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Monitoring Recovery of Benthic Fauna in Spirits Bay

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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 Māori and also supports valuable commercial fisheries. The Spirits Bay area is a very dynamic habitat, exposed to considerable wave disturbance, and strong tides, and is an area of unusually high biodiversity. In response to concerns over the effects of fishing on the highly unusual, sponge, bryozoan and hydroid dominated epifaunal community observed in the area, voluntary (applying only to the scallop fishery) and then regulated (applying to all mobile bottom fishing) fishery closures were introduced in 1997 and 1999, respectively.

In 1998 the Ministry of Fisheries commissioned an initial survey of the region, and following this, has developed a series of projects to monitor changes in the benthic communities in relation to fishing patterns. Following a broad-scale survey of the area between North Cape and Cape Reinga in 1999, surveys focussing on a more limited study area were conducted in 2006 and 2010. The current project provides the fourth survey of the benthic communities in the area, and the third survey that particularly focussed on the study area. These surveys collected infaunal community samples collected using grab sampling, and data on epifaunal communities based on seabed photography. The survey in 2006 also included acoustic mapping components, and the subsequent surveys were stratified on the basis of habitat classes that had been determined from this acoustic mapping.

Within the current study, analysis of benthic community data from surveys in 2006, 2010 and 2017 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, and up to 50% of the explained variance), with effects still detectable 7–9 years after fishing in some analyses. The effects detected were independent of similarity measure, analysis approach or data set used, and, as we might expect, the effects of fishing were weaker in analyses of more recent survey data, where recent fishing effort was lower.

Strong year effects were observed for both epifauna and infauna, which may partly reflect recovery of the communities from previous fishing disturbance, as there has been no scallop fishing and low levels of trawl 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 within the modelled analysis. Most of the most sensitive species were only found in areas with no recent fishing history. These sensitive species could potentially be considered as useful monitoring species for future investigations of the effects of fishing and benthic community recovery in this region, or in areas with similar communities.

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. In recent decades the area has also supported recreational fishing interests and several commercial fisheries including, but not restricted to, an important part of the Northland scallop fishery and some bottom trawling for snapper and trevally.

The scallop grounds in the broader Northland scallop fishery region 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 Northland 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 confirmed that the community was highly unusual, dominated by a diverse fauna of 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, and 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 the Spirits Bay and Tom Bowling Bay region 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 Northland scallop 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. There was also concern, therefore, that destruction of the colonial, filter-feeding fauna of Spirits Bay may lead to recruitment problems in the scallop fishery as well as the loss of an important ecological archetype.

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 (project 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 habitats of particular significance for fisheries management (e.g., that containing much “spat catching” foliose colonial fauna) were likely to be affected.

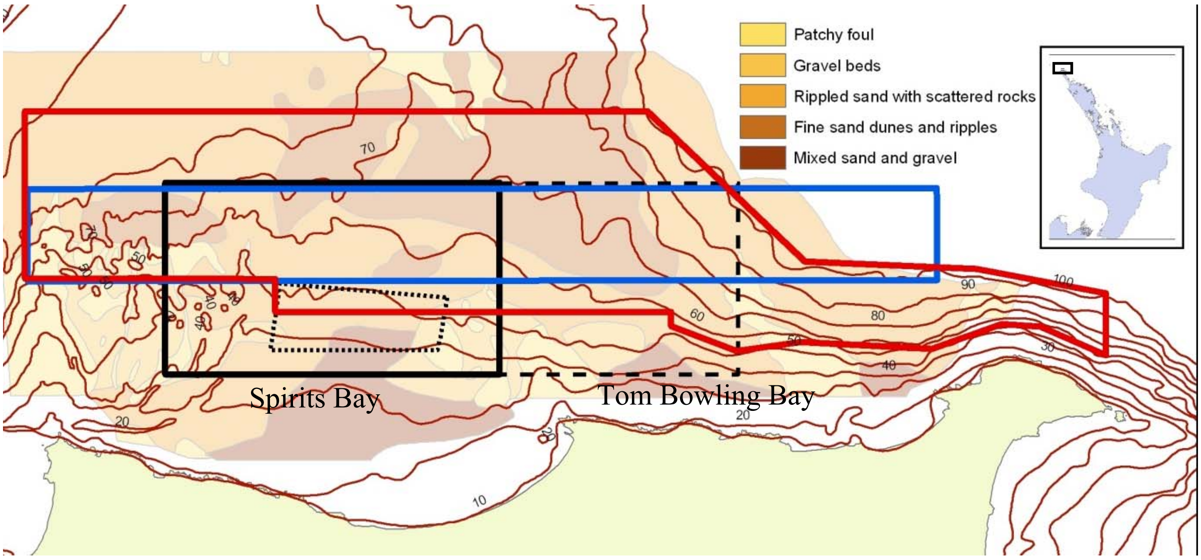

Figure 1: Map showing area surveyed in 1999 (ENV9805 - showing habitat map generated from side-scan sonar in 1999), the areas closed to fishing in the region, and the primary (solid black line) and secondary (dashed black line) survey areas surveyed in 2006 (ENV2005-23). Black dotted line represents scallop survey stratum 93. Depths in metres. Red polygon depicts extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue polygon depicts extent of voluntary closure area (applying to scallop dredging since 1997). Small box in inset map indicates region of study.

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 area around stratum 93 (Figure 1). Project 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, although the level of sampling within the 2006 survey area was relatively low in the 1999 study. In 2010, a further Ministry for Primary Industries project (BEN2009-02) funded another focussed survey and analysis of the benthic communities around stratum 93 (Tuck & Hewitt 2013). The analysis of both epifaunal and infaunal community data consistently identified year, habitat and depth effects, but the fishing terms (trawl and scallop dredge effort) 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 (Thrush et al. 1998; Cryer et al. 2002; Tuck et al. 2017). Comparison with previous epifaunal work on sensitivity to fishing disturbance (Tuck et al. 2010) demonstrated that species identified as most sensitive to fishing 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. 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 (BEN2014-03) provides the fourth survey of the benthic communities in the area, and the third focussed particularly on the area around stratum 93, enabling examination of changes in benthic communities since 2006. Objective 1 of the current project was completed and presented to the MPI AEWG in May 2017, prior to the survey. This is documented within Appendix 1 of this report.

Overall Objectives:

1. To monitor changes in the benthic invertebrate communities between North Cape and Cape Reinga following closure of an area to bottom trawling and dredging.

Specific Objectives:

1. Using previous survey results, conduct a power analysis to estimate the likelihood of a range of survey designs consistent with the monitoring programme from project ENV2005/23 detecting changes in key indicators of the state of the benthic communities in Spirits Bay and Tom Bowling Bay since the last survey.
2. To survey Spirits Bay and Tom Bowling Bay benthic invertebrate communities in accordance with an agreed design from Objective 1.
3. To assess changes in benthic communities inside and outside of the closed area since 1997.

2. METHODS

2.1 Study area

The 1999 survey covered a very broad area (Cryer et al. 2000), and used side-scan sonar to generate a broad scale habitat map of the whole region (Figure 1). More recent surveys have focussed on a far smaller study area, centred on an area of biogenic habitat identified during scallop surveys. During the study in 2006 (Tuck et al. 2010), sidescan and multibeam sonar surveys were conducted to provide data on acoustic habitat patterns within this smaller study area. These data were used to generate an acoustic habitat map for the area (on the basis of expert interpretation of the multibean 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 was quite similar to the habitat maps generated and presented within ENV2005-23 (Tuck et al. 2010) using the NOAA Benthic Terrain Modeller software (BTM) (Lundblad et al. 2006) and interpretation of the sidescan mosaic. This acoustic habitat map (Figure 2) was used to stratify community analysis for the 2006 survey, and both sampling and analysis for the 2010 and current (2017) survey data.

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 Fisheries New Zealand Catch Effort and 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 3. 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, and no scallop dredging in the area since 2009.

In the initial 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 pre-season survey catches within the region. Survey results were made available to fishers prior to the start of the fishery, and so this is plausible. However, to make better use of all available information, following discussions with the Northland Scallop Enhancement Company prior to the 2010 benthic community survey, 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 4 to Figure 6). 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) in 1999, 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 took place in the region in 2007 and 2008 was in the shallower area (25–40 m) to the south of stratum 93. Assuming that the hours of fishing reported within each year (Figure 3) were distributed evenly within the area identified as being fished each year (Figure 4 to Figure 6), the overall fishing intensity (hours.km^{-2}) can be estimated, and this is plotted in Figure 7. 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 the 2006 and 2010 surveys, and used as explanatory variables in the analysis of community structure (Tuck & Hewitt 2013). This approach has been repeated for the 2017 survey, although there has been no scallop dredging in the region since the 2010 survey.

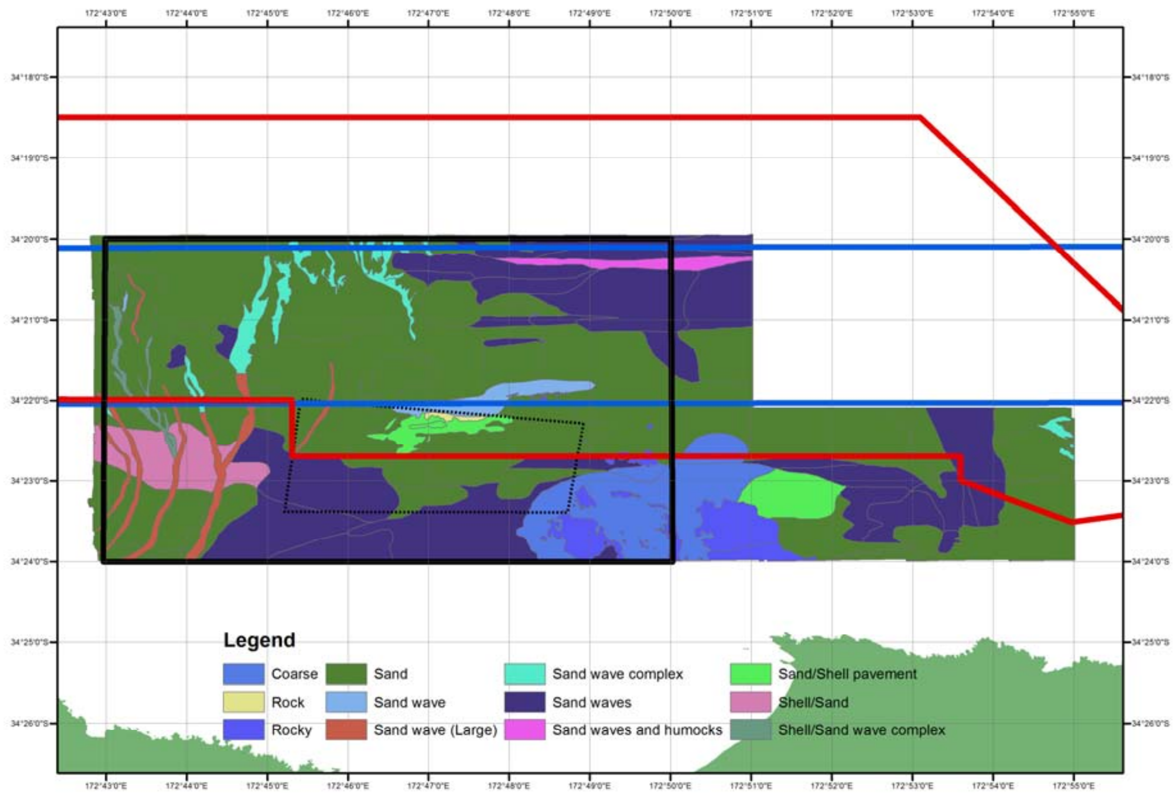

Figure 2: Spirits Bay habitat map, generated on the basis of expert interpretation of multibeam bathymetry and backscatter, sidescan mosaic, and groundtruthing with video and still images. Other details as for Figure 1.

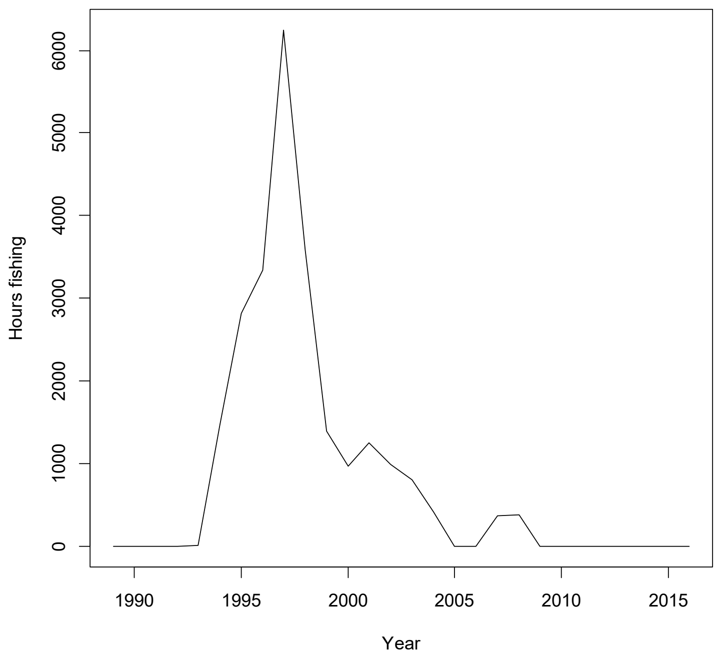

Figure 3: Hours fishing (by scallop dredge) reported on CELR by fishing year (1990 representing the 1990/91 fishing year) for scallop statistical area 9A.

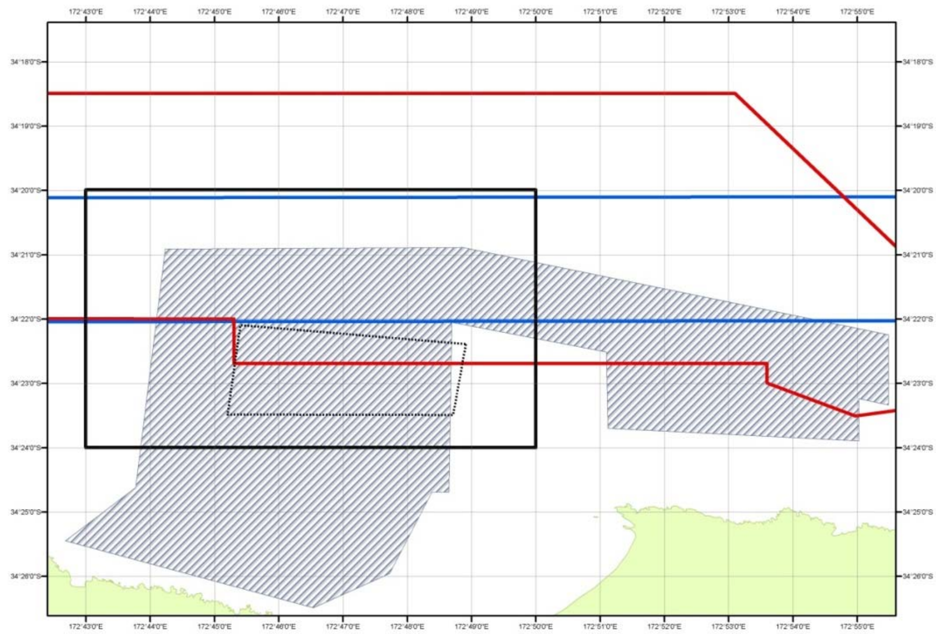

Figure 4: Map of spatial extent of scallop fishing in Spirits Bay area (hatched polygon) prior to introduction of voluntary scallop dredging closure in 1997. Other details as for Figure 1. Map provided by the Northland Scallop Enhancement Company Ltd.

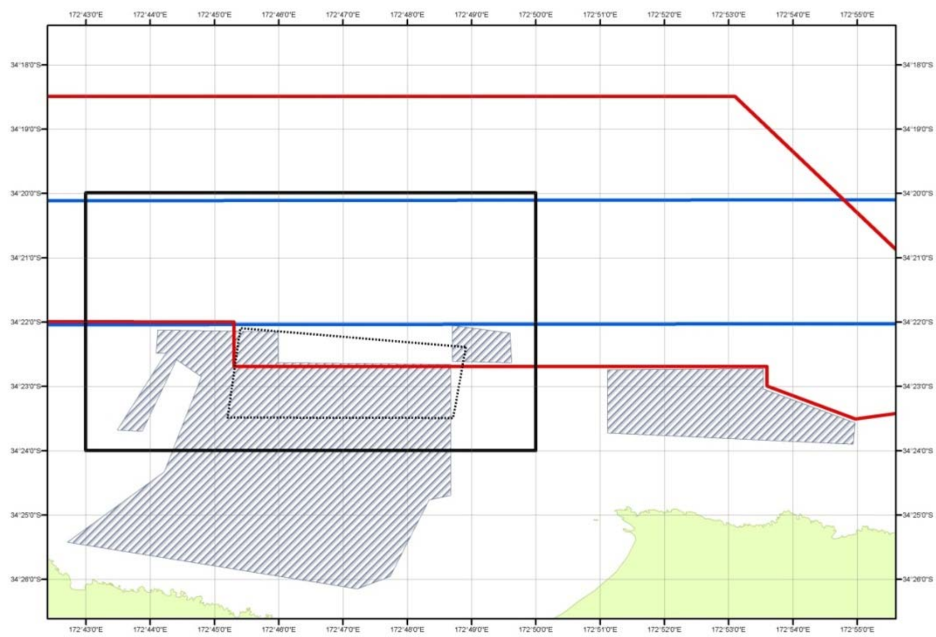

Figure 5: Map of spatial extent of scallop fishing in Spirits Bay area (hatched polygons) following the introduction of voluntary scallop dredging closure in 1997. Other details as for Figure 1. Map provided by the Northland Scallop Enhancement Company Ltd.

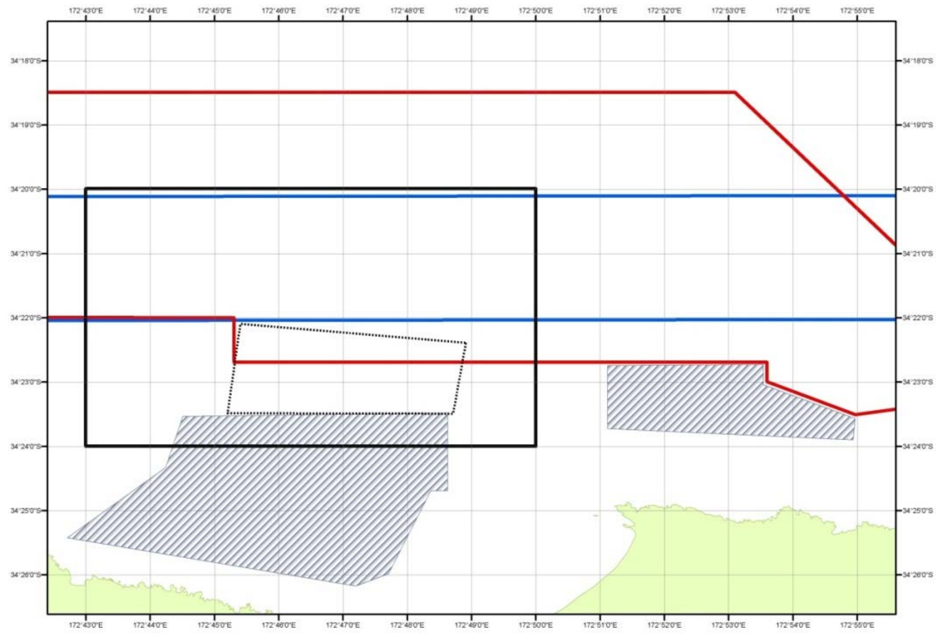

Figure 6: Map of spatial extent of scallop fishing in Spirits Bay (hatched polygons) area since the start of the 2007–08 season. Other details as for Figure 1. Map provided by the Northland Scallop Enhancement Company Ltd.

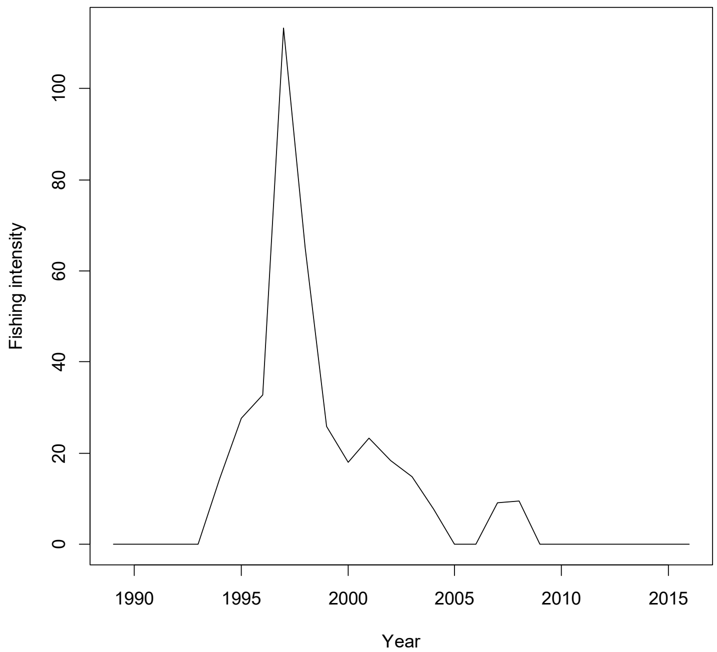

Figure 7: Overall fishing intensity (hours.km^{-2}) of scallop fishing in Spirits Bay area, estimated from hours fished and area over which fishing took place.

For the analysis conducted after the 2010 survey (Tuck & Hewitt 2013), bottom trawl, bottom pair trawl and midwater trawl (within 1 m of the seabed) tow data were provided by the Fisheries New Zealand 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 over that time (as some landings were 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. For the current analysis, a new data extract covering the period from 1 October 2007 to 30 September 2017 was provided from the TCEPR and TECR datasets, and the fishing effort data used in the analysis have been updated accordingly.

Latitude and longitude values are truncated to the minute below (rather than rounded to the nearest minute) when provided from the Fisheries New Zealand 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 analyses 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 that the start time of the second tow was consistent with a short steam after hauling the first (and so on). Number of tows and swept area (length of tow multiplied by estimated door spread; 70 m or 90 m door spread, for vessels less than or equal to 28 m in length, or longer, respectively) 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 effort for all years are plotted in Figure 8, as a colour coded grid of fishing effort (number of tows summed across all years). Numbers of tows, distance fished and area swept between trawl doors all showed a similar pattern, and the area swept between the doors was used as an explanatory variable in the analysis of community structure.

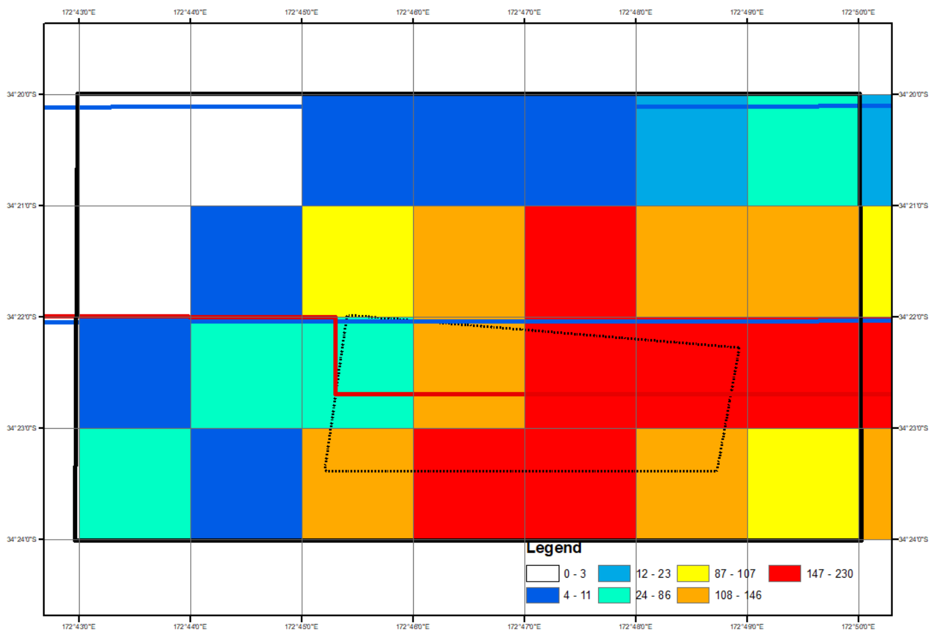

Figure 8: Trawl fishing tows (1991 – 2017) in vicinity of study area, overlaid on 1 n.mile by 1 n.mile grid. Grid cells from which benthic biological data are available are colour coded by the number of tows passing through them. The location of the study area in relation to larger regulated areas is shown in Figure 2. 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 averaged over different three or four-year time periods in Figure 9 to Figure 13. It can be seen that the pattern of effort has changed over time, but also that trawl effort has been allocated to grid cells within the regulated closure area in all 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 these figures, 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 in the study area are low, compared to other inshore regions (Baird et al. 2015). Assuming a 2 knot fishing speed, and a 2 m dredge width, the recorded scallop fishing intensity (hours.km^{-2}) in the most recent years fishing took place equated to about 5% of the defined fished area (from NSEC data) being disturbed each year. The revised analysis of trawl fishing effort data presented here updates Tuck & Hewitt (2013), and includes all records reported on TCER and TCEPR forms. On the basis of this 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 trawl doors (and assume that the whole cell is available to fishing), and neither scallop nor trawl figures allow for far field effects (e.g. smothering by disturbed resuspended sediment). The overall levels and spatial pattern of effort vary between years, but are generally higher in the southern part of the study area, and highest in the central part of this southern area.

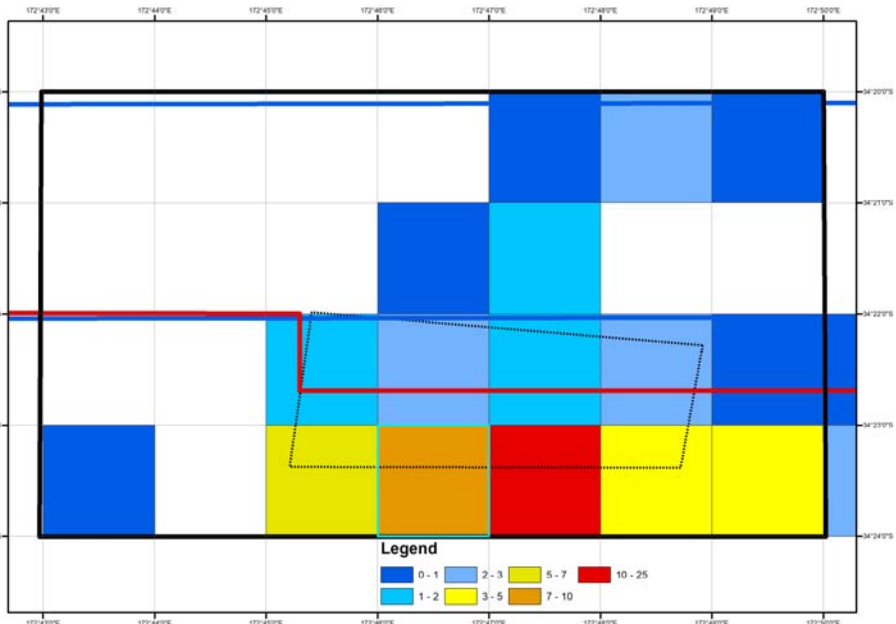

Figure 9: Average annual fishing intensity for fishing years 2001–02 to 2003–04 (aggregated area swept (distance fished × distance between wings) as a percentage of 1 n.mile by 1 n.mile grid cell in vicinity of study area). Grid cells from which biological data are available are colour coded by fishing intensity. 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). Dotted polygon shows stratum 93.

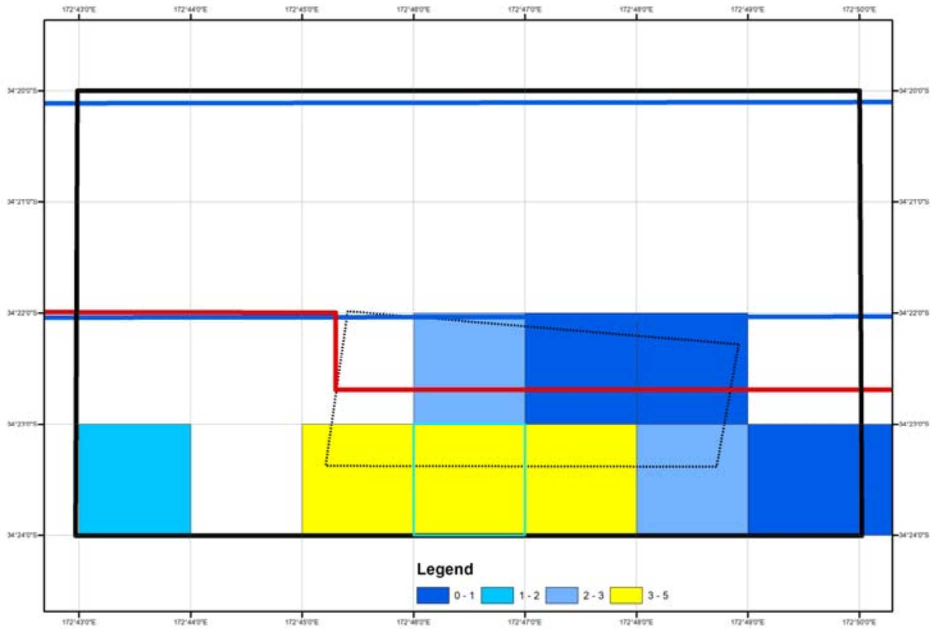

Figure 10: Average annual swept area for fishing years 2004–05 to 2006–07 (aggregated area swept (distance fished × distance between wings) as a percentage of 1 n.mile by 1 n.mile grid cell in vicinity of study area). Grid cells from which biological data are available are colour coded by fishing intensity. 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). Dotted polygon shows stratum 93.

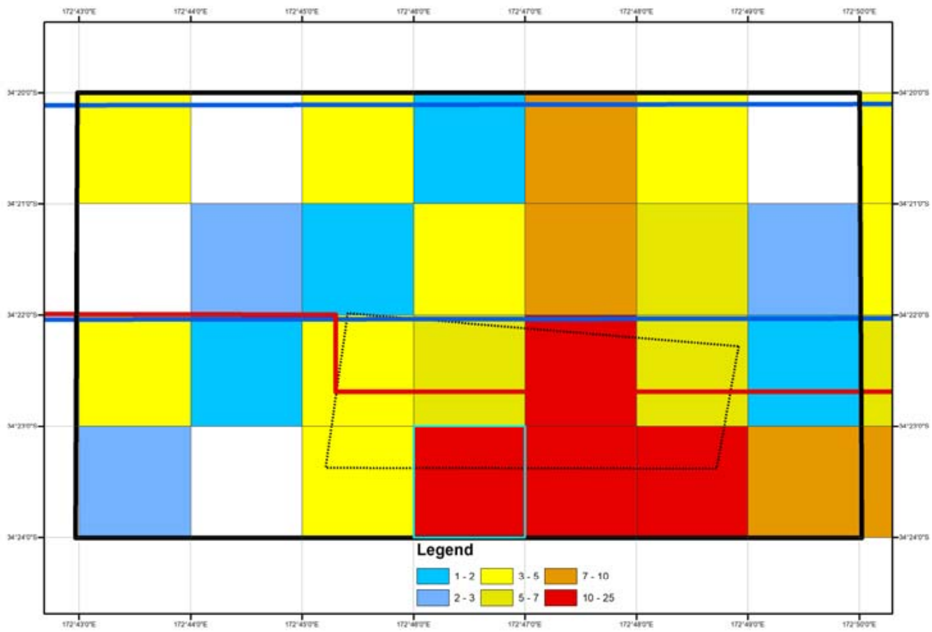

Figure 11: Average annual swept area for fishing years 2007–08 to 2009–10 (aggregated area swept (distance fished × distance between wings) as a percentage of 1 n.mile by 1 n.mile grid cell in vicinity of study area). Grid cells from which biological data are available are colour coded by fishing intensity. 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). Dotted polygon shows stratum 93.

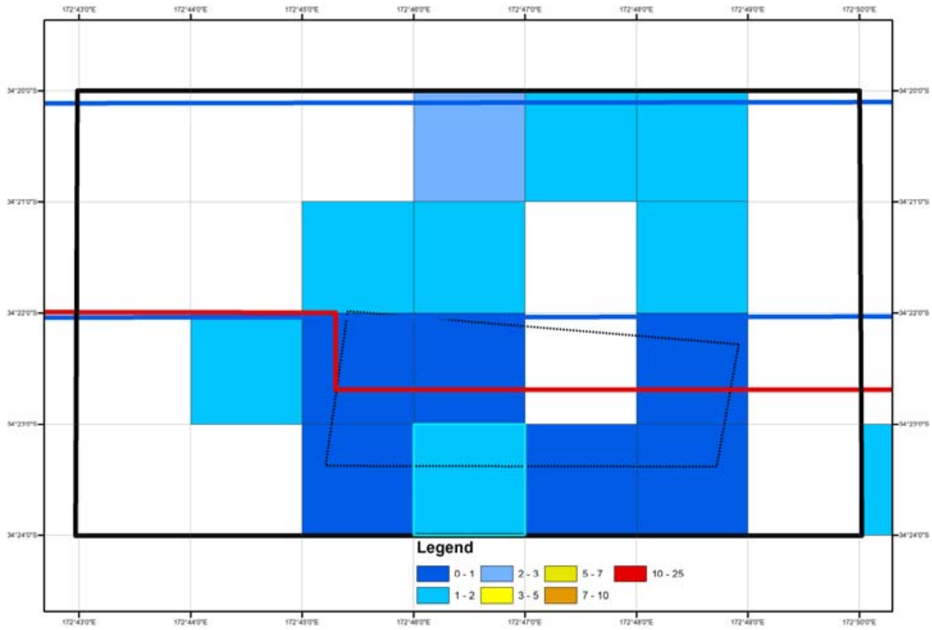

Figure 12: Average annual swept area for fishing years 2010–11 to 2012–13 (aggregated area swept (distance fished × distance between wings) as a percentage of 1 n.mile by 1 n.mile grid cell in vicinity of study area). Grid cells from which biological data are available are colour coded by fishing intensity. 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). Dotted polygon shows stratum 93.

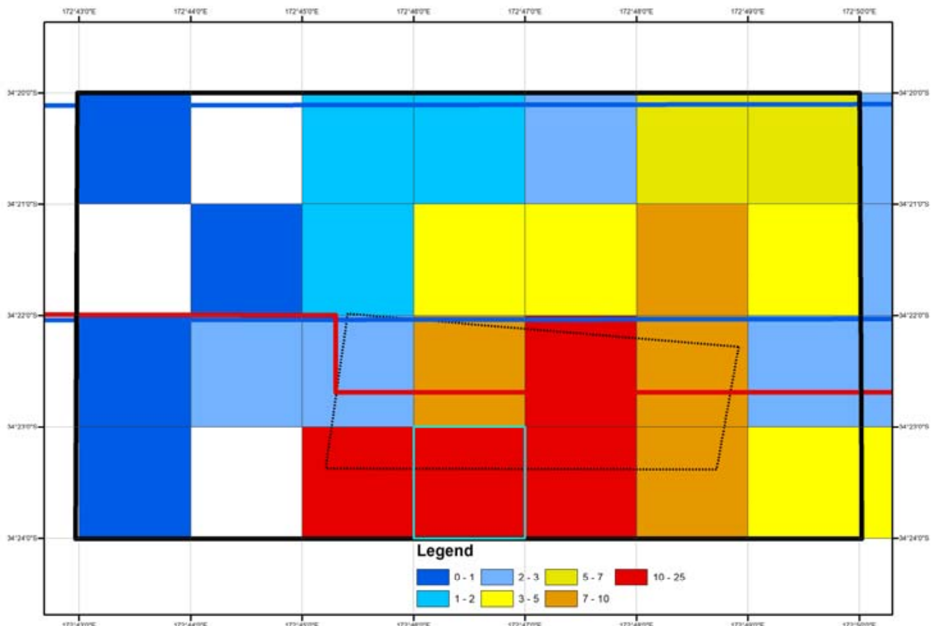

Figure 13: Average annual swept area for fishing years 2013–14 to 2016–17 (aggregated area swept (distance fished × distance between wings) as a percentage of 1 n.mile by 1 n.mile grid cell in vicinity of study area). Grid cells from which biological data are available are colour coded by fishing intensity. 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). Dotted polygon shows stratum 93.

2.3 Sampling the benthic community

Sampling in 2006 was conducted prior to the generation of the habitat map (Figure 2), and was conducted as camera deployments and grab stations within a series of north-south transects (Figure 14). The camera system used was the Middle depths/Scampi system, using a 5.0 MP Nikon Coolpix 5000 camera. Sampling in 2010 was stratified within the acoustic habitats (Figure 15), with consideration of the data available on the spatial pattern of fishing within this area. Photographic sampling was undertaken using NIWA's DTIS (Deep Towed Imaging System), which used a Canon EOS 450 10MP camera at that time. Planned station locations for the 2010 survey are shown in Figure 15. 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. Following analysis to determine the best sampling strategies (Appendix 1), the 2010 survey design was adopted for the 2017 survey, but again poor weather meant it was not possible to sample all stations (Figure 16). 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. For image stations, numbers in parenthesis represent number of images analysed within each habitat. For grab stations, numbers in parentheses represent number of grab samples analysed within each habitat. Those habitats that are summed to form sandy habitats are indicated by an asterisk.

Acoustic habitat class	Image stations			Grab stations		
	2006	2010	2017	2006	2010	2017
Coarse	2 (36)	3 (54)	3 (63)		3 (6)	3 (5)
Sand shell over pavement*	1 (18)	4 (72)	4 (60)	1 (2)	3 (5)	4 (8)
Rocky	3 (52)	2 (36)	2 (30)	1 (2)		2 (3)
Sand*	11 (197)	19 (345)	18 (274)	20 (35)	20 (39)	18 (33)
Sandwaves*	3 (53)	8 (144)	8 (121)	4 (7)	8 (16)	8 (12)
Sandwaves deep*	3 (54)	4 (72)	4 (60)	4 (7)	4 (8)	4 (8)
Shell/sand*	1 (18)	1 (18)	1 (15)	1 (2)	1 (2)	1 (1)
Combined sandy habitats	19 (340)	36 (651)	35 (530)	30 (53)	36 (70)	35 (62)

In 2017, a standard set of sampling procedures was applied at each survey station. Photographic sampling was undertaken using NIWA's DTIS (upgraded since the 2010 survey, and now using a Nikon D3200 24MP camera), collecting high resolution still images. 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. 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 0.1 m^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 previous surveys (Tuck et al. 2010; Tuck & Hewitt 2013), with epifaunal species identified using the identification keys developed within the previous Ministry of Fisheries / Ministry for Primary Industries projects and subsequent NIWA Capability Fund projects, based on colour and morphological features identifiable from images. Image resolution has increased over the surveys, and even only using easily recognised species we cannot discount the possibility of any increase in abundance over time being partly related to this. Image area was estimated, and the image was magnified to 100% to assist with identification of organisms. All epifauna larger than 50 mm were counted and identified. Images from each survey 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, J. J. et al. 2006; Bell, J.J. 2007).

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.

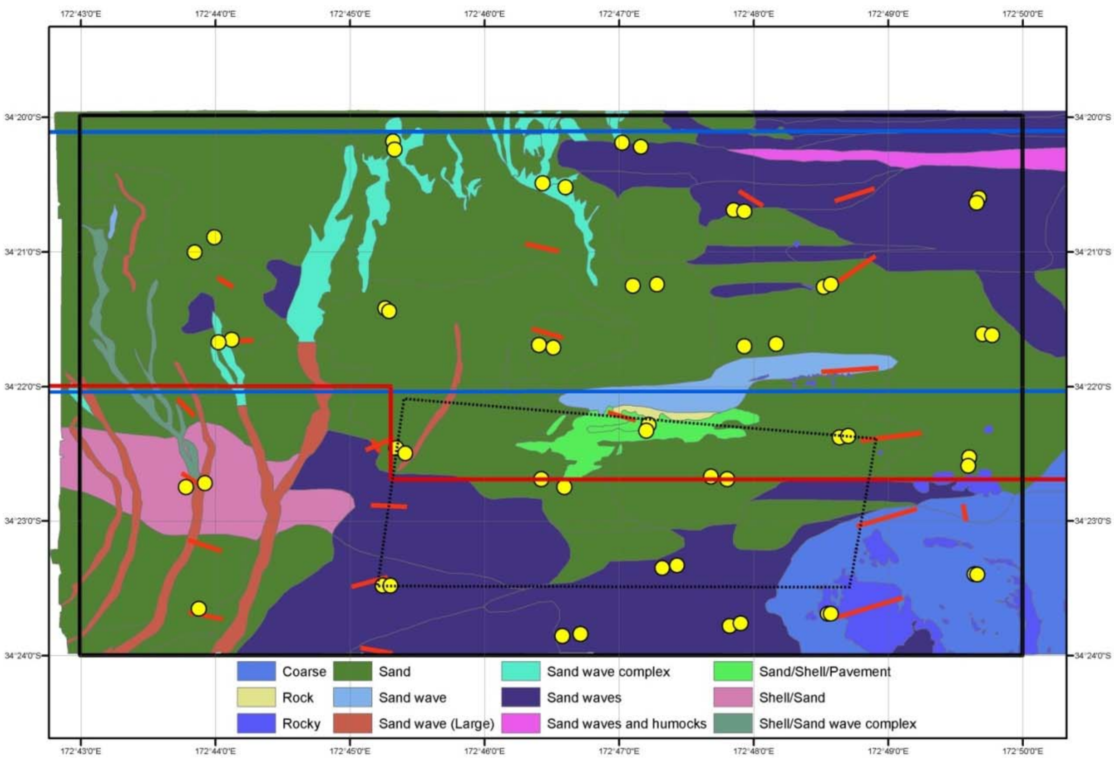

Figure 14: Spirits Bay survey, 2006 stations. Yellow symbols represent individual grab locations (which were combined into pairs at a site for analysis), while red lines represent still photograph transects. Dotted polygon in central region of map represents scallop survey stratum 93. Red lines depict 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).

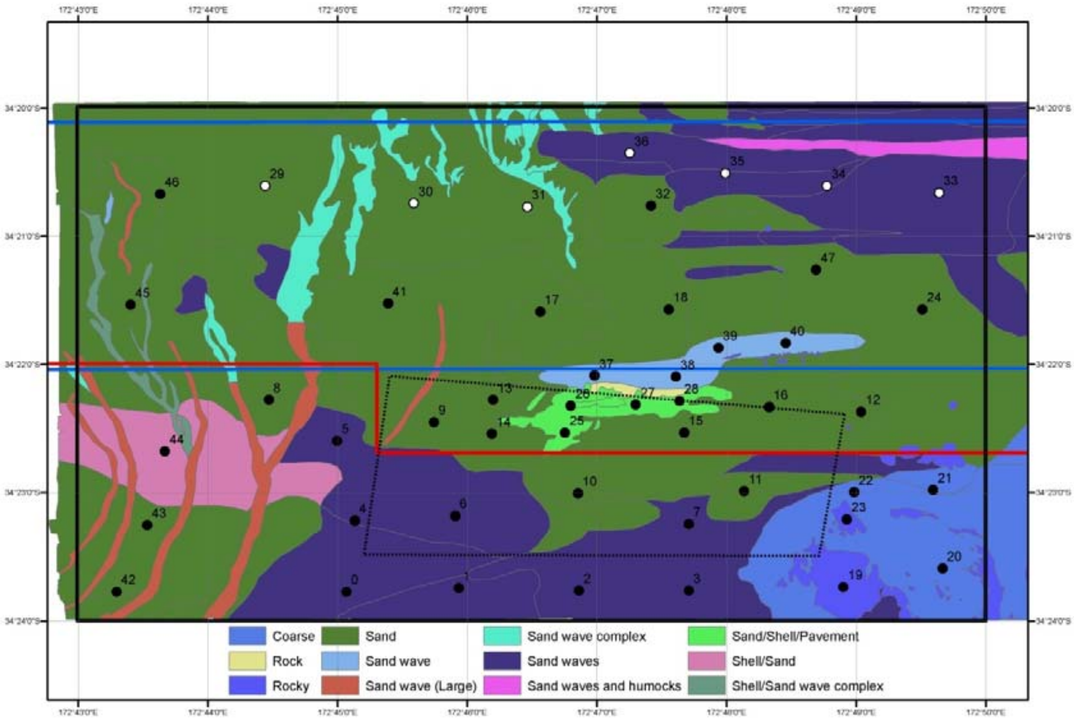

Figure 15: Spirits Bay survey, 2010 stations. Black symbols represent stations completed during the survey. White symbols represent stations not sampled. Dotted polygon in central region of map represents scallop survey stratum 93. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997).

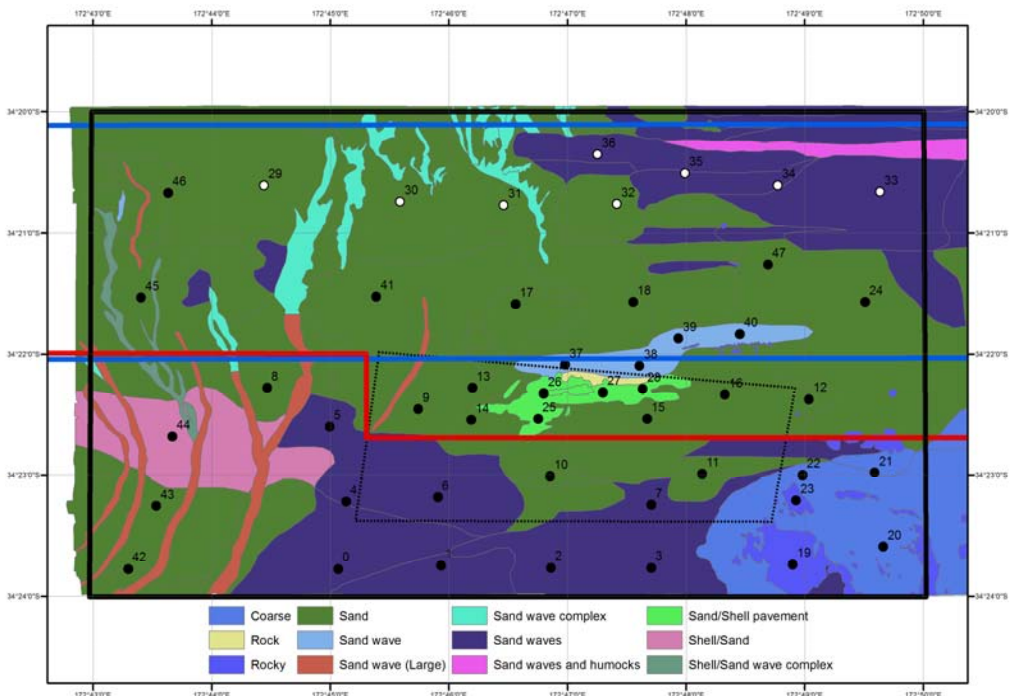

Figure 16: Spirits Bay survey, 2017 stations. Black symbols represent stations completed during the survey. White symbols represent stations not sampled. Dotted polygon in central region of map represents scallop survey stratum 93. Red lines depict extent of regulated closure area (applying to all mobile bottom fishing since 1999). Blue lines depict extent of voluntary closure area (applying to scallop dredging since 1997).

2.4 Effects of fishing on the benthic community

The analysis approaches followed those applied by Tuck & Hewitt (2013). 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, M. J. 2001; McArdle & Anderson 2001) described in *PERMANOVA+ for PRIMER* (Anderson, M. J. 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 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.*). Sensitivity studies conducted as part of previous analyses confirmed that the results gained were not driven by analysis type (Tuck & Hewitt 2013).

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 species); 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 surveys dataset, and for the three surveys separately. Fishing effort terms are described in a consistent manner throughout the analysis. Within the plots, terms are prefixed by *s* or *t* when representing the scallop or trawl fishery, 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. An explanation of all the abbreviations used for terms within the model plots and tabulated results is provided in Table 2.

Taxonomic identifications from photographs are to some degree uncertain, and we avoided dredging to collect voucher specimens to minimise benthic disturbance. Therefore, while we have referred to the identification guides developed within the previous studies, and been as consistent as possible, the confidence over identifications varies. Of the 246 species (or taxonomic units) identified within the survey images, 100 were considered to be reliably identified, representing taxa across all the main phyla present. These most distinct epifaunal species were therefore categorised as “trustworthy”, and while the main analysis was conducted using this subset of the epifaunal community, sensitivity analyses were also conducted on the whole epifaunal community.

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, although the conclusions drawn from our previous analyses comparing Bray-Curtis similarity with the Hellinger distance matrix, were not sensitive to this (Tuck & Hewitt 2013).

While DistLM offers a number of advantages over alternative approaches (as discussed above), and is able to attribute proportions of the total variability to factors, it does not provide a plotting method to examine effects of individual factors on individual species. To identify the species particularly sensitive to fishing (either positively or negatively) having accounted for (partialled out) the effects of the other variables, we have followed approaches applied by Tuck et al. (2017), and used Constrained Analysis of Principal Coordinates (CAP, (Anderson, M.J. & Willis 2003)) with fishing effort conditioned on the other retained explanatory variables. These analyses were conducted with the *capscale* function within the R library *vegan*. CAP is an ordination method similar to RDA that allows the use of non-Euclidian dissimilarity indices.

Table 2: Abbreviations and variable type for each term used within the modelling.

Abbreviation in model output tables	Abbreviations in plots	Model term	Variable type
D	*depth*	Depth (m)	Continuous
Y	*y….*	Year	Categorical
H	named habitat	Habitat (as defined from acoustic data)	Categorical
SE3	*s_effort3*	average scallop dredging intensity 1–3 years prior to sampling	Continuous
SE9	*s_effort9*	average scallop dredging intensity 7–9 years prior to sampling	Continuous
SF	*s_fallow*	years fallow from scallop dredging	Continuous
TE3	*t_effort3*	average trawling intensity 1–3 years prior to sampling	Continuous
TE6	*t_effort6*	average trawling intensity 4–6 years prior to sampling	Continuous
TE9	*t_effort9*	average trawling intensity 7–9 years prior to sampling	Continuous
TF	*t_fallow*	years fallow from trawling	Continuous
SED		particle size composition	Continuous
ORG		% organic content in sediment	Continuous

3. RESULTS

3.1 Epifaunal community data

Environment and fishing variables

It was not possible to sample for both epifauna and infauna at all sites, and so the environmental variables available for each analysis 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 and redundancy. Where strong correlations were identified between explanatory variables, only one was included in the analysis, to avoid confounding. 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.

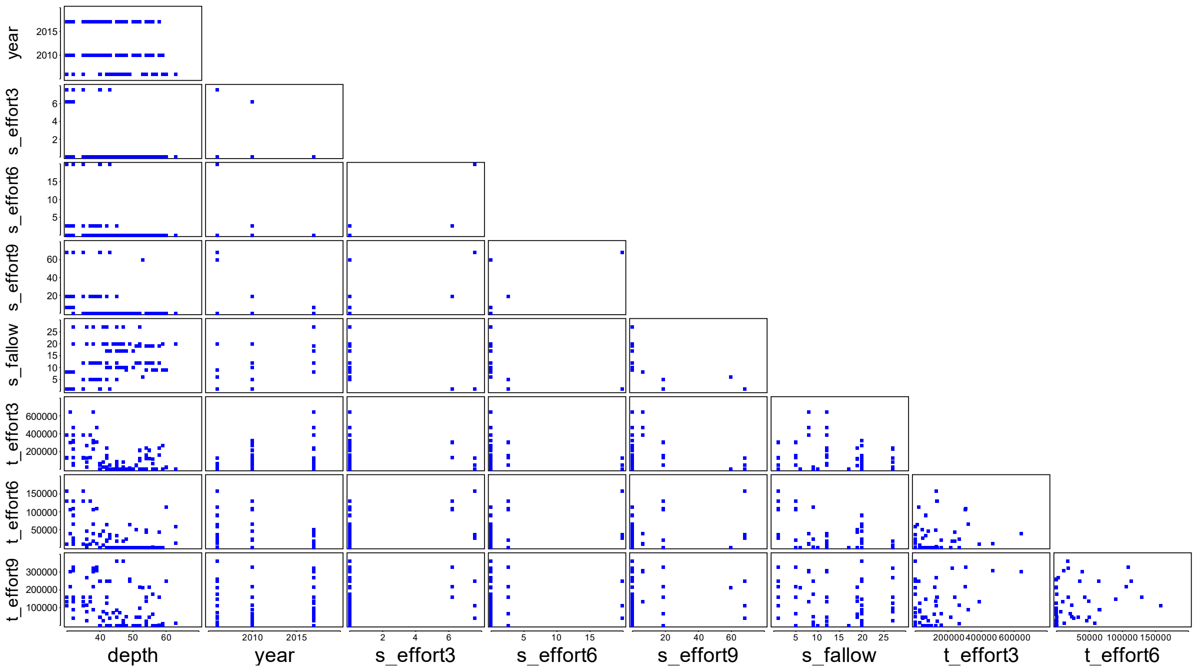

Figure 17: Pairwise (draftsman) plot of normalised explanatory variables for analysis of epifaunal data.

Pairwise correlations from Figure 17 are provided in Table 3. Scallop effort variables were highly correlated, and therefore only the 3-year average was included within models, unless there was no contrast in this variable, as was the case when only examining the 2017 survey data. The range of the continuous variables is shown in relation to the acoustic habitat classes in Figure 18. 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 19. This plot shows the very 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.

Table 3: Correlation matrix for normalised explanatory variables for analysis of epifaunal data.

	depth	year	s_effort3	s_effort6	s_effort9	s_fallow	t_effort3	t_effort6	t_effort9
year	-0.148								
s_effort3	-0.360	-0.347							
s_effort6	-0.266	-0.373	0.878						
s_effort9	-0.294	-0.398	0.847	0.934					
s_fallow	0.227	0.424	-0.590	-0.540	-0.629				
t_effort3	-0.360	0.514	-0.141	-0.202	-0.186	-0.091			
t_effort6	-0.414	-0.301	0.460	0.330	0.415	-0.455	0.021		
t_effort9	-0.316	0.222	0.138	0.074	0.124	0.007	0.400	0.228	
t_fallow	0.372	-0.255	-0.029	0.019	0.008	0.013	-0.461	-0.268	-0.202

Multivariate community analyses - epifauna

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. DISTLM marginal tests for each variable for each dataset are provided in Appendix 2. 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 (except for the analysis of the 2017 survey data, where SE9 and years fallow were the only scallop effort variables), given the strong correlation between the average of previous 3 years and the other terms (Table 3).

Community analyses were initially conducted on the subset of 100 species considered to be identified reliably from survey images. For this subset 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 50.5% of the variance in the community data (Figure 20). 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 vector 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 separation between the datasets from the different survey years, but habitat, depth and fishing terms also explained significant components of the variation. The combined fishing related terms explained 16.7% of the total variance (33.1% of explained variance) (Table 4). 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 2), although there is some overlap between the terms (sum of marginal tests explains 17.2% of variance, combined fishing terms explain 16.7%). A longer survey was possible in 2006 than later studies, and stations sampled a deeper range of habitats. Excluding these deeper stations from 2006 slightly improved the overall explanatory power of the model (51.8% of the variance explained), but all the same terms were retained in the minimum adequate model.

To explore whether longer term effects of fishing were also detectable, average trawl effort over 4–6 years and 7–9 years were also included in the model, fixing those terms originally selected. Both of the longer term fishing effort terms were retained (Figure 21), increasing the overall explanatory power of the model (51.9% of variance explained), with the combined fishing terms explaining 19.9% (Table 4).

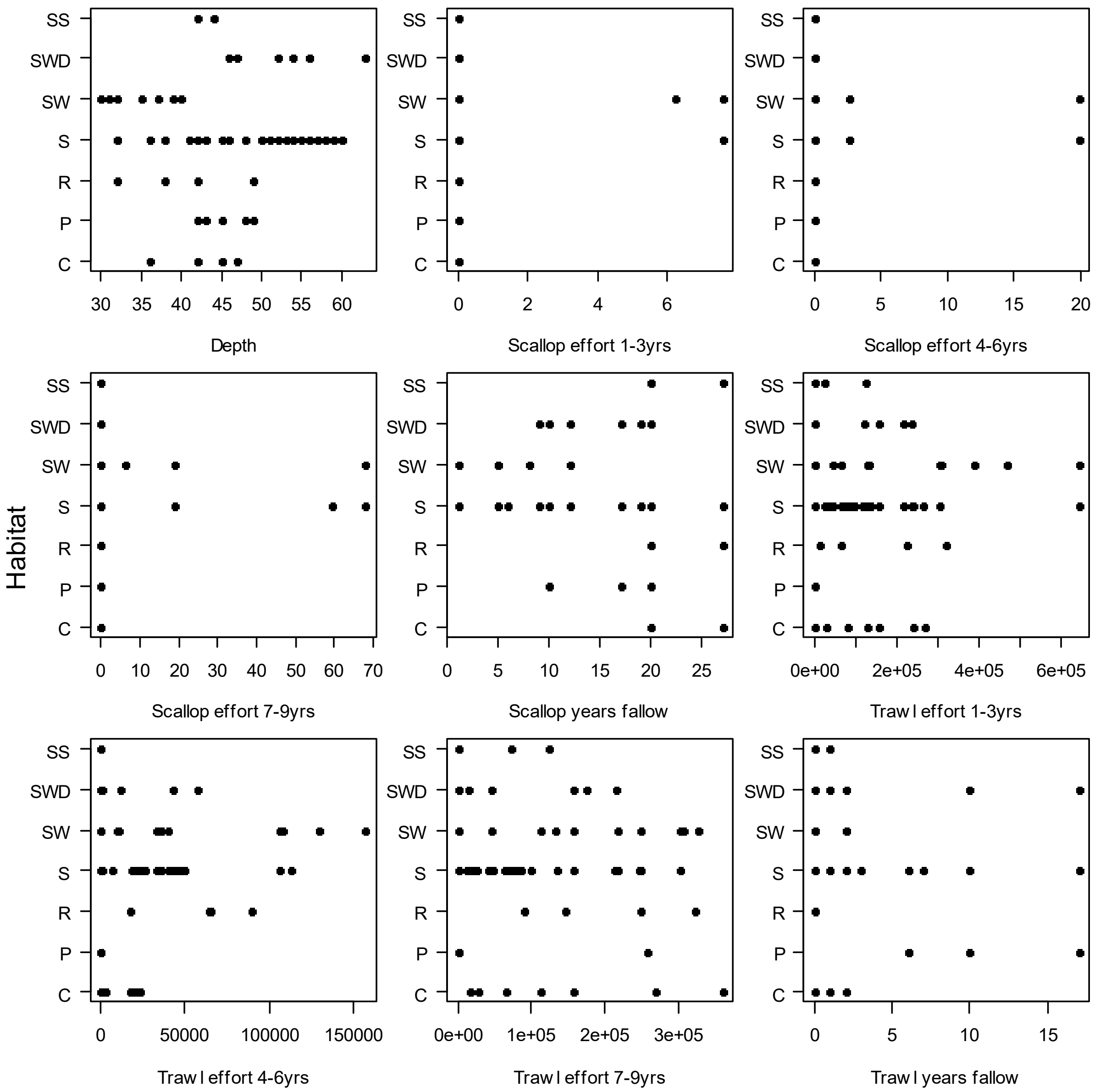

Figure 18: Epifauna: Pairwise (Draftsman) plot of environmental and fishing variables for image stations in relation to acoustic habitat classes. Within each plot, the dots represent the values (on the x axis) for sites within that acoustic habitat class. Habitats: C – coarse, P – sand over pavement, R – rocky, S – sand, SW – sandwaves, SWD – sandwaves deep, SS – sand/shell.

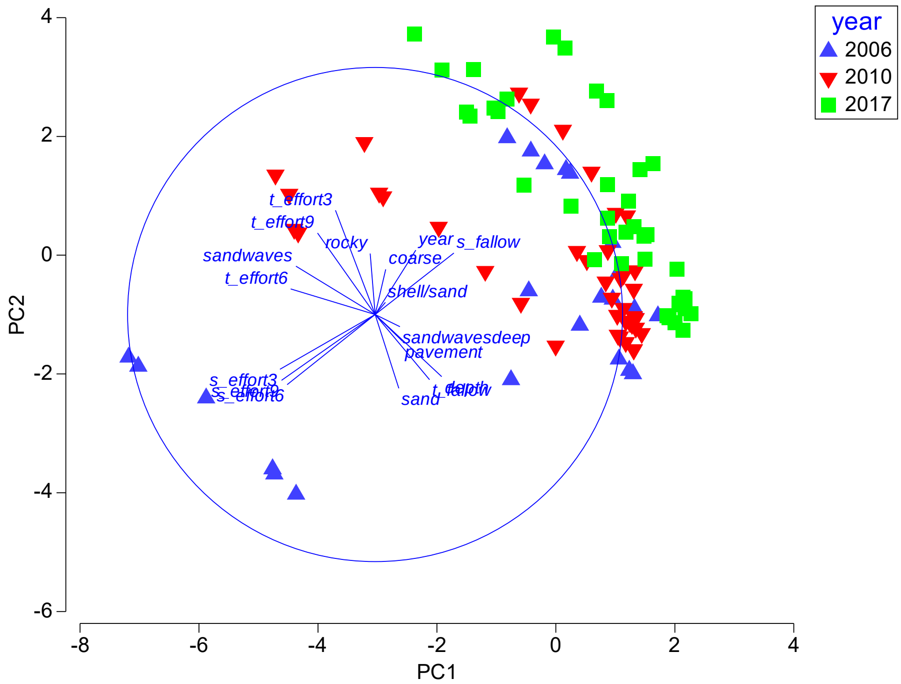

Figure 19: Epifauna: PCA eigenvector plot of environmental variables for image stations. Variables include depth, year, habitat (sand, sand/shell, sandwaves, deeper sandwaves, pavement, rocky and coarse) and fishing (effort over different time periods as described in text, and years fallow by scallop dredge or bottom trawl). Symbols represent individual stations, coded by year.

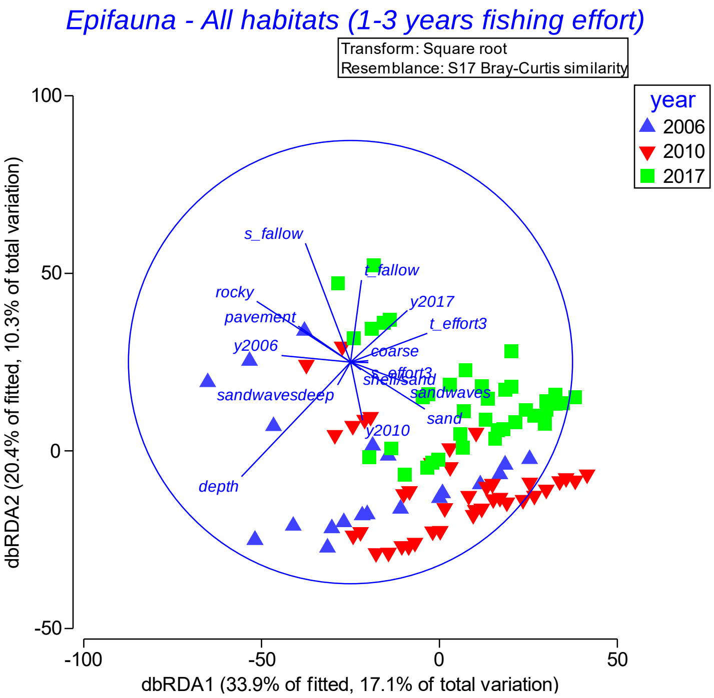

Figure 20: Epifauna and most recent effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

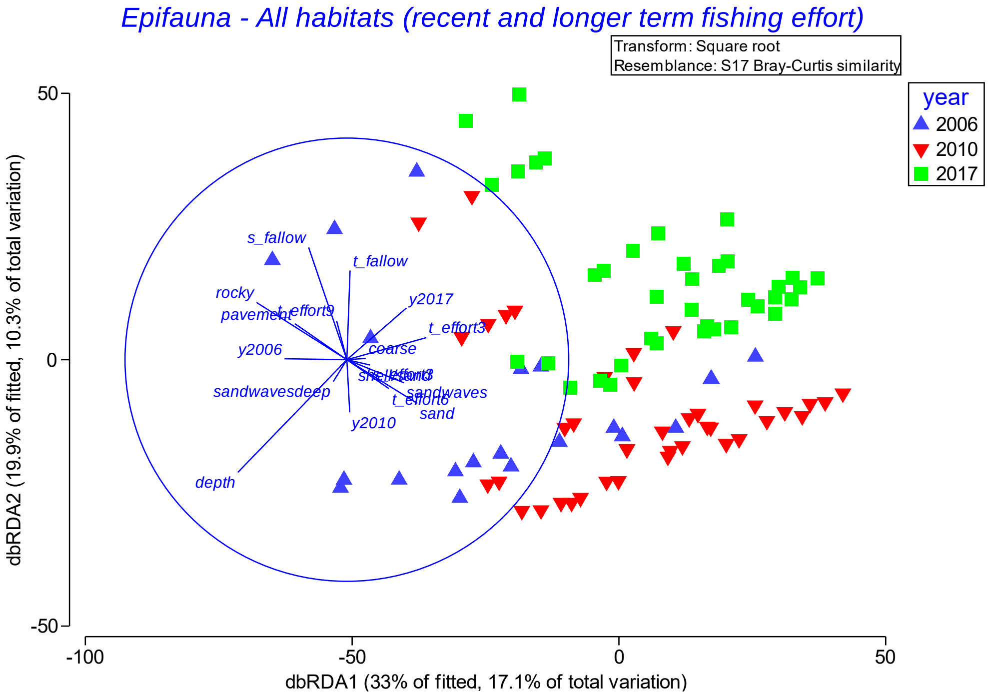

Figure 21: Epifauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the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

Similar analyses were also conducted on data sets limited to only those stations from the sandy (rock and coarse excluded) and sand habitat classes, and individual surveys (Table 4).

For the sandy habitats (Figure 22), the initial minimum adequate model (including depth, year, habitat, and both recent fishing effort and years fallow for scallop and trawl fisheries) explained 50.1% of the variance, with the fishing terms explaining 20.5%. When offered, the average trawl effort over the previous 4–6 years (t_effort6) was also retained in the model (Figure 23), increasing the overall variance explained to 50.9% (22.0% by fishing terms), but the average effort over 7–9 years (t_effort9) was not.

Examining the sand habitat class only (Figure 24), a model including year, depth, recent scallop and trawl effort (average of previous 3 years), and years fallow for the scallop fishery explained 48.1% of the variance, with the fishing terms explaining 15.7%. Of the additional trawl effort terms, only the average over 7–9 years was retained in the model (Figure 25), increasing the overall variance explained to 49.9% (19.2% by fishing terms).

Data from all habitat classes were then examined for individual survey years. Restricting the analysis to data collected in 2006 (Figure 26), habitat, and scallop effort (average of previous 3 years) explained 62.2% of the variance, with the effort term explaining 26.8%. As with the sand habitat class, only the older longer-term trawl effort variable (t_effort9) was retained (Figure 27), increasing the overall variance explained to 66.0%, 32.6% by the two fishing terms. Examining only the 2010 dataset (Figure 28), 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 61.7% of the variance, with the fishing terms explaining 25.0%. Only the older longer-term trawl effort variable (t_effort9) was retained when offered (Figure 29), increasing the overall variance explained to 64.5%, 33.1% by fishing. For the 2017 dataset (Figure 30), depth, habitat, and years fallow for both fisheries were retained in the initial model, explaining 59.1% of the variance. Only 11.4% was explained by the fishing terms, probably reflecting the lack of fishing activity within the study region in recent years. There has been no scallop fishing in the region for a number of years, and the short and medium-term scallop effort terms were not included in the model, since they were zero across all sites. Longer term scallop and trawl fishing effort (average of previous 7–9 years) were both retained when offered, increasing the overall variance explained to 64.4%, 22.2% by fishing.

Fishing terms were retained in all models. Across all the analyses, a median of 55.5% of total variance was explained by the models, with 21.2% (median) by fishing terms, equating to 39.5% of the explained variance accounted for by fishing terms. Examining the analyses of the individual year datasets, the variation explained by fishing terms, and the proportion of the variance explained accounted for by fishing terms, has generally declined over the period 2006 to 2017 (dropping from about a half to a third).

Some of the analyses were also repeated on the full species list (lower portion Table 4). While there were some differences in the fishing effort terms retained, the overall pattern, in terms of relative proportion of total variance explained, and the proportion explained by fishing terms, were similar.

Table 4: 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 (therefore order of retained variables is arbitrary), 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). Main analysis was conducted with the "trustworthy" species group (T), with some sensitivity runs using all species (A).

Dataset	Species	R^2	Retained variables	Fishing/Total	Fishing/Explained
Complete	T	0.505	D, Y, H, SE3, SF, TE3, TF	16.7	33.1
	T	0.519	D, Y, H, SE3, SF, TE3, TF, TE6, TE9	19.9	38.3
Sandy	T	0.501	D, Y, H, SE3, SF, TE3, TF	20.5	40.9
	T	0.509	D, Y, H, SE3, SF, TE3, TF, TE6	22.0	43.2
Sand	T	0.481	D, Y, SE3, SF, TE3	15.7	32.6
	T	0.499	D, Y, SE3, SF, TE3, TE9	19.2	38.5
2006	T	0.622	H, SE3	26.8	43.1
	T	0.660	H, SE3, TE9	32.6	49.4
2010	T	0.617	D, H, SE3, SF, TE3, TF	25.0	40.5
	T	0.645	D, H, SE3, SF, TE3, TF, TE9	33.1	51.3
2017	T	0.591	D, H, SF, TF	11.4	19.3
	T	0.644	D, H, SE9, SF, TF, TE9	22.2	34.5
Complete	A	0.488	D, Y, H, SE3, SF, TE3, TF	16.7	34.2
	A	0.497	D, Y, H, SE3, SF, TE3, TF, TE9	18.8	37.8
Sandy	A	0.488	D, Y, H, SE3, SF, TE3, TF	19.7	40.4
	A	0.498	D, Y, H, SE3, SF, TE3, TF, TE6	21.8	43.8
2006	A	0.667	D, H, SE3, SF, TF	26.5	39.7
	A	0.702	D, H, SE3, SF, TF, TE9	30.7	43.7
2017	A	0.580	D, H, SF, TE3, TF	17.7	30.5
	A	0.638	D, H, SE9, SF, TF, TE3, TE6, TE9	26.7	41.8

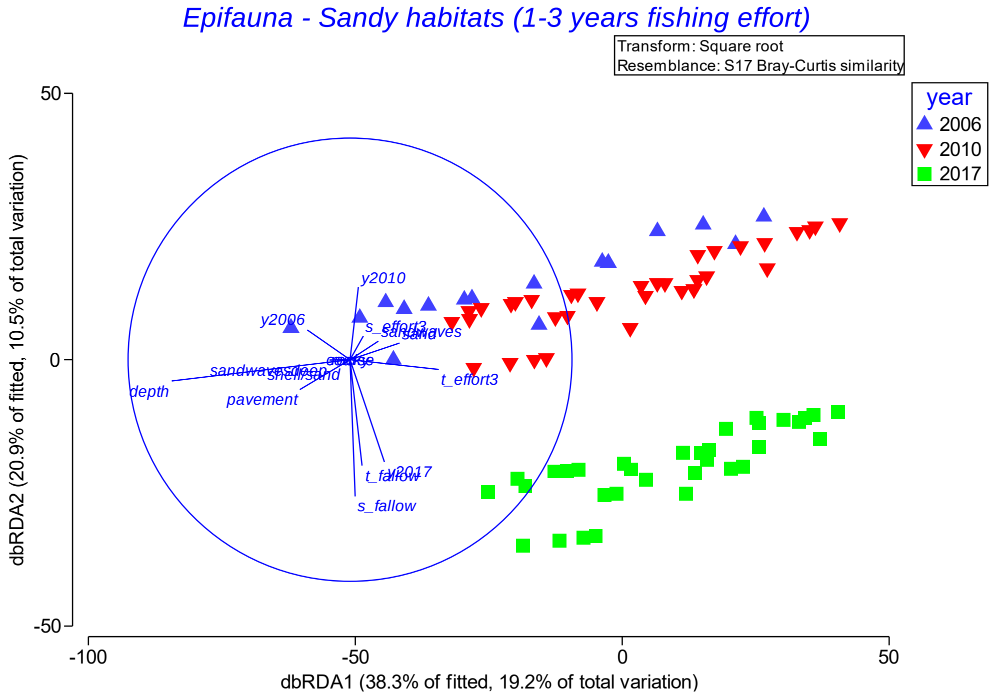

Figure 22: Epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images within sandy habitat (excluding rocky and coarse areas), with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

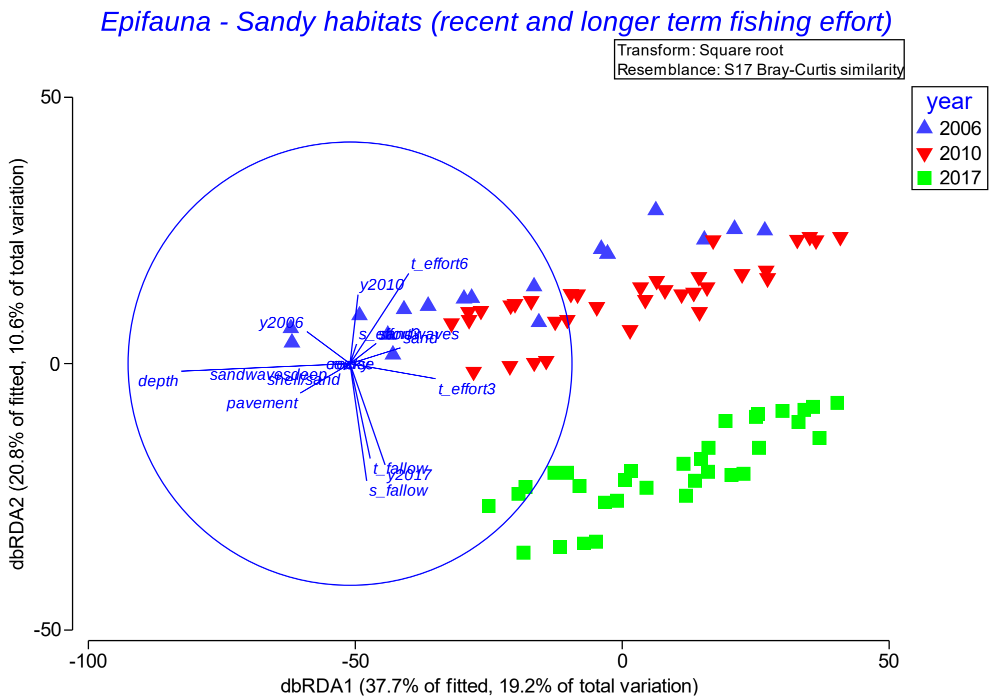

Figure 23: Epifauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images within sandy habitat (excluding rocky and coarse areas), with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

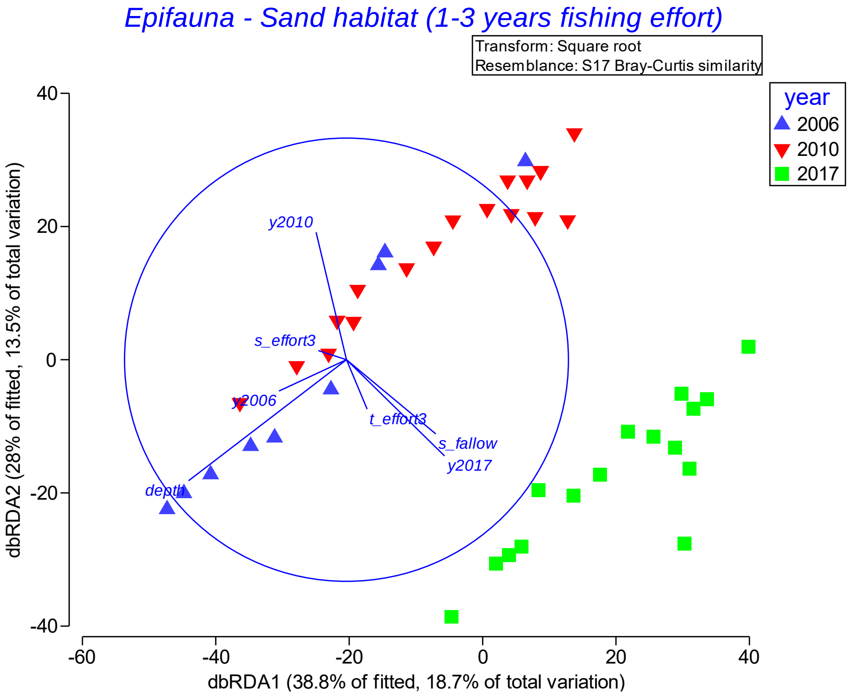

Figure 24: Epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images within sand habitat, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

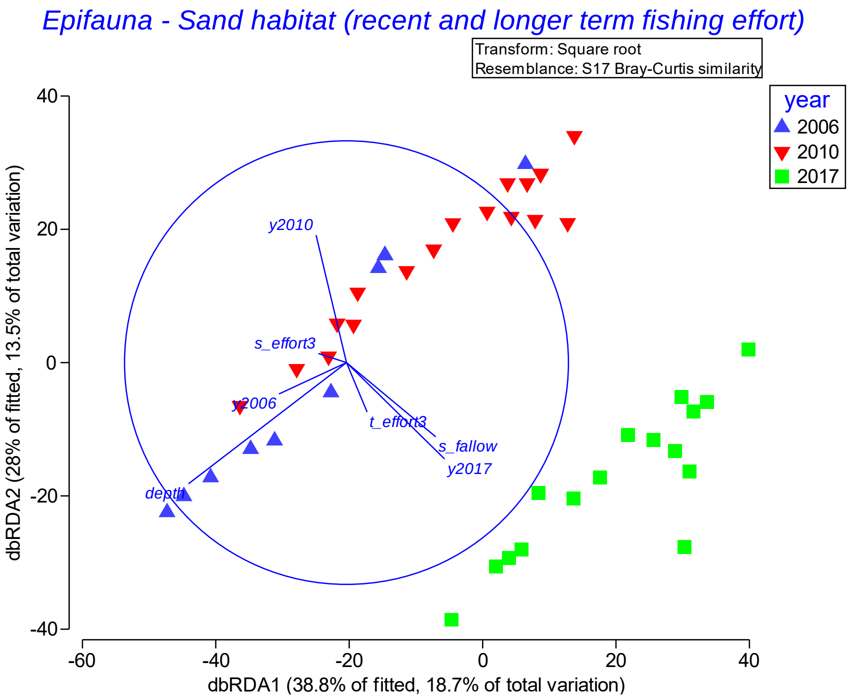

Figure 25: Epifauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from seabed images within sand habitat, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

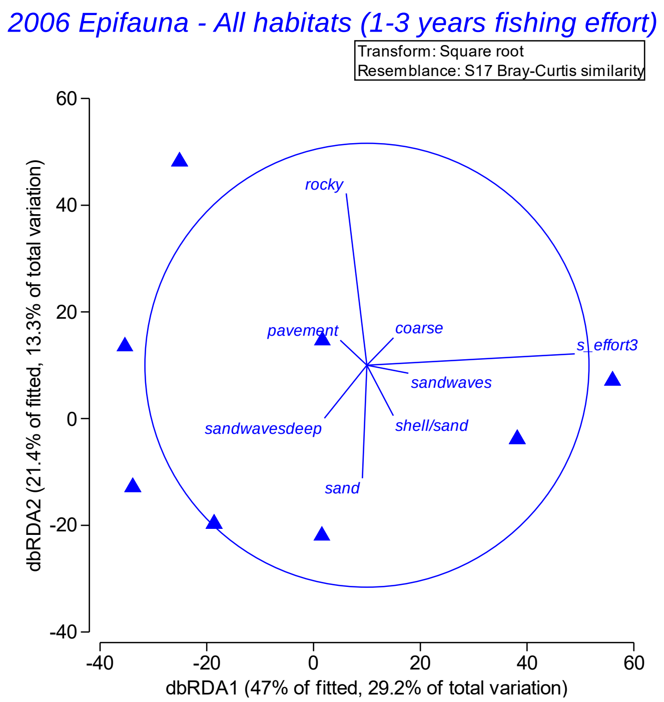

Figure 26: Epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2006 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

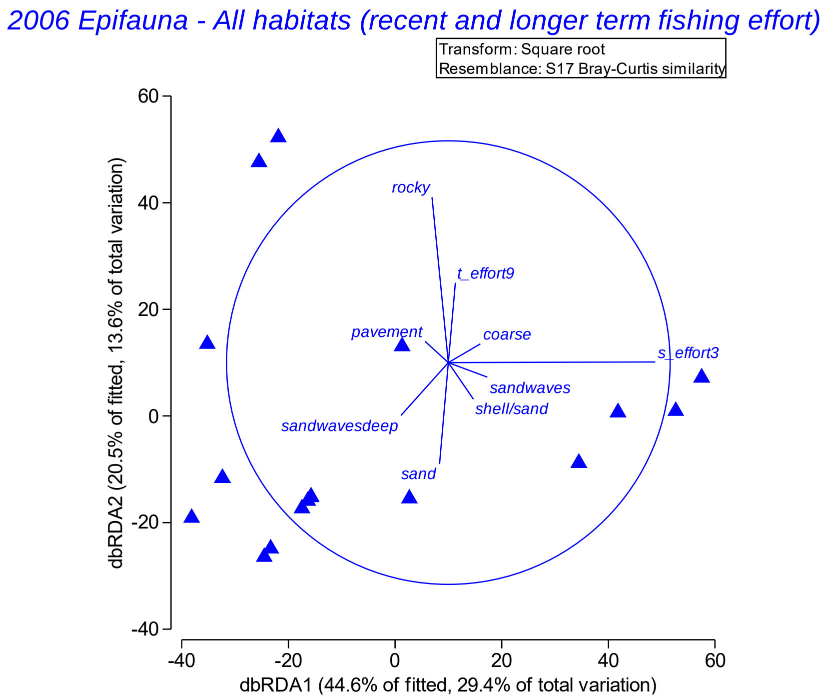

Figure 27: Epifauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2006 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

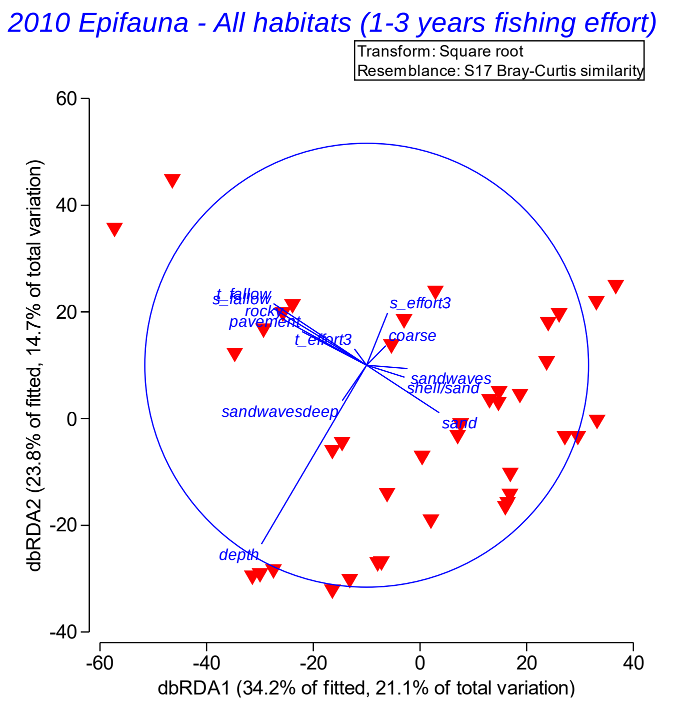

Figure 28: Epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2010 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

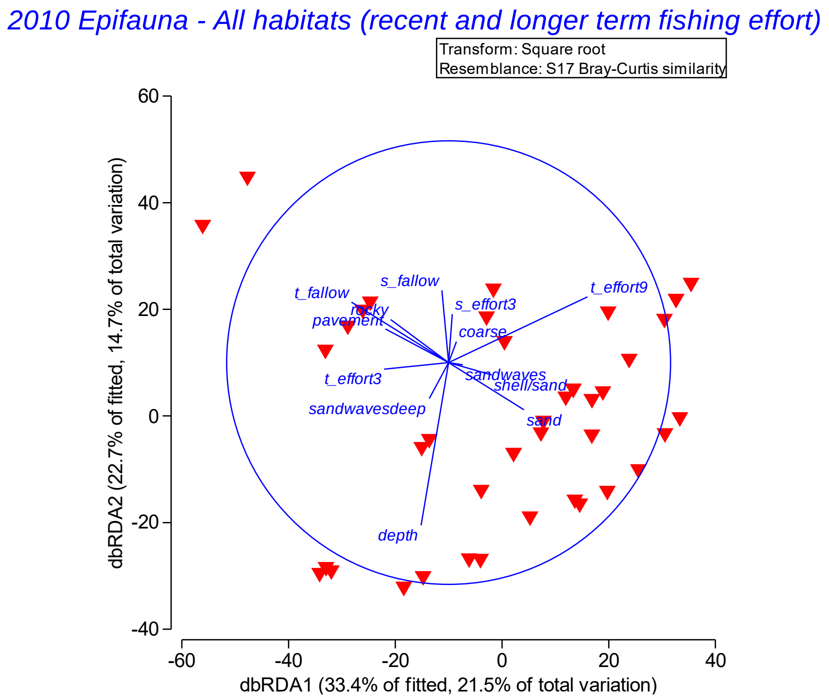

Figure 29: Epifauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2010 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

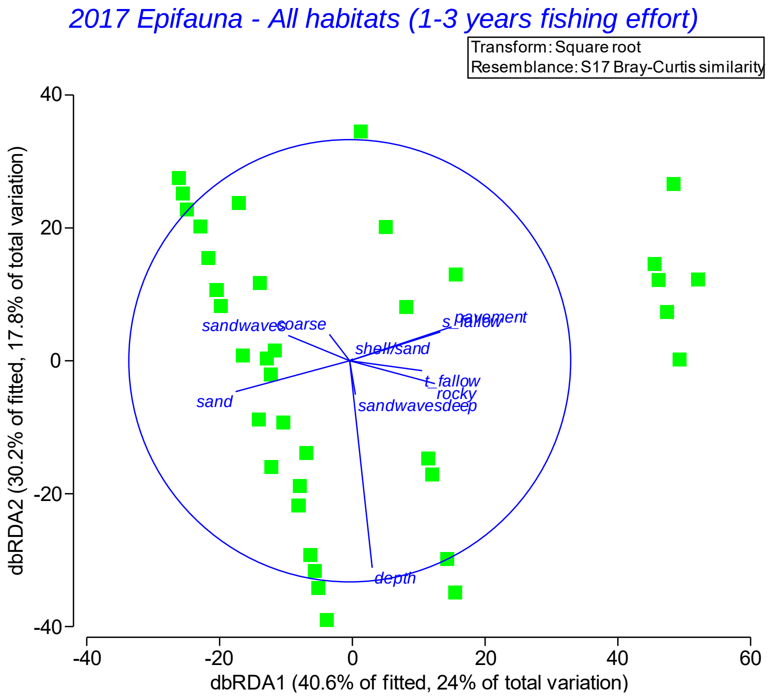

Figure 30: Epifauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2017 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

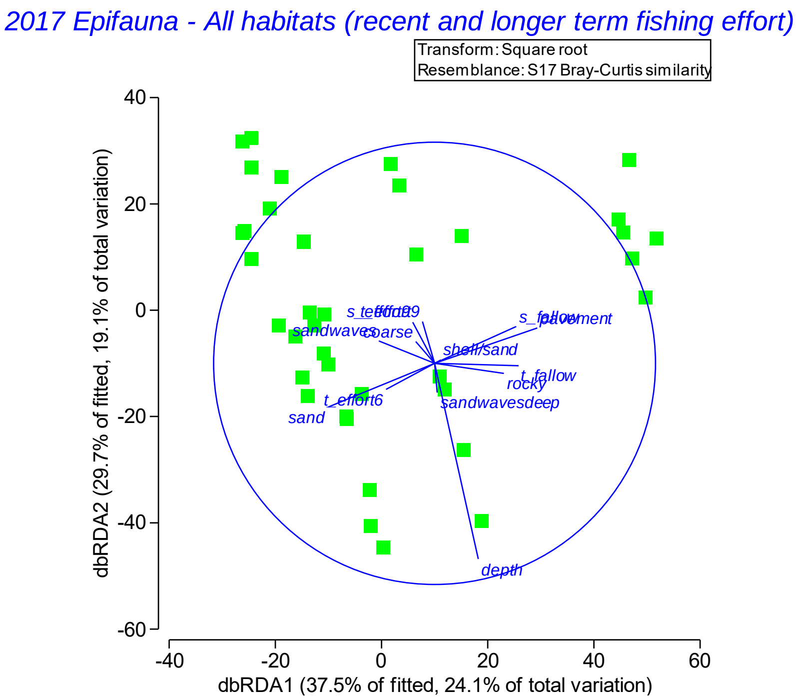

Figure 31: Epifauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed epifaunal community data from 2017 seabed images, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

Univariate community analyses - epifauna

Analyses were also conducted using the DISTLM approach examining a range of univariate measures, calculated on the basis of the "trustworthy" and full species list. The models are summarised in Table 5.

For the limited data set, the initial model examining log (x+1) transformed species richness did not retain any fishing variables, with 74.9% of the variance explained by depth, year and habitat. When offered to the model, the historical trawl effort (7–9 years prior to sampling) was also retained. For log (x+1) transformed number of individuals, year and habitat explained 51.7% of the variance in the initial model (no fishing terms retained), and medium-term trawl effort (4–6 years prior to sampling) was also retained when offered. For Peilou's evenness and the Shannon-Weiner index, initial models retained depth, year, habitat, and years fallow and recent effort from the trawl fishery (no scallop fishery terms retained), explaining 38.3% and 74.6% of the variance, respectively. The two fishing effort terms explained 5.5% and 9.6% of the variance in the two models, respectively, and longer-term effort variables were not retained in either model. Overall, while the percentage of total variance explained by the minimum adequate models (64% median) were slightly higher than those from the community composition analysis (Table 4), the variance explained by fishing effort related terms (median 1.4%), and the proportion of the explained variance (median 1.9%) accounted for by fishing terms was lower for these univariate measures.

Examining the univariate metrics calculated from the full data set, the models generally retained more fishing terms, with these terms explaining a greater percentage of both the total (median 11.1%) and explained (median 19.9%) variance than for the limited data set, but fishing terms still contributed less explanatory power than for the community composition analysis (Table 4). Across both these univariate analysis, less of the variance was explained for the Pielou's evenness models (median 33.7%) than for the other diversity measures (median 74.5%).

Table 5: 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 (therefore order of retained variables is arbitrary), 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). Analyses were conducted with the "trustworthy" species group (T), and using all species (A).

Dataset	Species	R^2	Retained variables	Fishing/Total	Fishing/Explained
Species richness	T	0.749	Y, D, H	0	0
	T	0.752	Y, D, H, TE9	2.7	3.6
No. individuals	T	0.517	Y, H	0	0
	T	0.536	Y, H, TE6	0.1	0.2
Pielou's evenness	T	0.383	D, Y, H, TE3, TF	5.5	14.4
			Longer term effort not retained		
Shannon-Weiner	T	0.746	D, Y, H, TE3, TF	9.6	12.9
			Longer term effort not retained		
Species richness	A	0.784	Y, D, H, TE3, TF	15.6	19.9
	A	0.790	Y, D, H, TE3, TF, TE9	15.6	19.7
No. individuals	A	0.629	Y, H	0	0
			Longer term effort not retained		
Pielou's evenness	A	0.327	Y, D, H, SE3	7.6	23.2
	A	0.337	Y, D, H, SE3, TE6	11.1	32.9
Shannon-Weiner	A	0.741	Y, D, H	0	0
	A	0.744	Y, D, H, TE6	15.1	20.3

3.2 Infaunal community data

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 and redundancy (Figure 32 and Table 6). As with the data for the epifaunal stations, the average scallop effort over the previous 3 years (s_effort3) was strongly correlated with the other measures of average scallop effort, and so other than for the analysis of the 2017 data alone, these other effort measures were not included.

The range of the continuous variables is shown in relation to the acoustic habitat classes in Figure 33. As with the image stations, the range of some of the effort variables was quite limited for some habitat classes.

The PCA eigenvector plot of the combined environmental and fishing data is shown in Figure 34. This plot shows the very strong correlation between the scallop effort averaged over the different time periods. Other variables (e.g. depth and years fallow from trawling) show correlation in 2D space, but these relationships separate out on the third and fourth axes. The first axis explained 28% of the variance, with over 90% explained by the first 10 axes. Examining the years individually (not presented) shows a similar pattern.

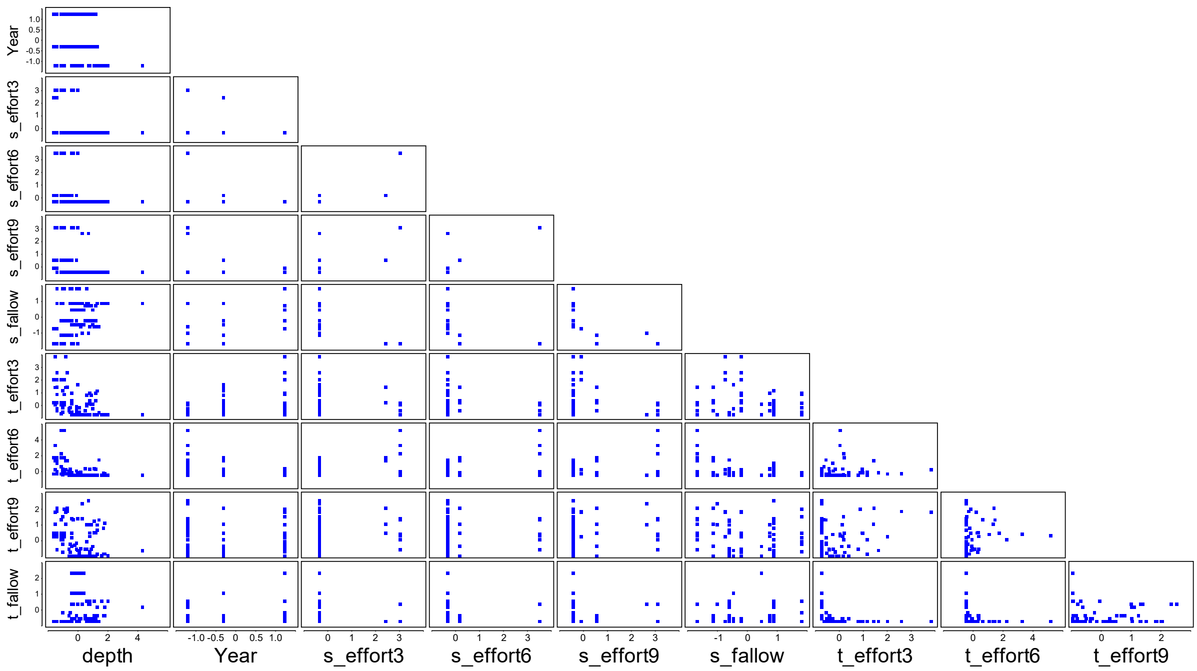

Figure 32: Pairwise (draftsman) plot of normalised explanatory variables for analysis of infaunal data.

Table 6: Correlation matrix for normalised explanatory variables for analysis of infaunal data.

	depth	year	s_effort3	s_effort6	s_effort9	s_fallow	t_effort3	t_effort6	t_effort9
year	-0.2865								
s_effort3	-0.3615	-0.3288							
s_effort6	-0.2876	-0.3534	0.8894						
s_effort9	-0.3024	-0.3922	0.8239	0.9008					
s_fallow	0.2640	0.4298	-0.5883	-0.5420	-0.6303				
t_effort3	-0.4236	0.3550	0.0122	-0.0534	-0.0303	-0.1438			
t_effort6	-0.3897	-0.2334	0.6063	0.5610	0.5380	-0.4416	0.1862		
t_effort9	-0.2584	-0.0517	0.2493	0.1927	0.3103	-0.1478	0.4352	0.2652	
t_fallow	0.1502	0.1858	-0.1503	-0.1201	-0.1308	0.0771	-0.5106	-0.3309	-0.4096

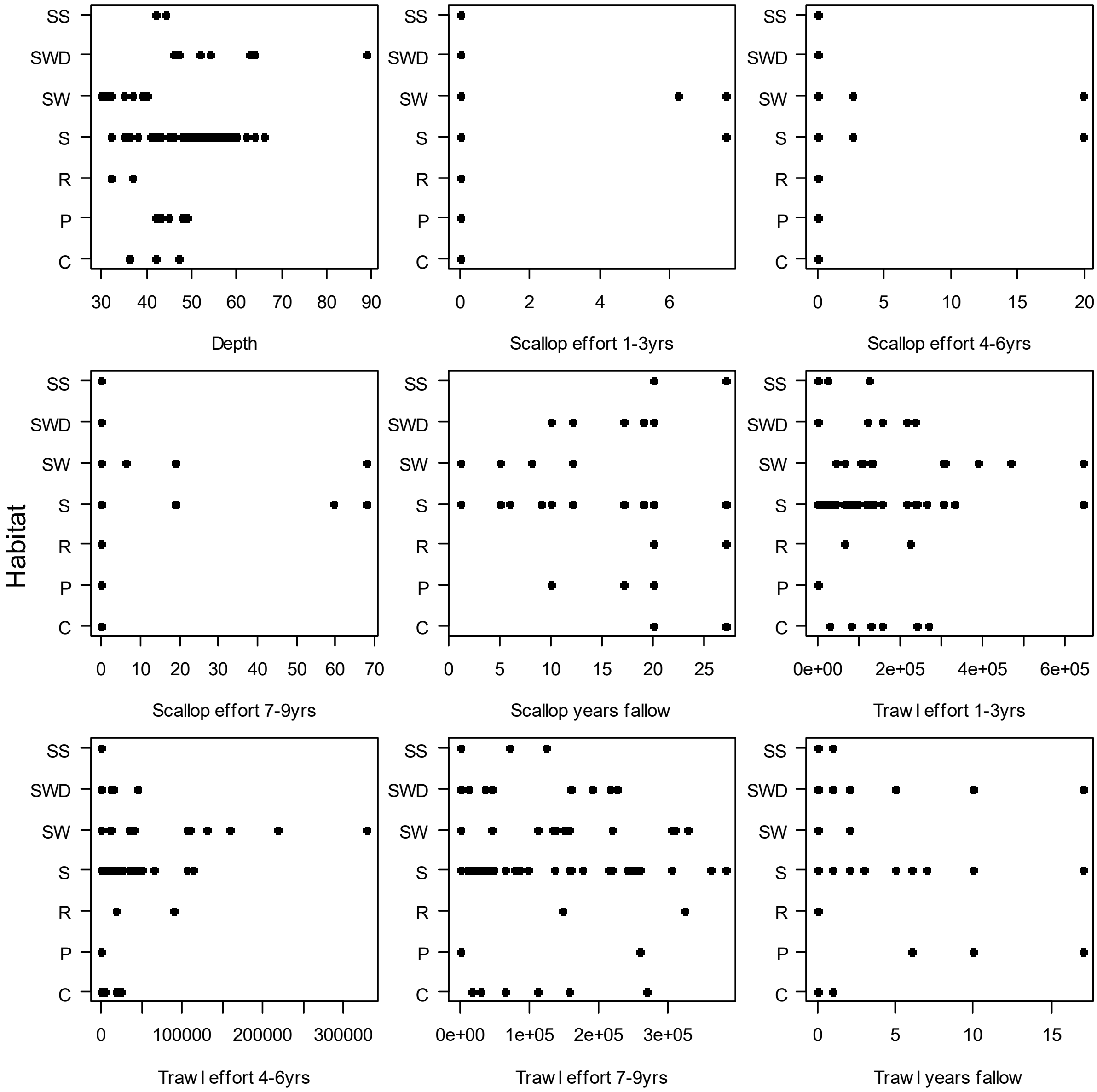

Figure 33: Infauna: Pairwise (Draftsman) plot of environmental and fishing variables in relation to acoustic habitat classes. Within each plot, the dots represent the values (on the x axis) for sites within that acoustic habitat class. Habitats: C – coarse, P – sand over pavement, R – rocky, S – sand, SW – sandwaves, SWD – sandwaves deep, SS – sand/shell.

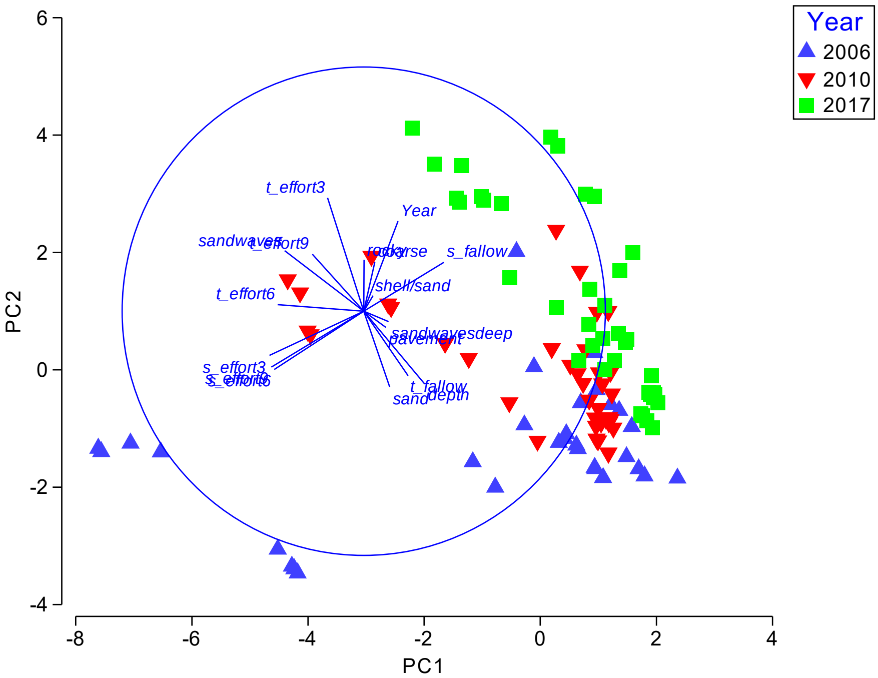

Figure 34: Infauna: PCA eigenvector plot of environmental variables. Variables include depth, year, habitat (sand, sand/shell, sandwaves, deeper sandwaves, pavement, rocky and coarse) and fishing (effort over different time periods as described in text, and years fallow by scallop dredge or bottom trawl). Symbols represent individual stations, coded by year.

Multivariate community analyses - infauna

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 an adjusted R^2 criterion. Model outputs are summarised in Table 7.

For the complete grab dataset, depth, habitat, year, scallop and trawl effort (averaged over previous 3 years), and years fallow from scallop fishing were retained in the model, which explained 35.3% of the variance in the community data (Figure 35). There was a clear separation between the datasets from the three surveys, but depth, habitat and fishing terms always explained significant components of the variation. The combined fishing related terms explained 12.0% of the total variance (34% of the explained variance) (Table 7). Examination of the marginal tests suggested that the scallop fishing terms explained more variance than the trawl fishing terms (Appendix 2), although there is some overlap between the terms (sum of marginal tests for retained terms explains 13.4% of variance, combined fishing terms explains 12.0%). As with the analysis of the epifaunal community data, exclusion of the deepest stations from the 2006 survey slightly improved the overall variance explained (37.8%), but all the same terms were retained in the minimum adequate model. The inclusion of the average trawl effort over 4–6 and 7–9 years improved the model (38.3% of variance explained, variance explained by fishing terms increasing to 15.5%) (Figure 36).

As with the epifaunal dataset, similar analyses were also conducted on subsets of the data (Table 7). For the 2010 and 2017 data sets, additional information on sediment characteristics (particle size composition and percentage organic content) were available, and these have been added to the analysis in separate models.

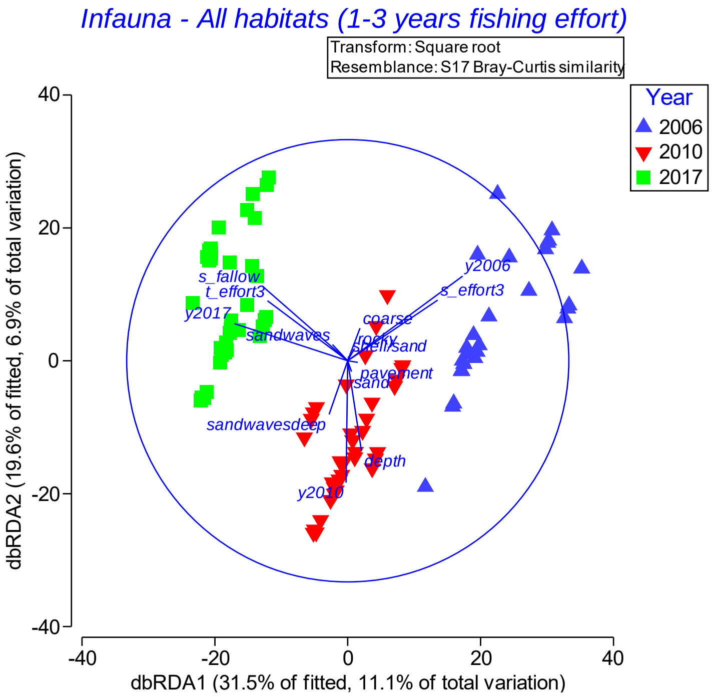

Figure 35: Infauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray Curtis similarity matrix of square root transformed infaunal community data from grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the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

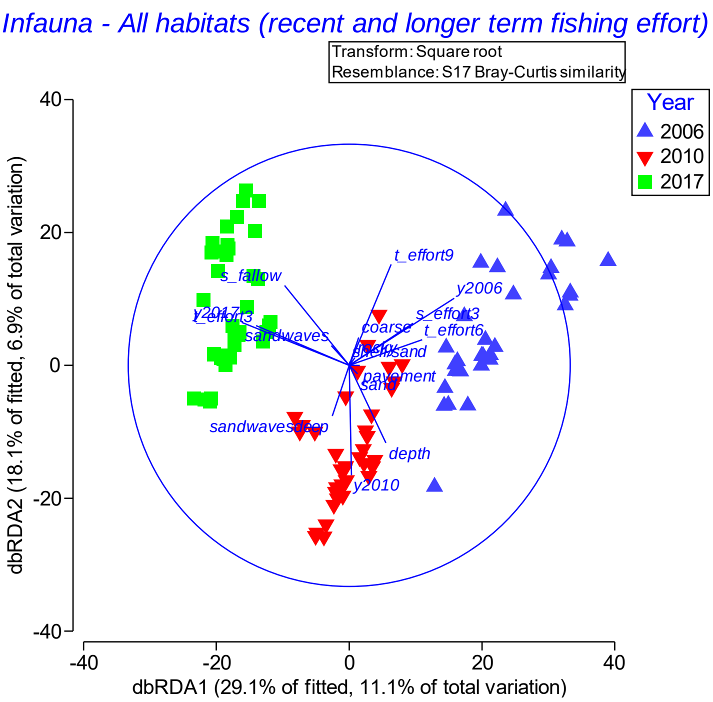

Figure 36: Infauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray Curtis similarity matrix of square root transformed infaunal community data from grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis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

Table 7: Infauna: Summary of DISTLM models fitted to infaunal community data, showing data set used, adjusted R^2 value, variables retained following backwards selection (therefore order of retained variables is arbitrary), 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 – SED (proportion by size classes, based on Wentworth scale) and percentage organic material – ORG, were available for 2010 and 2017 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	0.353	D, H, Y, SE3, SF, TE3	12.0	34.0
	0.383	D, H, Y, SE3, SF, TE3, TE6, TE9	15.5	40.5
Sandy	0.329	D, H, Y, SE3, SF, TE3, TF	14.7	44.7
	0.370	D, H, Y, SE3, SF, TE3, TF, TE6, TE9	18.5	50.0
Sand	0.330	D, Y, SE3, SF, TE3, TF	15.7	47.6
	0.388	D, Y, SE3, SF, TE3, TF, TE9	21.9	56.4
2006	0.204	D, SE3, TF	16.1	78.9
	0.349	D, SE3, TF, TE6, TE9	30.7	88.0
2010	0.394	D, H, SE3, SF, TE3, TF	17.8	45.2
	0.422	D, H, SE3, SF, TE3, TF, TE9	23.3	55.2
2017	0.406	D, H, SF, TE3	13.2	32.5
	0.455	D, H, SF, TE3, SE9, TE9	19.8	43.5
2010*	0.559	D, H, SE3, SF, TE3, TF, SED, ORG	17.8	31.8
*	0.583	D, H, SE3, SF, TE3, TF, SED, ORG, TE9	23.3	40.0
2017*	0.519	D, H, SF, TE3, SED, ORG	13.2	25.4
*	0.573	D, H, SF, TE3, SED, ORG, TE6, TE9, SE9	22.3	38.9

* - 2010 models 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 32.9% of the variance, with the fishing terms explaining 14.7% (Figure 37). Inclusion of the longer-term trawl effort variables (both being retained) increased the variance explained to 37%, with 18.5% explained by fishing terms (Figure 38).

Limiting the dataset further to only the sand habitat, the initial minimum adequate model (Figure 39) retained depth, year and the four fishing variables, and explained 33.0% of the variance, with the fishing terms explaining 15.7%. The inclusion of the average trawl effort over the previous 7–9 years (Figure 40) increased the variance explained to 38.8% (21.9% of total by fishing terms, 56.4% of explained variance).

For the 2006 data (Figure 41), depth, scallop effort (average of previous 3 years) and years fallow from trawl fishing explained 20.4% of the variance, with 16.1% explained by the two fishing terms. Both of the additional trawl effort terms were also retained when included in the model (Figure 42), increasing the variance explained to 34.9% (30.7% by fishing terms, 88% of the explained variance). For the 2010 data (Figure 43), depth, habitat and the four fishing variables were all retained in the initial model, explaining 39.4% of the variance (17.8% explained by the fishing terms). Only the additional longer term trawl effort term (average over previous 7–9 years) was retained when offered to the model (Figure 44), increasing the overall variance explained to 42.2%, and that by fishing terms to 23.3% (55.2% of the explained variance). For the 2017 data (Figure 45), depth, habitat, recent trawl effort and years fallow from scallop fishing were retained in the initial model, explaining 40.6% of the variance (13.2% explained by fishing terms). When longer term fishing effort was offered to the model, both scallop and trawl effort (both averaged over previous 7–9 years) were retained (Figure 46), increasing the overall variance explained to 45.5% (19.8% explained by fishing terms).

Sediment samples were available for the 2010 and 2017 survey data, to provide particle size and percentage organic content variables. Both of these terms were retained by all four models examining these two data sets (examining the two surveys separately, with most recent and longer term fishing effort), generally increasing the overall variance explained by 10–15%, relative to the models without these terms (Table 7). Inclusion of the additional sediment parameters did not replace the influence of the other terms within the minimum adequate models, although for the analysis of the 2017 data set with longer term effort, inclusion of the sediment parameters also led to the retention of the trawl effort averaged over the previous 4–6 years.

As with the epifaunal community composition data set (Table 4), fishing terms were retained in all models. Excluding the models incorporating sediment parameters (since they are only available for the 2010 and 2017 surveys), a median of 37.6% of total variance was explained by the models, 16.9% (median) by fishing terms, equating to 46.4% of the explained variance accounted for by fishing terms. The variation explained by fishing terms, and the proportion of the variance explained accounted for by fishing terms, has generally declined since 2006. The models examining infaunal community composition (Table 7) generally explained less of the variation than the models for the epifaunal community (Table 4)

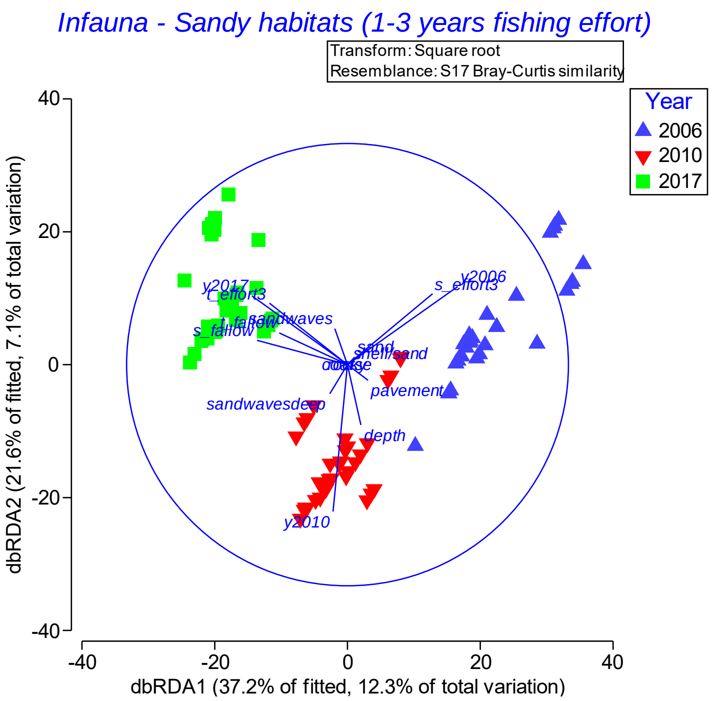

Figure 37: Infauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from grab samples within sandy habitat (excluding rocky and coarse areas), with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

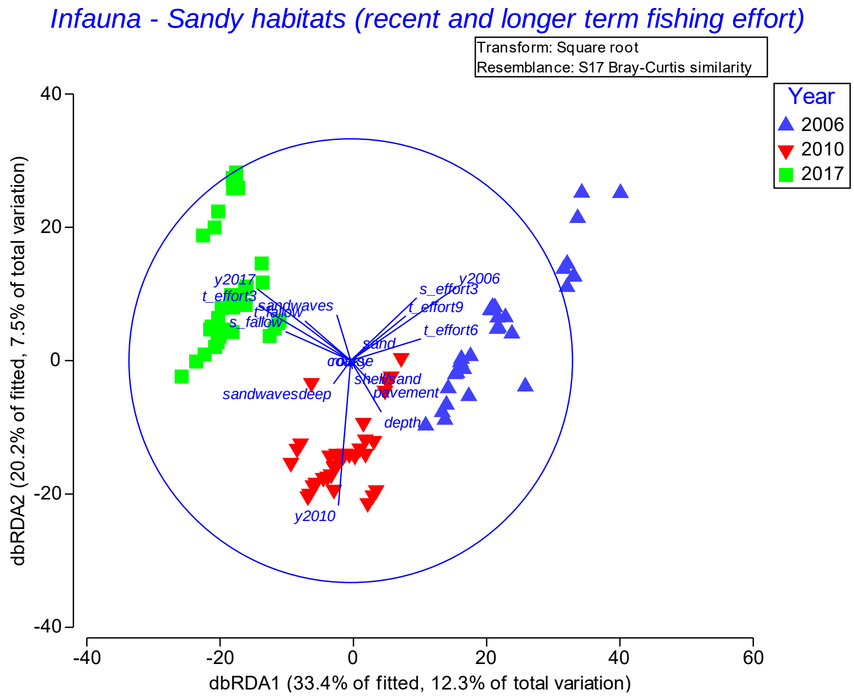

Figure 38: Infauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from grab samples within sandy habitat (excluding rocky and coarse areas), with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

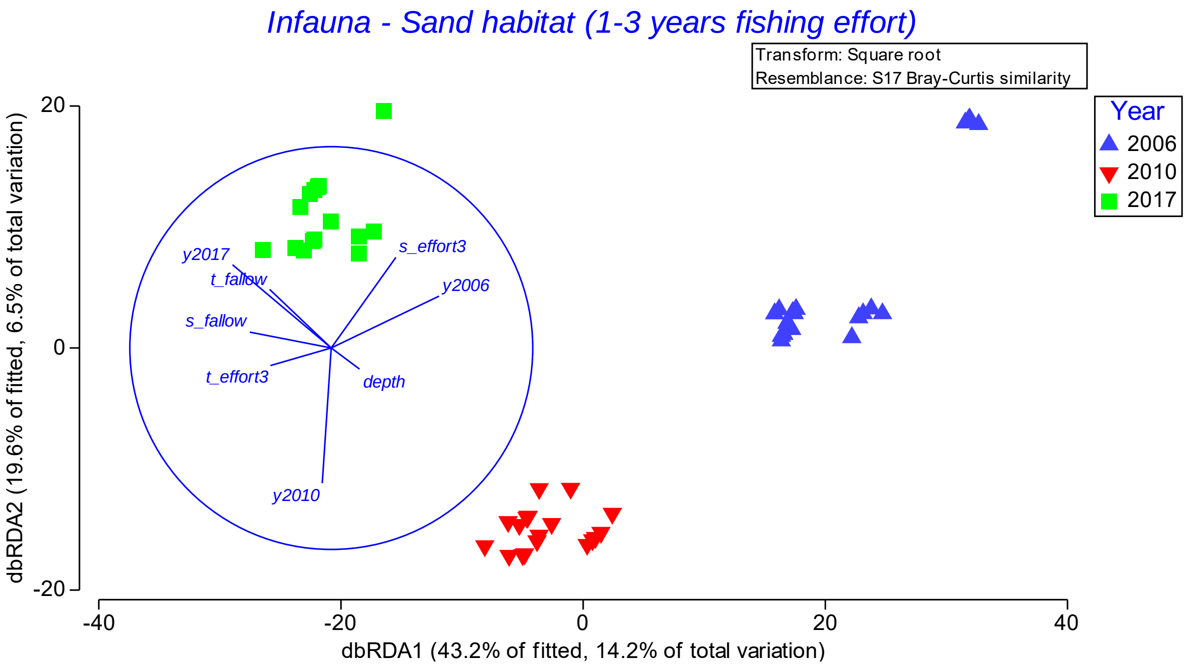

Figure 39: Infauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from grab samples within sand habitat, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

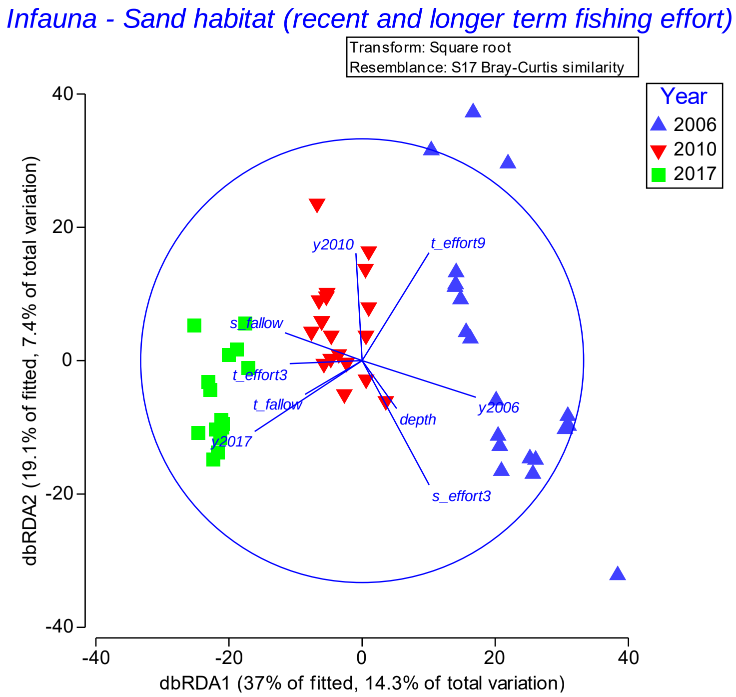

Figure 40: Infauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from grab samples within sand habitat, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations, coded by year.

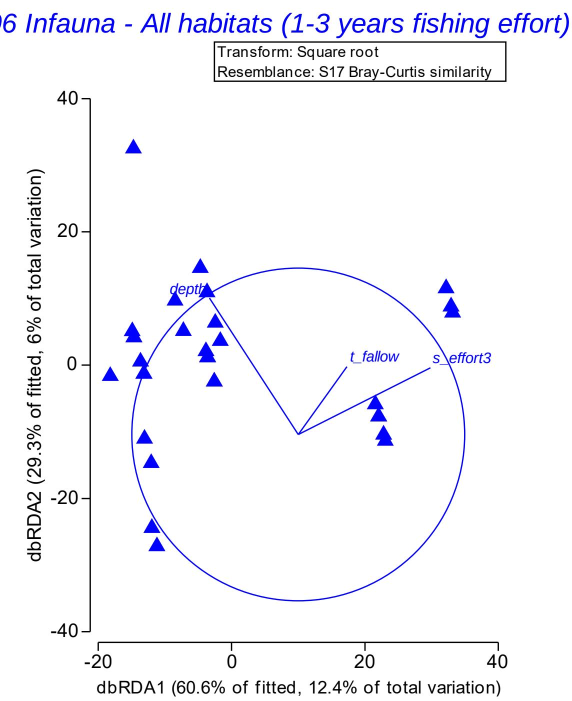

Figure 41: Infauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2006 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

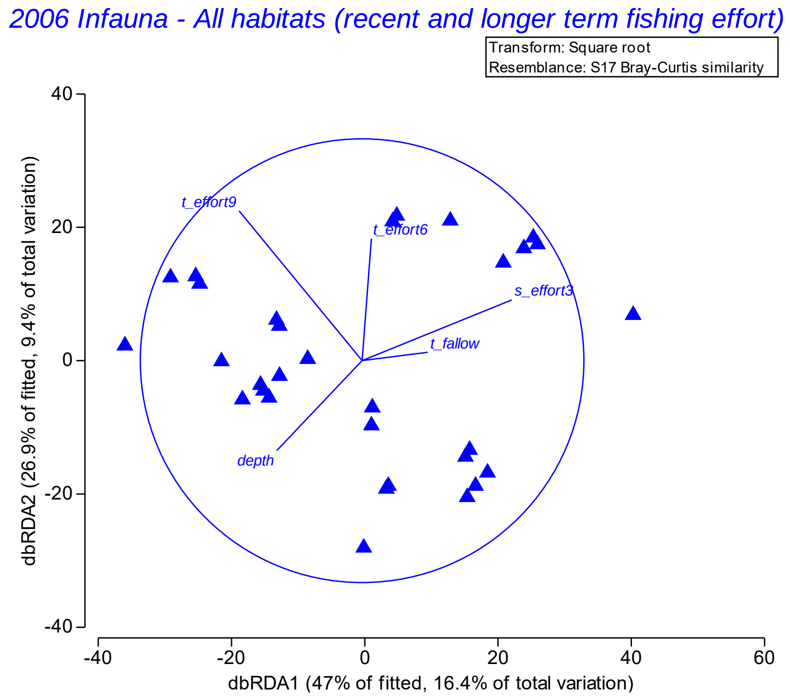

Figure 42: Infauna and longer term trawl effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2006 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

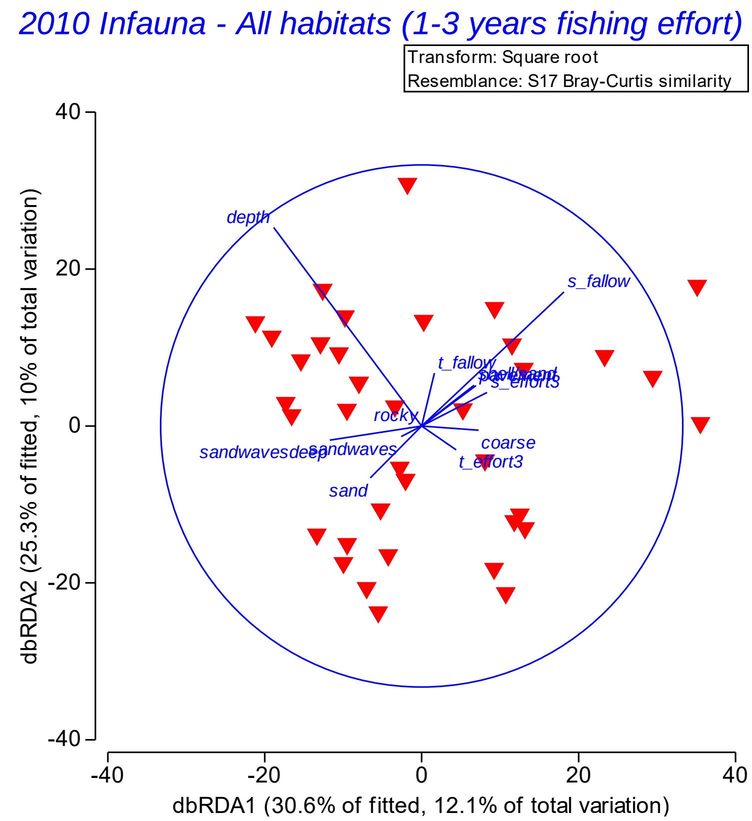

Figure 43: Infauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2010 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

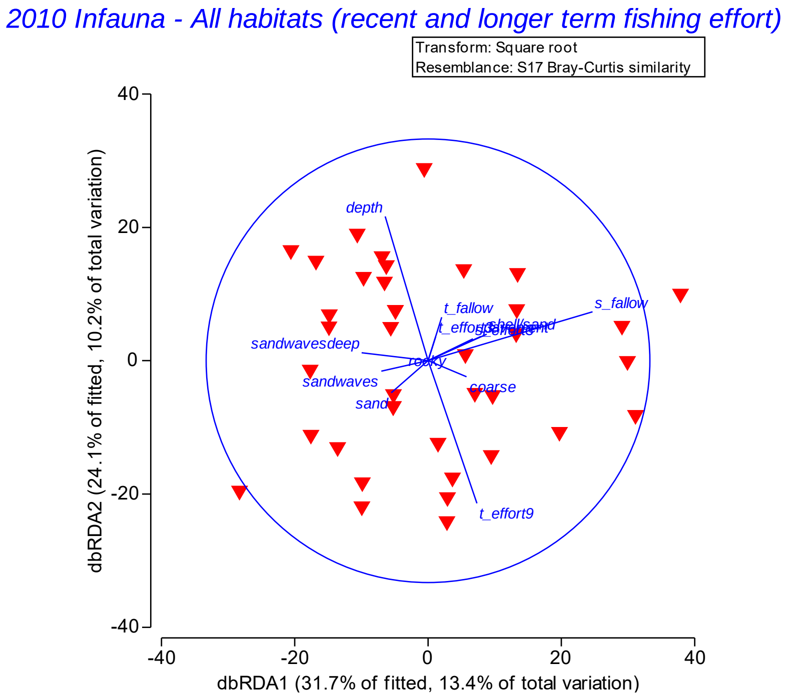

Figure 44: Infauna, most recent fishing effort and sediment composition terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2010 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

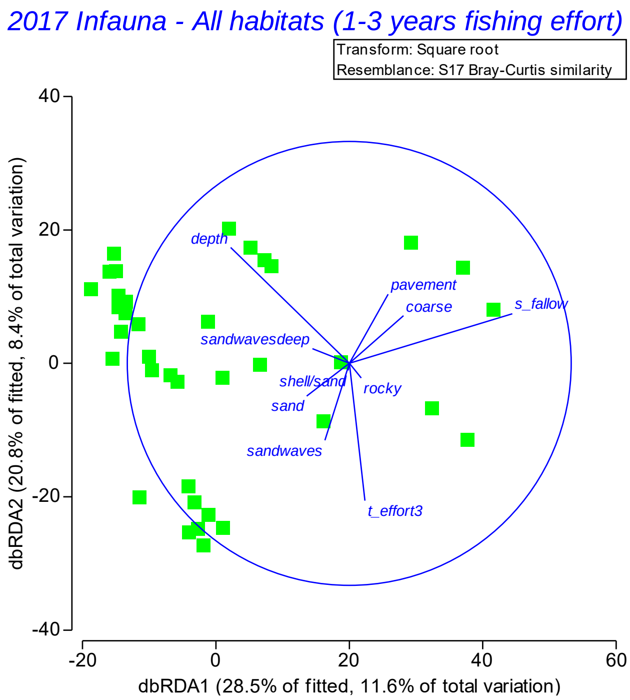

Figure 45: Infauna and most recent fishing effort terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2017 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

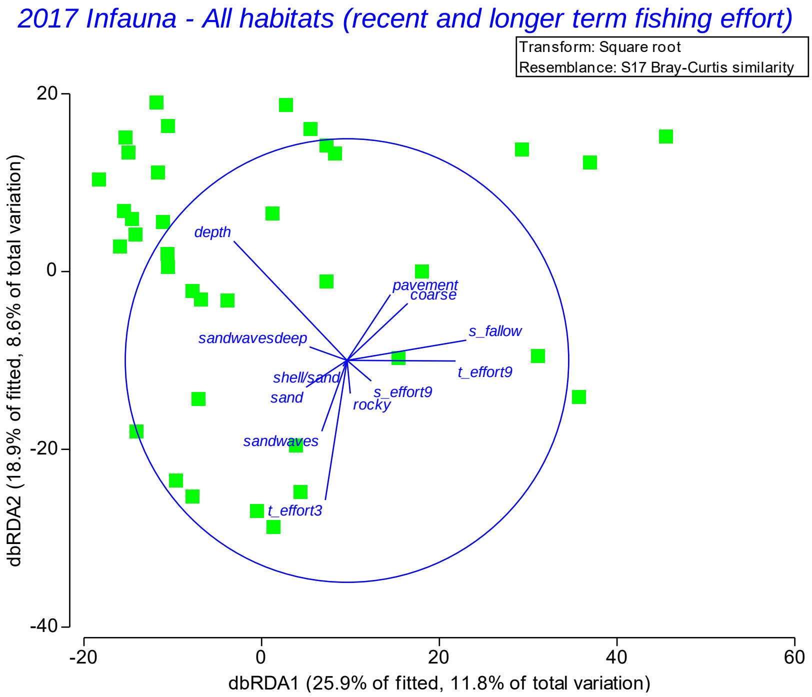

Figure 46: Infauna, most recent fishing effort and sediment composition terms: Distance based redundancy analysis plot of Bray-Curtis similarity matrix of square root transformed infaunal community data from 2017 grab samples, with PCA overlay of environmental factors, for minimum adequate model from backward selection on the basis of adjusted R^2. Symbols represent individual stations.

Univariate community analyses - infauna

As with the epifaunal data, analyses were also conducted using the DISTLM approach to examine environmental relationships with a range of univariate measures (models summarised in Table 8).

The initial model examining log (x+1) transformed species richness retained depth, habitat, year and the two scallop fishing terms, explaining 24.8% of the variance (2.8% by fishing terms) (Table 8). When offered to the model, both longer term trawl effort terms were retained, increasing the model's explanatory power to 31.1%, but the contribution by fishing terms remained low (3.6% of total variance). The initial model for log (x+1) transformed number of individuals only retained year and habitat terms, explaining 20.7% of the variance. When offered, the two longer term trawl effort terms were retained, with the model explaining 32.2% of the variance, 1.7% by fishing terms. For Pielou's evenness, only depth and years fallow from trawling were retained in the initial model (explaining 10.6% of variance, 2.3% explained by fishing term), but both the historical trawl effort terms were retained when offered (increasing overall variance explained to 19.2%, 6.9% by fishing terms). Examining the Shannon-Weiner index, depth, year, habitat, recent scallop effort and years fallow from trawling explained 18.6% of the variance (4.2% explained by fishing), with only the longer term (7–9 years prior to sampling) trawl effort term retained when offered (increasing overall variance explained to 19.6%, 4.3% by fishing).

The total variance explained by the minimum adequate models (median 20.1%), and both the variance accounted for by fishing terms (median 3.2%) and the proportion of explained variance accounted for by fishing terms (median 16.6%) were lower than for the analysis of the infaunal community composition data (Table 7).

Table 8: Infauna: Summary of DISTLM models fitted to univariate measures of infaunal community, showing data set used, adjusted R^2 value, variables retained following backwards selection (therefore order of retained variables is arbitrary), 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	0.248	D, Y, H, SE3, SF	2.8	11.3
	0.311	D, Y, H, SE3, SF, TE6, TE9	3.6	11.6
No individuals	0.207	Y, H	0	0
	0.322	Y, H, TE6, TE9	1.7	5.3
Pielou's evenness	0.106	D, SF, TF	2.3	21.7
	0.192	D, SF, TF, TE6, TE9	6.9	35.9
Shannon-Weiner	0.186	D, Y, H, SE3, TF	4.2	22.6
	0.196	D, Y, H, SE3, TF, TE9	4.3	21.9

3.3 Changes between surveys

The consistent year effect detected across both the epifaunal and infaunal data suggests there has been substantial change in the community composition between the surveys. It must be remembered that image resolution has increased over the surveys, which may be contributing to this apparent year effect in the epifaunal data. 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 epifaunal species were recorded on all surveys, but overall, 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 (Tuck & Hewitt 2013), and more still in 2017. The species contributing most to the dissimilarity between successive surveys (averaged across the sandy habitats) are presented in Table 9. Sampling in other habitats was quite sparse, and so these have not been examined in detail in this way.

While most (17 out of 29) of the epifaunal species listed in Table 9 (contributing more than 1% to dissimilarity between successive surveys) showed an overall increase in abundance across the surveys (including 6 species only reported in 2017), three species did show a consistent decline, including the sponges *Oceanapia* n. sp. 4, *Callyspongia* n. sp. 16 and *Dactylia velcatum*.

Many more species were identified from the infaunal samples than from the epifaunal samples, and no species contributed more than 4% to the dissimilarity between surveys, averaged across habitats (Table 10). Unlike the epifaunal data (Table 9), species only reported from the 2017 survey did not feature in those contributing most to the dissimilarity between surveys. Of the 41 species groups contributing more that 1% to the dissimilarity between successive surveys, most (28) showed no clear pattern over time, six showed a consistent increase, and seven showed a consistent decline.

Table 9: Epifaunal taxa contributing over 2% to the dissimilarity between successive surveys (averaged across sandy habitats), the overall direction of change in abundance observed from 2006 to 2017, and the average number of individuals per station). Where no consistent change in abundance was observed across surveys, this has been left blank.

			Average number per station			Contribution to dissimilarity	
Taxon	Type	Change	2006	2010	2017	2006 v 2010	2010 v 2017
Crateritheca novaezelandiae	Hydroid		0.42	2.88	0.26	22.92	12.19
Crateritheca? sp. 1	Hydroid	increase	0	0	2.91	0	10.95
Hydrodendron mirabile	Hydroid	increase	0.46	2.17	2.26	15.11	9.1
Ascidian sp. 10	Ascidian	increase	0	0	1.68	0	6.65
Ascidian sp. 16	Ascidian	increase	0	0	0.95	0	3.8
Oceanapia n. sp. 4	Sponge	decrease	1.99	0.74	0.42	9.63	3.38
Oceanapia cf arcifera	Sponge	increase	0	0	1.1	0	2.48
Nemertesia elongata	Hydroid		1.25	0.18	0.54	7.79	2.15
Euptilota formosissima	Macroalgae	increase	0	0	0.55	0	2.1
'*Heteropora' neozelanica*	Bryozoan	increase	0	0.03	0.43	0.2	1.91
Steginoporella perplexa	Bryozoan		0.66	0.44	1.89	4.38	4.3
Tethyopsis mortenseni	Sponge		0.61	0.5	0.72	4.26	3.23
Pseudodistoma novaezelandiae	Ascidian		0.38	0.23	0.4	2.62	1.24
Polymastia croceus	Sponge	increase	0.42	0.46	0.58	2.61	1.82
Aplidium powelli	Ascidian	increase	0.13	0.49	0.57	2.48	2.27
Callyspongia n. sp. 16	Sponge	decrease	0.42	0.03	0	2.32	0.1
Hymeniacidon sp. 1	Sponge		0.65	0.07	0.57	2.27	0.94
Callyspongia ramosa	Sponge	increase	0.21	0.3	0.35	2.13	1.93
Axinella australensis	Sponge		0.27	0.37	0.29	2.08	1.56
Iophon minor	Sponge	increase	0.19	0.33	0.47	1.64	1.78
Diplosoma velcatum	Ascidian		0.09	0.28	0.23	1.36	0.99
Aaptos sp	Sponge	increase	0	0.39	0.55	1.28	1.75
Dactylia varia	Sponge	decrease	0.23	0.13	0.06	1.27	0.49
Crella incrustans	Sponge		0.28	0.15	0.17	1.19	1.63
Axinella sp. 3	Sponge	increase	0	0.24	0.26	1.11	1.01
Latrunculia oxydiscorhabda	Sponge	increase	0.09	0.31	0.87	1.1	1.53
Steginoporella neozelanica	Bryozoan	increase	0	0.08	1.05	0.18	1.37
Latrunculia oxydiscorhabda	Sponge	increase	0.09	0.31	0.45	1.1	1.2
Ascidian sp. 13	Ascidian	increase	0	0	0.37	0	1.18

Table 10: Infaunal taxa contributing over 1% to the dissimilarity between surveys (averaged across habitats), the direction of change in abundance observed from 2006 to 2017, and the average number of individuals per grab. Where no consistent change in abundance was observed across surveys, this has been left blank.

Species	Type	Change	Average number per station			Contribution to dissimilarity	
			2006	2010	2017	2006 v 2010	2010 v 2017
Spionidae	Polychaete		3.48	0.21	0.58	3.88	0.84
Maldanidae	Polychaete		2.34	3.56	0.95	3.66	4.4
Urothoidae	Amphipod		0.48	2.5	1.88	3.18	2.95
Onuphidae	Polychaete		1.23	2.79	1.64	2.56	2.48
Opheliidae	Polychaete		2.29	0.06	0.15	2.46	0.98
Phoxocephalidae	Amphipod		1.59	3.01	2.17	2.44	1.9
Cirratulidae	Polychaete		1.13	2.68	0.8	2.41	2.89
Otionellidae	Bryozoan	increase	1.72	1.77	2.39	2.39	2.93
Liljeborgiidae	Amphipod		0.73	2.04	1.27	2.39	1.85
Maeridae	Amphipod	decrease	1.91	1.47	0	2.14	1.77
Orbiniidae	Polychaete		1.54	2.49	1.38	2.12	2.3
Syllidae	Polychaete	decrease	2.08	1.94	1.35	1.94	2.11
Lysianassidae	Amphipod	decrease	1.27	1.19	0.95	1.81	1.73
Amphiuridae	Ophiuroid		1.08	1.5	2.45	1.76	2.6
Spionidae	Polychaete		0.92	1.45	0.45	1.7	1.74
Sabellidae	Polychaete	decrease	1.36	1.12	0.68	1.69	1.44
Mactridae	Bivalve		0	1.24	0.68	1.66	1.67
Caprellidae	Polychaete		0.71	1.08	1.04	1.53	1.79
Oligochaete	Oligocheate		0.95	1.37	0.87	1.51	1.51
Tulearidae like	Amphipod	decrease	1.39	0.79	0	1.49	0.93
Tanaidacea	Tanaid		0.78	1.19	0.48	1.34	1.45
Cumacea	Cumacean		0.89	1.03	0.36	1.32	1.25
Scleractinia	Stony coral	decrease	1.29	0.4	0	1.3	0.55
Spionidae	Polychaete		1.04	0.52	0.65	1.3	1.13
Capitellidae	Polychaete		0.91	1.08	0.69	1.27	1.29
Ischnochitonidae	Chiton		0.56	0.94	0.65	1.24	1.45
Leptanthuridae	Isopod		0.42	1.07	0	1.19	1.42
Chioninae	Bivalve		0.73	0.5	1.02	1.1	1.45
Oedicerotidae	Amphipod		0.11	0.79	0.06	1.05	1.11
Ascidiacea	Ascidian	increase	0.16	0.54	1.07	0.74	1.41
Bryozoa	Bryozoan	decrease	1.18	1.03	0	0.65	1.4
Melitidae	Amphipod		0.66	0.34	0.92	0.73	1.24
Dexaminidae	Amphipod		0.22	0.79	0.54	0.87	1.21
Corophilidae	Amphipod		0.3	0.87	0.38	0.97	1.16
Psammobiidae	Bivalve	increase	0	0.04	0.85	0.03	1.12
Lumbrineridae/Oeninidae	Polychaete	increase	0.53	0.62	0.66	0.97	1.1
Marginellidae	Gastropod		0.06	0.73	0.41	0.83	1.07
Philobryidae	Bivalve	increase	0.12	0.35	0.69	0.49	1.06
Nereididae	Polychaete		0.37	0.7	0.47	0.93	1.05
Paraonidae	Polychaete		0.3	0.74	0.19	0.98	1.04
Calyptraeidae	Gastropod	increase	0.34	0.36	0.75	0.6	1.02

3.4 Measures of recovery

One of the main areas of interest of this study for fishery and environmental managers, is understanding trajectories of community recovery following disturbance. Although trawl fishing was active in the region in the early 1990s and earlier, the general assumption (supported by the high levels of bycatch observed in 1996) has been that the major impacts within the study area were related to the development of the scallop dredge fishery. This fishery started in 1994, with part of the study area voluntarily closed to scallop fishing in 1997, and a larger area closed to all mobile bottom fishing methods in 1999. Outside these closures both scallop dredging and bottom trawling have continued, although no scallop fishing has taken place in the region since 2008, and bottom trawling is at a low intensity, compared to other inshore areas.

We have no sampling prior to fishing disturbance, and the sampling conducted in 1999 was based on video (to describe broad habitats) and semi-quantitative epifaunal samples collected using a rock or epibenthic sledge. More recent sampling has taken a non-destructive photographic approach to sampling the epifauna, and so consistent samples only date from 2006. While the fishing effort data provided by the scallop industry is considerably more useful than the Statistical Area reporting, it is still at broad scales relative to the study area, and we cannot with certainty identify any sites within the relevant (scallop) habitats that have never been fished, to determine a "pristine" recovery target.

One approach to measuring recovery (as applied above) is to partition variation in the community composition data cloud, as described by a resemblance matrix, according to a multiple regression model, and examine how the contribution of fishing effort terms changes over time. As the community recovers we would expect gradients in fishing pressure to explain less of the total variation, and this is what is observed in both the epifaunal (Table 4) and infaunal (Table 7) data.

An alternative approach is to examine the change in between sample similarity within consistent habitats over time. While there will always be a natural level of variability between samples even in undisturbed habitats, we would expect between sample similarity to increase as any effects that historical fishing impacts may have had on any of the sites reduces, as time since fishing increases.

Levels of sampling have varied within habitats over time (Table 1), and three surveys is a very short time series. Within group average similarities cannot be calculated when no species are recorded for a sample, or if there are fewer than two useable samples within a group. However, where possible, average within habitat similarity has been calculated for each survey (Table 11). *A priori*, and as discussed elsewhere in this report, we would expect epifauna to be more vulnerable to fishing disturbance than infauna, and scallop fishing to have mostly operated on the sand habitat (and not at all on the rocky habitat), with the diverse epifauna recorded within the sand shell over pavement habitat perhaps being the most sensitive. Over the three surveys, within habitat similarity of epifauna has increased for sand, sand shell over pavement and coarse habitats (values only available for 2010 and 2017 for the latter two habitats), and decreased for the two sandwave habitats (values only available for 2010 and 2017 for the shallower of these) (Table 11). Rocky habitat epifauna does not show a consistent trend. Examining the combined sandy habitat data within years, which will be sensitive to the difference between habitats and the relative level of sampling between habitats within a given year, shows an increase in similarity over time. The increase in within year similarity over time was considerably greater between 2006 and 2010 (17.26 to 34.94) than 2010 and 2017 (34.94 to 36.98), which might imply the rate of recovery of impacted sites has reduced, but it is not clear if "linear" interpretation of these changes is appropriate.

Patterns are less clear for the infaunal data, but both the coarse and sand shell over pavement habitats show an increase in within habitat similarity between 2010 and 2017 (insufficient data for 2006). Other habitats did not show a consistent pattern.

Table 11: Average within habitat Bray Curtis similarity of square root transformed abundance data from each survey.

	2006	2010	2017
Epifauna			
Coarse		26.74	44.01
Rocky	53.30	67.49	55.37
Sand shell over pavement		44.37	55.38
Sand	11.79	33.90	36.31
Sandwaves		28.14	17.83
Sandwaves deep	49.58	41.81	32.11
Combined sandy habitats	17.26	34.94	36.98
Infauna			
Coarse		47.79	51.70
Sand shell over pavement		33.55	43.60
Sand	33.01	44.53	40.71
Sandwaves	39.48	44.92	31.06
Sandwaves deep	48.62	58.21	40.95
Combined sandy habitats	34.81	42.63	35.30

3.5 Taxa sensitive to fishing

In addition to a consistent year effect indicating changes between the surveys, the various fishing terms were frequently retained within the minimum adequate models, with fishing terms often accounting for 40–50% of the explained variance, 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 species categorisation is reliant on expert knowledge (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 and 2017 surveys, and the sensitivity table for the rocky (Table 12) and sandy and coarse (gravelly) habitats (Table 13) 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 12: A summary of the sensitivity and recoverability factors (at the individual organism/colony level) for the main rocky habitat species identified (with confidence) 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.

				Sensitivity to:					Recovery by:		
Species	Frequency	Shape	Size	Dredging	Wash	Currents	Sediments	Growth	Wedging	Anchoring	Rolling
Ascidian: Ascidian sp. 16 (cream encrusting)	C	thin	Sm	M	M	M	M	R	P	P	P
Ascidian: *Diplosoma velcatum*	C	digitate	Sm	S	S	S	M	R	P	P	P
Sponge: *Callyspongia ramosa*	C	strappy	L	S	S	R	R	M	P	P	P
Sponge: *Iophon minor*	C	strappy	L	M	R	R	R	Sl	P	P	P
Ascidian: *Synoicum kuranui*	Mc	spherical	Sm	S	S	M	M	R	G	M	G
Sponge: *Crella incrustans*	Mc	thick	Md	S	S	S	M	R	M	M	M
Sponge: *Dactylia varia* (was *palmata*)	Mc	leafy/fan	L	S	S	M	M	M	M	M	M
Sponge: *Darwinella oxeata*	Mc	digitate	Sm	M	R	R	R	R	P	P	P
Sponge: *Dendrilla rosea*	Mc	bushy	Md	M	R	R	M	R	P	P	P
Sponge: *Ecionemia alata*	Mc	Bowl	L	S	M	M	M	VS	P	M	M
Sponge: *Halichondrida* sp. 5 (mustard encrustor, many oscules)	Mc	thick	Md	M	R	R	R	M	P	P	P
Sponge: *Haliclona* sp. 1 (little orange tubes)	Mc	spherical	Sm	M	M	R	M	R	P	P	P
Sponge: *Latrunculia oxydiscorhabda*	Mc	thick	Md	M	R	R	M	M	P	P	P
Sponge: *Leucettusa lancifer*	Mc	spherical	Sm	S	M	M	M	R	P	P	P
Sponge: *Penares vermiculatus* sp. nov.	Mc	spherical	Md	M	R	R	R	Sl	P	P	G
Sponge: *Stelletta conulosa*	Mc	leafy/fan	Md	S	R	R	R	M	P	P	P
Ascidian: *Aplidium* sp. 1 (orange brain)	U	loaf	Md	M	R	R	M	M	M	P	M
Ascidian: Ascidian sp. 3 (tan smooth encruster)	U	thin	Md	R	R	R	M	M	P	P	P
Ascidian: Ascidian sp. 4 (orange and white stripes)	U	thin	Md	M	R	R	R	M	P	P	P
Ascidian: Ascidian sp. 11 (pink didemnum)	U	thin	Sm	R	R	R	M	R	P	P	P
Ascidian: Ascidian sp. 20 (white brain)	U	loaf	Md	M	R	R	M	M	M	P	M
Ascidian: Ascidian sp. 7 (blue/white knobby smooth)	U	lollipop	Sm	M	M	M	R	R	M	P	M
Ascidian: *Botrylloides leachii*	U	thick	Md	S	R	R	M	M	M	P	P
Ascidian: *Hypsistozoa fasmeriana*	U	lollipop	Sm	S	M	M	R	R	P	P	P
Ascidian: *Sycozoa sigillinoides*	U	lollipop	Sm	S	M	R	R	R	P	P	P
Bryozoan: *Diaperoecia purpurascens*	U	bushy	Md	S	S	M	M	Sl	M	M	P
Bryozoan: *Hornera* sp.	U	bushy	Md	M	R	R	R	R	P	P	P
Gorgonian: Isididae	U	strappy	L	S	R	R	M	M	P	M	P
Hydroid: *Halopteris campanula*	U	feathery	Sm	M	M	M	M	M	P	P	P
Macroalgae: *Curdiea coriacea*	U	leafy/fan	Sm	S	M	M	M	R	P	M	M
Macroalgae: *Ecklonia radiata*	U	strappy	L	M	M	M	R	M	P	P	M
Sponge: *Acanthella dendyi*	U	leafy/fan	Md	S	R	R	R	M	P	P	P
Sponge: *Biemna rufescens*	U	loaf	Md	S	M	M	M	M	P	P	M
Sponge: *Callyspongia annulata*	U	strappy	L	S	S	R	R	M	P	P	P
Sponge: Dysideidae sp. 2 (Blue grey encrustor, many oscules)	U	thick	Md	S	M	M	M	R	P	P	P
Sponge: *Iophon laevistylus*	U	strappy	Md	M	M	M	R	M	P	M	P
Sponge: *Latrunculia procumbens*	U	thick	Md	M	R	R	M	M	P	P	P
Sponge: *Leucosolenia asconoides*	U	digitate	Sm	S	S	S	M	R	P	P	P
Sponge: *Lithoplocamia* n. sp. 1 (MK: blue sandy North Cape)	U	thick	M	S	M	M	M	M	M	M	M
Sponge: *Orina regis*	U	bowl	L	S	M	M	M	Sl	P	P	P
Sponge: *Penares mollis* n.sp.	U	digitate	L	S	M	M	R	M	P	P	M
Sponge: *Polymastia aurantium*	U	loaf	Md	M	R	R	R	R	P	P	M
Sponge: *Raspailia topsenti*	U	bushy	Sm	M	R	R	R	M	P	P	P
Sponge: *Stelletta crater*	U	bowl	L	S	R	R	R	VS	M	P	M
Sponge: *Stelletta sandalinum*	U	loaf	Sm	M	R	R	R	Sl	P	P	M
Sponge: *Tethya burtoni*	U	spherical	Sm	S	R	R	R	R	P	P	M
Sponge: *Tethya fastigata*	U	spherical	Sm	S	R	R	M	M	P	P	P
Sponge: *Thorecta reticulata*	U	digitate	Md	S	R	R	R	S	P	P	P
Sponge: *Trachycladus stylifer*	U	bushy	L	M	R	R	R	Sl	P	P	M
Sponge: UnID sp. 6 (mooth yellow squiggles)	U	thick	Md	M	R	R	M	Sl	P	P	P

Table 13: 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 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.

				Sensitivity to:					Recovery by:		
Species	Frequency	Shape	Size	Dredging	Wash	Currents	Sediments	Growth	Wedging	Anchoring	Rolling
Sand											
Hydroid: *Crateritheca novaezelandiae*	C	feathery	Md	S	R	R	M	M	P	M	P
Hydroid: *Crateritheca*? sp. 1 (yellow brown feather)	C	feathery	Sm	S	M	M	M	M	G	G	P
Hydroid: *Hydrodendron mirabile*	C	feathery	L	S	R	R	M	S	P	P	P
Hydroid: *Nemertesia elongata*	C	feathery	Md	S	R	R	R	Sl	M	M	P
Macroalgae: '*Gigartina' atropurpurea*	C	strappy	L	S	S	M	M	R	P	M	M
Sponge: *Oceanapia* n. sp. 4 (pink translucent turnip)	C	spherical	Sm	S	M	M	R	M	P	M	P
Sponge: *Tethyopsis mortenseni*	C	spherical	Sm	S	M	S	R	M	P	P	P
Macroalgae: *Euptilota formosissima*	Mc	feathery	L	S	M	M	R	M	P	M	M
Ascidian: Ascidian sp. 4 (pale green fat knobs)	U	digitate	Md	S	M	M	R	M	P	P	P
Ascidian: Ascidian sp. 15 (*Sycozoa*-like)	U	lollipop	Md	S	M	M	R	M	P	P	P
Bryozoan: Bryozoan sp. 13 (crimson, petals)	U	bushy	Sm	S	M	M	R	M	P	M	P
Bryozoan: *Canda filifera* (branching red)	U	bushy	Md	S	S	M	R	S	P	P	P
Hydroid: *Amphisbetia operculata*	U	feathery	L	S	R	R	M	M	P	M	P
Hydroid: Hydroid sp. 18 (grey twiggy)	U	strappy	Md	S	M	M	R	M	P	M	P
Sponge: *Callyspongia* n. sp. 16 (Spirits Bay serrated)	U	strappy	Md	S	S	R	R	M	P	P	P
Sponge: *Chelonaplysilla violacea*	U	thin	Md	M	R	R	R	R	P	P	P
Sponge: *Polymastia hirsuta*	U	loaf	S	S	R	R	R	R	P	P	M
Sponge: *Xestospongia* sp. 1 (cf *novaezelandiae*)	U	leafy/fan	Md	S	M	R	R	M	P	P	M
Sand with basement											
Ascidian: *Aplidium powelli*	C	digitate	Md	S	R	R	M	M	P	P	P
Ascidian: *Pseudodistoma novaezelandiae*	C	spherical	Sm	S	M	M	R	R	P	P	P
Bryozoan: *Steginoporella perplexa*	C	fan	Md	S	S	M	R	M	P	P	M
Sponge : *Aaptos* sp. (smooth pinkish orange)	C	spherical	Sm	S	R	R	R	M	M	P	G
Sponge : *Chondropsis kirkii*	C	bulbous	Md	S	M	R	R	M	M	P	P
Sponge : *Polymastia croceus*	C	loaf	Md	S	R	R	R	R	P	P	M
Bryozoan: *Amastigia* sp. ? (orange brown divaricating)	Mc	bushy	Md	M	R	R	R	M	P	M	P
Bryozoan: *Margaretta barbata*	Mc	bushy	Md	S	R	R	R	M	M	M	M
Bryozoan: *Steginoporella neozelanica*	Mc	bushy	Sm	S	R	R	R	M	M	M	M
Soft coral: *Alcyonium* sp. 1	Mc	digitate	Sm	S	S	M	M	R	P	M	P
Sponge: *Axinella australensis*	Mc	strappy	Md	M	R	R	R	M	P	P	P
Sponge: *Axinella* sp. 3 (yellow knobby bush)	Mc	bushy	Md	M	M	R	R	M	P	P	P
Sponge: *Dragmacidon* n. sp. 2 (Spirits Bay flanged)	Mc	leafy/fan	Sm	S	R	R	R	M	P	P	P
Sponge: *Hymeniacidon* sp. 1 (orange, conulose, oscules)	Mc	loaf	Md	S	M	M	M	R	M	M	G
Sponge: *Oceanapia* cf *arcifera*	Mc	spherical	Sm	S	M	M	R	Ra	P	M	P
Ascidian: Ascidian sp. 23 (huge foliose sandy)	U	digitate	L	S	R	R	R	VS	M	P	M
Bryozoan: *Gregarinidra* sp. ?	U	leafy/fan	Sm	M	R	R	R	R	P	P	P
Hydroid: Hydroid sp. 15 (yellow/brown fine tips)	U	leafy/fan	Sm	S	M	M	R	M	P	P	P
Hydroid: Hydroid sp. 17 (white/grey twiggy)	U	feathery	Md	S	M	M	R	M	P	M	P
Macroalgae: *Codium* sp.	U	bushy	Sm	S	M	M	M	R	P	P	M
Sponge: *Axinella* sp. 2A (Bright brick diverging fingers)	U	strappy	Md	M	R	R	R	M	P	P	P
Sponge: *Desmacidon mamillatum*	U	digitate	Md	S	M	M	M	M	P	P	P
Sponge: *Myxilla columna*	U	digitate	Md	S	R	R	R	M	M	M	M
Sponge: *Polymastia* cf. *lorum*	U	digitate	Sm	S	S	S	M	R	P	P	M
Sponge: UnID sp. 29 (*Psammopemma* sp.)	U	loaf	L	M	R	R	M	SL	P	P	M
Coarse											
Ascidian: Ascidian sp. 10 (long thin rabbit tails)	Mc	lollipop	Md	S	M	M	R	R	P	P	P
Ascidian: Ascidian sp. 13 (thick feather duster)	Mc	lollipop	Md	S	S	R	R	M	P	P	P
Bryozoan: '*Heteropora' neozelanica*	Mc	bushy	Sm	S	S	S	M	S	P	M	M
Bryozoan: *Celleporaria agglutinans*	U	spherical	Md	S	S	M	R	S	P	P	M
Bryozoan: *Viridentula dentata*	U	bushy	Sm	M	R	R	M	M	P	M	P
Hydroid: *Dictyocladium* cf. *monilifer*	U	leafy/fan	Sm	S	S	M	M	M	P	P	P
Sponge: *Cliona celata*	U	thin	L	R	R	R	M	R	P	P	P

Analysis of the community data sets in relation to the explanatory variables with Constrained Analysis of Principal Coordinates (CAP) 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 (across the three surveys) were considered.

A CAP on the epifaunal data set with backwards stepwise model selection using AIC, retained terms for habitat, year, depth, years fallow from scallop fishing and recent effort from both trawl and scallop fishing. The sensitivities of individual species to the effects of the three individual retained effort terms (using CAP with effort conditioned on other retained variables) were ranked in terms of their eignevectors and are presented in Table 14. In addition, the ranks against the three retained effort variables were averaged to identify the species most sensitive to overall fishing impact. While the individual species sensitivity ranks vary between fishing terms, the hydroid *Crateritheca novaezelandiae* appears particularly sensitive (top ranked against all three measures), and a number of other species (sponges *Aaptos* sp., *Callyspongia ramosa*, *Callyspongia* n. sp. 16; ascidians Ascidian sp. 10, Ascidian sp. 16, *Pseudodistoma novaezelandiae*; hydroid *Crateritheca* sp. 1, *Hydrodendron mirabile*) were recorded in the top ten sensitive species for more than one fishing measure (Table 14).

The same approach was applied to the infaunal community data, with retained terms for year, depth, recent scallop fishing effort, longer term trawl fishing effort, and years fallow from both trawl and scallop fishing. The sensitivity of individual species to the effects of the four individual retained effort terms (using CAP with effort conditioned on other retained variables) were ranked in terms of their eignevectors and are presented in Table 15, along with an overall ranked sensitivity, averaged across the measures. The infaunal community data set included more species than the epifaunal data, and the top ranked sensitive species appeared more variable. However, there were some consistent species identified, with bryozoans (Otionellidae and other Bryozoa), errant polychaetes (Onuphidae), sedentary polychaetes (Sabellidae, Spionidae, Cirratulidae, Maldanidae, Opheliidae and Orbiniidae) and amphipods (Maeridae, Phoxocephalidae and Urothoidae) recorded in the top ten sensitive species for more than one fishing measure (Table 15).

Table 14: 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 retained in the minimum adequate model having been partialled out within CAP), to identify those species most sensitive to the measures of fishing effort examined. Overall column represents species ranked on the average of the three retained effort variable ranks. Eigenvector ranking for "Years fallow" have been reversed, so that rank 1 in each column is the species most negatively related to fishing activity.

	Scallop effort	Trawl effort	Years fallow - scallop	Overall
1	*Crateritheca novaezelandiae*	*Crateritheca novaezelandiae*	*Crateritheca novaezelandiae*	*Crateritheca novaezelandiae*
2	*Hydrodendron mirabile*	*Gigartina atropurpurea*	Ascidian sp. 10	Aaptos sp.
3	*Callyspongia* n. sp. 16	*Aaptos* sp.	*Nemertesia elongata*	Ascidian sp. 16
4	*Callyspongia ramosa*	*Crateritheca* sp. 1	*Crateritheca* sp. 1	*Callyspongia ramosa*
5	*Hymeniacidon* sp. 1	Ascidian sp. 16	*Aaptos* sp.	*Pseudodistoma novaezelandiae*
6	*Polymastia croceus*	*Steginoporella neozelanica*	*Hydrodendron mirabile*	*Synoicum kuranui*
7	*Pseudodistoma novaezelandiae*	*Iophon.minor*	Ascidian sp. 16	*Stelletta conulosa*
8	Ascidian sp. 10	*Pseudodistoma novaezelandiae*	*Callyspongia ramosa*	*Callyspongia* n. sp. 16
9	*Ecionemia alata*	*Euptilota formosissima*	*Callyspongia* n. sp. 16	Ascidian sp. 10
10	*Stelletta conulosa*	*Margaretta barbata*	*Steginoporella perplexa*	*Raspailia topsenti*

Table 15: Infaunal species groups (labelled X##family) from grab samples ranked in order of their eigenvector values in relation to axes associated with individual fishing effort variables (all other variables retained in the minimum adequate model having been partialled out within CAP), to identify those species most sensitive to the measures of fishing effort examined. Overall column represents species ranked on the average of the three retained effort variable ranks. Eigenvector ranking for "Years fallow" have been reversed, so that rank 1 in each column is the species most negatively related to fishing activity.

	Scallop effort	Trawl effort	Years fallow - scallop	Years fallow - trawl	Overall
1	X36Spionidae	X43Cirratulidae	X54Orbiniidae	X151Otionellidae	X151Otionellidae
2	X52Opheliidae	X51Maldanidae	X81Phoxocephalidae	X36Spionidae	X55Paraonidae
3	X75Maeridae	X81Phoxocephalidae	X43Cirratulidae	X52Opheliidae	X11Onuphidae
4	X27Sabellidae	X156Hydrozoa	X172Mactridae	X11Onuphidae	X43Cirratulidae
5	X155Scleractinia	X89Urothoidae	X11Onuphidae	X74Lysianassidae	X156Hydrozoa
6	X40Spionidae	X11Onuphidae	X89Urothoidae	X27Sabellidae	X213Marginellidae
7	X151Otionellidae	X54Orbiniidae	X51Maldanidae	X231Retusidae	X184Philobryidae
8	X150Bryozoa	X151Otionellidae	X73Liljeborgiidae	X40Spionidae	X1Oligochaete
9	X19Nephtyidae	X75Maeridae	X8Lumbrineridae Oeninidae	X88Tulearidae like	X81Phoxocephalidae
10	X184Philobryidae	X150Bryozoa	X78Oedicerotidae	X3Dorvilleidae	X197Eatoniellida

3.6 Changes inside and outside the closed area

The final objective of the project was to assess the changes in benthic communities inside and outside the closed area since 1997. The first analysis of the 2006 survey data (Tuck et al. 2010) used the legislative areas (open, voluntarily closed to scallop fishing in 1997, closed to all mobile fishing in 1999) as the measure of fishing pressure, in the absence of finer resolution fishing effort data. Following this first study, the availability of finer spatial scale 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 (described in Section 2.2), made the use of these categorical levels of fishing pressure unnecessary within the analyses conducted after the 2010 survey (Tuck & Hewitt 2013), and these fine scale effort data have been updated for the current analysis. While we have assumed that no fishing has taken place within the closed areas since their introduction, the relative levels of both scallop and trawl effort within the area still open to fishing appear to have varied spatially (Figure 9 – Figure 13) by an order of magnitude, and so the use of these relative effort data, in conjunction with the years fallow term, was considered more powerful 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. When examined in preliminary analyses, the combined retained fishing effort and years fallow terms accounted for a greater proportion of the total variance than a categorical (closed since 1997, closed since 1999, open) fishing pressure term.

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 studies (Tuck et al. 2010; Tuck & Hewitt 2013) on the basis of the categories defined in Appendix 3, independently of the statistical analysis 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, speed of growth, ability to recover, and likelihood of being disturbed) to the effects of fishing, abundance is plotted against recent fishing effort in Figure 47. These may potentially be considered as monitoring species for future effects of fishing and benthic community recovery investigations for this community. The sensitive species were either only observed at sites with no or low fishing in the previous three years or were observed at lower abundances at more heavily fished sites (*Hydrendron mirabile* and *Nemertesia elongata*). Data within the plots represent all habitats, with the sand habitat (which includes both open and closed areas) showing a similar pattern.

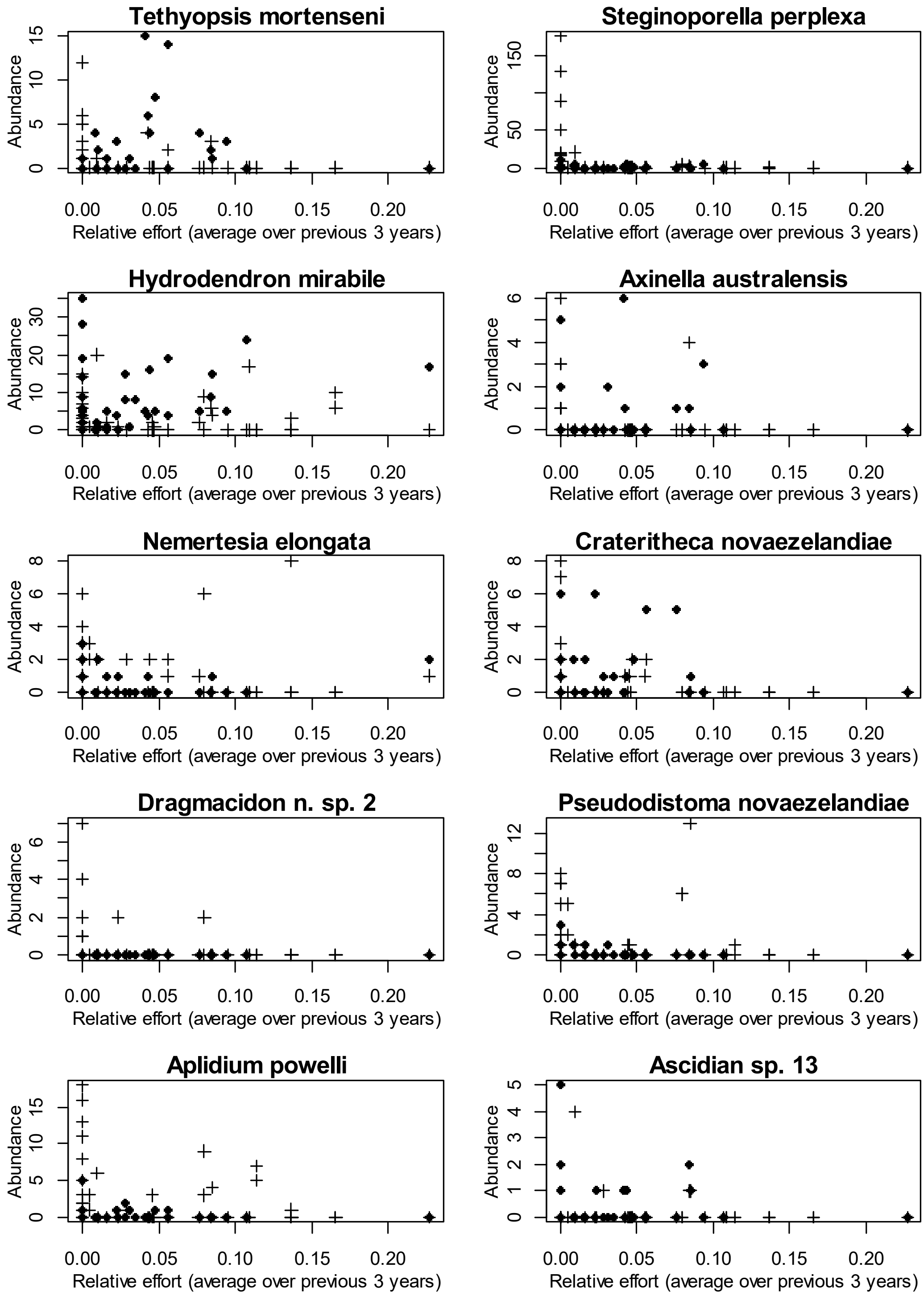

Figure 47: Abundance of epifaunal species identified as likely to be most vulnerable to fishing in relation to estimated trawl effort (average over 3 years prior to sampling). Solid symbols represent stations within sand habitat, while crosses represent all other habitats.

4. DISCUSSION

The impacts of trawling and scallop dredging have been subject to a number of reviews (Collie et al. 2000; DFO 2006; Kaiser et al. 2006; Rice 2006), and an overview of studies conducted in New Zealand is provided by Tuck et al. (2017). 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 very dynamic habitat, exposed to considerable wave disturbance, and strong tides. The area has been an important part of the Northland scallop fishery in previous years, and is also the focus of trawl fishing, generally targeting snapper, trevally and tarakihi. 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. There has been no scallop dredging in the Spirits Bay area in recent years, but the trawl fishery remains active, with relatively more effort in the shallower part of the study area, although overall levels of effort are low compared to other inshore regions (Baird et al. 2015). Previous studies in the area (Cryer et al. 2000; Tuck et al. 2010; Tuck & Hewitt 2013) 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 and previous surveys in the region, a number of previously undescribed sponge species have been recorded, and within the current analysis of the infauna, it has been estimated that a number of previously undescribed species (ten amphipod, and five isopod) have been recorded (Rachael Peart, NIWA, *pers. com.*).

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, 2010 and 2017, 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. The results presented from the most recent analysis are consistent with those provided after the 2010 survey (Tuck & Hewitt 2013). Distance based linear modelling (DISTLM; McArdle & Anderson 2001) of the community composition data in relation to environmental and fishing variables consistently identified strong year, depth and habitat effects, but also consistently detected effects related to fishing terms (except for analysis of some univariate diversity measures), with typically 15–30% of the total variance explained by fishing (median 20%), where just under half of the explainable variation was attributed to fishing. This proportion of the explained variance attributable to fishing is comparable to previous analyses of the earlier surveys in the region (Tuck & Hewitt 2013), and other investigations into the effects of fishing on benthic communities in New Zealand (Thrush et al. 1998; Cryer et al. 2002; Tuck et al. 2017).

Longer term fishing effort patterns were retained within the minimum adequate models for most of the 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 also that 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 habitat effect of fishing through an association between infauna and epifauna. Image resolution has increased over time (potentially increasing the likelihood to detecting/recording small individuals), and this may have influenced the results from the epifaunal data, but the consistent detection of fishing effects in analyses of the individual survey data sets confirms a detectable fishing impact.

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 and year subsets, implies major community differences across gradients of fishing pressure.

DISTLM analysis of univariate measures of the community also detected fishing effects, but in general the variance explained by the minimum adequate models, and that explained by fishing terms was lower than for the multivariate community data (particularly for univariate measures of the infaunal community), as was the proportion of explained variance accounted for by fishing terms. With both the multivariate and univariate measures, the minimum adequate models for the epifaunal community data generally explained more of the variance than those for infaunal community data. This was also observed previously (Tuck & Hewitt 2013), and 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 (often increases) 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), subsequent NIWA Capability Fund projects and BEN2009-02 (Tuck & Hewitt 2013), based on colour and morphological features identifiable from images. The keys have been ground-truthed where possible with physical samples, and the identification of taxa from images 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, J. J. et al. 2006; Bell, J.J. 2007), but will not be as accurate to the species level as physical sampling. To address this concern we have identified a group of distinctive species for which we are particularly confident of the identifications ("trustworthy" species), and conducted the analysis for this subset of species, as well as the full community dataset. Improved image resolution may have introduced a survey effect over time, but the "trustworthy" species are considered distinctive and easily identifiable, and so any effect should be less on these than on other less easily identified organisms. There has been no scallop fishing and relatively little trawl 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, potentially introducing high levels of variability between years.

With no consistent sampling prior to fishing disturbance (to determine the undisturbed community), or immediately after the introduction of the closed areas (to determine where the community is recovering from), estimating a recovery trajectory, and where the community currently is on this, is difficult. Examining the individual survey analyses, the proportion of total variance explained by fishing terms has reduced over time, implying the effects of fishing are becoming less detectable, and the community is recovering from any fishing impacts. Failure to detect any effect of fishing would imply the community had fully recovered. The communities within potentially the most impacted habitats are also becoming more similar over time, implying a reduced gradient of impact within these habitats. The rate of increase in similarity has reduced over time, but with only 3 surveys to compare, and uncertainty over the "natural" levels of similarity one would expect within undisturbed communities, it would be premature to predict a time when an asymptote of within habitat similarity might be reached.

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 (Hiscock & Tyler-Walters 2006). While this is necessarily somewhat subjective, we are confident that the categorisations are on the basis of the best available information. CAP 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 were consistent with those previously identified (Tuck & Hewitt 2013) which had been categorised as either sensitive to dredging disturbance, or moderately sensitive to dredging but growing slowly to a medium or large size, prior to the analysis of the community composition. Most of these species were also considered to have a poor probability of recovery following disturbance, and most were generally only found in areas with no recent fishing history. A similar analysis of the infaunal data was conducted using CAP to identify species responses to the fishing terms, but no *a priori* classification of species by sensitivity or recoverability had been conducted.

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7. APPENDIX 1

Power analysis to explore survey designs

7.1 Introduction

Because the 2006 and 2010 surveys were conducted in different ways, in 2017 NIWA was contracted to conduct a power analysis to determine a study design and number of samples needed to be able to detect changes in key indicators of the state of the benthic communities in Spirits Bay and Tom Bowling Bay since the last survey. Specifically, the Specific Objective One was:
Using previous survey results, conduct a power analysis to estimate the likelihood of a range of survey designs consistent with the monitoring programme from project ENV2005/23 detecting changes in key indicators of the state of the benthic communities in Spirits Bay and Tom Bowling Bay since the last survey.

Power analysis has a long history of use in design of studies that expect to determine change. The power to detect change depends on the magnitude of the change required to be detected, the variability of the response variable, the number of factors that might drive the change and the statistical test used to detect the change (see Cohen 1988 for power analysis equations associated with different statistical tests). For example, regression (continuous) or ANOVA (categorical) analyses relative to the functional form of the response (the way in which the response variable relates to the explanatory variable(s)), and randomization tests are less affected by the number of independent samples than some other tests (e.g., F tests). Also for tests that assume a specific form of probability distribution, the degree to which the data matches this form is important.

Simplification of power analysis can be achieved using simulations, either using simulations constrained to a specific probability distribution (e.g., LeBlanc et al. 2015) or by splitting an existing dataset and applying a change in abundance of a particular species, or univariate diversity measure to random subsets (e.g., Hewitt et al. 2001). The latter has the advantage of not requiring the data to match a specific probability distribution, instead utilizing its natural variation in whatever form it might be. Randomization tests resampling from the original data have a long history in statistics (Edgington 1987) and underlie most of the significance tests undertaken for multivariate data (e.g., PermANOVA, CCA, RDA, DIstLM).

For these reasons simulations were used in the power analysis of the Spirits Bay data. Following consultation with MPI the following reductions and increases of abundance were imposed on the data: reductions of 10%, 25%, 50%, 90% and 95%; and increases of 110%, 125% 150%, 200% and 500%. For the image data, these simulated changes were applied to three species groups designated as sensitive by Tuck & Hewitt (2013) (*Homaxine*, *Tethyopsis*, *Hyrodendron*). For the grab data we used the NIWA Biological traits database to select taxa designated as sensitive (large and protruding from the sediment surface and sedentary or living less than 2 cm deep, slow moving and soft bodied (Otionellidae, Scleractinia, Marginellinae, Solariellidae and *Spiophanes* spp)). Other variables that had simulated changes applied to them were total abundance, number of taxa and the Shannon Weiner diversity index.

Simulated increases and decreases were applied to randomly selected subsets of the data, either randomly across the full dataset or randomly within strata. The sampling was stratified to understand whether habitat type (as defined from the acoustic data; Figure 2), depth or bottom fishing effort (3 yearly average) affected the variability and the likelihood of detection of change (Table 16) and thus whether these needed to be taken into account in both the power analysis and the new survey design. Data from 2010 only was used because greater numbers of species and higher abundances were observed in 2010 compared to 2006. There were also only 24 sites sampled in 2006 and the sites were not well stratified, thus the predicting power of different designs for up to 40 sites and with depth and habitat data would be problematic.

From the simulations, standard errors were generated to use as estimates of precision in each of the strata for a range of sample sizes from 3 to 15. Note that the maximum sample size that can be used is approximately half the number of samples available in each strata. Pairwise comparisons of the simulated vs unmodified datasets were used to calculated the probability of detection using the same data points (Figure 48), and across the whole dataset or within strata (Figure 49). For the image and grab data, 100 random sets of samples were created based on sample sizes between 3 and 30. The impacts of reductions of 10% (P90 in the results text), 25% (P75 in the results text), 50% (P50 in the results text), 90% (P10 in the results text), and 95% (P05 in the results text) were used. The reductions were applied to species designated as sensitive only, and removed them completely if their abundances fell below the minimum abundance previously detected (that is remove all zeros and what was the lowest abundance for each species). Increases of 10% (P110 in the results text) to 500% (P500 in the results text) were applied as well, but there was no objective way to make these increase the number of taxa; thus we did not apply increases to the number of taxa or the Shannon-Weiner index.

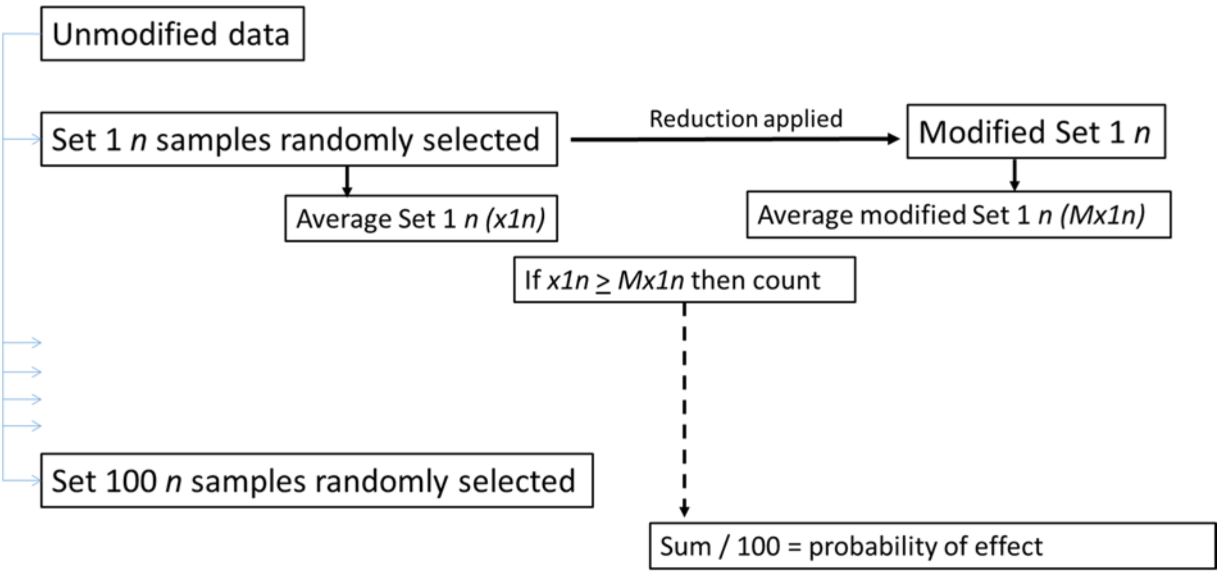

Figure 48: Process used to calculate probability of detecting an effect – using same data point.

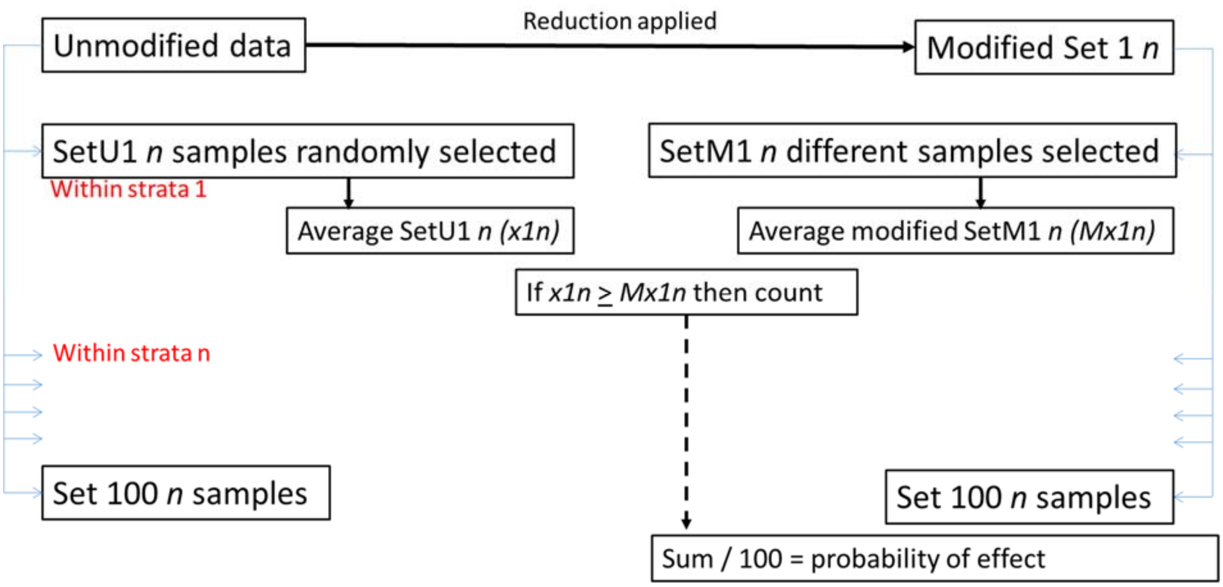

Figure 49: Process used to calculate probability of detecting an effect- across whole dataset or within a stratum.

Table 16: Stratification of 2010 image and grab datasets. Number of samples per subset.

		Image data	Grab data	Regulated area
Habitat type	Coarse	10	7	
	Sandwaves	10	12	
	Sand	20	20	
Depth	30–39m	12	10	All open
	40–49m	18	17	Mixed
	50–59m	11	12	All closed
Fishing regulation	Open	19	17	
	Closed	22	22	

7.2 Results

Precision

Increasing sample size improved precision (as evidenced by convergence of the mean standard error and 90th percentile of the standard error). No consistent differences in precision between habitat types or depths for either selected species groups or biodiversity indicators for image or grab data were observed (see Table 17 to Table 22). Similarly, no consistent differences in precision between fishing regulation for selected species groups were observed, however biodiversity indicators had higher variability for image data.

This lack of consistent differences in variability between strata meant that there was no need to consider placing different numbers of samples within different habitats, depth classes or fishing effort.

Table 17: Image samples stratified by habitat type; effect of sample size on standard errors (mean and 90th percentile) of key indicators of the state of the benthic communities (diversity measures and abundance of key species groups). 2010 data. Orange = highest value, green = lowest value. Note that the maximum sample size is constrained by the number of 2010 samples in each habitat, ns=number of samples.

subset	ns	type	Abundance	Number of taxa	Shannon Weiner	Homaxine	Tethyopsis	Hyrodendron
coarse	3	mean	50.54	8.97	0.45	3.70	0.22	6.55
sand	3		25.87	4.12	0.33	2.50	0.86	7.68
sandwave	3		56.07	3.27	0.39	1.93	0.77	3.56
coarse	4		53.25	9.10	0.40	3.30	0.17	5.25
sand	4		24.60	3.70	0.31	2.17	0.69	7.55
sandwave	4		46.07	3.37	0.35	2.45	0.65	3.23
coarse	5		51.40	9.05	0.38	2.69	0.20	4.29
sand	5		21.91	3.21	0.29	1.98	0.70	6.61
sandwave	5		39.49	2.98	0.31	2.09	0.62	4.68
sand	6		20.40	3.11	0.27	1.79	0.60	5.68
sandwave	6		38.65	2.71	0.29	1.98	0.58	4.21
sand	8		19.62	2.80	0.24	1.83	0.61	4.89
sandwave	8		33.53	2.40	0.25	1.92	0.55	3.87
coarse	3	90th	78.02	14.19	0.72	8.16	0.67	11.59
sand	3		64.93	7.95	0.56	4.33	2.40	23.45
sandwave	3		113.53	6.63	0.79	3.38	2.67	5.04
coarse	4		69.50	12.14	0.58	6.27	0.50	8.75
sand	4		54.47	7.63	0.46	3.49	1.74	21.66
sandwave	4		85.80	5.38	0.59	6.14	2.00	4.75
coarse	5		57.25	10.29	0.47	4.98	0.60	6.88
sand	5		44.60	6.07	0.42	2.78	1.59	18.42
sandwave	5		69.00	4.53	0.52	5.00	1.60	10.80
sand	6		37.55	5.33	0.37	2.49	1.32	16.16
sandwave	6		69.33	4.10	0.43	4.21	1.33	8.89
sand	8		29.28	4.05	0.29	3.14	1.72	12.20
sandwave	8		55.40	3.36	0.34	3.23	1.68	6.84

Table 18: Image data stratified by depth; effect of sample size on standard errors (mean and 90th percentile) of key indicators of the state of the benthic communities. 2010 data (diversity measures and abundance of key species groups). Orange = highest value, green = lowest value. Note that the maximum sample size is constrained by the number of 2010 samples in each depth, ns=number of samples.

subset	ns	type	Abundance	Number of taxa	Shannon Weiner	Homaxine	Tethyopsis	Hyrodendron
shallow	3	mean	79.89	6.97	0.48	1.95	0.92	4.38
mid	3		40.18	8.43	0.52	2.65	0.45	1.88
deep	3		28.84	2.03	0.28	1.29	1.48	10.49
shallow	4		71.92	6.46	0.43	1.78	0.80	3.69
mid	4		37.84	7.49	0.46	2.60	0.48	1.69
deep	4		24.62	1.92	0.26	1.31	1.59	10.94
shallow	5		65.81	5.75	0.38	1.66	0.74	3.38
mid	5		34.53	6.84	0.41	2.34	0.47	1.58
deep	5		22.87	1.76	0.24	1.21	1.51	10.34
shallow	6		65.49	5.54	0.35	1.57	0.71	3.14
mid	6		32.84	6.33	0.37	2.20	0.43	1.47
deep	6		21.88	1.67	0.22	1.08	1.39	9.79
shallow	8		59.05	4.95	0.30	1.43	0.64	2.68
mid	8		29.19	5.58	0.33	2.01	0.37	1.33
deep	8		19.46	1.45	0.19	0.97	1.29	8.80
shallow	3	90th	207.55	16.41	0.77	3.33	2.67	7.31
mid	3		78.09	14.31	0.80	4.73	1.00	4.51
deep	3		54.98	3.51	0.47	3.00	4.67	31.26
shallow	4		159.34	13.03	0.61	2.63	2.00	5.68
mid	4		65.39	11.55	0.63	6.03	0.75	3.62
deep	4		45.65	2.74	0.38	2.25	3.50	24.13
shallow	5		128.78	10.72	0.50	2.32	1.60	4.92
mid	5		54.68	10.22	0.56	4.88	0.64	2.96
deep	5		38.68	2.40	0.32	1.83	2.80	19.55
shallow	6		111.61	8.99	0.45	2.11	1.39	4.39
mid	6		47.72	8.83	0.49	4.23	0.61	2.59
deep	6		33.42	2.16	0.28	1.65	2.90	16.59
shallow	8		97.74	7.90	0.38	1.77	1.29	3.56
mid	8		39.17	7.26	0.40	3.29	0.49	2.25
deep	8		27.22	1.75	0.23	1.44	2.29	15.26

Table 19: Image data stratified by legislative type; effect of sample size on standard errors (mean and 90th percentile) of key indicators of the state of the benthic communities. 2010 data (diversity measures and abundance of key species groups). Orange = highest value, green = lowest value. Note that the maximum sample size is constrained by the number of 2010 samples in each legislative type, ns=number of samples.

subset	ns	type	Abundance	Number of taxa	Shannon Weiner	Homaxine	Tethyopsis	Hyrodendron
open	3	mean	82.97	7.20	0.45	0.00	0.00	9.99
closed	3		29.69	6.29	0.37	2.99	1.22	1.86
open	4		73.08	6.23	0.41	0.00	0.00	8.47
closed	4		28.92	5.63	0.32	2.72	1.16	1.82
open	5		68.98	6.11	0.37	0.00	0.00	8.31
closed	5		27.44	5.21	0.30	2.48	1.15	1.67
open	6		62.47	5.68	0.34	0.00	0.00	7.48
closed	6		26.07	4.96	0.27	2.30	1.11	1.57
open	8		53.02	4.77	0.29	0.00	0.00	6.95
closed	8		23.46	4.49	0.24	1.98	0.95	1.42
open	10		49.62	4.50	0.26	0.00	0.00	6.83
closed	10		21.66	4.16	0.22	1.77	0.94	1.28
open	12		46.06	4.23	0.24	0.00	0.00	6.46
closed	12		20.18	3.84	0.20	1.62	0.88	1.18
open	15		41.59	3.86	0.21	0.00	0.00	5.92
closed	15		18.57	3.51	0.18	1.47	0.79	1.08
open	3	90th	201.17	17.67	0.85	0.00	0.00	31.01
closed	3		61.36	13.45	0.63	7.54	4.02	4.12
open	4		150.65	13.35	0.68	0.00	0.00	23.99
closed	4		55.23	10.15	0.48	5.50	3.28	3.36
open	5		127.69	10.76	0.55	0.00	0.00	19.60
closed	5		46.26	8.53	0.40	4.68	2.71	2.71
open	6		107.46	10.15	0.48	0.00	0.00	16.54
closed	6		39.41	7.37	0.36	3.91	2.29	2.38
open	8		82.69	8.05	0.39	0.00	0.00	13.62
closed	8		33.37	6.28	0.30	3.10	1.72	1.99
open	10		71.74	6.93	0.35	0.00	0.00	12.21
closed	10		28.48	5.62	0.27	2.57	1.46	1.76
open	12		69.42	6.30	0.32	0.00	0.00	11.12
closed	12		25.60	5.01	0.24	2.25	1.31	1.57
open	15		57.94	5.48	0.27	0.00	0.00	9.38
closed	15		23.36	4.37	0.21	1.90	1.23	1.33

Table 20: Grab samples stratified by habitat type; effect of sample size on standard errors (mean and 90th percentile) of key indicators of the state of the benthic communities. 2010 data (diversity measures and abundance of key species groups). Orange = highest value, green = lowest value. Note that the maximum sample size is constrained by the number of 2010 samples in each habitat type, ns=number of samples.

type	ns	type	Abundance	Number of taxa	Shannon Weiner	Otionellidae	Scleractinia	Marginellinae	Solariellidae	Spiophanes spp
coarse	3	mean	87.27	8.03	0.15	2.54	0.11	1.05	0.09	0.00
sand	3		23.91	4.83	0.19	1.52	0.29	0.60	0.19	0.81
sandwave	3		41.17	5.05	0.13	0.80	0.13	0.39	0.08	0.07
coarse	4		91.87	7.43	0.13	2.78	0.11	1.15	0.09	0.00
sand	4		22.33	4.07	0.17	1.34	0.29	0.47	0.17	0.77
sandwave	4		34.80	4.72	0.14	0.75	0.11	0.37	0.07	0.06
coarse	5		96.83	6.93	0.12	3.19	0.11	1.28	0.09	0.00
sand	5		21.14	3.72	0.15	1.26	0.25	0.43	0.15	0.66
sandwave	5		31.60	4.11	0.13	0.70	0.12	0.34	0.06	0.07
coarse	3	90th	211.42	11.68	0.25	9.50	0.17	3.67	0.17	0.00
sand	3		44.24	7.45	0.33	3.18	0.83	3.17	0.33	2.67
sandwave	3		88.43	8.95	0.26	1.50	0.50	0.67	0.17	0.33
coarse	4		168.16	9.98	0.18	7.13	0.14	2.71	0.14	0.00
sand	4		36.07	5.55	0.25	2.31	0.60	2.29	0.25	2.00
sandwave	4		68.95	7.60	0.24	1.13	0.38	0.58	0.13	0.25
coarse	5		158.97	8.19	0.15	6.66	0.12	2.51	0.12	0.00
sand	5		32.70	5.63	0.24	2.06	0.48	1.85	0.24	1.60
sandwave	5		55.36	6.06	0.21	0.90	0.30	0.49	0.12	0.20

Table 21: Grab data stratified by depth; effect of sample size on standard errors (mean and 90th percentile) of key indicators of the state of the benthic communities. 2010 data (diversity measures and abundance of key species groups). Orange = highest value, green = lowest value. Note that the maximum sample size is constrained by the number of 2010 samples in each depth type, ns=number of samples.

type	ns	type	Abundance	Number of taxa	Shannon Weiner	Otionellidae	Scleractinia	Marginellinae	Solariellidae	Spiophanes spp
deep	6	mean	21.07	4.29	0.17	1.09	0.25	0.77	0.14	0.35
mid	6		56.37	5.15	0.09	2.09	0.07	0.83	0.10	0.39
shallow	6		52.59	5.75	0.16	0.02	0.04	0.00	0.00	0.00
deep	8		17.67	3.56	0.15	0.93	0.23	0.65	0.13	0.31
mid	8		51.96	4.44	0.08	1.96	0.07	0.77	0.09	0.36
shallow	8		47.64	5.09	0.13	0.03	0.04	0.00	0.00	0.00
deep	10		16.14	3.22	0.13	0.84	0.21	0.59	0.12	0.28
mid	10		45.44	4.04	0.07	1.69	0.06	0.67	0.08	0.37
shallow	10		47.08	4.86	0.12	0.03	0.03	0.00	0.00	0.00
deep	6	90th	29.55	5.59	0.21	1.68	0.40	1.55	0.18	0.52
mid	6		118.60	7.68	0.13	4.54	0.11	1.78	0.11	1.33
shallow	6		81.98	7.94	0.20	0.08	0.08	0.00	0.00	0.00
deep	8		23.16	4.25	0.18	1.38	0.31	1.16	0.16	0.44
mid	8		115.88	6.20	0.10	4.22	0.09	1.66	0.09	0.99
shallow	8		70.85	6.76	0.17	0.06	0.06	0.00	0.00	0.00
deep	10		20.48	4.08	0.16	1.18	0.31	1.22	0.15	0.40
mid	10		92.74	5.35	0.09	3.59	0.08	1.41	0.08	0.80
shallow	10		62.59	6.08	0.14	0.07	0.07	0.00	0.00	0.00

Table 22: Grab data stratified by legislative type; effect of sample size on standard errors (mean and 90th percentile) of key indicators of the state of the benthic communities. 2010 data (diversity measures and abundance of key species groups). Orange = highest value, green = lowest value. Note that the maximum sample size is constrained by the number of 2010 samples in each legislative type, ns=number of samples.

type	ns	type	Abundance	Number of taxa	Shannon Weiner	Otionellidae	Scleractinia	Marginellinae	Solariellidae	Spiophanes spp
closed	6	mean	45.61	4.29	0.12	1.89	0.21	0.92	0.12	0.48
open	6		43.05	5.94	0.16	0.38	0.05	0.11	0.05	0.00
closed	8		40.56	3.84	0.11	1.66	0.18	0.86	0.11	0.45
open	8		39.09	5.15	0.14	0.32	0.05	0.10	0.04	0.00
closed	10		40.84	3.60	0.10	1.62	0.18	0.81	0.10	0.43
open	10		35.87	4.73	0.13	0.30	0.04	0.09	0.04	0.00
closed	6	90th	122.91	7.45	0.17	4.36	0.42	1.79	0.17	1.28
open	6		77.85	7.25	0.22	0.64	0.09	0.22	0.11	0.00
closed	8		92.07	5.87	0.15	3.32	0.33	1.57	0.15	0.98
open	8		59.26	6.67	0.19	0.49	0.08	0.17	0.08	0.00
closed	10		74.26	5.36	0.13	2.76	0.28	1.39	0.13	0.82
open	10		52.09	5.77	0.17	0.45	0.07	0.18	0.08	0.00

Pairwise comparisons

Pairwise comparisons of 100 random sets of samples drawn from the 2010 dataset (stratified based on habitat type, fishing legislation and depth) also demonstrated that the likelihood of detecting impacts increased with sample size, regardless of how the data were stratified (Table 23 to Table 25). For this reason, the rest of the analyses were conducted on unstratified data, but randomly adding a degree of temporal variability (10%).

At low levels of impact (P90) the likelihood of detection from the image data was generally low (less than 0.8). At higher levels of impact (≤P75) the likelihood of detection improved. However, this was dependent on the indicator used and the variability of the dataset (see Figure 50, Table 26). Sensitive species generally had slightly higher likelihood of detection than other biodiversity indicators, although no one measure was consistently better than others.

7.3 Recommendations

Due to lack of any consistent differences between strata in precision and sample size relationships, and because the ability to detect changes was not increased by the use of strata, the most effective sampling strategy is to attempt to resample the 2010 sites. Point by point comparisons suggested that this may result in the ability to detect a 50% change in most indicators with 30 samples, with 25% reductions in number of taxa and 25% increases in overall abundance likely to be able to be detected with fewer samples. For some indicators it seems likely that even collecting 40 samples will not be sufficient to allow a 25% change to be detected between 2010 and 2017 data. However, it is likely that the ability to detect a change in community composition would be able to be detected (although this was beyond our ability to test using simulations).

Table 23: Image data (stratified by habitat type); effect of sample size and magnitude of change on probability of detecting effect on key indicators of the state of the benthic communities. 2010 data. Likelihood of detection colour coded; green = 0.95 - 1, orange = 0.9 – 0.94, yellow = 0.8 – 0.89. Note that p90 is the largest reduction and p500 is the largest recovery imposed.

Abundance

# samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.50	0.53	0.62	0.77	0.81	0.56	0.58	0.63	0.72	0.90
5	0.52	0.62	0.71	0.81	0.81	0.61	0.65	0.69	0.74	0.94
6	0.55	0.64	0.72	0.81	0.81	0.55	0.60	0.70	0.80	0.95
8	0.58	0.63	0.72	0.85	0.87	0.58	0.61	0.72	0.79	0.99
10	0.54	0.59	0.71	0.88	0.88	0.55	0.60	0.69	0.83	1.00
12	0.56	0.64	0.75	0.89	0.89	0.57	0.62	0.69	0.84	1.00
15	0.56	0.63	0.73	0.92	0.92	0.52	0.61	0.71	0.87	1.00
20	0.56	0.66	0.80	0.89	0.90	0.56	0.67	0.72	0.84	1.00
25	0.61	0.69	0.79	0.94	0.94	0.64	0.68	0.76	0.91	1.00
30	0.60	0.70	0.83	0.96	0.97	0.54	0.67	0.81	0.93	1.00

Number of taxa

	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.61	0.61	0.61	0.73	0.80					
5	0.59	0.59	0.60	0.73	0.78					
6	0.62	0.62	0.63	0.74	0.78					
8	0.63	0.63	0.64	0.83	0.88					
10	0.64	0.64	0.64	0.84	0.93					
12	0.69	0.69	0.69	0.91	0.92					
15	0.71	0.71	0.71	0.93	0.97					
20	0.74	0.74	0.75	0.97	0.98					
25	0.74	0.74	0.75	0.98	1.00					
30	0.76	0.76	0.78	0.98	1.00					

Shannon Weiner

	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.55	0.56	0.58	0.78	0.80					
5	0.59	0.59	0.59	0.79	0.84					
6	0.61	0.62	0.65	0.80	0.83					
8	0.54	0.55	0.55	0.87	0.90					
10	0.61	0.61	0.62	0.90	0.95					
12	0.59	0.59	0.60	0.94	0.96					
15	0.59	0.58	0.60	0.96	0.97					
20	0.64	0.65	0.65	0.99	0.99					
25	0.63	0.65	0.68	0.98	0.99					
30	0.65	0.65	0.71	0.99	0.99					

Homaxine

	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.71	0.76	0.85	0.99	0.99	0.69	0.71	0.81	0.86	0.95
5	0.68	0.75	0.84	0.99	1.00	0.62	0.71	0.81	0.88	0.96
6	0.60	0.71	0.82	0.99	1.00	0.60	0.64	0.71	0.84	0.97
8	0.59	0.67	0.83	0.98	0.99	0.62	0.67	0.73	0.84	0.97
10	0.57	0.68	0.85	1.00	1.00	0.57	0.64	0.76	0.86	0.98
12	0.59	0.69	0.85	1.00	1.00	0.59	0.69	0.81	0.87	0.98
15	0.61	0.73	0.87	1.00	1.00	0.59	0.68	0.78	0.89	0.97
20	0.62	0.73	0.89	1.00	1.00	0.61	0.72	0.80	0.90	0.98
25	0.62	0.72	0.90	1.00	1.00	0.61	0.67	0.77	0.90	1.00
30	0.63	0.78	0.91	1.00	1.00	0.61	0.71	0.86	0.92	1.00

Tethyopsis

	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.65	0.65	0.70	1.00	1.00	0.72	0.74	0.78	0.78	0.91
5	0.55	0.60	0.69	1.00	1.00	0.71	0.71	0.73	0.74	0.89
6	0.51	0.57	0.68	1.00	1.00	0.73	0.73	0.76	0.78	0.86
8	0.55	0.59	0.76	0.99	1.00	0.58	0.62	0.65	0.69	0.92
10	0.56	0.61	0.78	0.99	1.00	0.60	0.64	0.69	0.74	0.90
12	0.60	0.67	0.84	1.00	1.00	0.59	0.63	0.73	0.78	0.99
15	0.58	0.70	0.85	1.00	1.00	0.55	0.61	0.77	0.82	0.99
20	0.62	0.69	0.88	1.00	1.00	0.53	0.65	0.72	0.85	0.99
25	0.64	0.71	0.88	1.00	1.00	0.56	0.60	0.76	0.87	1.00
30	0.63	0.76	0.91	1.00	1.00	0.55	0.64	0.80	0.89	1.00

Hyrodendron

	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.58	0.61	0.76	0.96	1.00	0.55	0.59	0.67	0.73	0.84
5	0.58	0.62	0.70	0.98	1.00	0.58	0.60	0.63	0.71	0.88
6	0.58	0.62	0.72	0.98	1.00	0.57	0.63	0.66	0.74	0.90
8	0.54	0.63	0.73	0.98	1.00	0.53	0.59	0.64	0.71	0.93
10	0.53	0.58	0.77	0.98	1.00	0.54	0.61	0.66	0.76	0.91
12	0.56	0.66	0.84	0.99	1.00	0.57	0.65	0.69	0.82	0.92
15	0.51	0.65	0.86	0.99	1.00	0.59	0.63	0.72	0.81	0.94
20	0.59	0.67	0.88	1.00	1.00	0.57	0.65	0.74	0.87	0.99
25	0.56	0.68	0.91	1.00	1.00	0.56	0.66	0.79	0.90	1.00
30	0.59	0.71	0.94	1.00	1.00	0.58	0.67	0.81	0.96	0.99

Table 24: Image data (stratified by habitat type without coarse); effect of sample size and magnitude of change on probability of detecting effect on key indicators of the state of the benthic communities. 2010 data. Likelihood of detection colour coded; green = 0.95 – 1, orange = 0.9 – 0.94, yellow = 0.8 – 0.89. Note that p90 is the largest reduction and p500 is the largest recovery imposed.

No. individuals

#samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.48	0.50	0.60	0.75	0.79	0.53	0.55	0.59	0.69	0.88
5	0.48	0.58	0.68	0.78	0.78	0.60	0.61	0.66	0.70	0.89
6	0.51	0.60	0.68	0.78	0.78	0.55	0.58	0.66	0.75	0.90
8	0.56	0.61	0.71	0.84	0.85	0.54	0.56	0.69	0.76	0.94
10	0.51	0.56	0.68	0.86	0.86	0.51	0.55	0.65	0.80	0.94
12	0.54	0.61	0.71	0.85	0.85	0.54	0.59	0.65	0.81	0.94
15	0.51	0.59	0.71	0.89	0.89	0.50	0.60	0.68	0.83	0.94
20	0.53	0.63	0.76	0.85	0.86	0.53	0.66	0.70	0.80	0.94
25	0.56	0.66	0.76	0.90	0.90	0.60	0.65	0.74	0.86	0.94
30	0.58	0.68	0.80	0.91	0.93	0.49	0.65	0.81	0.89	0.94

Number of taxa

#samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.61	0.61	0.61	0.70	0.75					
5	0.58	0.58	0.59	0.68	0.74					
6	0.59	0.59	0.60	0.69	0.73					
8	0.59	0.59	0.60	0.78	0.83					
10	0.61	0.61	0.61	0.80	0.90					
12	0.64	0.64	0.64	0.86	0.88					
15	0.68	0.68	0.68	0.89	0.91					
20	0.73	0.73	0.74	0.91	0.93					
25	0.69	0.69	0.70	0.91	0.94					
30	0.71	0.71	0.74	0.93	0.94					

Shannon Weiner

#samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.54	0.54	0.56	0.75	0.78					
5	0.56	0.56	0.56	0.76	0.80					
6	0.58	0.59	0.63	0.74	0.78					
8	0.50	0.51	0.51	0.81	0.84					
10	0.58	0.58	0.59	0.88	0.93					
12	0.55	0.55	0.55	0.90	0.93					
15	0.56	0.55	0.56	0.93	0.94					
20	0.59	0.60	0.60	0.94	0.94					
25	0.59	0.60	0.63	0.93	0.93					
30	0.63	0.63	0.68	0.94	0.94					

Homaxine

#samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.63	0.68	0.77	0.90	0.90	0.58	0.61	0.72	0.77	0.86
5	0.59	0.67	0.77	0.90	0.91	0.52	0.62	0.74	0.82	0.87
6	0.51	0.64	0.78	0.91	0.92	0.53	0.58	0.66	0.80	0.88
8	0.52	0.63	0.79	0.91	0.92	0.55	0.61	0.68	0.80	0.89
10	0.51	0.64	0.84	0.93	0.93	0.54	0.63	0.77	0.87	0.92
12	0.54	0.66	0.83	0.93	0.93	0.56	0.68	0.81	0.86	0.92
15	0.56	0.70	0.85	0.94	0.94	0.55	0.66	0.79	0.86	0.91
20	0.58	0.70	0.84	0.94	0.94	0.56	0.69	0.76	0.86	0.91
25	0.60	0.71	0.88	0.94	0.94	0.59	0.66	0.75	0.88	0.94
30	0.60	0.78	0.88	0.94	0.94	0.59	0.70	0.81	0.89	0.94

Tethyopsis

#samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.55	0.55	0.60	0.85	0.85	0.62	0.63	0.66	0.66	0.78
5	0.49	0.53	0.62	0.89	0.89	0.63	0.63	0.65	0.66	0.79
6	0.45	0.51	0.61	0.89	0.89	0.65	0.65	0.68	0.70	0.77
8	0.51	0.55	0.70	0.91	0.92	0.53	0.57	0.60	0.64	0.85
10	0.52	0.57	0.72	0.91	0.93	0.55	0.59	0.64	0.68	0.84
12	0.56	0.63	0.78	0.93	0.93	0.55	0.59	0.68	0.73	0.92
15	0.54	0.66	0.80	0.93	0.93	0.52	0.57	0.72	0.77	0.92
20	0.58	0.64	0.82	0.93	0.93	0.49	0.61	0.67	0.80	0.92
25	0.60	0.66	0.83	0.94	0.94	0.53	0.56	0.71	0.81	0.94
30	0.59	0.71	0.85	0.94	0.94	0.51	0.60	0.75	0.84	0.94

Hyrodendron

#samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.56	0.59	0.75	0.91	0.93	0.51	0.56	0.63	0.70	0.82
5	0.54	0.58	0.68	0.92	0.93	0.54	0.56	0.59	0.68	0.83
6	0.57	0.61	0.71	0.91	0.93	0.53	0.58	0.62	0.69	0.86
8	0.51	0.61	0.68	0.92	0.93	0.51	0.57	0.63	0.67	0.86
10	0.49	0.54	0.74	0.93	0.94	0.53	0.58	0.60	0.71	0.85
12	0.53	0.63	0.80	0.93	0.94	0.54	0.60	0.63	0.76	0.86
15	0.49	0.59	0.80	0.93	0.94	0.56	0.60	0.65	0.74	0.89
20	0.54	0.63	0.84	0.94	0.94	0.55	0.63	0.69	0.81	0.93
25	0.51	0.64	0.89	0.94	0.94	0.53	0.65	0.78	0.85	0.94
30	0.55	0.66	0.89	0.94	0.94	0.55	0.63	0.75	0.90	0.93

Table 25: Image data (stratified by depth); effect of sample size and magnitude of change on probability of detecting effect on key indicators of the state of the benthic communities. 2010 data. Likelihood of detection colour coded; green = 0.95 – 1, orange = 0.9 – 0.94, yellow = 0.8 – 0.89. Note that p90 is the largest reduction and p500 is the largest recovery imposed.

										Abundance
# samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.61	0.68	0.73	0.85	0.85	0.50	0.54	0.71	0.79	0.95
5	0.58	0.66	0.74	0.83	0.83	0.52	0.58	0.68	0.78	0.98
6	0.57	0.65	0.78	0.89	0.89	0.53	0.63	0.71	0.81	0.98
8	0.60	0.71	0.77	0.87	0.87	0.55	0.63	0.73	0.80	0.98
10	0.61	0.69	0.80	0.90	0.90	0.58	0.64	0.77	0.85	0.99
12	0.60	0.70	0.79	0.93	0.93	0.57	0.70	0.81	0.85	1.00
15	0.65	0.74	0.83	0.92	0.92	0.62	0.71	0.80	0.86	1.00
20	0.65	0.78	0.89	0.92	0.92	0.60	0.68	0.83	0.94	1.00
25	0.65	0.77	0.86	0.97	0.97	0.58	0.70	0.83	0.93	1.00
30	0.66	0.74	0.86	0.96	0.96	0.61	0.73	0.84	0.91	1.00
										Number of taxa
	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.61	0.61	0.61	0.76	0.76					
5	0.66	0.66	0.66	0.78	0.78					
6	0.63	0.63	0.63	0.78	0.78					
8	0.65	0.65	0.65	0.84	0.84					
10	0.65	0.65	0.65	0.81	0.81					
12	0.63	0.63	0.65	0.83	0.83					
15	0.65	0.65	0.65	0.82	0.82					
20	0.68	0.68	0.68	0.90	0.90					
25	0.69	0.69	0.69	0.90	0.90					
30	0.73	0.73	0.73	0.93	0.93					
										Shannon Weiner
	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.52	0.52	0.53	0.75	0.75					
5	0.61	0.61	0.63	0.80	0.80					
6	0.59	0.59	0.63	0.80	0.80					
8	0.60	0.59	0.62	0.86	0.86					
10	0.59	0.59	0.60	0.82	0.82					
12	0.59	0.60	0.62	0.87	0.87					
15	0.59	0.59	0.63	0.88	0.88					
20	0.64	0.64	0.66	0.90	0.90					
25	0.63	0.63	0.66	0.95	0.95					
30	0.66	0.68	0.72	0.95	0.95					
										Homaxine
	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.61	0.65	0.85	1.00	1.00	0.59	0.66	0.75	0.82	0.97
5	0.58	0.69	0.80	1.00	1.00	0.57	0.61	0.73	0.85	0.99
6	0.61	0.73	0.84	1.00	1.00	0.58	0.65	0.72	0.84	0.97
8	0.65	0.77	0.84	1.00	1.00	0.55	0.64	0.73	0.81	0.95
10	0.65	0.76	0.83	1.00	1.00	0.57	0.67	0.77	0.83	0.96
12	0.65	0.73	0.88	1.00	1.00	0.61	0.75	0.80	0.84	0.96
15	0.65	0.81	0.91	1.00	1.00	0.63	0.71	0.83	0.89	0.96
20	0.73	0.85	0.91	1.00	1.00	0.64	0.71	0.83	0.92	1.00
25	0.75	0.89	0.95	1.00	1.00	0.65	0.81	0.92	0.96	1.00
30	0.75	0.88	0.97	1.00	1.00	0.68	0.79	0.87	0.96	1.00
										Tethyopsis
	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.77	0.77	0.83	1.00	1.00	0.71	0.71	0.75	0.83	0.98
5	0.73	0.78	0.85	1.00	1.00	0.66	0.66	0.71	0.76	0.97
6	0.73	0.73	0.83	1.00	1.00	0.63	0.64	0.69	0.78	0.98
8	0.77	0.78	0.81	1.00	1.00	0.59	0.63	0.67	0.74	0.99
10	0.78	0.84	0.91	1.00	1.00	0.65	0.66	0.72	0.84	0.99
12	0.78	0.82	0.92	1.00	1.00	0.61	0.68	0.72	0.82	1.00
15	0.81	0.88	0.92	1.00	1.00	0.53	0.60	0.75	0.91	1.00
20	0.81	0.85	0.97	1.00	1.00	0.59	0.67	0.79	0.84	1.00
25	0.83	0.88	0.99	1.00	1.00	0.53	0.68	0.83	0.95	1.00
30	0.84	0.91	0.99	1.00	1.00	0.52	0.65	0.81	0.96	1.00
										Hyrodendron
	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.56	0.64	0.78	0.97	0.97	0.60	0.63	0.71	0.81	0.93
5	0.55	0.62	0.79	0.96	0.96	0.55	0.62	0.71	0.81	0.92
6	0.56	0.64	0.86	0.98	0.98	0.52	0.62	0.72	0.87	0.96
8	0.55	0.65	0.82	0.99	0.99	0.59	0.64	0.74	0.85	0.94
10	0.59	0.71	0.84	0.98	0.98	0.60	0.65	0.75	0.82	0.96
12	0.60	0.77	0.87	0.99	0.99	0.62	0.71	0.78	0.85	0.97
15	0.57	0.71	0.91	1.00	1.00	0.61	0.72	0.78	0.87	0.97
20	0.62	0.76	0.94	1.00	1.00	0.59	0.72	0.82	0.92	0.97
25	0.64	0.76	0.96	1.00	1.00	0.62	0.73	0.83	0.92	1.00
30	0.56	0.78	0.97	1.00	1.00	0.62	0.71	0.81	0.95	1.00

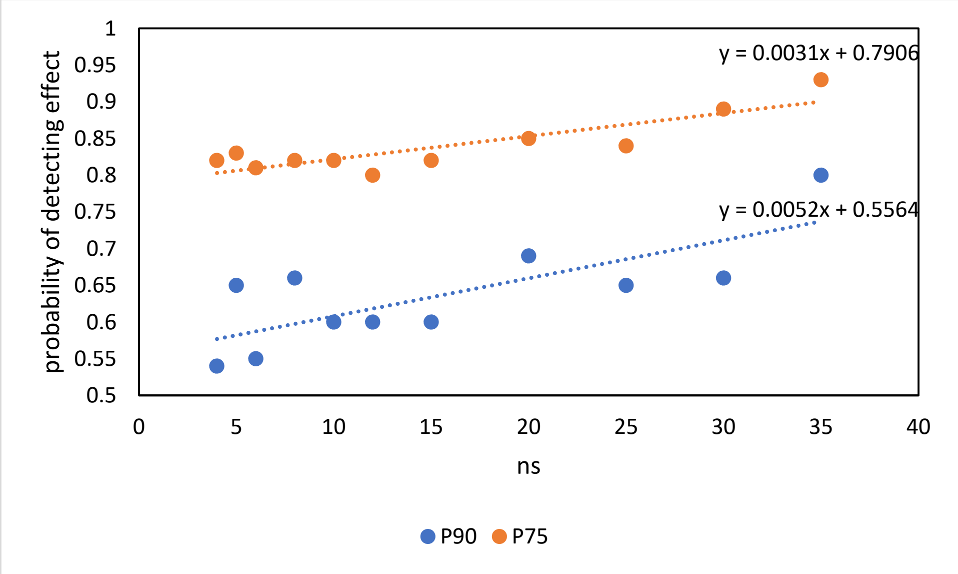

Figure 50: Image data (not stratified – point comparison with temporal variability added); effect of sample size and magnitude of change (P90 representing a 10% reduction, P75 representing a 25% reduction) on probability of detecting effect on abundance. 2010 data, ns=number of samples.

Table 26: Image data (not stratified – point comparison with temporal variability added); effect of sample size and magnitude of change on probability of detecting effect on key indicators of the state of the benthic communities. 2010 data. Likelihood of detection colour coded; green = 0.95 – 1, orange = 0.9 – 0.94, yellow = 0.8 – 0.89. Note that p90 is the largest reduction and p500 is the largest recovery imposed.

Abundance

# samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.54	0.82	0.94	0.98	0.98	0.76	1.00	1.00	1.00	1.00
5	0.65	0.83	0.97	0.99	0.99	0.71	1.00	1.00	1.00	1.00
6	0.55	0.81	0.99	1.00	1.00	0.78	1.00	1.00	1.00	1.00
8	0.66	0.82	0.98	1.00	1.00	0.69	1.00	1.00	1.00	1.00
10	0.60	0.82	1.00	1.00	1.00	0.63	1.00	1.00	1.00	1.00
12	0.60	0.80	1.00	1.00	1.00	0.68	1.00	1.00	1.00	1.00
15	0.60	0.82	1.00	1.00	1.00	0.68	1.00	1.00	1.00	1.00
20	0.69	0.85	1.00	1.00	1.00	0.70	1.00	1.00	1.00	1.00
25	0.75	0.84	1.00	1.00	1.00	0.74	1.00	1.00	1.00	1.00
30	0.82	0.91	1.00	1.00	1.00	0.65	1.00	1.00	1.00	1.00

Number of taxa

# samples	p90	p75	p50	p10	p05
4	0.83	0.83	0.84	1.00	1.00
5	0.86	0.86	0.87	1.00	1.00
6	0.86	0.86	0.86	1.00	1.00
8	0.85	0.85	0.86	1.00	1.00
10	0.86	0.87	0.87	1.00	1.00
12	0.88	0.88	0.88	1.00	1.00
15	0.94	0.94	0.95	1.00	1.00
20	0.97	0.97	0.97	1.00	1.00
25	0.97	0.97	0.97	1.00	1.00
30	0.95	0.95	0.96	1.00	1.00

Shannon Weiner

# samples	p90	p75	p50	p10	p05
4	0.55	0.55	0.52	0.93	0.96
5	0.64	0.66	0.67	0.97	0.98
6	0.55	0.54	0.55	0.97	1.00
8	0.65	0.62	0.64	0.97	0.99
10	0.60	0.78	0.78	0.98	1.00
12	0.61	0.62	0.65	0.98	1.00
15	0.60	0.60	0.62	0.98	1.00
20	0.69	0.69	0.70	1.00	1.00
25	0.65	0.65	0.67	1.00	1.00
30	0.66	0.66	0.68	1.00	1.00

Homaxine

# samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.56	0.56	0.61	1.00	1.00	0.75	0.75	0.75	1.00	1.00
5	0.65	0.65	0.76	1.00	1.00	0.71	0.71	0.71	1.00	1.00
6	0.56	0.56	0.76	1.00	1.00	0.78	0.78	0.78	1.00	1.00
8	0.65	0.65	0.79	1.00	1.00	0.69	0.69	0.69	1.00	1.00
10	0.60	0.60	0.89	1.00	1.00	0.63	0.63	0.63	1.00	1.00
12	0.60	0.60	0.84	1.00	1.00	0.68	0.68	0.68	1.00	1.00
15	0.60	0.60	0.88	1.00	1.00	0.68	0.68	0.68	1.00	1.00
20	0.69	0.69	0.89	1.00	1.00	0.70	0.70	0.70	1.00	1.00
25	0.65	0.65	0.92	1.00	1.00	0.74	0.74	0.74	1.00	1.00
30	0.66	0.66	0.94	1.00	1.00	0.65	0.65	0.65	1.00	1.00

Tethyopsis

# samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.72	0.72	0.79	1.00	1.00	0.72	0.72	0.72	1.00	1.00
5	0.69	0.69	0.73	1.00	1.00	0.76	0.76	0.76	1.00	1.00
6	0.65	0.65	0.87	1.00	1.00	0.78	0.78	0.78	1.00	1.00
8	0.69	0.69	0.86	1.00	1.00	0.67	0.67	0.67	1.00	1.00
10	0.61	0.61	0.91	1.00	1.00	0.63	0.63	0.63	1.00	1.00
12	0.66	0.66	0.94	1.00	1.00	0.68	0.68	0.68	1.00	1.00
15	0.65	0.67	0.92	1.00	1.00	0.68	0.68	0.68	1.00	1.00
20	0.69	0.71	0.92	1.00	1.00	0.70	0.70	0.70	1.00	1.00
25	0.65	0.67	0.95	1.00	1.00	0.74	0.74	0.74	1.00	1.00
30	0.67	0.70	0.97	1.00	1.00	0.65	0.65	0.65	1.00	1.00

Hyrodendron

# samples	p90	p75	p50	p10	p05	p110	p125	p150	p200	p500
4	0.54	0.54	0.70	1.00	1.00	0.77	0.77	0.77	1.00	1.00
5	0.65	0.65	0.82	1.00	1.00	0.71	0.71	0.71	1.00	1.00
6	0.55	0.55	0.81	1.00	1.00	0.78	0.78	0.78	1.00	1.00
8	0.65	0.65	0.81	1.00	1.00	0.69	0.69	0.69	1.00	1.00
10	0.60	0.60	0.93	1.00	1.00	0.63	0.63	0.63	1.00	1.00
12	0.60	0.60	0.90	1.00	1.00	0.68	0.68	0.68	1.00	1.00
15	0.60	0.60	0.96	1.00	1.00	0.68	0.68	0.68	1.00	1.00
20	0.69	0.69	0.99	1.00	1.00	0.70	0.70	0.70	1.00	1.00
25	0.65	0.65	0.98	1.00	1.00	0.74	0.74	0.74	1.00	1.00
30	0.66	0.66	0.97	1.00	1.00	0.65	0.65	0.65	1.00	1.00

8. APPENDIX 2

DISTLM marginal tests for analysis of epifaunal community data from seabed images for complete dataset (Figure 20 and Figure 21). These show how much of the total variance each variable explains when taken alone, ignoring all other variables. Terms listed in decreasing order of variance explained. SS(trace) – diagonal elements of Gower's centred matrix (Anderson, M. J. 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). Details of abbreviations provided in Table 2.

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	83086	5.465	0.001	0.255	96	7	*	*
year	51285	9.322	0.001	0.157	100	3	*	*
depth	37284	13.027	0.001	0.114	101	2	*	*
se3	20205	6.666	0.001	0.062	101	2	*	*
sf	18225	5.974	0.001	0.056	101	2	*	*
te6	9416.9	3.001	0.005	0.029	101	2		*
te3	9138.1	2.910	0.001	0.028	101	2	*	*
tf	8697.8	2.766	0.006	0.027	101	2	*	*
te9	5948.1	1.875	0.038	0.018	101	2		*

DISTLM marginal tests for analysis of epifaunal community data from seabed images for sandy habitat dataset (Figure 22 and Figure 23).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	50014	4.909	0.001	0.189	84	5	*	*
year	48815	9.756	0.001	0.185	86	3	*	*
depth	42800	16.837	0.001	0.162	87	2	*	*
se3	20334	7.261	0.001	0.077	87	2	*	*
sf	16182	5.682	0.001	0.061	87	2	*	*
tf	12009	4.147	0.001	0.045	87	2	*	*
te6	11986	4.138	0.001	0.045	87	2		*
te3	10661	3.662	0.001	0.040	87	2	*	*
te9	7117.7	2.411	0.012	0.027	87	2		X

DISTLM marginal tests for analysis of epifaunal community data from seabed images for sand habitat dataset (Figure 24 and Figure 25).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
year	33700	7.552	0.001	0.256	44	3	*	*
depth	18790	7.477	0.001	0.142	45	2	*	*
sf	10324	3.822	0.001	0.078	45	2	*	*
se3	9272.2	3.403	0.001	0.070	45	2	*	*
tf	5029.7	1.784	0.074	0.038	45	2	X	X
te9	3693.1	1.297	0.212	0.028	45	2		*
te3	2684.2	0.935	0.506	0.020	45	2	*	*
te6	829.25	0.285	0.985	0.006	45	2		X

DISTLM marginal tests for analysis of epifaunal community data from seabed images for 2006 dataset (Figure 26 and Figure 27).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	41988	2.638	0.001	0.513	15	7	*	*
se3	21976	7.350	0.001	0.269	20	2	*	*
sf	16987	5.244	0.001	0.208	20	2	X	X
depth	16781	5.164	0.001	0.205	20	2	X	X
te3	9830.4	2.733	0.011	0.120	20	2	X	X
te6	6413.6	1.702	0.094	0.078	20	2		X
tf	5829.1	1.535	0.157	0.071	20	2	X	X
te9	4714.3	1.224	0.28	0.058	20	2		*

DISTLM marginal tests for analysis of epifaunal community data from seabed images for 2010 dataset (Figure 28 and Figure 29).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	43053	4.040	0.001	0.416	34	7	*	*
depth	14621	6.420	0.001	0.141	39	2	*	*
te6	8703.2	3.583	0.004	0.084	39	2		X
se3	8574.9	3.525	0.004	0.083	39	2	*	*
sf	8067.9	3.299	0.003	0.078	39	2	*	*
te9	5870.5	2.346	0.025	0.057	39	2		*
tf	4198	1.650	0.105	0.041	39	2	*	*
te3	1914.2	0.735	0.665	0.019	39	2	*	*

DISTLM marginal tests for analysis of epifaunal community data from seabed images for 2017 dataset (Figure 30 and Figure 31).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	40282	4.470	0.001	0.448	33	7	*	*
depth	14423	7.267	0.001	0.161	38	2	*	*
se9	7141.4	3.281	0.007	0.079	38	2		*
sf	5115.1	2.294	0.03	0.057	38	2	*	*
te3	4929.8	2.206	0.034	0.055	38	2	X	X
tf	4956	2.219	0.037	0.055	38	2	*	*
te9	2342.3	1.017	0.39	0.026	38	2		*
te6	1743.9	0.752	0.573	0.019	38	2		*

DISTLM marginal tests for analysis of infaunal community data from seabed images for complete dataset (Figure 35 and Figure 36).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
year	43541	10.3820	0.001	0.164	106	3	*	*
habitat	37241	2.7698	0.001	0.140	102	7	*	*
se3	13178	5.5811	0.001	0.050	107	2	*	*
sf	13010	5.5063	0.001	0.049	107	2	*	*
depth	12191	5.1430	0.001	0.046	107	2	*	*
te3	9180.6	3.8277	0.001	0.035	107	2	*	*
te9	7938.1	3.2937	0.001	0.030	107	2		*
te6	6591.9	2.7209	0.001	0.025	107	2		*
tf	5899.4	2.4286	0.003	0.022	107	2	X	X

DISTLM marginal tests for analysis of infaunal community data from seabed images for sandy habitat dataset (Figure 37 and Figure 38).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
year	41811	10.4610	0.001	0.177	97	3	*	*
habitat	20942	2.3164	0.001	0.089	95	5	*	*
se3	12938	5.6927	0.001	0.055	98	2	*	*
depth	11230	4.9038	0.001	0.048	98	2	*	*
sf	10514	4.5764	0.001	0.045	98	2	*	*
te3	8883.6	3.8390	0.001	0.038	98	2	*	*
te9	7576.2	3.2553	0.001	0.032	98	2		*
te6	6500.4	2.7799	0.002	0.028	98	2		*
tf	5302	2.2556	0.003	0.022	98	2	*	*

DISTLM marginal tests for analysis of infaunal community data from seabed images for sand habitat dataset (Figure 39 and Figure 40).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
year	25201	6.6148	0.001	0.197	54	3	*	*
se3	8338	3.8303	0.001	0.065	55	2	*	*
te9	7832.4	3.5829	0.001	0.061	55	2		*
sf	7371.5	3.3592	0.001	0.058	55	2	*	*
depth	5280.3	2.3653	0.005	0.041	55	2	*	*
te3	3086.5	1.3583	0.152	0.024	55	2	*	*
tf	2541.6	1.1136	0.295	0.020	55	2	*	*
te6	2485.7	1.0887	0.326	0.019	55	2		X

DISTLM marginal tests for analysis of infaunal community data from seabed images for 2006 dataset (Figure 41 and Figure 42).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	13029	1.2146	0.119	0.195	25	6	X	X
se3	7574.6	3.7175	0.001	0.114	29	2	*	*
te9	6758.8	3.2719	0.002	0.101	29	2		*
depth	5556.2	2.6368	0.004	0.083	29	2	*	*
sf	5144.5	2.4251	0.011	0.077	29	2	X	X
te3	3944.8	1.8240	0.033	0.059	29	2	X	X
te6	2990.4	1.3620	0.149	0.045	29	2		*
tf	2589.5	1.1720	0.273	0.039	29	2	*	*

DISTLM marginal tests for analysis of infaunal community data from seabed images for 2010 dataset (Figure 43 and Figure 44).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	15073	1.9524	0.002	0.228	33	6	*	*
depth	6544.5	4.0709	0.001	0.099	37	2	*	*
sf	4287.8	2.5697	0.005	0.065	37	2	*	*
te6	4195.6	2.5107	0.002	0.064	37	2		X
te9	3343.6	1.9736	0.022	0.051	37	2		*
se3	2849.9	1.6691	0.057	0.043	37	2	*	*
tf	2412.3	1.4031	0.115	0.037	37	2	*	*
te3	1871.8	1.0795	0.305	0.028	37	2	*	*

DISTLM marginal tests for analysis of infaunal community data from seabed images for 2017 dataset (Figure 45 and Figure 46).

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	28355	2.4698	0.001	0.317	32	7	*	*
depth	7460.3	3.3611	0.001	0.083	37	2	*	*
sf	6886.7	3.0811	0.001	0.077	37	2	*	*
te3	4828.4	2.1078	0.006	0.054	37	2	*	*
se9	4773.1	2.0823	0.01	0.053	37	2		*
te9	4264.1	1.8491	0.02	0.048	37	2		*
tf	3710.8	1.5988	0.037	0.041	37	2	X	X
te6	2141.5	0.9061	0.565	0.024	37	2		X

DISTLM marginal tests for analysis of infaunal community data from seabed images for 2010 dataset, including particle size composition and percentage organic material.

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	15073	1.9524	0.002	0.228	33	6	*	*
sed	14461	2.3838	0.001	0.219	34	5	*	*
depth	6544.5	4.0709	0.001	0.099	37	2	*	*
org	6326.6	3.9210	0.001	0.096	37	2	*	*
sf	4287.8	2.5697	0.005	0.065	37	2	*	*
te6	4195.6	2.5107	0.002	0.064	37	2		X
te9	3343.6	1.9736	0.022	0.051	37	2		*
se3	2849.9	1.6691	0.057	0.043	37	2	*	*
tf	2412.3	1.4031	0.115	0.037	37	2	*	*
te3	1871.8	1.0795	0.305	0.028	37	2	*	*

DISTLM marginal tests for analysis of infaunal community data from seabed images for 2017 dataset, including particle size composition and percentage organic material.

Group	SS(trace)	Pseudo-F	P	Prop.	res.df	regr.df	Recent effort	All effort
habitat	28355	2.4698	0.001	0.317	32	7	*	*
sed	18786	2.4314	0.001	0.233	32	5	*	*
org	10932	5.4922	0.001	0.136	35	2	*	*
depth	7460.3	3.3611	0.001	0.083	37	2	*	*
sf	6886.7	3.0811	0.001	0.077	37	2	*	*
te3	4828.4	2.1078	0.006	0.054	37	2	*	*
se9	4773.1	2.0823	0.01	0.053	37	2		*
te9	4264.1	1.8491	0.02	0.048	37	2		*
tf	3710.8	1.5988	0.037	0.041	37	2	X	X
te6	2141.5	0.9061	0.565	0.024	37	2		*

9. APPENDIX 3

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

Category	Explanation
Shape	**Morphology and profile of sponge**
Strappy	Tree-like with long straps
Spherical	Round, brain-like
Bushy	Tree-like with short bushy branches
Bowl	Cup or bowl
Digitate	Thin to fat fingers arising from a common base
Feathery	Shaped like a large feather
Leafy/fan	Like leaves, narrow base of attachment
Loaf	Loaf or hemisphere
Lollipop	Body on the end of a stalk
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
Moderate	Compressible texture with high profile and weak base of attachment, or has tough texture but weak base
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
Moderate	Compressible texture with high profile and weak base of attachment, or has tough texture but weak base
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