other data, it was assumed that the fishing effort followed the pattern of relative scallop density from survey catches within the region. Following discussions with the Northland Scallop Enhancement Company, key participants in the Spirits Bay fishery provided NIWA with a map of the areas fished for scallops over time within the area (plotted over three time periods in Figure 5 to Figure 7). Prior to 1997, scallop fishing was distributed across all suitable substrate, out to about 60 m depth. Following the introduction of the voluntary closure (applicable only to scallop dredging) in 1997, scallop fishing was limited to the area to the south of the closure, and the northern area of stratum 93 (with particularly high sponge bycatch) was also avoided. Following the introduction of the regulated closure (applicable to all mobile gear), two further areas around the northern half of stratum 93 were closed to fishing, but the remainder of the area was fished until 2004. No scallop fishing took place in 2005 or 2006, and the relatively low level of scallop fishing that has taken place in the region since 2007 was in the shallower area (25–40 m) to the south of stratum 93. Assuming the hours fishing reported within each year (Figure 4) were distributed evenly within the area identified as being fished each year (Figure 5 to Figure 7), the overall fishing intensity (hours.km⁻²) can be estimated, and this is plotted in Figure 8. This provides a very similar pattern to the overall hours fished, although the 1997 peak in fishing intensity is more dominant, as the area fished almost halved between 1996 and 1997 with the introduction of the voluntary closure.

Recent average scallop fishing intensity (examined over different time scales) and years since last fished were estimated at the station level for both surveys, and used as explanatory variables in the analysis of community structure.

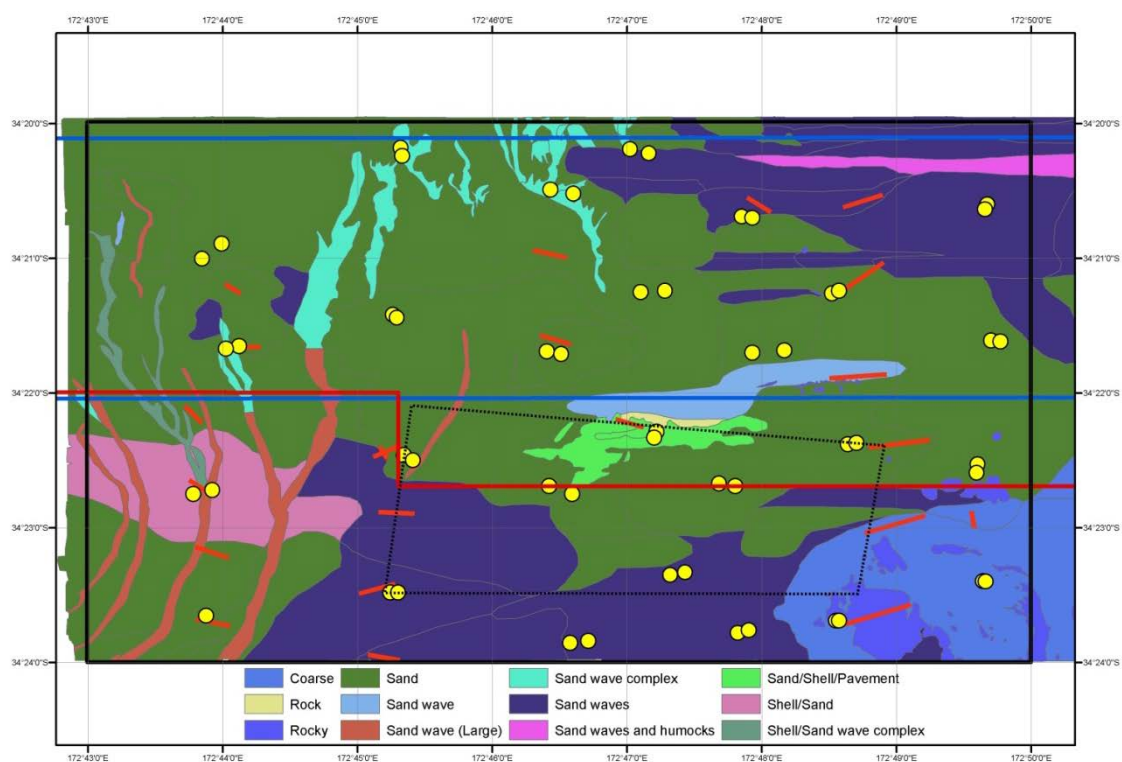


Figure 2: Spirits Bay survey, 2006 stations. Yellow symbols represent individual grab locations (which were combined into pairs at a site for analysis), while red lines represent still photograph transects. Dotted polygon in central region of map represents scallop survey stratum 93. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997).

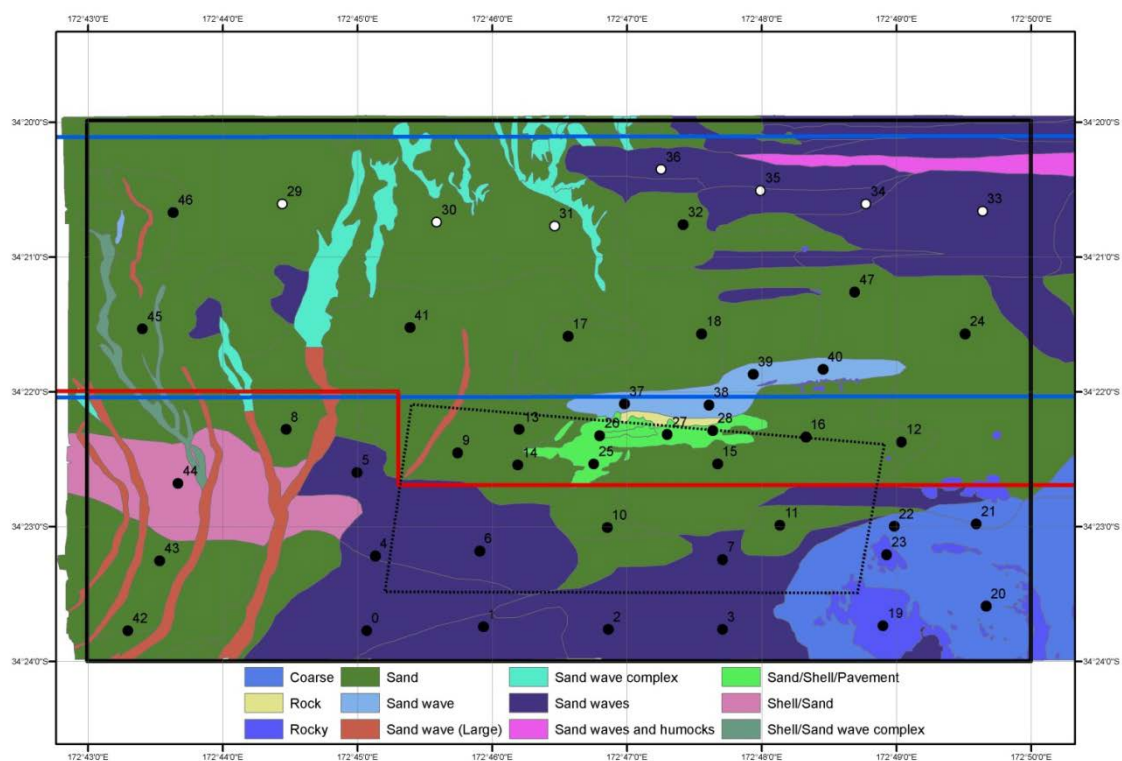


Figure 3: Spirits Bay survey, 2010 stations. Black symbols represent stations completed during the survey. White symbols represent stations not sampled. Dotted polygon in central region of map represents scallop survey stratum 93. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997).

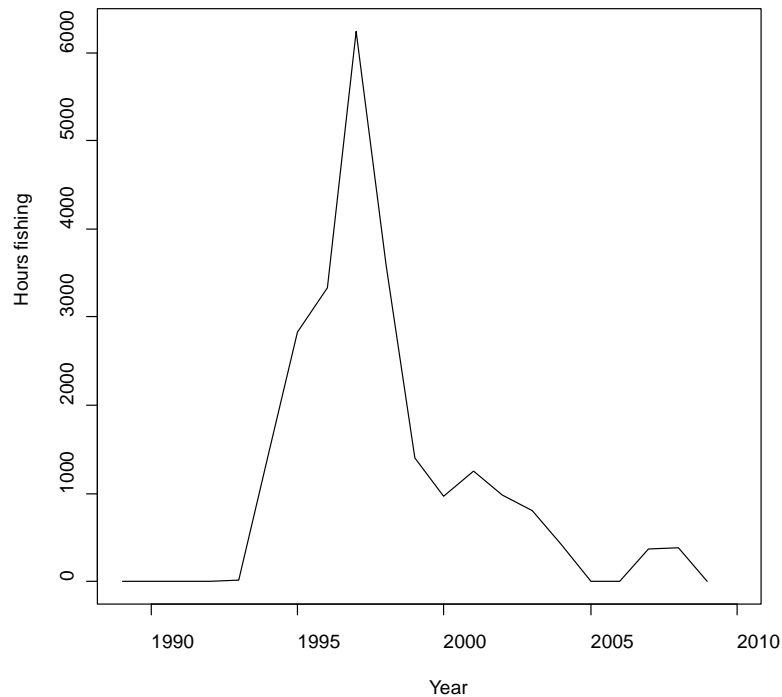


Figure 4: Hours fishing (by scallop dredge) reported on CELR by fishing year (1990 representing the 1990/91 fishing year) for scallop statistical area 9A.

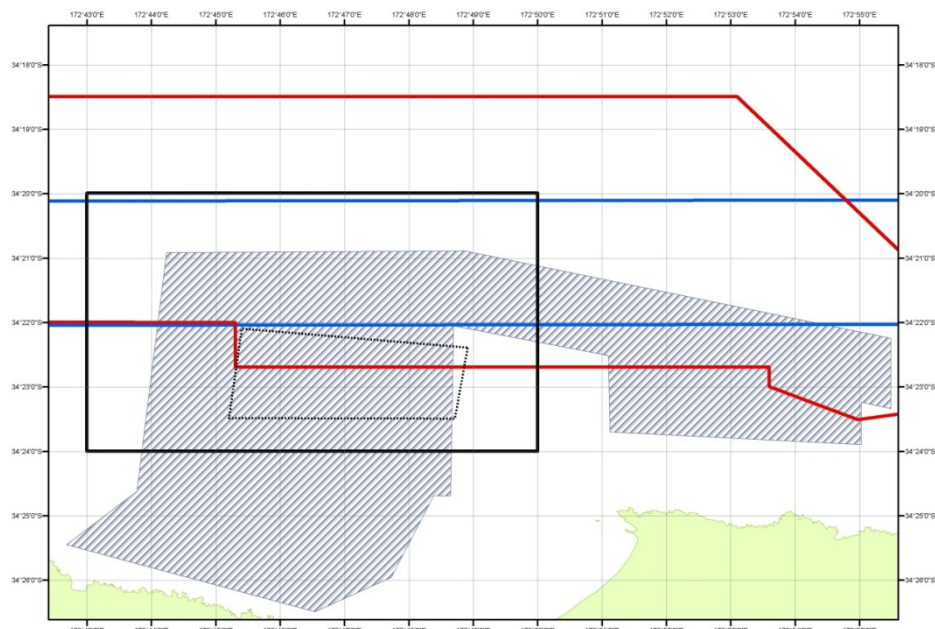


Figure 5: Map of spatial extent of scallop fishing in Spirits Bay area (hatched polygon) prior to introduction of voluntary scallop dredging closure in 1997. Solid black polygon shows study area, dotted polygon shows stratum 93. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997). Map provided by the Northland Scallop Enhancement Company Ltd.

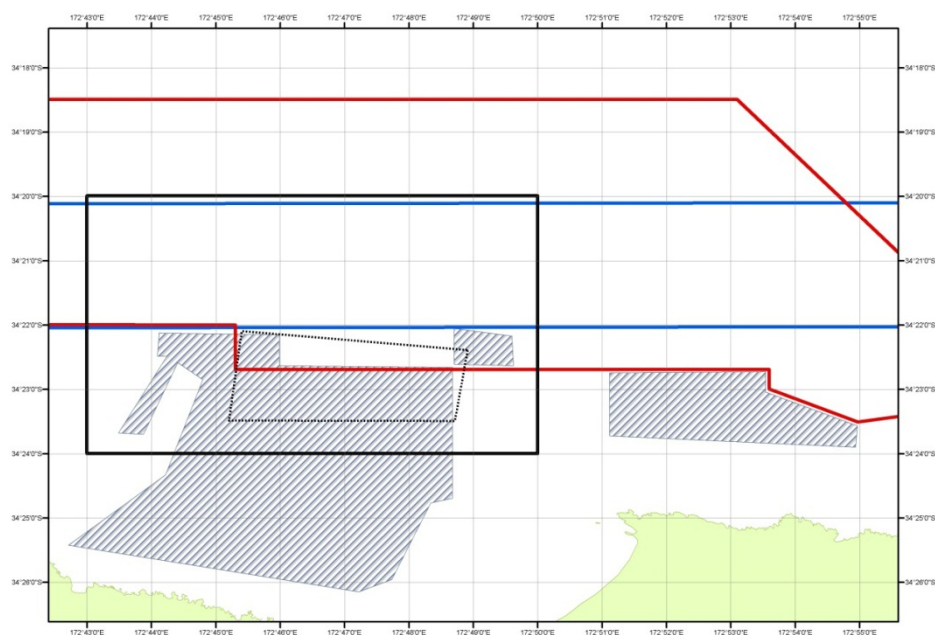


Figure 6: Map of spatial extent of scallop fishing in Spirits Bay area (hatched polygons) following the introduction of voluntary scallop dredging closure in 1997. Fishing within the regulated closure (shown by red line) ceased following its introduction in 1999. Solid black polygon shows study area, dotted polygon shows stratum 93. Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997). Map provided by the Northland Scallop Enhancement Company Ltd.

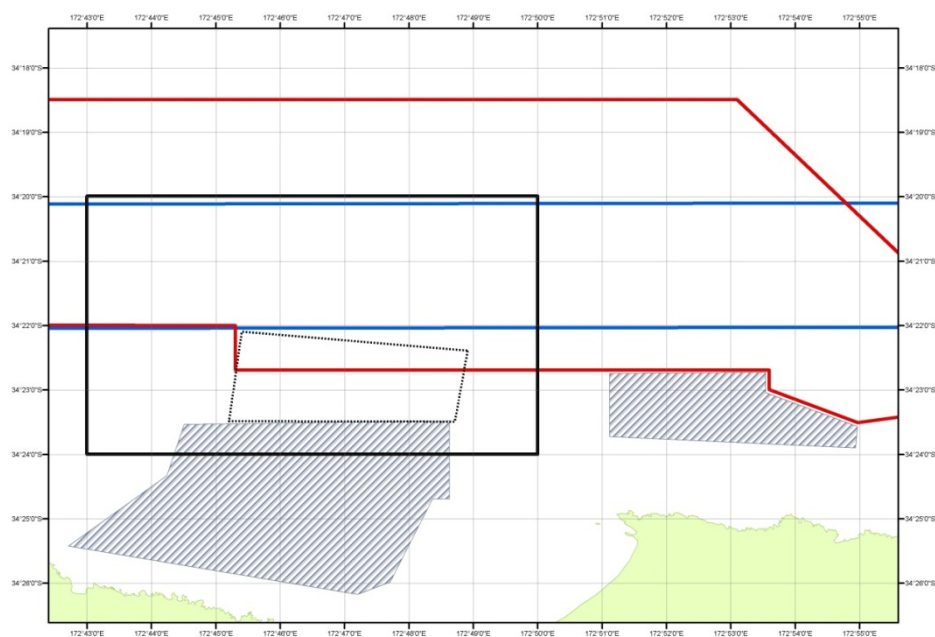


Figure 7: Map of spatial extent of scallop fishing in Spirits Bay (hatched polygons) area since the start of the 2007–08 season. Solid black polygon shows study area, dotted polygon shows stratum 93. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997). Map provided by the Northland Scallop Enhancement Company Ltd.

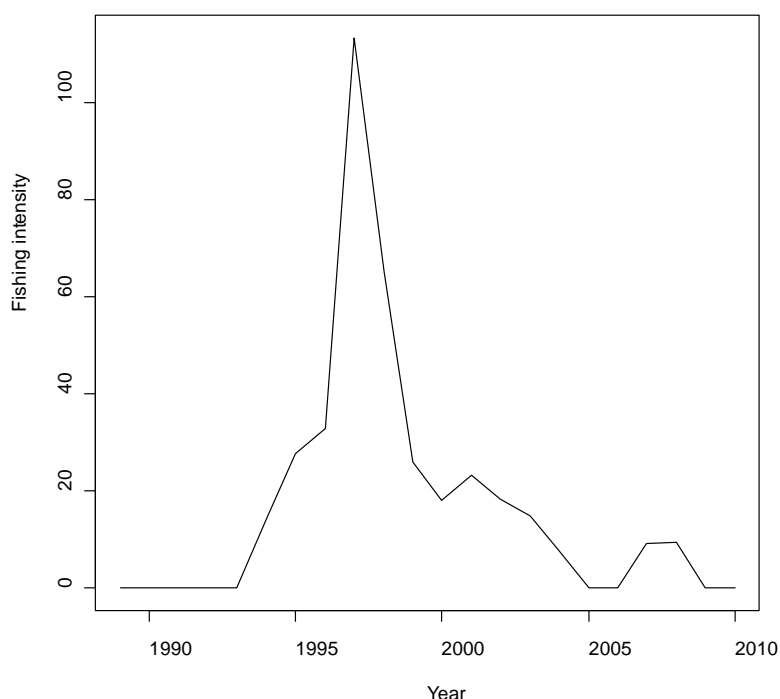


Figure 8: Overall fishing intensity (hours.km⁻²) of scallop fishing in Spirits Bay area, estimated from hours fished and area over which fishing took place.

Bottom trawl, bottom pair trawl and midwater trawl (within 1 m of the seabed) tow data were provided by the Ministry of Fisheries Data Management Group (from TCEPR data) for the Spirits Bay area from 1 October 1989 to 31 May 2010. This does not represent all non-scallop fishing activity in the area (as some landings are reported by statistical area rather than by tow, and hence not recorded within this database), but since 1996 the dataset is thought to cover over 90% of the effort. Since 2007, the introduction of the TCER form will have increased the proportion of bottom tows reported at finer scales than statistical areas further.

Latitude and longitude values are truncated to the minute below (rather than rounded to the nearest minute) when provided from the Ministry of Fisheries databases, and a random offset has been added to each coordinate of each start and end point to jitter the positions. Start and end points of tows (groomed to exclude likely errors) were plotted using a GIS, and overlaid on a grid (1 n.mile by 1 n.mile) covering the area of interest. This grid cell size is smaller than has been used in previous similar analysis of effort data (Baird et al. 2011), but this size was selected on the basis of the relatively small size of the study area. Where tows were reported on TCER forms (only start position being recorded), consecutive tows within a day by the same vessel were used to estimate finish positions, assuming the start time of the second tow was consistent with a short steam after hauling the first (and so on). Number of tows, length of tows, and swept area (length of tow multiplied by reported door spread) was summed over the grid by year, and the value for the appropriate grid cell taken for each station as a measure of trawl fishing effort.

Trawl fishing tows for all years are plotted in Figure 9, over the colour coded grid of fishing effort (number of tows summed across all years). All three measures of fishing effort showed a similar pattern, and the area swept between the wings was used as an explanatory variable in the analysis of community structure. Since 2007, about 25% of tows have been excluded from this plot (finish position not recorded, and not able to be estimated). However, the spatial distribution of start positions for these tows was consistent with positions for tows where both locations were available, and the map is considered to provide an indication of the spatial patterns of effort across the study area.

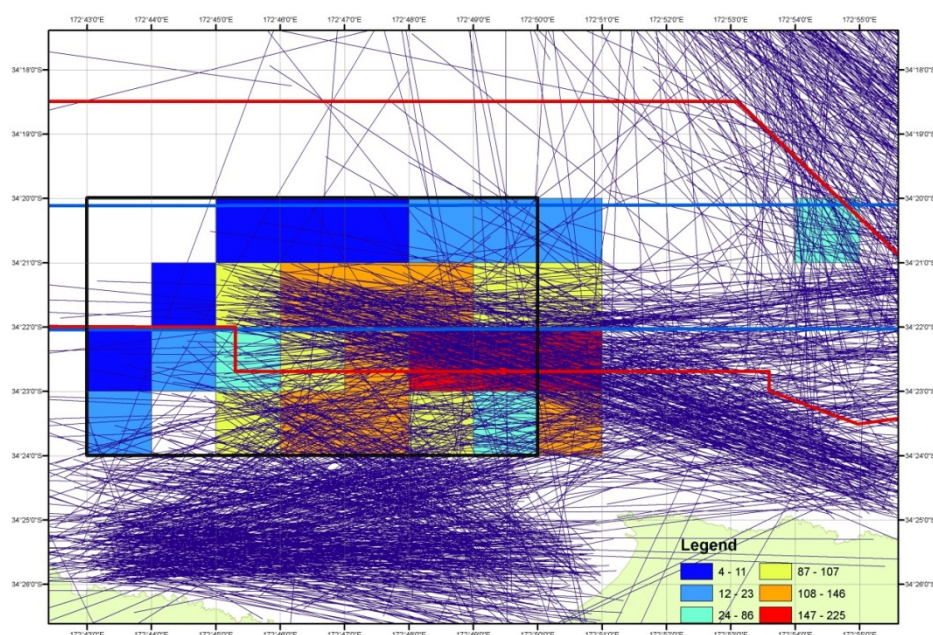


Figure 9: Trawl fishing tows (all years) in vicinity of study area, overlaid on 1 n.mile by 1 n.mile grid. Grid cells from which benthic biological data are available are colour coded by the number of tows passing through them. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997).

The relative patterns of trawl fishing effort in the survey area are plotted for different three-year time periods in Figure 10 to Figure 12. It can be seen that the pattern of effort has changed over time, but also that low levels of trawl effort have been allocated to grid cells within the regulated closure area in all three time periods. No mobile bottom fishing has been allowed in this area since 1999, and it is assumed that this allocation is either a result of errors in the start and finish positions not being identified by the grooming process, or because the assumption of a straight line tow between the start and finish positions was incorrect. Therefore, in addition to the effort data presented in the figures below, an adjusted effort data set was generated, where when a particular sample location was within the regulated area, the trawl effort allocated to that site was set to zero for years in which the regulated closure was in force. The analysis of the epifaunal and infaunal community structure in relation to environmental and fishing variables was conducted using both effort data sets to investigate sensitivity to this assumption.

Overall levels of fishing effort appear relatively low in recent years in the study area, both for scallop and trawl gears. Assuming a 2 knot fishing speed, and a 2 m dredge width, the recorded scallop fishing intensity (hours.km⁻²) in recent years equated to about 5% of the defined fished area (from NSEC data) being disturbed each year. While not all the trawl effort data could be included in the average annual swept area plots (Figure 10 to Figure 12), it is thought that only about 25% has been excluded from recent years. Making an allowance for these excluded data, the average annual swept area from the most intensively fished cells equate to about 10% being disturbed each year. These estimates for the trawl fishery are based on the area swept between the wings rather than the trawl doors (and so will be negatively biased by a factor of about three to five fold), and neither scallop or trawl figures allow for far field effects (e.g. smothering by disturbed resuspended sediment).

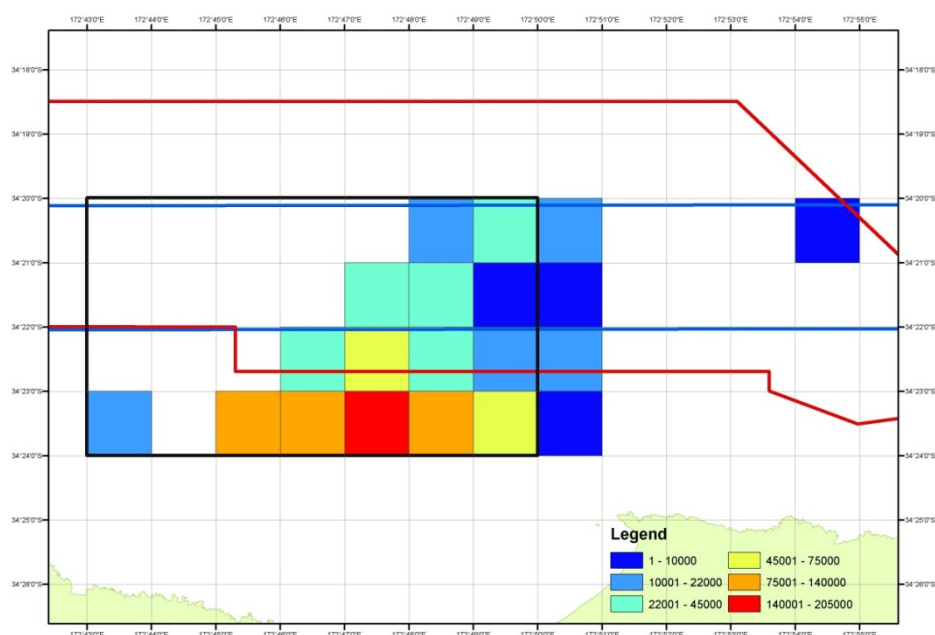


Figure 10: Average annual area swept (m^2 , estimated by trawl length times distance reported between wings) by bottom trawling by 1 n.mile by 1 n.mile grid cell in vicinity of study area for fishing years 2001–02 to 2003–04. Grid cells from which biological data are available are colour coded by the number of tows passing through them. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997).

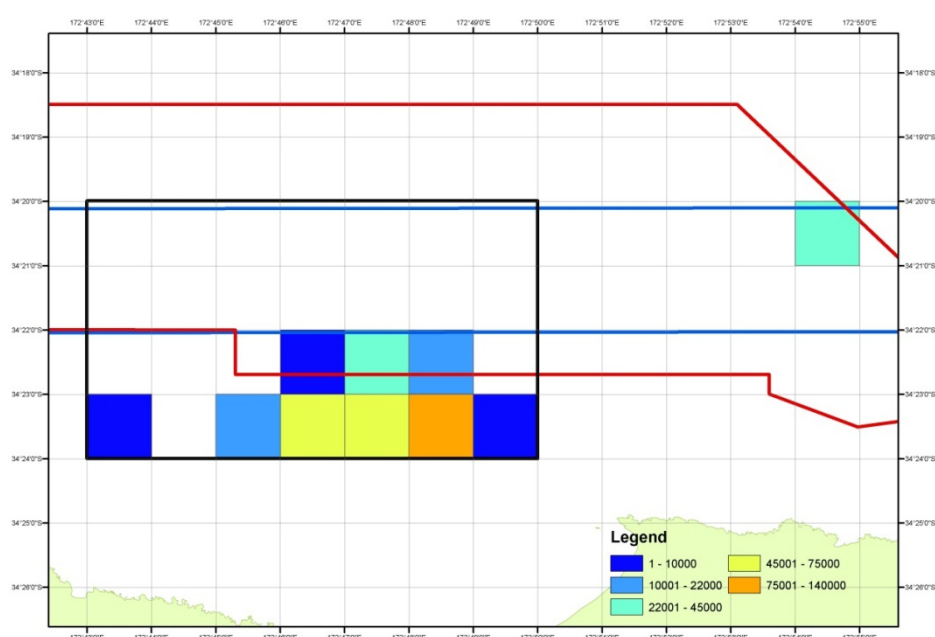


Figure 11: Average annual area swept (m^2 , estimated by trawl length times distance reported between wings) by bottom trawling by 1 n.mile by 1 n.mile grid cell in vicinity of study area for fishing years 2004–05 to 2006–07. Grid cells from which biological data are available are colour coded by the number of tows passing through them.

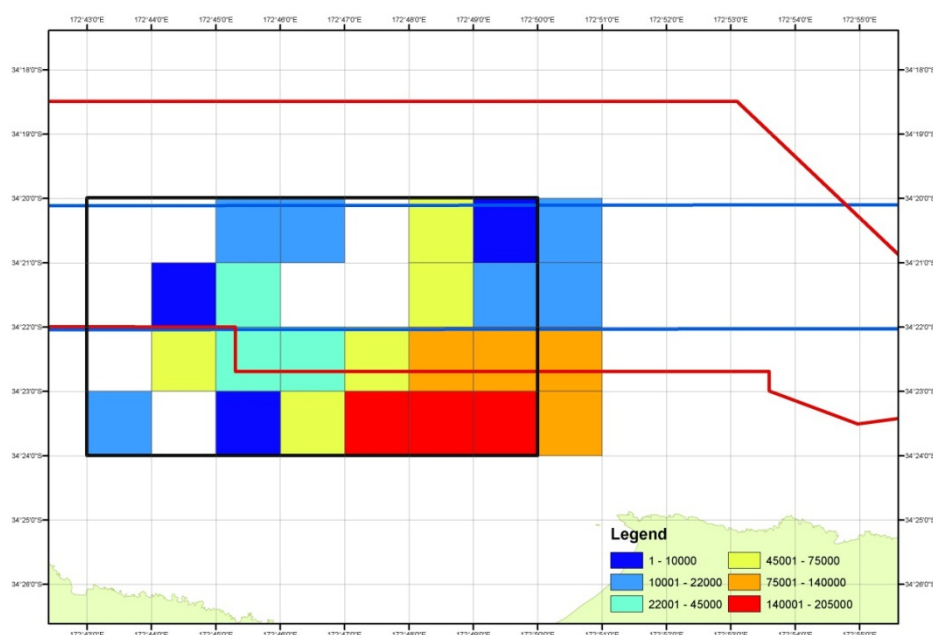


Figure 12: Average annual area swept (m^2 , estimated by trawl length times distance reported between wings) by bottom trawling by 1 n.mile by 1 n.mile grid cell in vicinity of study area for fishing years 2007–08 to 2009–10. Grid cells from which biological data are available are colour coded by the number of tows passing through them.

2.3 Sampling of benthic community

Sampling in 2010 was stratified within the acoustic habitats (Figure 3), with consideration of the data provided on the spatial pattern of fishing within this area (Figure 5 to Figure 7). Planned station locations for the 2010 survey are shown in Figure 3. Unfortunately, the weather was very poor during the voyage, and considerable time was lost when a sub-tropical cyclone moved across the north of New Zealand. This meant that some of the northernmost stations were not sampled, although sample coverage over the area where most of the fishing activity has taken place was not affected. Stations sampled in 2006 are shown in relation to the acoustic habitats in Figure 2. The breakdown of stations by acoustic habitat class and year is provided in Table 1.

Table 1: Number of stations within each acoustic habitat class sampled in each survey.

Acoustic habitat class	Image stations		Grab stations	
	2006	2010	2006	2010
Coarse	2	3		3
Sand shell over pavement	1	4	1	3
Rocky	3	2	1	
Sand	11	19	20	20
Sandwaves	3	8	4	8
Sandwaves deep	3	4	4	4
Shell/sand	1	1	1	1

A standard set of sampling procedures was applied at each survey station. Photographic sampling was undertaken using NIWA's DTIS (Deep Towed Imaging System), collecting high resolution still images and high definition video. At each station, the DTIS was deployed for 30 minutes, while the vessel drifted or steamed along a transect passing through the station, and a target speed of 0.5 to 1 kt. When the direction of drift was appropriate, two stations were combined into a single 1 hour DTIS deployment. Given the large swell and strong tide conditions in the area, control of the vessel speed was very difficult, but was generally maintained within these limits. Still images were taken at 15 second intervals during the DTIS transects. The DTIS system was maintained at an altitude of approximately 2.5 m above the seabed, although swell conditions made this variable. Benthic infaunal

sampling was conducted using a 0.1m⁻² Day grab (two replicates per station), with material retained on a 1 mm sieve preserved in 70 % alcohol. A small sediment sample was taken from each grab for granulometric analysis.

Still images collected with the DTIS system were analysed using the same approach as the previous survey (within ENV200523, and then updated in BEN200701), with epifaunal species identified using the identification keys developed within ENV200523 and subsequent NIWA Capability Fund projects, based on colour and morphological features identifiable from images. Images from both surveys were analysed in a consistent manner. The species or morphological types identified mostly comprised sponges, but also included soft corals, hydroids, bryozoans, algae and ascidians. These keys have been ground-truthed where possible with physical samples, and used successfully for sponge and other epifaunal assemblages elsewhere (Bell et al. 2006, Bell 2007).

Video data collected from DTIS has been quantified, but not fully analysed, as project resources were focussed on the still images and infaunal samples. As with the 2006 study, the poor weather conditions during much of the 2010 survey meant that it was difficult to maintain a constant altitude above the seabed with the video, and the still images were considered to provide a more useful dataset for examination of the epifaunal communities. The still images also had the advantage of being directly comparable with the 2006 dataset.

Infaunal samples were sorted, and identified to the lowest taxonomic level possible. Voucher specimens were sent to experts both within and outside NIWA for confirmation of identifications.

2.4 Effects of fishing on the benthic community

The relationships between the benthic community at each site, environmental drivers, and fishing pressure were examined using distance based linear modelling, with the DISTLM method (Anderson 2001, McArdle & Anderson 2001) within *PERMANOVA+* for *PRIMER* (Anderson et al. 2008). DISTLM partitions variation in a data cloud, as described by a resemblance matrix, according to a multiple regression model. Importantly, it supports the use of a number of different distance measures, including the frequently used Bray-Curtis similarity measure, and can be used in backwards selection mode. While both Redundancy analysis (RDA) and canonical correspondence analysis (CCA) also partition variance in a data cloud according to a multiple regression model, these two analyses are confined to the use of Euclidean and chi-square distances respectively, which are not used quite so frequently in analyses of community data. Moreover, there is no software package other than DISTLM that allows for simple backwards selection of variables, instead forwards selection is utilised, despite backwards selection being preferable when interactions and some correlations exist between explanatory variables (J.H. *pers. obs.*). However, to ensure that results gained were not wholly driven by analysis type, we also analysed the datasets using CCA (ter Braak 1986) within CANOCO (ter Braak & Smilauer 2002).

Previous studies (Thrush et al. 1995, Currie & Parry 1996, Thrush et al. 1998, Tuck et al. 1998, Cryer et al. 2002) have also identified changes in univariate, as opposed to multivariate, community measures related to fishing pressure, and therefore a limited selection of these measures have also been examined: species richness; number of individuals; Pielou's evenness, and Shannon-Weiner diversity. Multivariate measures are generally considered more sensitive to community changes, but univariate measures can be easier to interpret and communicate.

The epifaunal (image) and infaunal (grab) data were analysed separately. For each data set, analyses were conducted for the combined dataset, and for the two surveys separately. Fishing effort terms are described in a consistent manner throughout the analysis. Terms are prefixed by *s* or *t*, representing scallop or trawl fishery variables, respectively. *Fallow* terms represent the estimated number of years since the site was fished by the respective gears, with sites thought never to have been fished given an arbitrary value of 20 years. *Effort* terms represent the average annual area swept (trawl data) or average annual fishing intensity (scallop data), estimated over three consecutive 3-year periods (1–3, 4–6, and 7–9 years), labelled by the final year (e.g. *s_effort6* represents average annual scallop effort for a site 4–6 years prior to sampling). All effort estimates have been calculated relative to the year each survey was conducted.

The community data were square root transformed, and a Bray-Curtis similarity matrix calculated. This similarity measure is commonly used in assessing changes in benthic invertebrate communities. Square root transformation of the data enabled preliminary distance based redundancy analysis (dbRDA) to incorporate a higher proportion of the

variability into fewer axes than with untransformed data. The choice of similarity matrix can influence the results, and so analysis was also conducted using the Hellinger distance matrix. This distance measure is less sensitive to changes in overall abundance than Bray-Curtis similarity, and more sensitive to changes in community composition. Results were not sensitive to the effort data sets examined (original, or adjusted to exclude effort within restricted areas), and so only results using the adjusted effort are presented.

3. RESULTS

3.1 Seabed bathymetry

During the 2006 survey, large ridge features (with an elevation of up to 10 m) were identified from the sidescan and multibeam survey to the west of the main study area. These features can be seen running in a roughly north south direction across the western end of the study area in Figure 3. These features are very unusual (Peter Gerring, pers comm.) and are assumed to be generated by the strong tidal currents in the area. Sidescan and multibeam components were not included in the 2010 survey, but seabed depth was recorded continuously through the voyage by the Kaharoa's data acquisition system (DAS), and a number of transects were steamed across the study area (Figure 13, top left plot), which can be used to compare the depth profiles. Depth profiles along the five labelled transects are presented for the 2006 and 2010 surveys in Figure 13. Data from the 2010 survey are not tidally or heave/swell corrected, but can still be usefully used to examine changes in bathymetry, given the substantial contrast in depth along most transects. Comparison of the depth profiles does not suggest the ridges have moved between the two surveys.

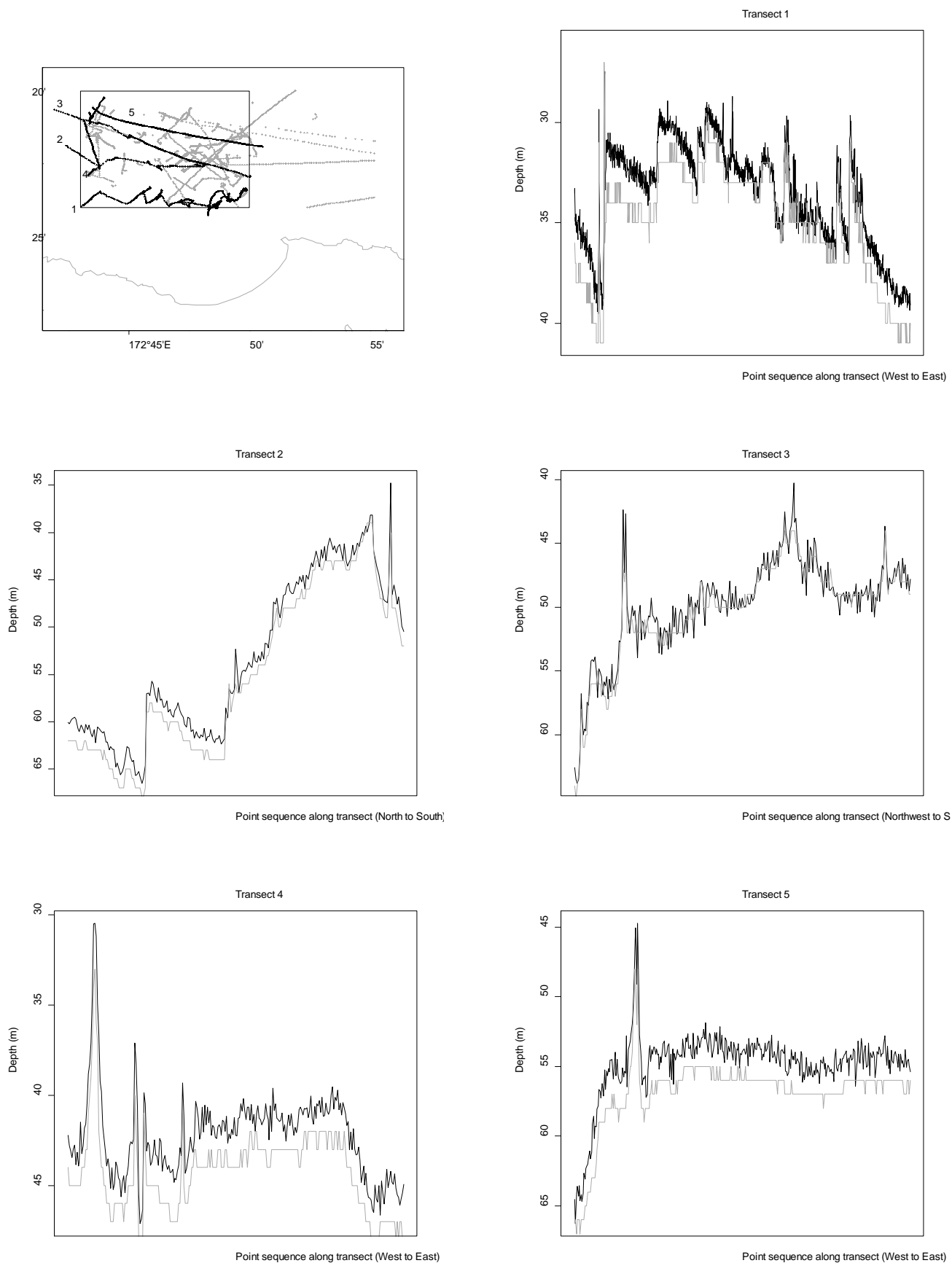


Figure 13: Location of transects across study area (top left), and depth profiles for five labelled transects from 2010 (black line) and 2006 (grey line) surveys.

3.2 Image data (epifauna)

Environment and fishing variables

The grab and image stations were not always at the same locations, and so the suites of environmental variables available for each were examined separately. The environmental variables for the image data were initially normalised and examined using pairwise (draftsman) plots and Principal Components Analysis (PCA) to check for correlation. Where strong correlations were identified between explanatory variables, only one was included in the analysis, to avoid confounding. Log transformation of the various fishing variables was also examined, but provided a very similar correlation matrix, and similar DISTLM model outputs in terms of variables retained within final models and variance explained by different terms. Environmental variables included depth, separate scallop and trawl effort terms (averaged over consecutive 3-year periods), separate years fallow terms for scallop and trawl fishing, and year code. Longer term average trawl effort variables (6 years and 9 years) were also considered, but the 6 year average was strongly correlated with the 3-year average, and preliminary sensitivity analysis suggested that inclusion of the 6 or 9 year average trawl effort in place of the 3-year average generally resulted in similar model outputs.

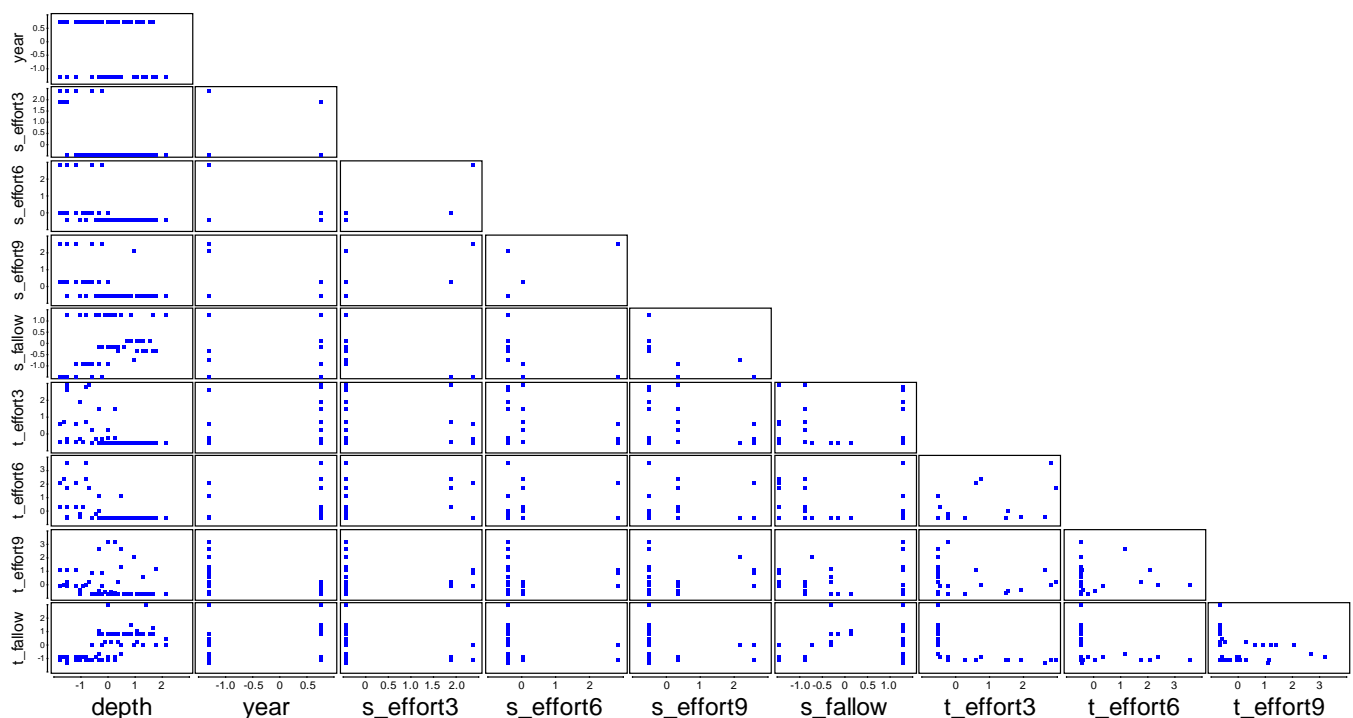


Figure 14: Benthic epifauna: Pairwise (draftsman) plot of normalised explanatory variables for analysis of image data.

Pairwise correlations from Figure 14 are provided in Table 2. The three scallop effort variables were all positively correlated. Other variables, including the trawl effort, did not show strong correlations. The range of the continuous variables is shown in relation to the acoustic habitat classes in Figure 15. This shows the spread of stations within each habitat class with respect to each of the potential drivers. Almost half of the stations were in the sand habitat class (Table 1), and the range of some of the effort variables was quite limited for some of the other habitat classes.

A PCA eigenvector plot of the combined environmental and fishing data is shown in Figure 16. This plot shows the strong correlation between the three scallop effort variables, but other correlations in two-dimensional (2D) space break down on higher axes. Each symbol on the plot represents a station (coordinates given by loadings on the principal components), while the lines represent a projection of the eigenvectors for each environmental variable (as labelled) onto the 2D plane. These vectors can be interpreted as the effect of a given predictor on the ordination picture, the longer the vector, the bigger the effect. If the 2D ordination explains a large proportion of the variation, then the vectors are also representative of the strength and direction of influence of the individual variables on the model itself. The circle on the plot (circle of correlations) represents the length of a vector if the data were perfectly represented by only two components. When more than two components are needed to represent the data perfectly, the vectors will be positioned inside the circle of correlations. The plot (Figure 16) does not portray the data

particularly well in two dimensions, with the first axis explaining only 28% of the variance, with over 90% explained by the first 9 axes (total variance referred to throughout report). Examining the years individually (not presented) shows a similar pattern, with neither suggesting any of the variables (other than those for scallop effort) were well correlated in 2D space.

Table 2: Benthic epifauna: Correlation matrix for normalised explanatory variables for analysis of image data.

	depth	year	s_effort3	s_effort6	s_effort9	s_fallow	t_effort3	t_effort6	t_effort9
year	-0.195								
s_effort3	-0.487	-0.290							
s_effort6	-0.365	-0.405	0.869						
s_effort9	-0.385	-0.380	0.836	0.931					
s_fallow	0.317	0.012	-0.663	-0.600	-0.685				
t_effort3	-0.498	0.187	0.065	0.010	0.041	0.048			
t_effort6	-0.527	0.102	0.246	0.144	0.176	-0.125	0.643		
t_effort9	-0.162	-0.609	0.226	0.240	0.306	0.026	0.083	0.242	
t_fallow	0.604	0.138	-0.336	-0.301	-0.363	0.166	-0.575	-0.485	-0.433

Multivariate community analyses

The Bray Curtis similarity matrix of the square root transformed community data was analysed in relation to the environmental variables with DISTLM, using backwards selection based on the adjusted R^2 criterion. This is a modification of R^2 that adjusts for the number of terms in the model, and only increases if the new term improves the model more than would be expected by chance. Model outputs are summarised in Table 3. DISTLM marginal tests for each variable for each dataset are provided in Appendix 1. For each model, the overall R^2 , explanatory variables retained in the model, and percentage of variance explained by the combined fishing components is tabulated. On the assumption that the effects of more recent fishing activity would be more detectable than older fishing patterns, models were initially examined fitting the most recent effort (average of previous 3 years) and fallow terms. Terms retained in this model were then fixed, with previous year's average trawl effort (4–6 years, and then 7–9 years) included to determine whether these older effort patterns explained significant additional variance. Previous year's scallop effort was not included in this way, given the strong correlation between the average of previous 3 years and the other terms (Table 2).

For the complete image dataset, acoustic habitat class, depth, scallop effort (averaged over previous 3 years), years fallow from scallop and trawl fishing, trawl effort (averaged over previous 3 years), and year were retained in the model, which explained 44.1% of the variance in the community data (Figure 17). These distance based redundancy analysis plots can be interpreted in much the same way as the PCA plots described above. Each symbol on the plot represents a station (coordinated given by loadings on the first two principal components), while the lines represent a projection of the eigenvectors for each environmental variable (as labelled) onto the 2D plane, the longer the vector, the bigger the effect. There was a clear separation between the datasets from the two years, but habitat, depth and fishing terms also explained significant components of the variation. The combined fishing related terms explained 17.1% of the total variance (39% of explainable variance) (Table 3). Examination of the marginal tests (test of relationships between community data and individual variables) suggested that the scallop fishing terms explained more variance than the trawl fishing terms (Appendix 1), although there is some overlap between the terms (sum of marginal tests explains 18.2% of variance, combined fishing terms explains 17.1%).

To investigate whether longer term effects of fishing were detectable, average trawl effort over 4–6 years and 7–9 years were also included in the model. The average effort over 7–9 years ($t_effort9$) was retained, in addition to the original terms (Figure 18), with the overall model explaining 45.7% of the variance, and the fishing terms explaining 19.9% (Table 3).

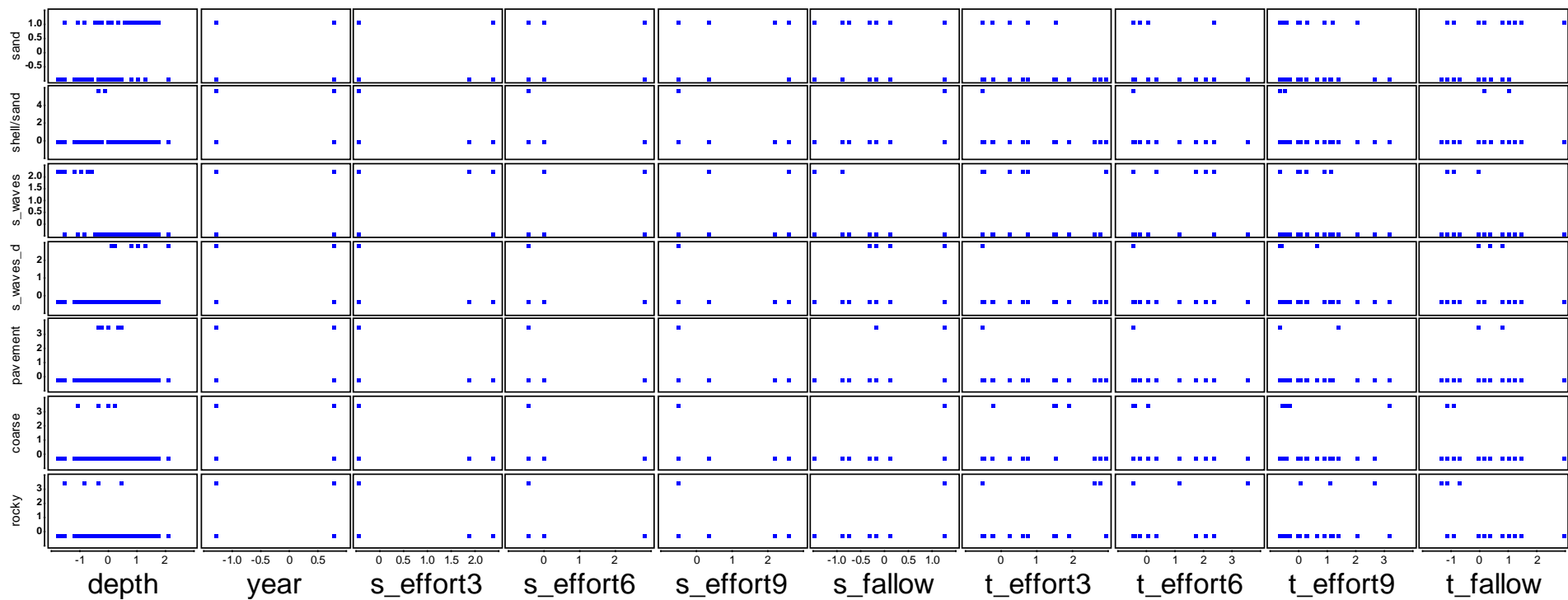


Figure 15: Benthic epifauna: Pairwise (Draftsman) plot of environmental and fishing variables for image stations in relation to acoustic habitat classes. Within each plot, upper line of dots represents sites within that acoustic habitat class.

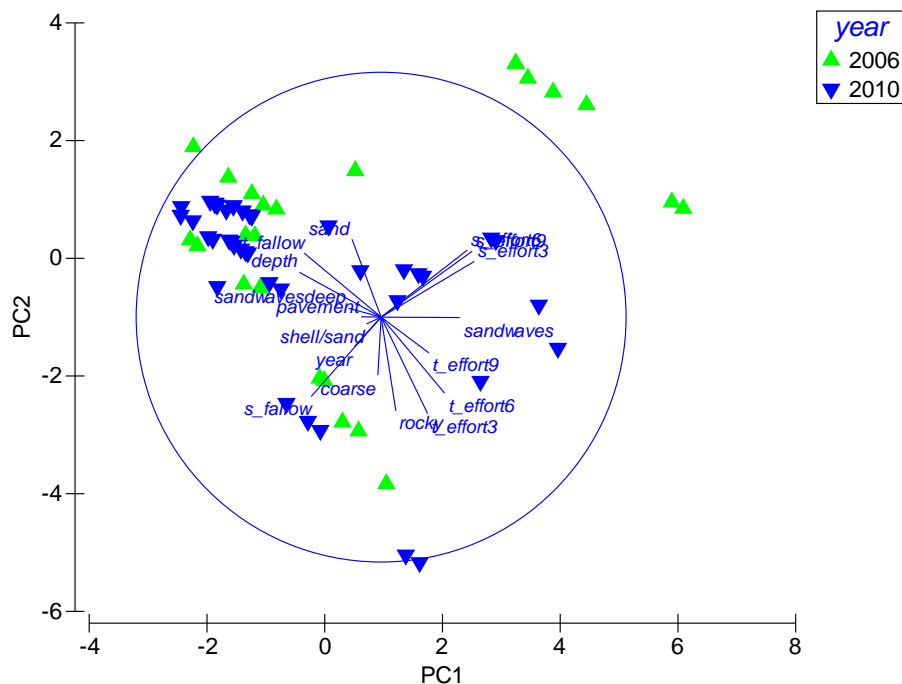


Figure 16: Benthic epifauna: PCA eigenvector plot of environmental variables for image stations. Variables include depth, year, habitat (sand, sand/shell, sandwaves, deeper sandwaves, pavement, rocky and coarse) and fishing (effort over different time periods as described in text, and years fallow by scallop dredge or bottom trawl). Symbols represent individual stations, coded by year.

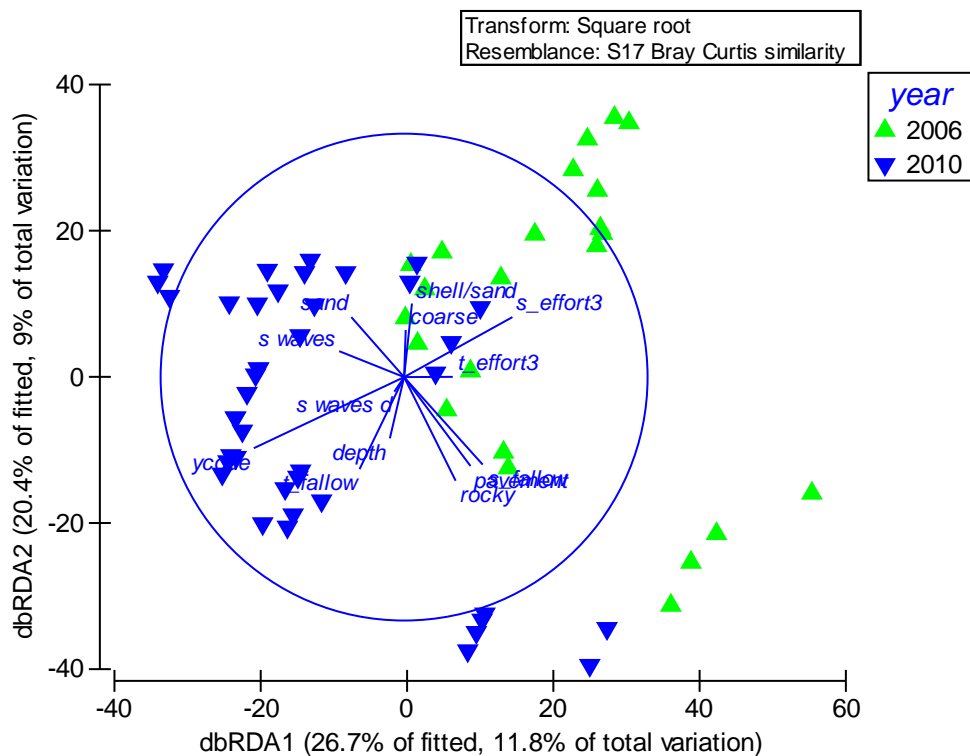
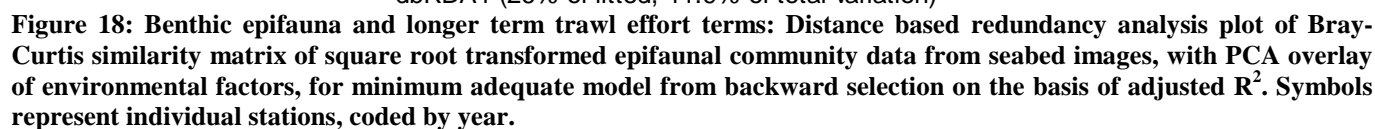


Figure 17: Benthic epifauna and most recent effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.



Examining the sand habitat class only (Figure 21), a model including year, depth, scallop effort (average of previous 3 years), and years fallow for both scallop and trawl fisheries explained 41.4% of the variance, with the fishing terms explaining 20.4%. The additional trawl effort variables were not retained in the model. Restricting the analysis to data collected in 2006 (Figure 22), habitat, scallop effort (average of previous 3 years), and years fallow from trawling explained 51.6% of the variance, with the two effort terms explaining 15.4%, and as with the sand habitat class, the additional trawl effort variables were not retained. Examining only the 2010 dataset (Figure 23), habitat, depth and both the scallop and trawl effort (average of previous 3 years) and years fallow terms were retained in the initial minimum adequate model, explaining 56.9% of the variance, with the fishing terms explaining 22.8%. Both the additional trawl effort terms were also retained when included in the model (Figure 24). This greater explanatory power (compared to the model for the 2006 data) may relate to greater number of stations in 2010 (Table 1), and their allocation across habitats.

Analysis using CCA (summarised in Appendix 2) provided very similar results (in terms of variables explaining the variation in the community data, and the overall variance accounted for) to the DISTLM analysis. Habitat, fishing, year and depth were retained in the minimum adequate model, which accounted for 41.4% of the total variance, with fishing accounting for 19.2%. Longer term fishing effects were also retained within the model when offered, explaining an additional 3.4% of the variation. Repeating the DISTLM analyses using the Hellinger distance similarity matrix (instead of the Bray-Curtis similarity matrix) generally retained the same variables in the minimum adequate models (Figure 25, plot only shown for full data set analysis, 41.3% of variance explained, 16.3% by fishing terms), but with slightly different levels of variance explained. The slight differences between the analysis based on the Hellinger distance and the Bray-Curtis similarity matrices suggests that the community

changes are related to both abundance and community composition. All three analyses examined identified fishing as a significant explanatory variable, accounting for a similar proportion of the total variance.

Table 3: Benthic epifauna: Summary of DISTLM models fitted to epifaunal community data from still images, showing data set used, adjusted R^2 value, variables retained following backwards selection, the proportion of total variance explained by all fishing variables (%), and the proportion of the explained variance attributable to fishing (%). All models based on Bray-Curtis similarity matrices. Variables represent Y – year, D – depth, H – acoustic habitat classes, SE – scallop effort, TE – trawl effort, SF – years fallow from scallop fishing, TF – years fallow from trawling. For each data set, results are shown for models excluding and including the longer-term fishing terms (i.e., TE6 and TE9).

Dataset	R^2	Retained variables	Fishing/Total	Fishing/Explained
Complete	0.441	Y, D, H, TF, SE3, SF, TE3	17.1	38.8
	0.457	Y, D, H, TF, SE3, SF, TE3, TE9	19.9	43.5
Sandy	0.432	Y, D, H, TF, SE3, SF, TE3	17.8	41.2
	0.445	Y, D, H, TF, SE3, SF, TE3, TE9	21.4	48.1
Sand	0.414	Y, D, TF, SE3, SF	20.4	49.3
		Longer term effort not retained		
2006	0.516	H, TF, SE3	15.4	29.8
		Longer term effort not retained		
2010	0.569	H, D, TE3, TF, SE3, SF	22.8	40.1
	0.614	H, D, TE3, TF, SE3, SF, TE6, TE9	29.8	48.5

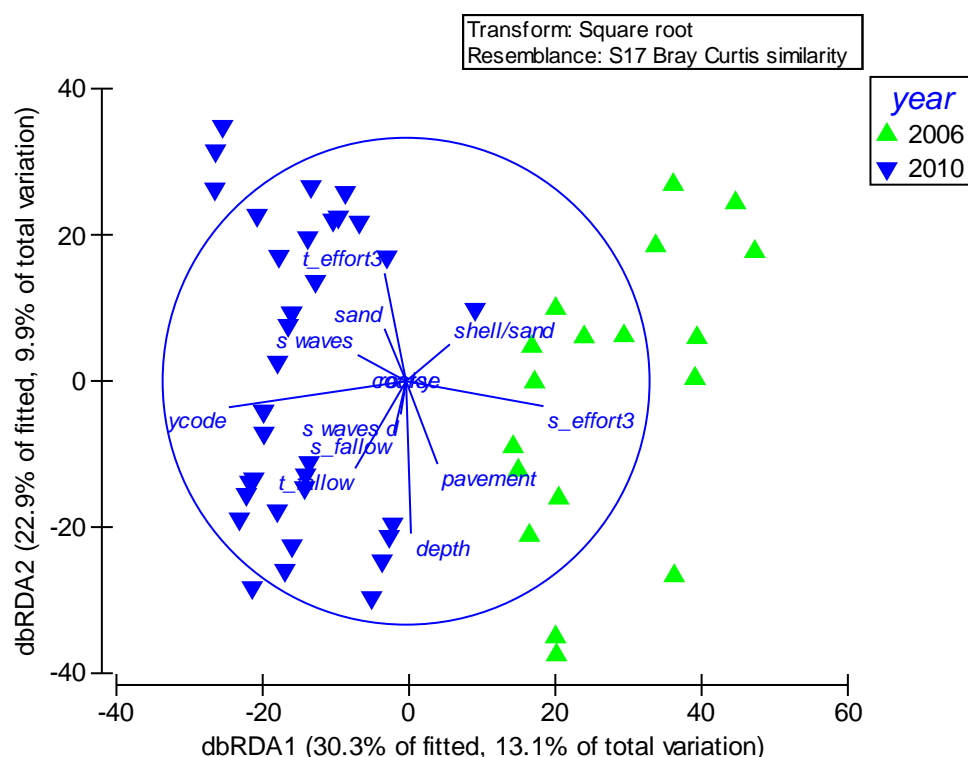


Figure 19: Benthic epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images within sandy habitat (excluding rocky and coarse areas), with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

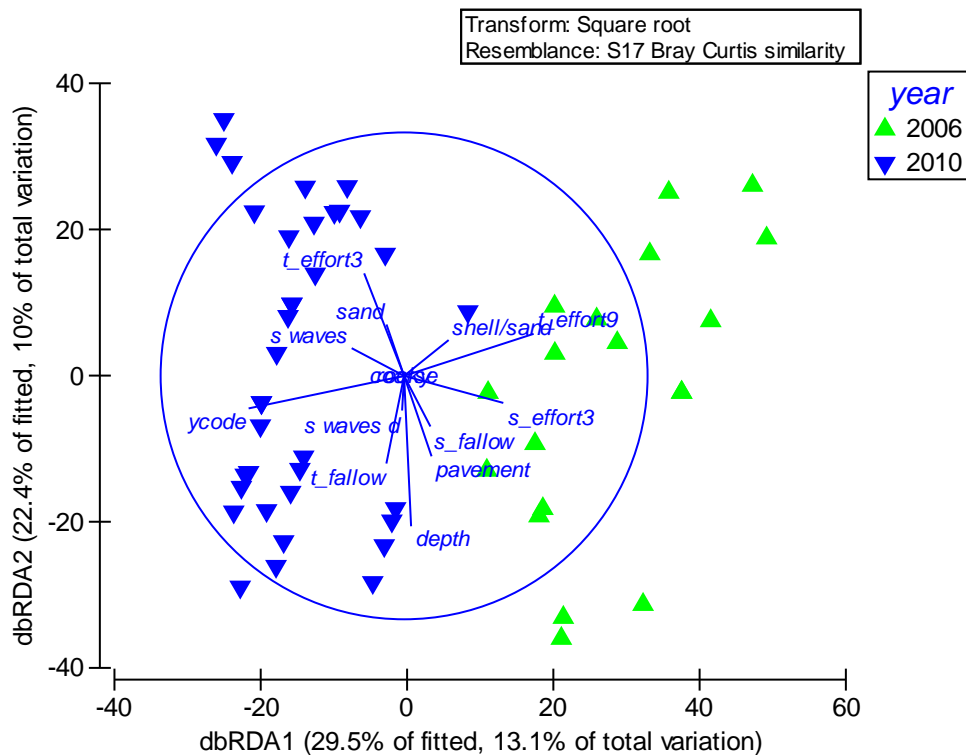


Figure 20: Benthic epifauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images within sandy habitat (excluding rocky and coarse areas), with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

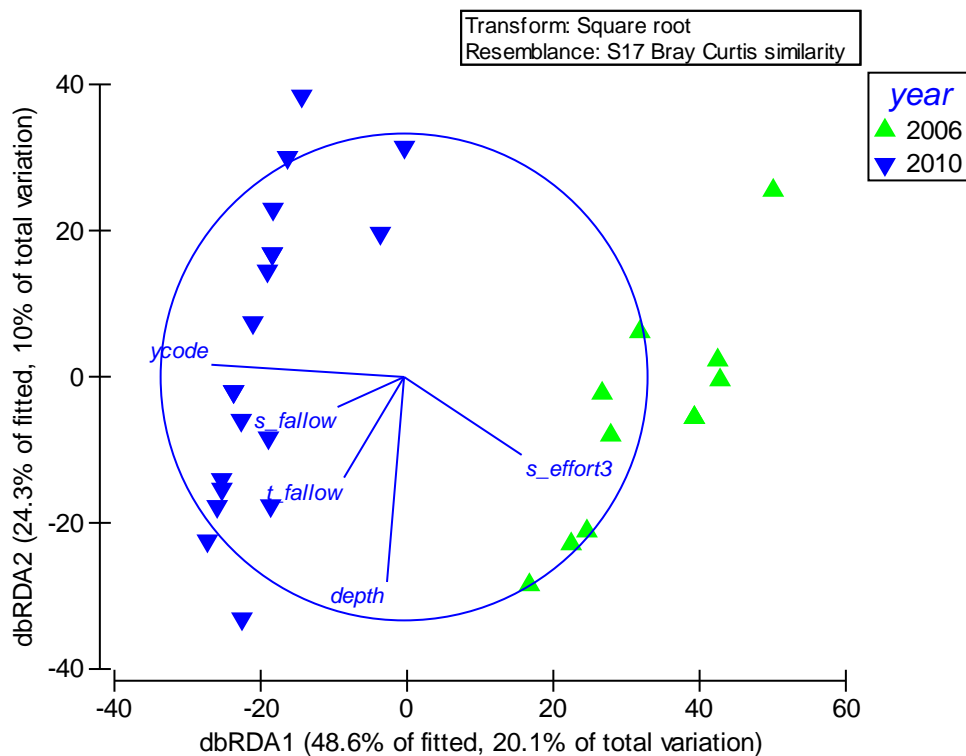


Figure 21: Benthic epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images within sand habitat, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

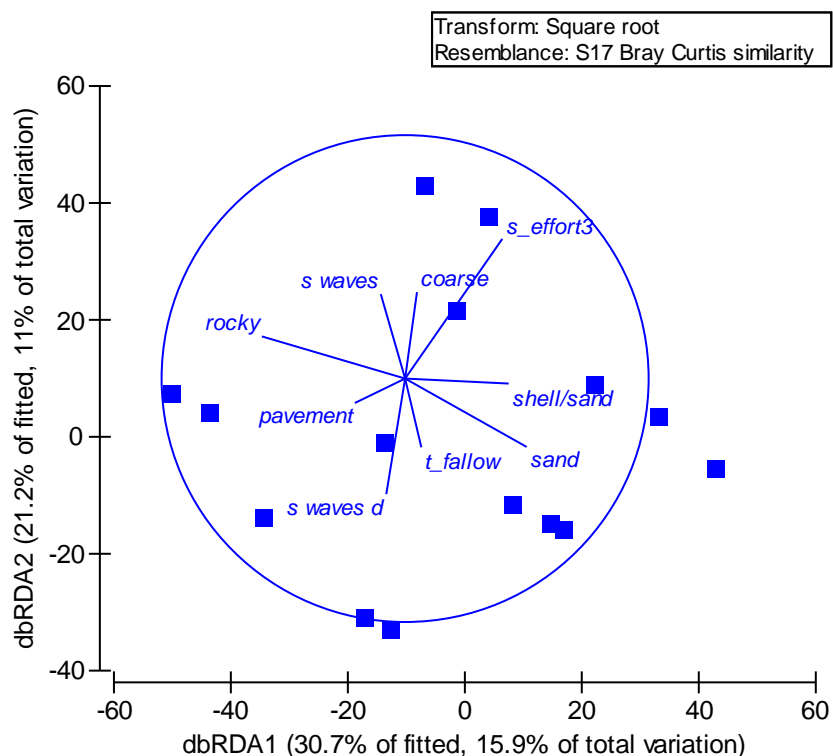


Figure 22: Benthic epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2006 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations.

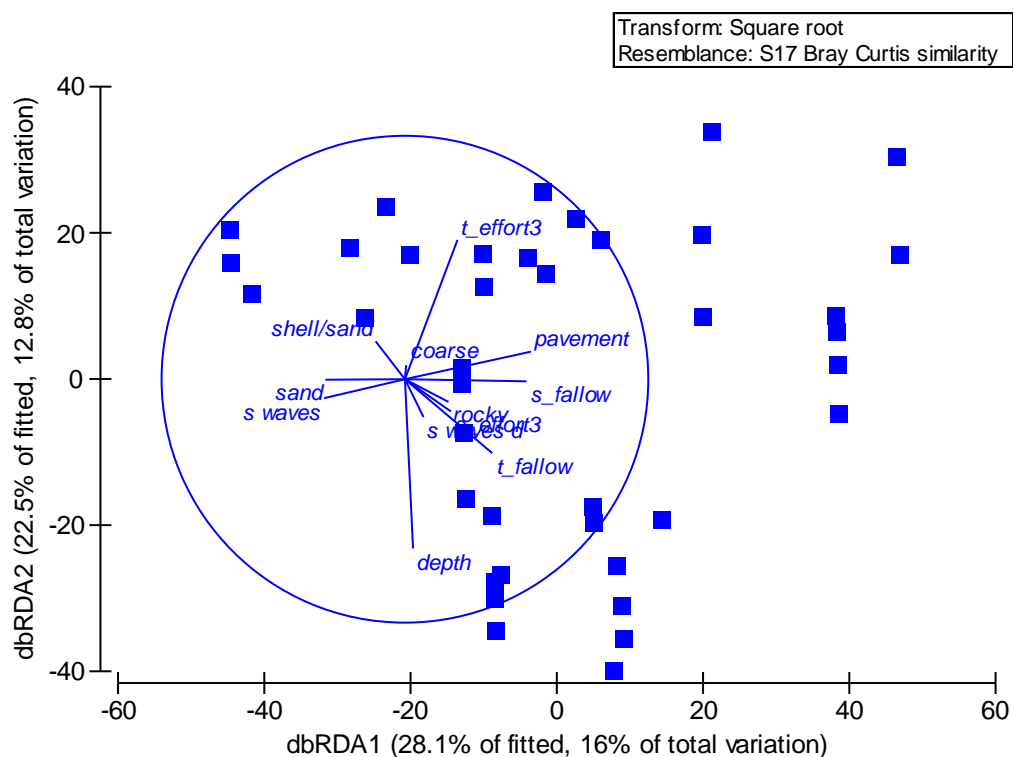


Figure 23: Benthic epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2010 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations.

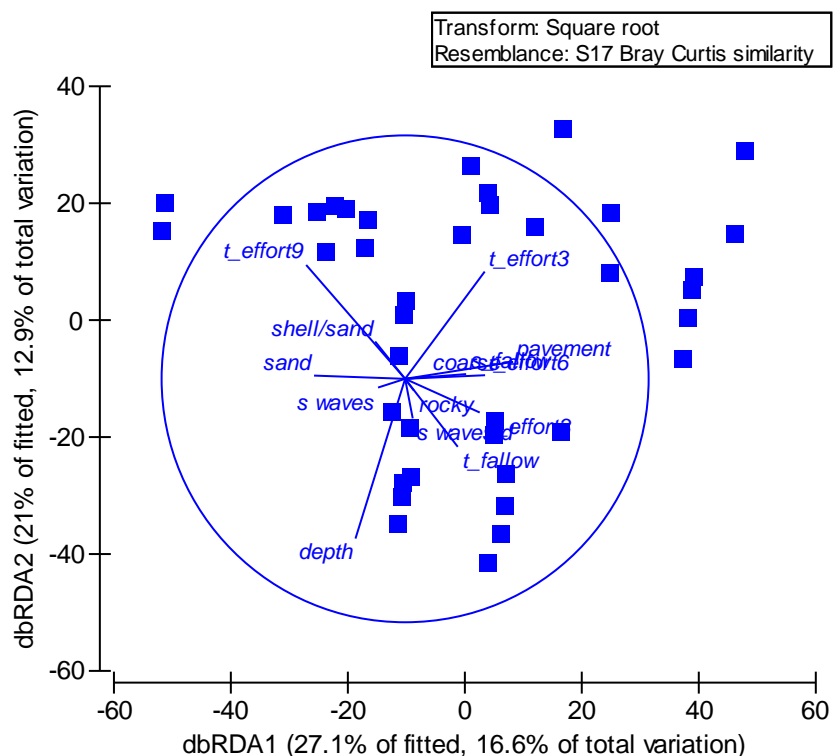


Figure 24: Benthic epifauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2010 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations.

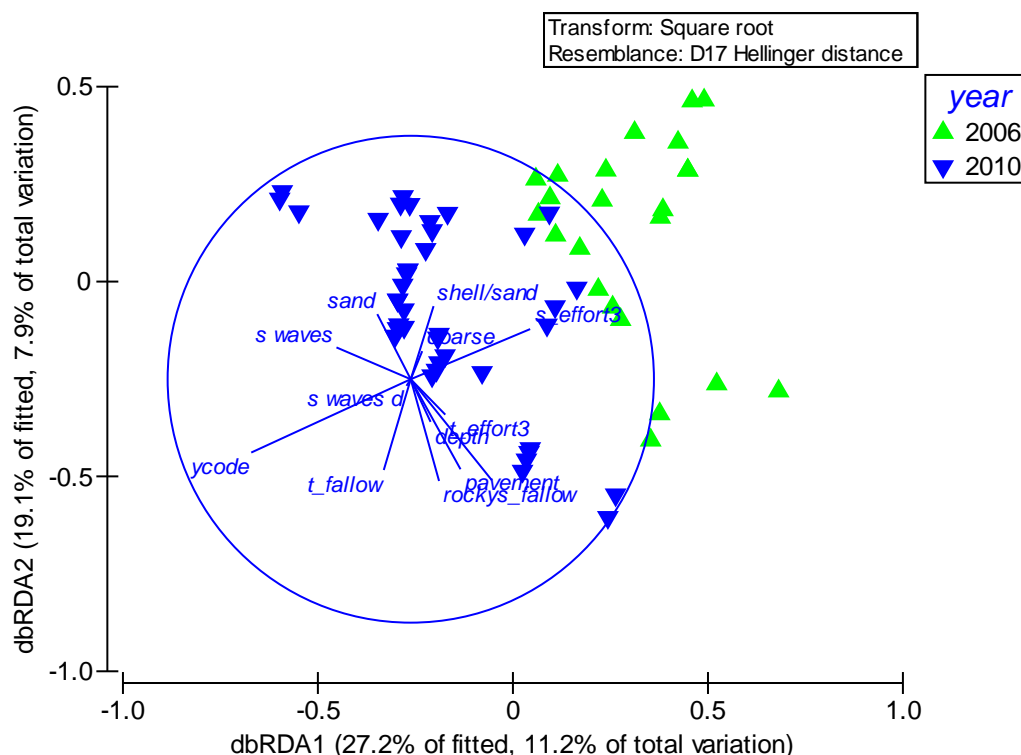


Figure 25: Benthic epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Hellinger distance similarity matrix of square root transformed epifaunal community data from seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

Univariate community measures from image data

Analyses were also conducted using the DISTLM approach examining a range of univariate measures. The models are summarised in Table 4. For log (x+1) transformed species richness using a Euclidian distance matrix, none of the initial fishing variables (recent 3 year average effort of years fallow by either fishing method) were retained in a minimum adequate model (of year, depth and habitat) that explained 66% of the variance in the samples. When offered to the model, the historical trawl effort (7 to 9 years prior to sampling) was retained. For log (x+1) transformed number of individuals, the scallop fishing terms were not retained in the initial minimum model, with the trawl fishing terms explaining 15.6% of the variance (overall model also including year depth and habitat, and explaining 76.1% of variance). When offered, the historical trawl effort (7 to 9 years prior to sampling) was also retained, slightly increasing the variance explained by fishing terms. For the model examining Pielou's evenness, habitat was not retained in the minimum adequate model that explained 36.5% of the variance, with fishing terms (recent scallop and trawl effort, and years fallow from trawling) explaining 22.7% of the variance. The historical effort terms were not retained in the model. Examining the Shannon-Weiner index, year, depth, habitat, and the trawl fishing terms explained 77.4% of the variance (16.4% by trawl terms), and as with Pielou's evenness, the historical effort terms were not retained.

Table 4: Benthic epifauna: Summary of DISTLM models fitted to univariate measures of epifaunal community from still images, showing data set used, adjusted R^2 value, variables retained following backwards selection, the proportion of total variance explained by all fishing variables (%), and the proportion of the explained variance attributable to fishing (%). All models based on Euclidian distance matrices. Variables represent Y – year, D – depth, H – acoustic habitat classes, SE – scallop effort, TE – trawl effort, SF – years fallow from scallop fishing, TF – years fallow from trawling. For each data set, results are shown for models excluding and including the longer-term fishing terms (i.e., TE6 and TE9).

Dataset	R^2	Retained variables	Fishing/Total	Fishing/Explained
Species richness	0.664	Y, D, H	0.0	0
	0.673	Y, D, H, TE9	3.2	4.8
No. individuals	0.761	Y, D, H, TE3, TF	15.6	20.5
	0.769	Y, D, H, TE3, TF, TE9	16.1	20.9
Pielou's evenness	0.365	Y, D, SE3, TE3, TF	22.7	62.2
Shannon-Weiner	0.774	Y, D, H, TE3, TF	16.4	21.2

3.3 Grab samples (infauna)

Environment and fishing variables

The environmental variables for the grab stations were normalised and examined using pairwise (draftsman) plots and PCA to check for correlation (Figure 26 and Table 5). As with the previous data, the average trawl effort over the previous 3 years was taken as the default trawl effort variable to use.

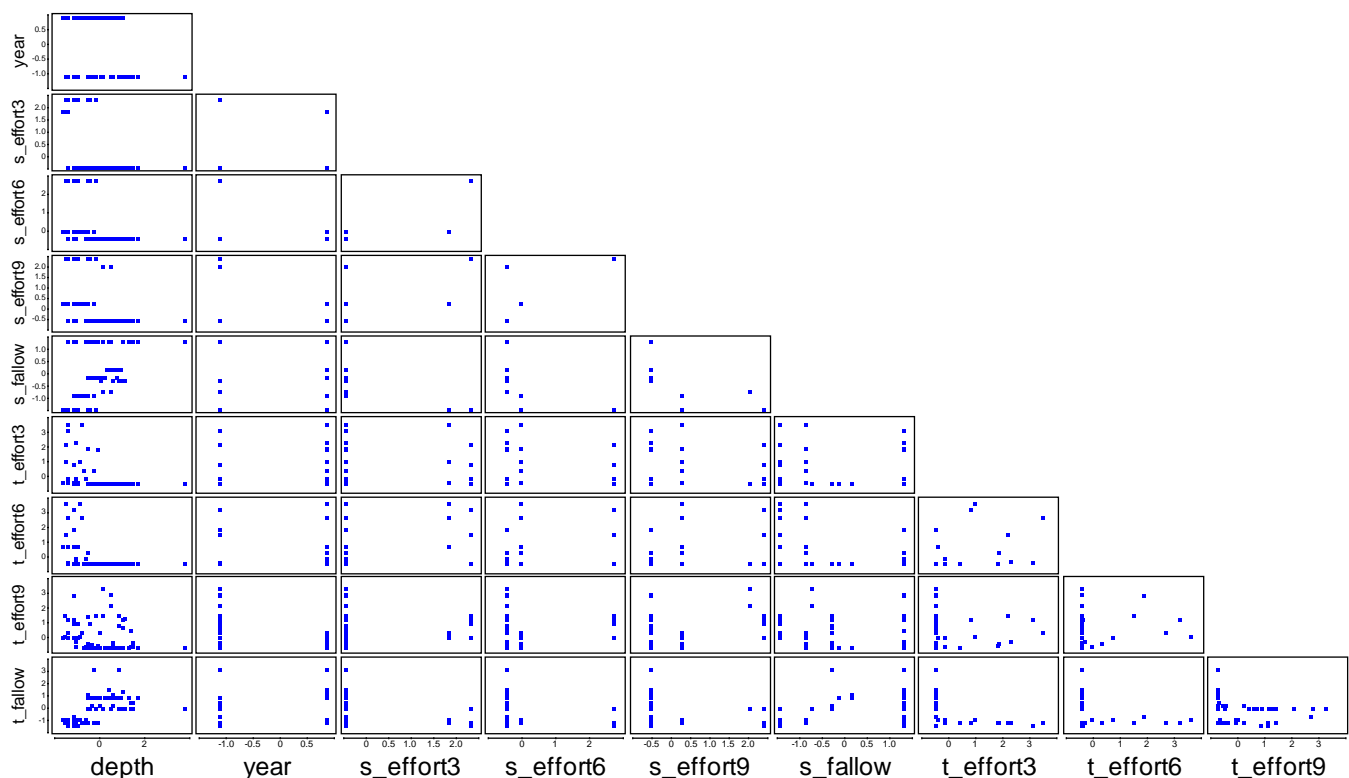


Figure 26: Grab samples: Pairwise (draftsman) plot of normalised explanatory variables.

Pairwise correlations from Figure 26 are provided in Table 5. As with the analysis for the image stations, the three scallop effort variables were all positively correlated. The range of the continuous variables is shown in relation to the acoustic habitat classes in Figure 27. As with the image stations, the range of some of the effort variables was quite limited for some habitat classes.

Table 5: Grab samples: Correlation matrix for normalised explanatory variables.

	depth	year	s_effort3	s_effort6	s_effort9	s_fallow	t_effort3	t_effort6	t_effort9
year	-0.3105								
s_effort3	-0.4942	-0.2426							
s_effort6	-0.4017	-0.3497	0.8817						
s_effort9	-0.4192	-0.3468	0.8110	0.8955					
s_fallow	0.4698	-0.0112	-0.6579	-0.5988	-0.6820				
t_effort3	-0.4425	0.1716	0.1532	0.0936	0.1179	-0.1023			
t_effort6	-0.4907	0.1444	0.3490	0.1928	0.2416	-0.3668	0.5481		
t_effort9	-0.1687	-0.6086	0.3275	0.3552	0.5201	-0.2441	0.0748	0.1988	
t_fallow	0.5078	0.1285	-0.4174	-0.3866	-0.4413	0.3313	-0.5503	-0.4579	-0.3813

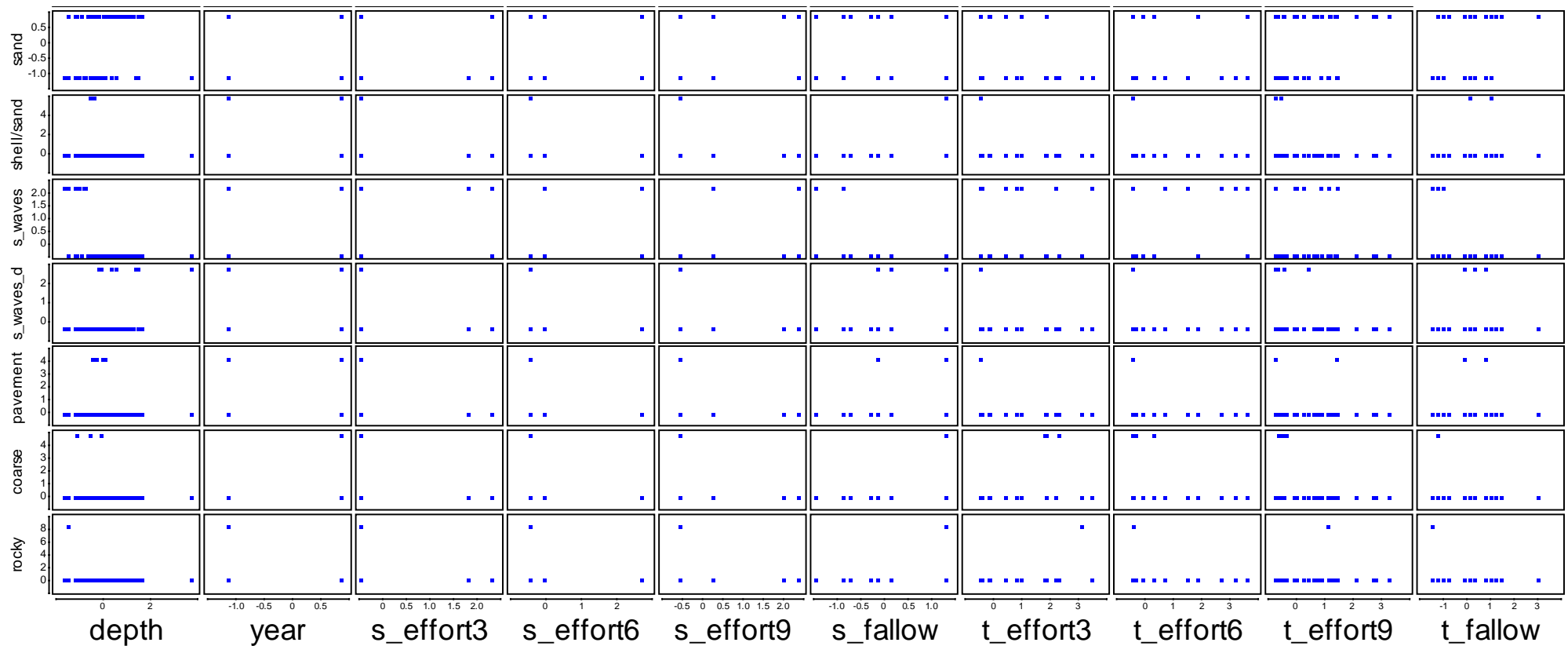


Figure 27: Grab samples: Pairwise (Draftsman) plot of environmental and fishing variables in relation to acoustic habitat classes. Within each plot, upper line of dots represents sites within that acoustic habitat class.

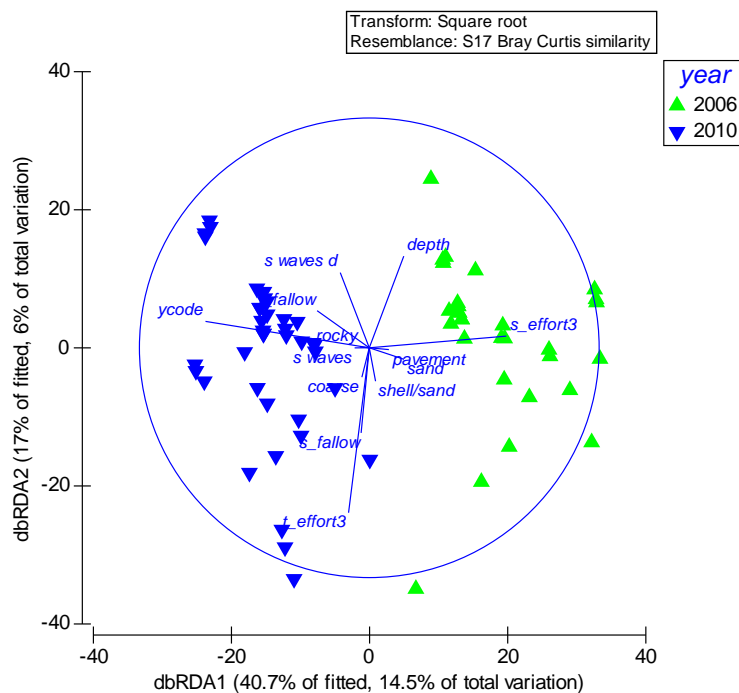


Figure 29: Grab samples and most recent fishing effort terms: Distance based redundancy analysis plot of Bray Curtis similarity matrix of square root transformed infaunal community data from grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

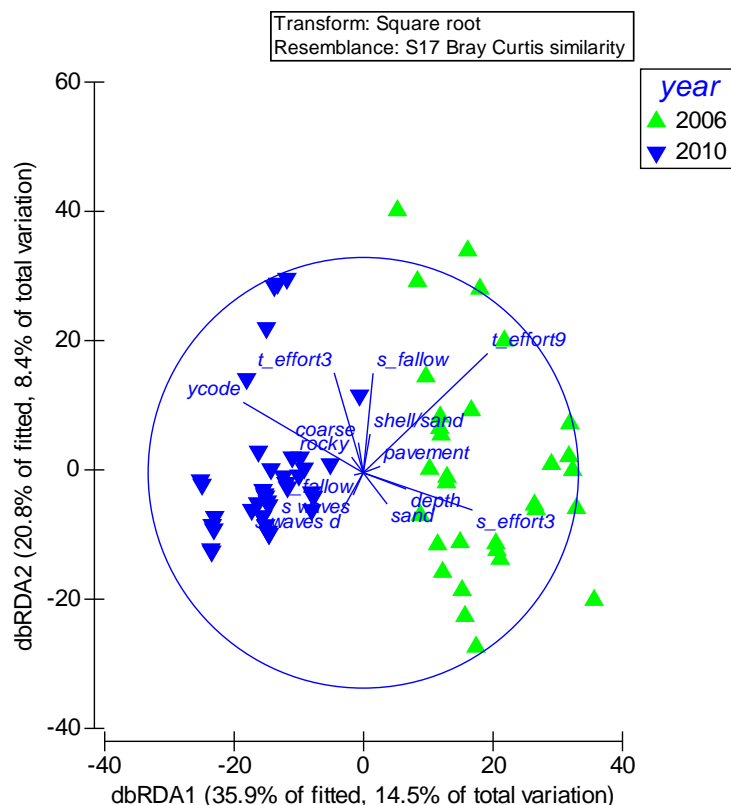


Figure 30: Grab samples and longer term trawl effort terms: Distance based redundancy analysis plot of Bray Curtis similarity matrix of square root transformed infaunal community data from grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

Table 6: Grab samples: Summary of DISTLM models fitted to infaunal community data, showing data set used, adjusted R² value, variables retained following backwards selection, the proportion of total variance explained by all fishing variables (%), and the proportion of the explained variance attributable to fishing (%). All models based on Bray-Curtis similarity matrices. Variables represent Y – year, D – depth, SE – scallop effort, TE – trawl effort, SF – years fallow from scallop fishing, TF – years fallow from trawling. Sediment particle size composition (proportion by size classes, based on Wentworth scale) and percentage organic material were available for 2010 samples. For each data set, results are shown for models excluding and including the longer-term fishing terms (i.e., TE6 and TE9).

Dataset	R ²	Retained variables	Fishing/Total	Fishing/Explained
Complete	0.355	Y, D, H, TF, SE3, SF, TE3	16.4	46.2
	0.404	Y, D, H, TF, SE3, SF, TE3, TE9	22.6	55.9
Sandy	0.327	Y, D, H, TF, SE3, SF, TE3	15.0	45.9
	0.380	Y, D, H, TF, SE3, SF, TE3, TE9	21.5	56.6
Sand	0.321	Y, D, TF, SE3, SF, TE3	19.8	61.7
	0.397	Y, D, TF, SE3, SF, TE3, TE9	27.1	68.3
2006	0.233	D, TF, SE3	18.5	79.4
	0.342	D, TF, SE3, TE6, TE9	29.3	85.7
2010	0.415	D, H, TF, SE3, SF, TE3	23.1	55.7
		Longer term effort not retained		
2010*	0.535	D, H, SED, ORG, SF, SE3, TE3	18.9	34.6
*		Longer term effort not retained		

* - 2010 mode also including sediment particle size and percentage organic terms

For the sandy habitats (i.e., excluding rocky and coarse areas), the initial model retained year, depth, habitat and the four fishing variables, and explained 32.7% of the variance, with the fishing terms explaining 15% (Figure 31). Inclusion of the additional effort variables (only average over 7–9 years retained) increased the variance explained to 38%, with 21.5% explained by fishing terms (Figure 32).

Examining the sand habitat class only (Figure 33), a model including year, depth and the four fishing variables explained 32.1% of the variance, with the fishing terms explaining 19.8%. The inclusion of the average trawl effort over the previous 7–9 years (Figure 34) increased the variance explained to 39.7% (27.1% of total by fishing terms, 68% of explained variance). For the 2006 data (Figure 35), depth, years fallow from trawl fishing and scallop effort (average of previous 3 years) explained 23.3% of the variance, with 18.5% explained by the two fishing terms. Both of the additional trawl effort terms were also retained when included in the model (Figure 36), increasing the variance explained to 34.2% (29.3% by fishing terms). For the 2010 data (Figure 37), depth, habitat and the four fishing variables were all retained in the initial model, explaining 41.5% of the variance (23.1% explained by the fishing terms). The additional trawl effort terms were not retained when offered to the model. Sediment samples were also analysed for the 2010 data, to provide particle size and percentage organic content variables. Both of these terms were retained by the DISTLM model for the 2010 data, with years fallow from trawl fishing being dropped from the model (Figure 38). This model explained 53.5% of the variance, with the fishing terms explaining 18.9%.

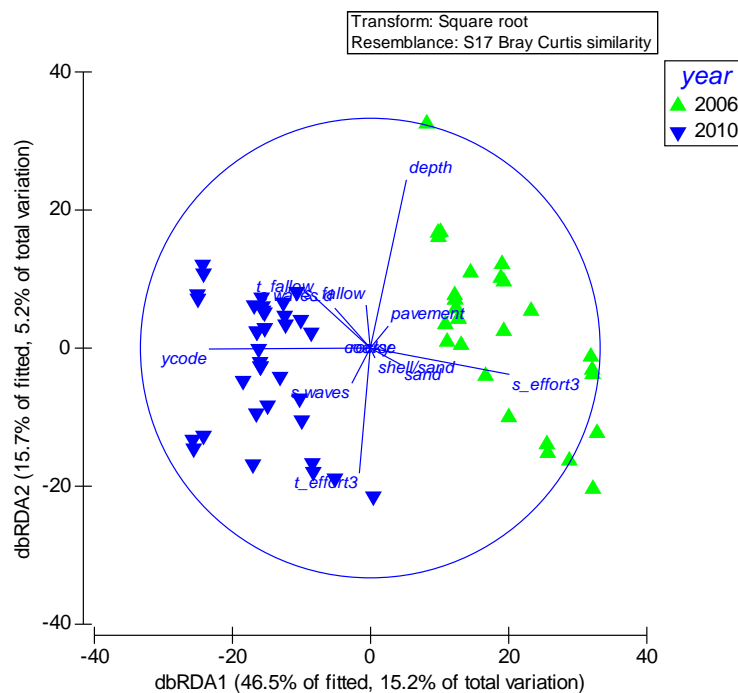


Figure 31: Grab samples and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from grab samples within sandy habitat (excluding rocky and coarse areas), with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

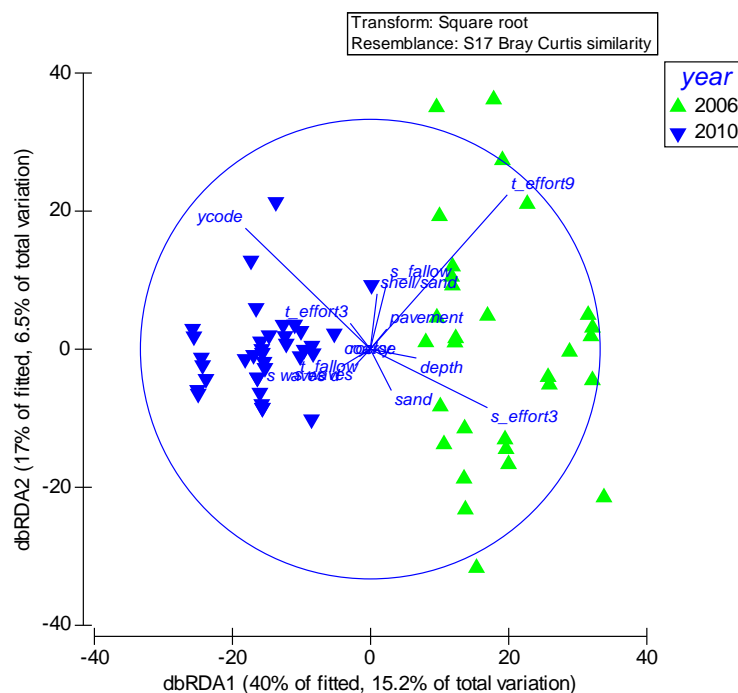


Figure 32: Grab samples and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from grab samples within sandy habitat (excluding rocky and coarse areas), with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

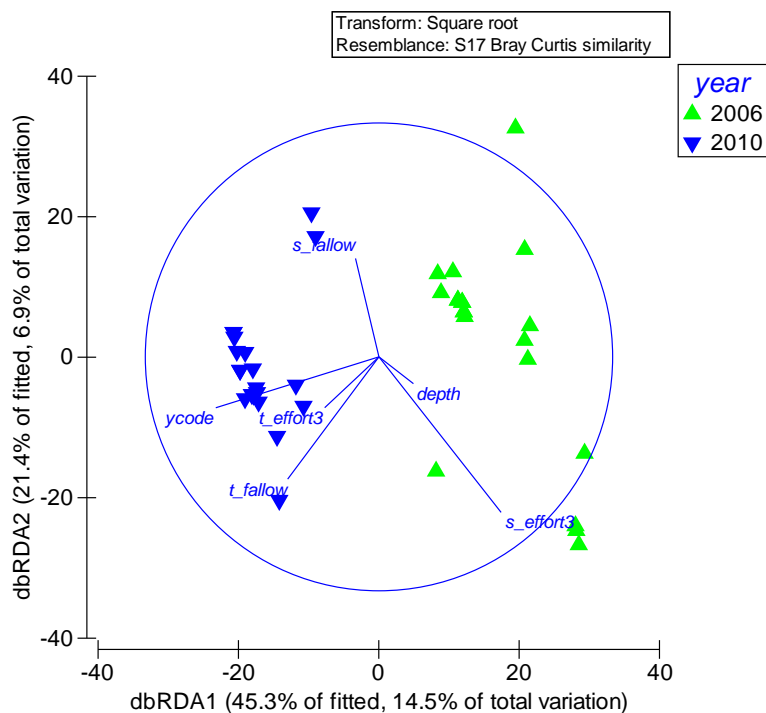


Figure 33: Grab samples and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from grab samples within sand habitat, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

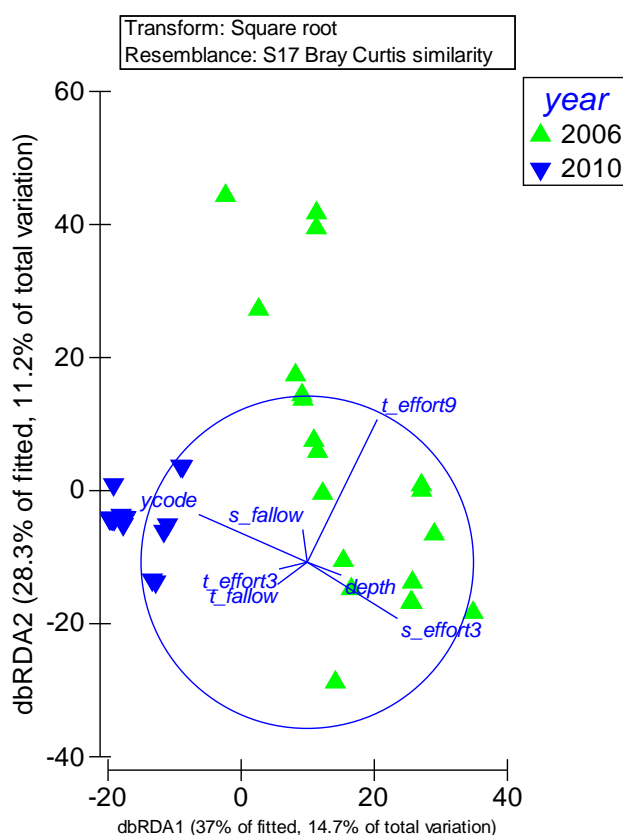


Figure 34: Grab samples and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from grab samples within sand habitat, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations, coded by year.

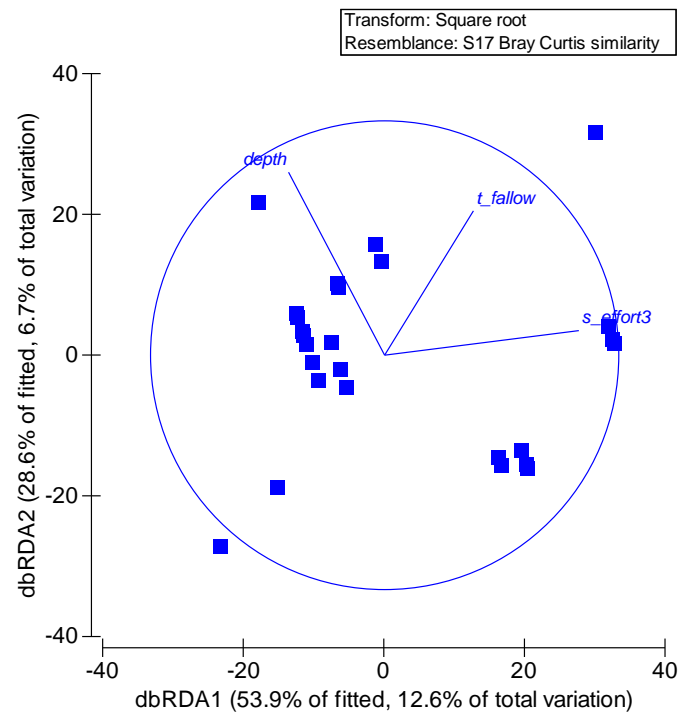


Figure 35: Grab samples and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2006 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations.

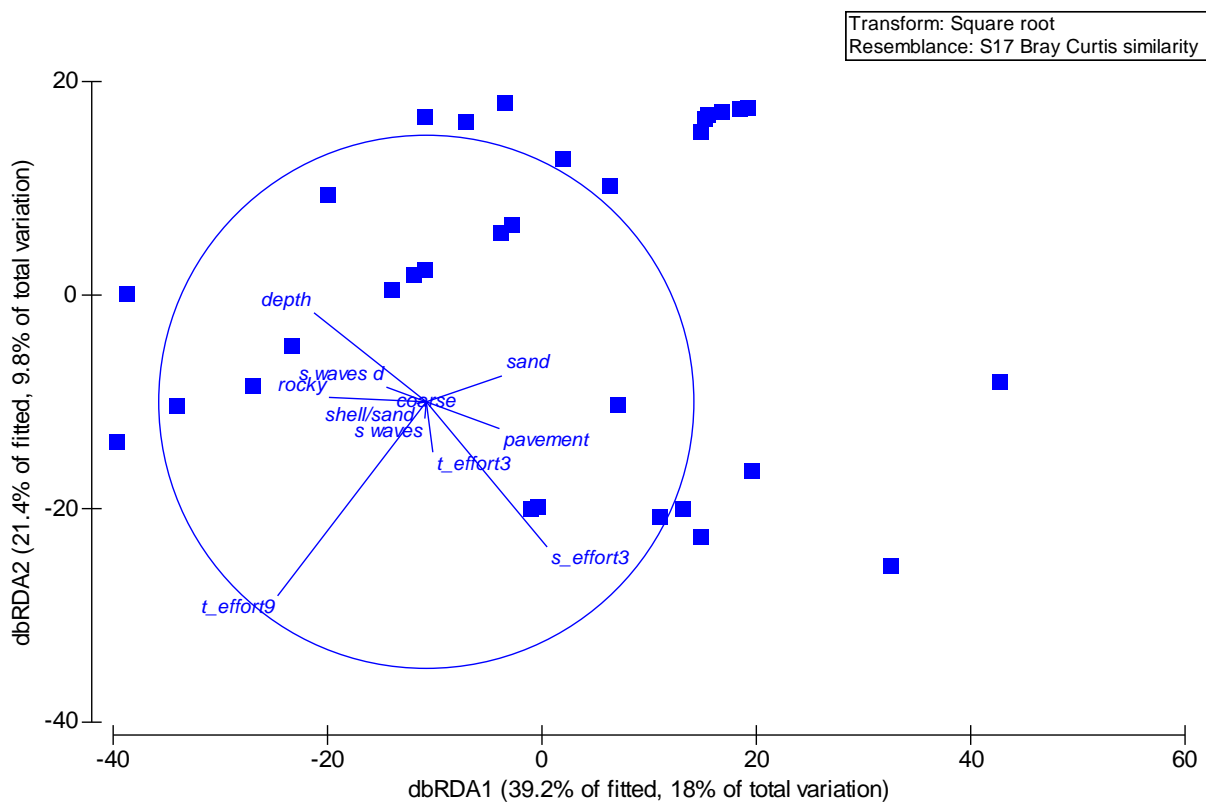


Figure 36: Grab samples and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2006 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations.

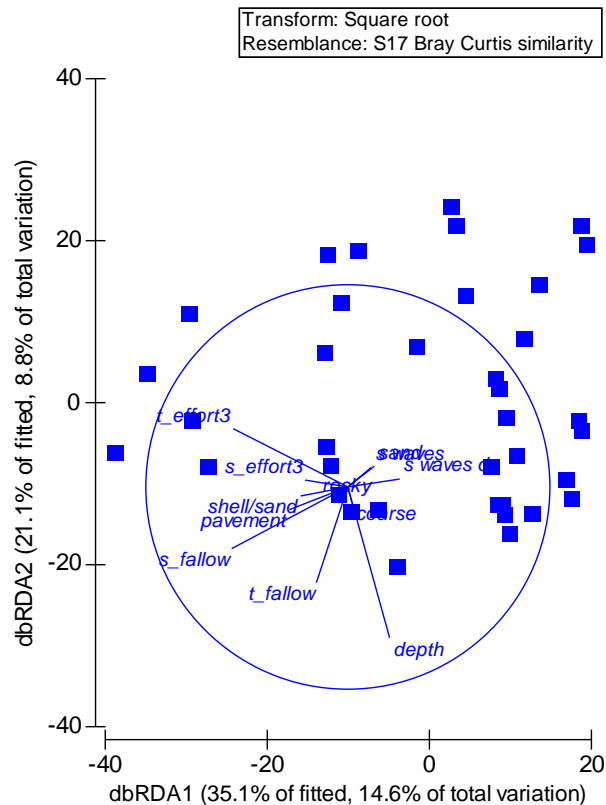


Figure 37: Grab samples and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2010 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations.

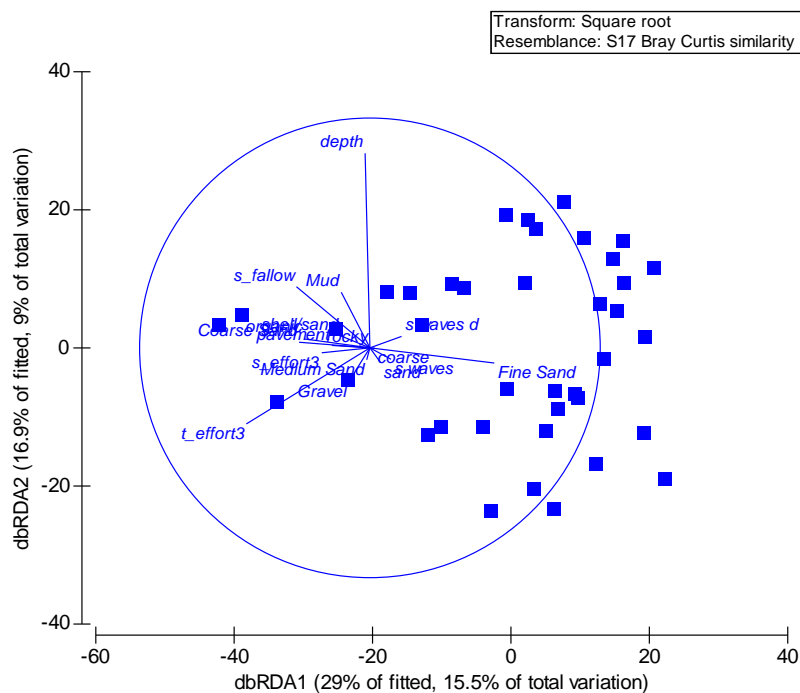


Figure 38: Grab samples, most recent fishing effort and sediment composition terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2010 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2 . Symbols represent individual stations.

As with the epifaunal community data, analysis using CCA (summarised in Appendix 2) provided very similar results (in terms of variables explaining the variation in the community data, and the overall variance accounted for) to the DISTLM analysis. Habitat, fishing, year and depth were retained in the minimum adequate model, which accounted for 37.5% of the total variance, with fishing accounting for 14.7%. Longer term fishing effects were also retained within the model when offered, explaining an additional 3.7% of the variation. Repeating the DISTLM analyses using the Hellinger distance similarity matrix (instead of the Bray-Curtis similarity matrix) retained the same variables in the minimum adequate models (full data set analysis, 31.5% of variance explained, 13.6% by fishing terms). All three analyses retained fishing terms as significant explanatory variables in the minimum adequate models, accounting for 13–16% of the total variance.

Univariate community analyses

As with the epifaunal data, analyses were also conducted using the DISTLM approach to examine environmental relationships with a range of univariate measures. The models are summarised in Table 7. Species richness and number of individuals, both log (x+1) transformed, showed similar patterns, with year, recent scallop effort and years fallow for both gears retained in the initial model, but both historical trawl effort terms were retained when offered to the model. The respective models for species richness explained more of the variance than those for number of individuals. For Pielou's evenness, only depth and years fallow from trawling were retained in the initial model (explaining 10.5% of variance, 7.6% explained by fishing term), but both the historical trawl effort terms were retained when offered (increasing overall variance explained to 19.8%, 15.4% by fishing terms). Examining the Shannon-Weiner index, year and the four initial effort terms explained 26.1% of the variance (23.4% explained by fishing), with the two additional trawl effort terms also retained when offered.

Table 7: Grab samples: Summary of DISTLM models fitted to univariate measures of infaunal community, showing data set used, adjusted R² value, variables retained following backwards selection, the proportion of total variance explained by all fishing variables (%), and the proportion of the explained variance attributable to fishing (%). All models based on Euclidian distance matrices. Variables represent Y – year, D – depth, H – acoustic habitat classes, SE – scallop effort, TE – trawl effort, SF – years fallow from scallop fishing, TF – years fallow from trawling. For each data set, results are shown for models excluding and including the longer-term fishing terms (i.e., TE6 and TE9).

Dataset	R ²	Retained variables	Fishing/Total	Fishing/Explained
Species richness	0.232	Y, SE3, SF, TF	17.8	76.7
	0.388	Y, SE3, SF, TF, TE6, TE9	25.3	65.2
No individuals	0.194	Y, SE3, SF, TF	14.8	76.3
	0.382	Y, SE3, SF, TF, TE6, TE9	18.9	49.5
Pielou's evenness	0.105	D, TF	7.6	72.4
	0.198	D, TF, TE6, TE9	15.4	77.8
Shannon-Weiner	0.261	Y, SE3, TE3, SF, TF	23.4	89.7
	0.368	Y, SE3, TE3, SF, TF, TE6, TE9	25.8	70.1

3.4 Changes between surveys

The consistent year effect detected across the various subsets of the epifaunal data suggests there has been substantial change in the epifaunal community between the surveys. The PRIMER routine SIMPER was used to identify species contributing most to the dissimilarity between years within habitat classes. SIMPER decomposes average Bray-Curtis dissimilarities between pairs of samples into percentage contributions from each species (Clarke 1993).

A diverse range of species were recorded on both surveys, but in general, the sand and sand/shell habitats that were found to be relatively sparse in fauna in 2006 (Tuck et al. 2010) had more species and individual organisms recorded in 2010. The species contributing most to the dissimilarity between surveys (averaged across the sandy habitats) are presented in Table 8. There were also some consistent changes (across habitats) in the observed density of some species between surveys, with the hydroid *Craterithea novaezelandiae* and the sponge *Tethyopsis mortensoni* increasing between 2006 and 2010, while the sponge genera *Oceanapia*, *Cinachyrella*, and

Hymeniacidon n.sp1. all decreased. In addition, a number of species or morphological types were only recorded in one or other of the surveys (e.g. Bryozoan sp. 9, *Chondropsis* cf n. sp. 2, *Tedania* n. sp. 1), and therefore also contributed significantly to the dissimilarity.

Table 8: Epifaunal taxa contributing over 2% to the dissimilarity between surveys (averaged across sandy habitats), the direction of change in abundance observed from 2006 to 2010 (if recorded in more than one habitat, and consistent across habitats), and the average number of individuals per station). Where no consistent change in abundance was observed across habitats, this has been left blank.

Taxon	Type	Consistent change between surveys	Contribution to dissimilarity	Average no. per station	
				2006	2010
<i>Craterithea novaezelandiae</i>	Hydroid	Increase	22.633	0.117	3.267
<i>Hydrodendron mirabile</i>	Hydroid		14.236	0.76	2.808
Hydroid sp 4 (grey/brown irregular multipinnate)	Hydroid	Decrease	9.163	1.88	0
Bryozoan sp. 9 (yellow coral bush)	Bryozoan		6.430	0	1
<i>Chondropsis</i> cf n. sp. 2 (gray/green mat)	Sponge		6.430	0	1
Red macroalgae	Algae		6.400	0.738	1.028
<i>Oceanapia</i>	Sponge	Decrease	6.153	3.447	1.083
<i>Homaxinella</i> sp. 1 (single yellow finger)	Sponge	Increase	5.137	0	1.77
<i>Steginoporella perplexa</i>	Bryozoan		4.003	1.897	1.013
Hydroid sp 1. (red/brown short multipinnate)	Hydroid		3.915	0.705	0.5
Algae sp 5 (red branching small)	Algae	Decrease	3.847	0.86	0
<i>Cinachyrella</i>	Sponge	Decrease	3.705	4.425	0.955
<i>Nemertesia elongata</i>	Hydroid		3.497	1.22	0.343
<i>Tedania</i> n. sp. 1 (Spirits Bay white filmy turrets)	Sponge	Decrease	3.295	1.985	0
<i>Hymeniacidon</i> n. sp. 1 (ENV9805 very rich orange mounded)	Sponge	Decrease	3.237	2.47	0.203
<i>Axinellidae</i> sp 5 (small orange upright fingers)	Sponge	Decrease	3.020	1.5	0
<i>Dragmacidon australe</i>	Sponge		2.927	0.447	0.69
<i>Poecilosclerida</i> sp 2 (bright orange thick encrustor, visible oscules)	Sponge	Increase	2.840	0	2.08
Microcionidae	Sponge	Increase	2.783	0	0.797
Ascidian sp 2 (green/grey fat fingers)	Ascidian		2.520	1	0
<i>Tethyopsis mortensoni</i>	Sponge	Increase	2.510	0.09	0.85
<i>Callyspongia</i> n. sp. 17 (Spirits Bay raised oscules)	Sponge	Decrease	2.480	0.95	0
<i>Aplidium</i> sp. 9 (huge foliose sandy)	Ascidian	Decrease	2.475	1.725	0
<i>Tetilla</i> n. sp. 1 (Spirits Bay umbrella anataenes)	Sponge		2.220	2.24	0
<i>Cellaria immersa</i>	Bryozoan		2.000	2.845	2.175

As with the epifaunal data analysis, a consistent year effect was also detected across the various subsets of the infaunal data, and SIMPER was used to identify species contributing most to the dissimilarity between years within habitat classes.

Many more species were identified from the infaunal samples than from the epifaunal samples, and no species contributed more than 5% to the dissimilarity between surveys, averaged across habitats (Table 9). Unlike the epifaunal data, the main contributors to the dissimilarity between surveys did not contain groups that were only identified in one survey, but there were a number of consistent patterns observed across habitats. The polychaetes *Prionospio* sp. and *Armandia* sp. showed consistent (across habitat) declines in abundance, while the amphipods Stenothoidea, Urothoidea, Liljeborgiidae, Phoxocephalidae, and the polychaetes Onuphidae, Cirratulidae and Orbiniidae showed a consistent increase.

Table 9: Infaunal taxa contributing over 2% to the dissimilarity between surveys (averaged across habitats), the direction of change in abundance observed from 2006 to 2010 (if consistent across habitats), and the average number of individuals per grab). Where no consistent change in abundance was observed across habitats, this has been left blank.

Taxon	Type	Consistent change between surveys	Contribution to dissimilarity	Average no. per grab	
				2006	2010
<i>Prionospio</i> sp.	Polychaete	Decrease	4.586	3.542	0.074
Stenothoidae	Amphipod	Increase	3.940	0.025	4.045
Urothoidae	Amphipod	Increase	3.298	0.546	2.932
<i>Armandia</i> sp.	Polychaete	Decrease	2.938	2.245	0.025
Otionellidae	Bryozoan		2.863	2.980	2.607
Onuphidae	Polychaete	Increase	2.834	1.328	3.318
Liljeborgiidae	Amphipod	Increase	2.685	0.520	2.123
Phoxocephalidae	Amphipod	Increase	2.645	1.485	3.150
Melphidippidae	Amphipod		2.640	0.230	2.223
Cirratulidae	Polychaete	Increase	2.558	1.098	2.733
Maeridae	Amphipod		2.442	1.496	2.214
Oligochaete	Oligochaete		2.203	1.170	1.403
Orbiniidae	Polychaete	Increase	2.193	1.158	2.480
Lysianassidae	Amphipod		2.008	0.944	1.574

3.5 Taxa sensitive to fishing

In addition to a consistent year effect indicating changes between the two surveys, the various fishing terms were consistently retained within the minimum adequate models, indicating that the fishing variables explained a significant component of the variance of both the epifaunal and infaunal community data.

The sensitivity of the sponges and other epifaunal species identified from images to various sources of physical disturbance, and factors influencing recoverability following disturbance, were categorised within the previous study (Tuck et al. 2010) on the basis of the categories defined in Appendix 3. This categorisation was conducted independently of the examination of species contributing to the differences between fishing areas. This is a relatively new field of research for marine communities (Hiscock & Tyler-Walters 2006), and is necessarily somewhat subjective. Some aspects of the categories have had to be interpreted from knowledge of life histories, since specific investigations into species sensitivities have not been conducted. However, we are confident that the categorisations are on the basis of the best available information. A number of additional species or morphological types were recorded in the 2010 survey, and the sensitivity table for the rocky (Table 10) and sandy and coarse (gravelly) habitats (Table 11) have been updated with these new records. Within these tables, species are allocated to the habitat within which they have been most often observed, although many species overlap habitats.

Table 10: A summary of the sensitivity and recoverability factors (at the individual organism/colony level) for the main rocky habitat species identified from images. Species are grouped by frequency of occurrence in the Spirits Bay data set (common – C; moderately common – Mc; uncommon – U). Size categories, L – large; Md – medium; Sm – small. Sensitivity categories; R – robust; M – moderate; S – sensitive. Growth categories, VS – very slow; Sl - slow; M – moderate; Ra – rapid. Recovery categories, G – good; M – moderate; P – poor. Definitions of terms in table explained in Appendix 3.

Species	4.	5.	6.	Sensitivity to:					Recovery by:			
	Frequency	Shape	Size	Dredging	Wash	Currents	Sediments	Growth	Wedging	Anchoring	G	Rolling
<i>Ancorina alata</i>	C	loaf	Lg	R	R	R	R	Sl	M	P	P	P
BRYOZOAN: <i>Cellaria immersa</i>	C	feathery	Sm	S	S	M	M	Ra	P	P	P	P
<i>Callyspongia latituba</i>	C	strappy	Lg	S	R	R	R	M	P	P	P	P
<i>Callyspongia ramosa</i>	C	strappy	Lg	S	R	R	R	M	P	P	P	P
<i>Dactylia palmata</i>	C	palmate	Lg	S	S	M	M	M	M	P	M	
HYDROID: Hydroid sp 1 (short multipinnate red)	C	feathery	Sm	S	R	R	M	M	M	M	P	
<i>Iophon minor</i>	C	strappy	Lg	M	R	R	R	Sl	P	P	P	
<i>Latrunculia kaakaariki</i>	C	loaf	Md	S	R	R	M	M	M	P	P	
<i>Latrunculia oxydiscorhabda</i>	C	thick	Md	M	R	R	M	M	P	P	P	
<i>Leucettusa lancifer</i>	C	spherical	Sm	M	M	M	M	Ra	P	P	P	
<i>Oceanapia cf aberrans</i>	C	spherical	Sm	S	M	M	R	Ra	P	M	P	
<i>Polymastia croceus</i>	C	loaf	Md	S	R	R	R	Ra	P	P	P	
<i>Trachycladus stylifer</i>	C	bushy	Md	M	R	R	R	Sl	P	P	P	
ALGAE: <i>Ecklonia radiata</i> (Ahipara variety)	Mc	strappy	Lg	M	M	M	R	M	P	P	P	
<i>Axinella</i> n sp 6 (like <i>Stylotella conulosa</i>)	Mc	loaf	Sm	M	R	R	M	M	P	P	P	
<i>Axinella</i> sp. 1 (bushy club)	Mc	bushy	Sm	M	R	R	R	M	P	P	P	
<i>Chondropsis</i> cf n. sp. 1 (brown tough strappy)	Mc	strappy	Sm	S	S	R	R	Ra	P	P	P	
<i>Clathria multitoxiformis</i>	Mc	palmate	Sm	M	R	R	R	M	P	P	P	
<i>Crella incrustans</i>	Mc	thick	Md	M	R	R	M	Ra	P	P	P	
<i>Crella</i> n. sp. 1 (pale blue cratered mass)	Mc	thick	Sm	M	R	R	M	Ra	P	P	P	
<i>Dendrilla rosea</i>	Mc	bushy	Md	M	M	M	S	Ra	P	P	P	
HYDROID: <i>Crateritheca novaezealandiae</i>	Mc	strappy	Md	S	R	R	M	M	M	P	P	
<i>Pararhaphoxya</i> n. sp. 1 (tiny orange branches)	Mc	bushy	Md	M	R	R	R	Ra	P	P	P	
<i>Petrosia hebes</i>	Mc	thick	Md	S	R	R	R	Sl	P	P	P	
<i>Psammocinia cf hawere</i>	Mc	fan	Md	S	R	R	R	M	P	P	P	
<i>Stelletta maori</i>	Mc	bowl	Md	R	R	R	R	VS	M	P	M	
ASCIDIAN: <i>Pseudistoma novaezealandiae</i>	U	spherical	Sm	M	R	R	R	Ra	P	P	P	
<i>Biemna rufescens</i>	U	loaf	Md	S	M	M	M	M	P	P	M	
BRYOZOAN: Bryozoan sp 1 (feathery mass)	U	feathery	Sm	S	M	M	M	Ra	P	P	P	
<i>Callyspongia</i> n. sp. 16 (Spirits Bay serrated)	U	strappy	Md	S	R	R	R	M	P	P	P	
<i>Callyspongia</i> n. sp. 17 (Spirits Bay raised oscules)	U	strappy	Md	S	R	R	R	M	P	P	P	
<i>Dragmacidon</i> n. sp. 1 (thick papillate encruster)	U	thick	Sm	M	R	R	M	Ra	P	P	P	
<i>Dragmacidon</i> n. sp. 2 (Spirits Bay flanged)	U	fan	Sm	M	R	R	R	M	P	P	P	
<i>Halichondrida</i> sp 5 (mustard encruster)	U	thick	Md	M	R	R	R	M	P	P	P	
<i>Leucettusa tubulosa</i>	U	spherical	Sm	S	R	R	R	M	M	P	P	
<i>Polymastia massalis</i>	U	loaf	Md	M	R	R	R	M	P	P	P	
<i>Psammocinia cf amodes</i>	U	palmate	Sm	M	R	R	R	Ra	P	P	P	
<i>Psammocinia beresfordi</i>	U	palmate	Md	M	R	R	R	Ra	P	P	P	
<i>Pseudaxinella australis</i>	U	thick	Sm	R	R	R	M	M	P	P	P	
<i>Raspailia</i> sp 5 (Spirits Bay palmate)	U	strappy	Sm	S	M	M	R	Ra	P	P	P	
<i>Raspailia topsenti</i>	U	bushy	Sm	M	R	R	R	M	P	P	P	
<i>Stelletta crater</i>	U	bowl	Lg	M	R	R	R	VS	M	P	M	
<i>Tethya fastigata</i>	U	spherical	Sm	S	R	R	M	M	P	P	P	
<i>Tetilla</i> n. sp. 1 (spirits Bay umbrella anataiaenes)	U	spherical	Sm	S	R	R	M	M	P	P	P	
<i>Xestospongia coralloides</i>	U	fan	Lg	S	R	R	M	Sl	M	P	P	

Table 11: A summary of the sensitivity and recoverability factors (at the individual organism/colony level) for the main sand, sand with basement and coarse habitat species identified from images. Species are grouped frequency of occurrence in the Spirits Bay data set (common – C; moderately common – Mc; uncommon – U). Size categories, L – large; Md – medium; Sm – small. Sensitivity categories; R – robust; M – moderate; S – sensitive. Growth categories, VS – very slow; Sl – slow; M – moderate; Ra – rapid. Recovery categories, G – good; M – moderate; P – poor. Definitions of terms in table explained in Appendix 3.

Species	7.	8.	9.	Sensitivity to:					Recovery by:		
	Frequency	Shape	Size	Dredging	Wash	Currents	Sediments	Growth	Wedging	Anchoring	Rolling
Sand											
ALGAE: Red algae sp 1 (filamentous streamers)	C	strappy	Md	S	M	M	M	Ra	P	P	P
<i>Homaxinella</i> sp. 1 (single yellow finger)	C	whip-like	Sm	M	M	R	R	M	P	P	P
HYDROID: <i>Gonaxia</i> sp 1 (irregular multipinnate)	C	feathery	Sm	S	R	R	M	Ra	P	P	P
HYDROID: <i>Nemertesia elongata</i>	C	feathery	Md	S	R	R	R	Sl	M	M	P
Hymeniacidon n. sp. 1 (ENV9805 very rich orange mounded)	C	loaf	Md	S	M	M	M	Ra	M	M	G
<i>Oceanapia</i> n. sp. 4 (pink translucent turnip)	C	spherical	Sm	S	M	M	R	M	P	M	P
<i>Tedania</i> n. sp. 1 (white filmy turrets)	C	loaf	Sm	S	M	M	R	Ra	M	M	P
<i>Tethyopsis mortensoni</i>	C	spherical	Sm	S	M	S	R	M	P	P	P
ASCIDIAN: Ascidian sp 1 (massive sandy foliose)	U	foliose	Lg	S	R	R	R	VS	P	M	P
ASCIDIAN: <i>Aplousobranchia</i> sp 1 (smoked roe)	U	spherical	Sm	S	M	M	M	Ra	P	P	P
BRYOZOAN: <i>Steginoporella perplexa</i>	U	fan	Sm	S	M	M	R	M	P	P	P
<i>Dysidea</i> cf. sp. 2 (blue tough + black stones)	U	palmate	Sm	M	R	R	R	Ra	G	G	M
<i>Hymeniacidon</i> n. sp. 1 (very rich orange mounded)	U	loaf	Md	S	M	M	M	Ra	M	M	P
<i>Hymeniacidon sphaerodigitata</i>	U	loaf	Md	S	M	M	M	Ra	M	M	P
<i>Oceanapia</i> cf <i>arcifera</i> (purple brown tipped papery fistules)	U	spherical	Sm	S	M	M	R	Ra	P	M	P
<i>Tedania</i> cf <i>connectens</i>	U	loaf	Md	S	M	M	M	Ra	G	G	G
Sand with basement											
<i>Poecilosclerida</i> sp 2 (bright orange thick encruster, visible oscules)	C	thick	Md	M	R	R	S	Ra		P	P
<i>Aaptos globosum</i>	MC	spherical	Sm	S	R	R	R	M	P	P	M
<i>Aaptos</i> sp. (smooth cream balls)	MC	spherical	Sm	S	R	R	R	M	M	P	G
<i>Adocia venustina</i> ?	MC	thin	Md	S	R	R	S	M		P	P
<i>Dictyodendrilla dendyi</i>	MC	bushy	Md	S	M	M	S	Ra	P	P	P
<i>Raspailia</i> sp.1 (rugose orange encruster)	MC	thick	Md	M	R	R	S	Ra		P	P
<i>Axinella</i> sp. 3 (orange spikey fan)	U	bushy	Md	M	M	R	R	M	P	P	P
<i>Chondropsis kirkii</i> ?	U	bulbous	Md	S	M	R	R	M	M	P	P
<i>Cinachyra</i> n sp 1 (large grey ball with porocalyces)	U	spherical	Sm	S	M	M	R	M	M	G	P
<i>Cinachyra uteoides</i>	U	spherical	Sm	S	S	S	R	M	M	G	P
<i>Cliona celata</i>	U	thin	Lg	R	R	R	M	Ra	P	P	P
GORGONACEAE: <i>Callogorgia</i> sp 1 (dull brownish pink)	U	feathery	Lg	S	R	R	R	Sl	P	P	P
HYDROID: <i>Hydrodendron mirabile</i>	U	feathery	Lg	S	R	R	M	Sl	P	P	P
<i>Pararhaphoxya pulchra</i>	U	bushy	Md	M	R	R	R	M	P	P	P
<i>Poecilosclerida</i> sp 5 (yellow encruster, oscules)	U	thin	Md	M	R	R	S	Ra		P	P
<i>Poecilosclerida</i> sp 8 (apricot oscules in rows)	U	thin	Md	M	R	R	S	Ra		P	P
<i>Polymastia aurantium</i>	U	loaf	Md	M	R	R	R	Ra	P	P	P
<i>Porhyria</i> sp.1 (fluro yellow smooth knobby)	U	bulbous	Md	S	M	R	S	M		P	P
<i>Stylissa</i> n. sp. 1 (fingery club)	U	fan	Sm	S	M	M	R	M	M	M	M
<i>Suberites</i> sp 1	U	spherical	Md	S	R	R	R	Sl	M	P	G
Coarse material (sand gravel shell)											
<i>Ciocalypa</i> cf <i>polymastia</i>	C	loaf	Md	S	S	M	M	M	M	G	G
<i>Oceanapia</i> n. sp. 5 (double blind fistules)	C	spherical	Sm	S	M	M	R	Ra	P	M	P
<i>Axinella australiensis</i>	Mc	strappy	Md	M	R	R	R	M	P	P	P

Analysis of the community data sets in relation to the explanatory variables with CCA allowed the effects of the other variables retained in the minimum adequate model to be partialled out, to determine the species eigenvector

values for each of the fishing terms. Rare species are likely to provide a less reliable indication of their relationship with the eigenvector axes (since they occur at few stations), and so only species occurring at five or more of the stations were considered. The species have been ranked in terms of their eigenvector values relating to each of the effort variables, and those that appear most sensitive to fishing (negative values on increasing effort axis, or positive values on increasing years fallow axis) are presented in Table 12 (epifauna) and Table 13 (infauna). In addition, the ranks against the effort, fallow and all four fishing variables have been averaged to identify the species most sensitive to the various fishing measures.

The epifaunal species identified as most sensitive to fishing using the eigenvector approach described above varied with the measure of fishing pressure considered (Table 12), although some species were identified as sensitive to more than one fishing term. The sponges *Latrunculia oxydiscorhabda* and *Axinella* sp. 3, and the hydroid *Nemertesia elongata* appear to be the most sensitive to the levels of recent fishing effort (average of rank against both effort terms), while *Nemertesia elongata*, *Halichondrida* sp. 5 and the hydroid *Iophon minor* appeared most sensitive to the years fallow. Overall (averaged across ranks of species against all four fishing terms), *Halichondrida* sp. 5, *Aaptos* sp. and *Iophon minor* were the most sensitive.

As with the examination of the epifaunal data, the infaunal taxa identified as being most sensitive varied between the effort terms (Table 13). The isopods Pseudidotheidae, amphipods Leucothoidae and gastropods Retusidae appeared to be the most sensitive to the recent effort, while the amphipods Podoceridae and Melphidippidae, and polychaetes Amphinomidae were the most sensitive to the years fallow. Overall (averaged across ranks of taxa against all four fishing terms), the amphipods Podoceridae and Melphidippidae, and polychaetes Amphinomidae were the most sensitive.

9.0 Recovery inside and outside the closed area

The second objective of the project was to assess the changes in benthic communities inside and outside the closed area since 1997. At the time of initial development of this project, it was assumed that analysis would have to be on the basis of the legislative areas (pers comm., Martin Cryer Ministry for Primary Industries). Although the spatial closure status of sites (still open to fishing, within 1997 voluntary closure, within additional area closed by 1999 regulated closure) was specifically included within the previous analysis of the 2006 survey (Tuck et al. 2010), the availability of finer scale spatial information on the relative levels of fishing pressure provided by the Northland Scallop Enhancement Company, and from analysis of data on trawl effort provided by the Ministry of Fisheries Data Management Group, made this unnecessary within the DISTLM and CCA analyses described above. While we have assumed that no fishing has taken place within the closed areas since their introduction, the relative levels of effort within the area still open to fishing appear to have varied spatially (Figure 10 – Figure 12) by an order of magnitude, and so the use of these relative effort data, in conjunction with the years fallow term, was considered more useful than a simple categorical fishing pressure term with two (open, closed) or three (closed since 1997, closed since 1999, open) levels, and likely to be more informative about the effects of fishing.

Table 12: Epifaunal species from seabed images ranked in order of their eigenvector values in relation to axes associated with individual fishing effort variables (all other variables having been partialled out within CCA), to identify those species most sensitive to the measures of fishing effort examined. Overall column represents species ranked on the average of the four effort variable ranks.

Rank	Scallop effort	Scallop fallow	Trawl effort	Trawl fallow	Effort	Fallow	Overall
1	<i>Halichondrida</i> sp. 5	<i>Axinella</i> sp. 3	<i>Chondropsis</i> cf n. sp. 2	<i>L. oxydiscorhabda</i>	<i>L. oxydiscorhabda</i>	<i>Nemertesia elongata</i>	<i>Halichondrida</i> sp. 5
2	<i>Adocia venustina</i> ?	<i>Latrunculia oxydiscorhabda</i>	<i>Hydrodendron mirabile</i>	<i>Raspailia</i> sp.1	<i>Axinella</i> sp. 3	<i>Halichondrida</i> sp. 5	<i>Aaptos</i> sp.
3	<i>Poecilosclerida</i> sp 5	<i>Adocia venustina</i> ?	<i>Trachycladus stylifer</i>	<i>Polymastia croceus</i>	<i>Nemertesia elongata</i>	<i>Iophon minor</i>	<i>Iophon minor</i>
4	<i>Aaptos rosacea</i>	<i>Nemertesia elongata</i>	Hydroid sp 5	<i>Poecilosclerida</i> sp 9	<i>Dragmacidon</i> n. sp. 2	<i>Homaxinella</i> sp. 1	<i>Trachycladus stylifer</i>
5	Bryozoan sp 3	<i>Jaspis novaezelandiae</i>	<i>Aaptos</i> sp.	<i>Axinella</i> sp. 3	<i>Adocia venustina</i> ?	<i>Dragmacidon</i> n. sp. 2	<i>Poecilosclerida</i> sp 5
6	<i>Axinella</i> sp. 4	<i>Psammoncinia hawere</i>	<i>Halichondrida</i> sp. 5	<i>Poecilosclerida</i> sp 5	<i>Homaxinella</i> sp. 1	<i>L. oxydiscorhabda</i>	<i>Nemertesia elongata</i>
7	Hydroid sp 4	<i>Latrunculia kaakaariki</i>	<i>Axinella</i> sp. 8	<i>Halichondriidae</i> sp 3	<i>Cellaria immersa</i>	<i>Poecilosclerida</i> sp 5	<i>Poecilosclerida</i> sp 2
8	<i>Poecilosclerida</i> sp 2	<i>Aplousobranchia</i> sp 1	<i>Jaspis novaezelandiae</i>	<i>Aaptos rosacea</i>	<i>Ciocalyptra</i> cf <i>polymastia</i>	<i>Aaptos</i> sp.	<i>Craterithea novaezelandiae</i>
9	<i>Iophon minor</i>	Algae sp 5	<i>Craterithea novaezelandiae</i>	<i>Dragmacidon</i> n. sp. 2	<i>Iophon minor</i>	<i>Axinella</i> sp. 3	Red macroalgae
10	<i>Pararhaphoxya</i> n. sp 1	<i>Homaxinella</i> sp. 1	<i>Ciocalyptra</i> cf <i>polymastia</i>	<i>Callyspongia ramosa</i>	Algae sp 5	<i>Poecilosclerida</i> sp 2	<i>Hydrodendron mirabile</i>

Table 13: Infaunal species from seabed images ranked in order of their eigenvector values in relation to axes associated with individual fishing effort variables (all other variables having been partialled out within CCA), to identify those species most sensitive to the measures of fishing effort examined. Overall column represents species ranked on the average of the four effort variable ranks.

Rank	Scallop effort	Scallop fallow	Trawl effort	Trawl fallow	Effort	Fallow	Overall
1	Pseudidotheidae	Podoceridae	Alpheidae	Melphidippidae	Pseudidotheidae	Podoceridae	Podoceridae
2	Polygordiidae	Solenogastres	Phyllodocidae	Armandia	Leucothoidae	Amphinomidae	Amphinomidae
3	<i>Neanthes</i>	<i>Solariella</i>	Pseudidotheidae	Stenothoidae	Retusidae	Melphidippidae	Melphidippidae
4	<i>Rissoina</i>	<i>Hiatella</i>	Leucothoidae	Podoceridae	Polygordiidae	Solenogastres	Leucothoidae
5	Aricidea	Amphinomidae	Podoceridae	Microparasellidae	Cephalochordata	<i>Processa</i>	Solenogastres
6	Capitellidae	Onuphidae	Cephalochordata	Terebratulida	Chiridotidae	Stenothoidae	Pantopoda
7	Leucothoidae	Otionellidae	Zemitrella	Sigalionidae	Stegocephalidae	Nereididae	Retusidae
8	Pantopoda	<i>Processa</i>	Oweniidae	Amphinomidae	Podoceridae	Dexaminidae	Polygordiidae
9	Retusidae	Iphimediidae	Stegocephalidae	Polygordiidae	Aricidea	<i>Hiatella</i>	Oligochaete
10	Melphidippidae	Dexaminidae	Retusidae	<i>Glycymeris</i>	Oedicerotidae	Terebratulida	Pseudidotheidae

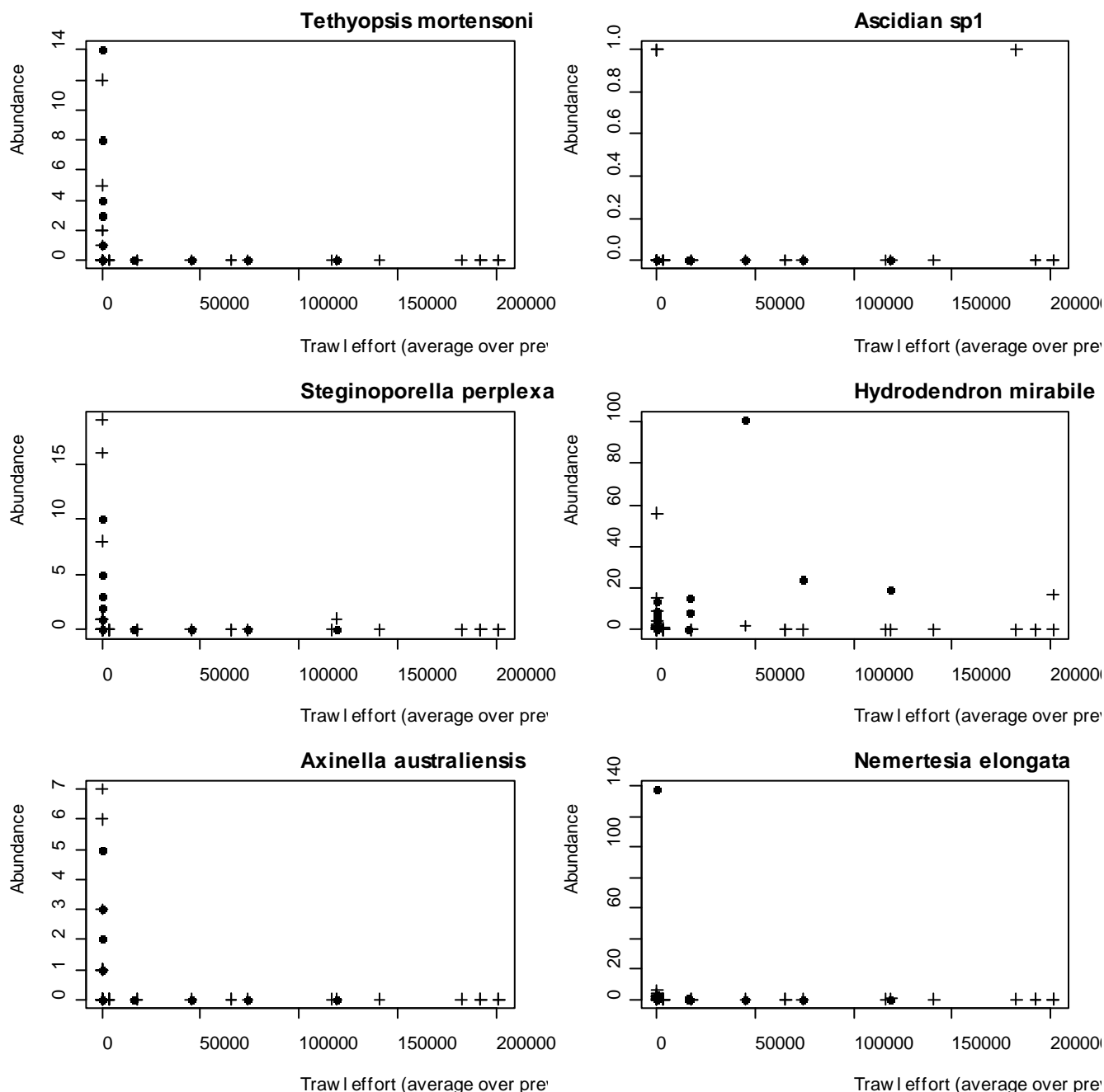


Figure 39: Abundance of epifaunal species identified as likely to be most vulnerable to fishing in relation to estimated trawl effort (average over 3 years prior to sampling). Solid symbols represent stations within sand habitat, while crosses represent all other habitats.

As described above, the sensitivity of the sponges and other epifaunal species identified from images to various sources of physical disturbance, and factors influencing recoverability following disturbance, were categorised within the previous study (Tuck et al. 2010) on the basis of the categories defined in Appendix 3, and independently of the examination of species contributing to the differences between fishing areas. For the epifaunal species identified as likely to be the most vulnerable (combining sensitivity to disturbance, ability to recover, and likelihood of being disturbed) to the effects of fishing, abundance is plotted against recent fishing effort in Figure 39. These could potentially be considered as monitoring species for future effects of fishing and benthic community recovery investigations. With the exception of the observation of a single *Ascidian sp1* at a site within a relatively heavily fished area, the sensitive species were either only observed at sites with no fishing in the previous three years, or were observed at lower abundances at more heavily fished sites (*Hydrendron mirabile*). Data within the plots represent all habitats, with the sand habitat (which includes both open and closed areas) showing a similar pattern.

10. DISCUSSION

The impacts of trawling and scallop dredging have recently been reviewed (DFO 2006, Rice 2006). Studies into the effects of fishing on the seabed and benthic communities have been conducted in a range of geographic locations, and while general impacts are quite consistent and predictable (large bodied, slow growing organisms reduce in abundance, smaller bodied, faster growing opportunists and scavengers increase), the specific effects detected have been found to vary with fishing gear and habitat encountered, with the most severe impacts occurring in biogenic habitats in response to scallop dredging (Kaiser et al. 2006).

The Spirits Bay area is considered to be a dynamic habitat, exposed to considerable wave disturbance, and strong tides. Large ridge features (with an altitude of up to 10 m) have been identified at the western end of Spirits Bay, running in a roughly north south direction. Comparison of depth profiles from surveys in 2006 and 2010 did not suggest these features had moved west to east over that time. The area has provided an important part of the Northland scallop fishery in previous years, and is also the focus of trawl fishing, generally targeting snapper, trevally and terakihi. A voluntary closed area was introduced by the Northland scallop fishery in 1997, and a regulated closure (applicable to all mobile bottom gear) was introduced in 1999. Activity in the scallop fishery has been low in all Northland areas in recent years, but the trawl fishery remains active in the inshore area of the study area. Previous studies in the area (Cryer et al. 2000, Tuck et al. 2010) have confirmed anecdotal observations that the colonial, filter feeding community of the area is very unusual, and the area is considered one of New Zealand's biodiversity hot spots. Within this study a number of previously undescribed sponge species have been recorded in the area, and within the analysis of the infauna, new records for New Zealand (largely polychaetes) and previously undescribed genera and species (isopods and gastropods) have been recorded.

Surveys of a limited area within Spirits Bay, focussed in the vicinity of a previously identified sponge habitat area, and overlapping the boundaries of the voluntary and regulated closures, were conducted in May 2006 and May 2010, collecting epifaunal (from seabed images) and infaunal (from grab sampling) community data, to conduct a broad scale examination of the effects of fishing on the benthic communities of the area. Distance based linear modelling (McArdle & Anderson 2001) of the community data (based on Bray-Curtis similarity matrices) in relation to environmental and fishing variables consistently identified strong year, depth and habitat effects, but also effects related to fishing, with typically 15–30% of the total variance explained by fishing (median 20%), where roughly half of the explainable variation was attributed to fishing. This proportion of the total variance attributable to fishing is comparable to previous investigations into the effects of fishing on benthic communities in New Zealand (Thrush et al. 1998, Cryer et al. 2002).

Longer term fishing effort patterns were retained within the minimum adequate models for most analyses, in addition to the more recent fishing effort data. This indicates that not only have the spatial patterns of fishing activity changed over time (to allow this detection of the longer term pattern), but that also this fishing had an effect on benthic communities that is still detectable almost a decade later. Detection of such an effect on the large sponge epifauna found in the region might be expected given their likely sensitivity and growth rates, but detection of an effect on infauna is more surprising, and may reflect an indirect effect of fishing through an association between infauna and epifauna.

Analyses were conducted for the full data set, and for subsets of habitat types. As habitats with more influence on community structure were omitted from the analysis (leaving only the sandy areas), the overall explained deviance decreased, but fishing terms remained important and the proportion of the explained component attributable to the effects of fishing showed a general increasing pattern.

Comparative analyses of the full data sets with CCA and DISTLM (using Hellinger distance similarity matrices) provided similar results, suggesting that the results were not driven by the analysis method. Type II errors (failure to detect an effect that actually exists) are considered likely in broad scale studies (Dayton et al. 1995, Jennings & Kaiser 1998), and the consistent detection of effects in both infaunal and epifaunal communities, across analytical approaches and habitat subsets, imply major community differences across gradients of fishing pressure.

DISTLM analysis of univariate measures of the community provided generally similar results to the analysis based on the full community data, although for the epifauna, species richness appeared far less sensitive to fishing than the other measures considered (number of individuals, Pielou's evenness and Shannon-Weiner diversity index). With both the multivariate and univariate measures, the models for the epifaunal community data generally explained more of the

variance than those for infaunal community data. This difference is thought to be most likely driven by the different scales of sampling of the two types of data relative to faunal abundance and the explanatory variables, the potential for fishing disturbance to be more important for epifauna than infauna, and the ability of key epifaunal species to affect surrounding infaunal species.

For the epifaunal data, the strong year effect was related to changes in the abundance of a number of species between surveys (sometimes consistently across habitats), including some species only being observed on one or other of the surveys. The community data from this analysis were derived from seabed images, with epifaunal species identified using the identification keys developed within ENV200523 (Tuck et al. 2010) and subsequent NIWA Capability Fund projects, based on colour and morphological features identifiable from images. The keys have been ground-truthed where possible with physical samples, and the analysis was conducted by the same individual. This visual approach to identifying epifaunal communities has been developed as a non destructive tool for sampling sensitive areas, and has been used successfully elsewhere (Bell et al. 2006, Bell 2007), but will not be as accurate to the species level as physical sampling. Species have been combined where identifications may be confused, to ensure confidence in the data set analysed. There appears to have been relatively little fishing effort in the most recent years within the study area, and the changes between surveys may partly reflect recovery of the epifaunal community from previous fishing disturbance, and also be influenced by the relatively low level of sampling in a (potentially patchy) high biodiversity area.

For the infaunal data, one of the main changes in the community between the surveys was an increase in amphipod abundance, which was often consistent across habitats. The epifaunal images from the 2010 survey showed a widespread distribution of what were identified as kelp fragments (average of 12 per station, with material observed at 36 of the 41 stations). Similar fragments were only recorded at 7 of the 24 stations in 2006, and at a far lower density. The fragments were not attached to the seabed, and were excluded from the analysis of the data from the seabed images, but may have contributed to the observed change in the infaunal community in some way.

The main epifaunal species observed in the area were classified in terms of their sensitivity to and recoverability from different types of disturbance, on the basis of morphology and life history characteristics. This is a relatively new approach for marine communities (Hiscock & Tyler-Walters 2006), and is necessarily somewhat subjective, although we are confident that the categorisations are on the basis of the best available information. CCA was used to partial out other significant effects, so that species responses to the fishing terms could be identified. The epifaunal species identified as most sensitive to the fishing variables in this analysis had also previously been categorised as either sensitive to dredging disturbance, or moderately sensitive to dredging but growing to a medium or large size. Most of these species were also considered to have a poor probability of recovery following disturbance, and most were only found in areas with no recent fishing history. A similar analysis of the infaunal data was conducted using CCA to identify species responses to the fishing terms, but no *a priori* classification of species by sensitivity or recoverability had been conducted.

11. CONCLUSIONS

Analysis of benthic community data from surveys in 2006 and 2010 was conducted to investigate the effects of fishing in the Spirits Bay area, and recovery in the closed areas within this region. Multivariate and univariate analyses of epifaunal and infaunal community data from the Spirits Bay area consistently identified year, habitat and depth effects, but scallop and trawl fishing were also retained in minimum adequate models (accounting for a median level of 20% of the total variance), with effects still detectable 7–9 years after fishing. Roughly half of the explained variance was attributable to fishing. The effects detected were independent of similarity measure, analysis approach or data set used.

Strong year effects were observed for both epifauna and infauna, which may partly reflect recovery of the communities from previous fishing disturbance, given the low levels of fishing in the area in recent years. Species sensitivities categorised on the basis of morphology and life history characteristics were consistent with species responses to fishing terms within the modelled analysis, and most of the most sensitive species were only found in areas with no recent fishing history. These could potentially be considered as monitoring species for future effects of fishing and benthic community recovery investigations.

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APPENDIX 1

DISTLM marginal tests for analysis of epifaunal community data from seabed images for complete dataset (Figure 17 and Figure 18). These show how much of the total variance each variable explains when taken alone, ignoring all other variables. Only variables retained in the final model are presented. SS(trace) – diagonal elements of Gower's centred matrix (Anderson et al. 2008); Pseudo-F - multivariate analogue of Fisher's F ratio; P - significance of term; Prop. - the proportion of total variance explained by that term; res.df – residual degrees of freedom; regr.df – degrees of freedom for term. Recent effort and All effort columns relate to terms included in model (*– term included and retained in minimum adequate model, X – term not retained in minimum adequate model; applies to all captions below).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
Depth	17 425	4.6027	0.001	0.068	63	2	*	*
Habitat	60 053	2.9637	0.001	0.235	58	7	*	*
se3	12 672	3.2818	0.002	0.050	63	2	*	*
sf	10 545	2.7073	0.001	0.041	63	2	*	*
te3	8 563.6	2.181	0.003	0.033	63	2	*	*
tf	14 746	3.8517	0.001	0.058	63	2	*	*
Year	23 221	6.2865	0.001	0.091	63	2	*	*
te6	7 921.4	2.0122	0.014	0.031	63	2		X
te9	13 286	3.4496	0.001	0.052	63	2		*

DISTLM marginal tests for analysis of epifaunal community data from seabed images for sandy habitat dataset (Figure 19 and Figure 20).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
Depth	16 891	4.7403	0.001	0.082	53	2	*	*
Habitat	34 128	2.4857	0.001	0.166	50	5	*	*
se3	14 171	3.9203	0.001	0.069	53	2	*	*
sf	9 334.7	2.5189	0.003	0.045	53	2	*	*
te3	6 805.2	1.813	0.026	0.033	53	2	*	*
tf	13 581	3.7455	0.001	0.066	53	2	*	*
Year	23 919	6.972	0.001	0.116	53	2	*	*
te6	7 829.5	2.0966	0.014	0.038	53	2		X
te9	11 228	3.0592	0.003	0.055	53	2		*

DISTLM marginal tests for analysis of epifaunal community data from seabed images for sand habitat dataset (Figure 21).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
Depth	9 591.2	2.8378	0.004	0.092	28	2	*	*
se3	10 385	3.0988	0.004	0.100	28	2	*	*
sf	7 054.9	2.0329	0.034	0.068	28	2	*	*
te3	6 981.9	2.0103	0.022	0.067	28	2	X	
tf	9 227.4	2.7197	0.006	0.089	28	2	*	*
Year	19 696	6.524	0.001	0.189	28	2	*	*
te6	4 148.9	1.1608	0.299	0.040	28	2		X
te9	8 560.8	2.5056	0.011	0.082	28	2		X

DISTLM marginal tests for analysis of epifaunal community data from seabed images for 2006 dataset (Figure 22).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
Depth	9 820.4	2.4987	0.002	0.102	22	2	X	
Habitat	40 064	2.0192	0.001	0.416	17	7	*	*
se3	8 067.7	2.012	0.015	0.084	22	2	*	*
sf	8 273.9	2.0683	0.016	0.086	22	2	X	
te3	4 745	1.1404	0.316	0.049	22	2	X	
tf	6 498.4	1.5923	0.048	0.067	22	2	*	*
te6	6 234.8	1.5233	0.075	0.065	22	2		X
te9	7 270.5	1.7969	0.038	0.076	22	2		X

DISTLM marginal tests for analysis of epifaunal community data from seabed images for 2010 dataset (Figure 23 and Figure 24).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
Depth	15 360	4.9482	0.001	0.113	39	2	*	*
Habitat	48 484	3.1242	0.001	0.355	34	7	*	*
se3	6 419.6	1.9258	0.028	0.047	39	2	*	*
sf	10 327	3.194	0.002	0.076	39	2	*	*
te3	7 802.1	2.3657	0.006	0.057	39	2	*	*
tf	12 238	3.8433	0.001	0.090	39	2	*	*
te6	6 640	1.9953	0.032	0.049	39	2		*
te9	8 872.6	2.7129	0.005	0.065	39	2		*

DISTLM marginal tests for analysis of infaunal community data from grab samples for complete dataset (Figure 29 and Figure 30).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
depth	7 261.1	3.3597	0.001	0.047	68	2	*	*
Habitat	20 702	1.628	0.002	0.134	63	7	*	*
se3	9 883.5	4.6562	0.001	0.064	68	2	*	*
sf	5 846	2.6792	0.002	0.038	68	2	*	*
te3	5 859.5	2.6856	0.001	0.038	68	2	*	*
tf	6 347	2.9186	0.002	0.041	68	2	*	*
year	19 701	9.9587	0.001	0.128	68	2	*	*
te6	3 672	1.6585	0.054	0.024	68	2		X
te9	12 732	6.119	0.001	0.083	68	2		*

DISTLM marginal tests for analysis of infaunal community data from grab samples for sandy habitat dataset (Figure 31 and Figure 32).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
depth	6 947.3	3.2468	0.001	0.048	64	2	*	*
Habitat	13 128	1.5311	0.014	0.091	61	5	*	*
se3	9 617.8	4.5843	0.001	0.067	64	2	*	*
sf	5 082	2.3432	0.006	0.035	64	2	*	*
te3	3 572.6	1.6295	0.044	0.025	64	2	*	*
tf	5 970	2.7703	0.003	0.041	64	2	*	*
year	19 286	9.9057	0.001	0.134	64	2	*	*
te6	3 783.2	1.7282	0.035	0.026	64	2		X
te9	12 461	6.0682	0.001	0.087	64	2		*

DISTLM marginal tests for analysis of infaunal community data from grab samples for sand habitat dataset (Figure 33 and Figure 34).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
depth	3 143.2	1.4276	0.125	0.036	38	2	*	*
se3	6 628.9	3.1417	0.001	0.076	38	2	*	*
sf	4 095.5	1.8816	0.03	0.047	38	2	*	*
te3	2 958.5	1.3408	0.129	0.034	38	2	*	*
tf	4 012.6	1.8416	0.034	0.046	38	2	*	*
year	11 523	5.8164	0.001	0.133	38	2	*	*
te6	1 815	0.81149	0.682	0.021	38	2		X
te9	9 781	4.8253	0.001	0.113	38	2		*

DISTLM marginal tests for analysis of infaunal community data from grab samples for 2006 dataset (Figure 35 and Figure 36).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
depth	5 194.5	2.4209	0.006	0.077	29	2	*	*
Habitat	13 244	1.2223	0.11	0.196	25	6	X	*
se3	7 137	3.4334	0.003	0.106	29	2	*	*
sf	5 144.4	2.3956	0.011	0.076	29	2	X	X
te3	2 318.1	1.0326	0.403	0.034	29	2	X	*
tf	4 103.8	1.8797	0.029	0.061	29	2	*	X
te6	3 174.1	1.4328	0.127	0.047	29	2		X
te9	7 509.2	3.6349	0.001	0.111	29	2		*

DISTLM marginal tests for analysis of infaunal community data from grab samples for 2010 dataset (Figure 37).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort	Sediment
depth	5 953	3.6019	0.001	0.089	37	2	*	*	*
Habitat	15 295	1.9485	0.001	0.228	33	6	*	*	*
se3	2 878.8	1.6585	0.056	0.043	37	2	*	*	*
sf	4 183.2	2.4599	0.004	0.062	37	2	*	*	*
te3	4 815.8	2.8606	0.002	0.072	37	2	*	*	*
tf	4 534.3	2.6813	0.003	0.068	37	2	*	*	X
te6	2 486.8	1.424	0.103	0.037	37	2		X	X
te9	3 653.3	2.1303	0.011	0.054	37	2		X	X
Organic	6 724	4.1203	0.001	0.100	37	2			*
Sediment	14 844	2.4142	0.001	0.221	34	5			*

APPENDIX 2

Summary of CCA analysis, showing data set used, adjusted R^2 value, variables retained following forward selection, the proportion of total variance explained by all fishing variables (%), and the proportion of the explained variance attributable to fishing (%). Variables represent Y – year, D – depth, H – acoustic habitat classes, F – combined fishing

Dataset	R^2	Retained variables	Fishing/Total	Fishing/Explained
Epifauna	0.414	H, F, Y, D	19.2	46.0
	0.448	with longer term fishing effects	22.3	49.7
Infauna	0.375	Y, D, F, H	14.7	38.5
	0.412	with longer term fishing effects	17.7	43.0

APPENDIX 3: Definitions of gross morphology, sensitivity to disturbance, and recoverability categories used to characterise benthic epifauna recorded at Spirits Bay (Tuck et al. 2010).

Category	Explanation
Shape	Morphology and profile of sponge
Strappy	Tree-like with long straps
Bushy	Tree-like with short bushy branches
Bowl	Cup or bowl
Loaf	Loaf or hemisphere
Thick	Thickly encrusting
Thin	Thinly encrusting
Size	Typical observed maximum size
Large	100–1000 cm largest dimension
Medium	10–100 cm largest dimension
small	<10 cm largest dimension
Dredging	Sensitivity to human-induced physical disturbance (dredges, trawling, anchor-drag etc)
Robust	Flexible structure with tough base or very tough stony texture with broad base, or flat profile Compressible texture with high profile and weak base of attachment, or has tough texture but weak base
Moderate	
Sensitive	Soft papery / crumbly texture, and/or rooted basally in sediments
Wash	Sensitivity to natural physical disturbance (multidirectional wash causing partial damage or total dislodgement)
Robust	Flexible structure with tough base or very tough stony texture with broad base, or flat profile Compressible texture with high profile and weak base of attachment, or has tough texture but weak base
Moderate	
Sensitive	Soft papery / crumbly texture, and/or rooted basally in sediments
Currents	Sensitivity to natural physical disturbance (unidirectional currents causing scouring, dislodgement, and sand-dune development)
Robust	Has a very flexible structure with a tough base or very tough stony texture with a broad base, or a flat profile
Moderate	Has a compressible texture with high profile and weak base of attachment, or has a tough texture but a weak base
Sensitive	Has a soft papery or crumbly texture, and/or is rooted basally in sediments
Sediments	Sensitivity to physical disturbance (terrigenous sedimentation from river flooding or industrial development)
Robust	High profile with flexible branches from previously clear-water habitat
Moderate	Medium hemispherical profile from previously clear-water habitat
Sensitive	Low profile with soft texture from previously clear-water habitat
Growth	Growth rate to typical observed maximum size
Rapid	0–2 years (ephemeral)
Moderate	2–10 years
Slow	10–20 years
Very slow	20+ years
Recovery by wedging	Recovery potential by reattachment (to hard substrate via wedging)
Good	Will reattach if wedged
Moderate	May reattach, but not very likely
Poor	Unlikely to reattach if wedged
Recovery by anchoring	Recovery potential by reattachment (burial and anchoring via agglomeration of loose substrate such as shell and sand)
Good	Will reattach if left to agglomerate loose substrate
Moderate	May reattach if can be left long enough to agglomerate
Poor	Unlikely to reattach as will not agglomerate to anchor
Recovery by rolling	Recovery potential as a 'roller'
Good	Will remain viable as a roller
Moderate	May remain viable as a roller
Poor	Unlikely to remain viable as a roller