



An Assessment of the Hauraki Gulf Cable Protection Area, Relative to the Adjacent Seafloor

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An Assessment of the Hauraki Gulf Cable Protection Area, Relative to the Adjacent Seafloor

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Executive summary

The Hauraki Gulf Cable Protection Area (CPA) provides a corridor that extends from Takapuna Beach to west of the Mokohinau Islands, where it continues out to the 12 mile territorial sea limits. A towed camera array was used over a four-night survey to assess whether the CPA's ban on all fishing and anchoring provides protection for seafloor assemblages. Five blocks were surveyed in the mid to outer Hauraki Gulf, ranging in depth from 35m to 129m. Within each block two transects were run across the CPA boundary from each side. Each transect consisted of two 200m long sampling segments inside the CPA and two segments outside.

Visual counts were made of all of the epifauna and epiflora seen, including fish, nominally of 2cm or greater in size. The number of species and relative abundance of the invertebrate and fish species present were modest.

Univariate and multivariate statistical models were used to assess the relative influence of sampling block, depth, being east or west of the CPA centre line, the density of burrows, proportion of mud, and being inside or outside the CPA. For univariate measures, many of these factors were significant for assemblage level response variables (e.g. species richness and abundance), as well as for many individual species. However, the effects of block and depth were much stronger than that of CPA status, and in general effects were relatively modest. For multivariate measures, a similar pattern was seen, with CPA status accounting for only 1.4 per cent of the variability in invertebrate assemblages, and having no effect on the fish assemblages. Overall, the effect of the CPA was negligible.

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1.0 Introduction

The Hauraki Gulf Cable Protection Area (CPA) is a protected corridor within which sits a major international communications cable. To protect the cable from disturbance and damage, all fishing and anchoring is prohibited within the CPA. New Zealand (NZ) is a very isolated nation and as such is extremely reliant upon global communications via submarine cables in the CPAs. Here in NZ over **97 per cent** of all international communication is carried via submarine fibre optic cables. These cables are critical components of NZ's infrastructure and play a significant role in our everyday lives, the general economy and future growth of NZ. These exclusions mean that the ecological impacts of these activities should have been removed from the CPA, potentially allowing for the 'recovery' of seafloor communities (invertebrates, plants, and fish species) from the impacts of these activities. The Sea Change -Tai Timu Tai Pari project group was interested in quantifying these possible changes, and on their behalf the Auckland Council and Waikato Regional Council commissioned a field survey with associated report to assess them.

There has been a designated "prohibited cable area" within the Hauraki Gulf from around 1920 but the current day cable protection areas as defined in the Submarine Cables and Pipelines Protection Order 2009, 2006 (SCPPO) and associated legislation – the Submarine Cables and Pipelines Protection Act 1996 (SCPPA) have been in place since the early 1990s. Initially there were no cable patrols (sea or air), but during the survey of the CPA for the introduction of the Southern Cross Cable Network in late 1998 a considerable number of trawling scars were detected on the seabed within the CPA. The discovery of these trawl scars prompted the cable owners to fund and introduce both sea and air patrols in 1999, which are still operational today (pers. comm. Mike McGrath, Spark New Zealand).

In the early days there was significant education provided to the commercial fishing industry and a "honeymoon period" for infringements. A cable awareness and education programme called "Catch fish not cables" which includes advertising and working with all maritime communities was then introduced. This included the fishing industry, boating and yachting clubs, and cable awareness stands were run at key boat shows. The cable owners continue to spend a considerable amount each year on the patrols and awareness programmes. There is a maximum fine of \$250,000 for damage to a cable under the SCPPA and a maximum of \$100,000 for commercial and \$20,000 for recreational (both skipper and owner) for fishing and or anchoring in the Cable Protection Areas covered by the SCPPO. The CPAs are patrolled all year

round; both on water and aerial patrols are used to both protect the cables and to gather evidence of illegal fishing and or anchoring within the CPA. All evidence is provided to the Maritime Police and Ministry of Transport in Wellington for potential prosecution under the SCPPA and SCPPO.

Fishing impacts background

The first documented concerns about the use of towed fishing gear on benthic habitats were from UK fishermen in the fourteenth century (Lokkeborg 2005). These concerns related to the capture of juvenile fish and the detrimental effects on food sources for harvestable fish. Despite this long history of concern, it is really only since the 1990s that international research has focused on the effects of fishing on benthic communities, biodiversity, and production. The rapid expansion of studies in this area, and the controversy associated with the effects of fishing has led to numerous reviews, summarizing the research and identifying overall patterns (Gislason 1994, Dayton et al. 1995, Jennings and Kaiser 1998, Lindeboom and de Groot 1998, Hall 1999, Collie et al. 2000, Gislason et al. 2000, Kaiser and de Groot 2000, Dayton et al. 2002, Thrush and Dayton 2002, Lokkeborg 2005, Department of Fisheries and Oceans 2006, Kaiser et al. 2006, Rice 2006, Watling et al. 2014).

These reviews are in general agreement, concluding that benthic disturbance from mobile fishing varies in relation to the habitat, fishing gear, and environment, and is likely to have predictable and potentially substantial effects on benthic community structure and function. These effects can lead to regional-scale reductions in some components of biodiversity, reduce benthic community productivity (Jennings et al. 2001, Hiddink et al. 2006), alter natural sediment fluxes and reduce organic carbon turnover (Pusceddu et al. 2014), and modify the shape of the upper continental slope (Puig et al. 2012), reducing morphological complexity and benthic habitat heterogeneity.

The effects of fishing on the seabed can be divided into geotechnical (the physical contact of the gear on the seabed) and hydrodynamic (the suspension of sediment into the water column) components, and vary with both fishing gear and benthic habitat (Ivanovic et al. 2011, O'Neill et al. 2011). Heavier fishing gears tend to penetrate deeper into the seabed (Ivanovic et al. 2011), while larger gears towed at faster speeds generate more drag, suspending greater quantities of seabed material, particularly in softer sediment (muddy) habitats (O'Neill et al. 2011). The likely effects and dispersal of this sediment will vary locally, depending on oceanographic conditions.

Within coastal regions, scallop dredges are generally considered to have a greater impact on benthic communities (per area fished) than trawls or Danish seines, as the gear is heavier and penetrates further into the seabed (Kaiser et al 2006). Habitats with relatively low natural levels of disturbance are generally considered to be more sensitive to fishing impacts than habitats in areas of frequent natural disturbance (Lokkeborg 2005). However, biogenic habitats (created by animals and plants) may occur in such areas (e.g., Spirits Bay), and are particularly sensitive to fishing impacts (e.g., Tuck and Hewitt 2013). Typically, larger, longer lived, slow growing, fragile, erect, sedentary species (e.g., sponges, sea pens, corals, horse mussels) tend to be more sensitive to the physical impacts of fishing gear than smaller, faster growing, less fragile species living below the sediment surface (Tuck and Hewitt 2013). Sensitivity to re-suspended sediment is likely to be related to different life history characteristics, with species and habitats relying on photosynthesis (e.g. rhodolith beds) or vulnerable to smothering (e.g., sponges) probably most at risk.

Other impacts

The other human impact that is likely to be large for the Auckland region is increased sedimentation from land-based activities (Morrison et al. 2009). However, while there is a significant body of research for adjacent Hauraki Gulf estuaries (e.g., Mahurangi Estuary) and some shallow embayments such as Whitford, little seafloor habitat research has been carried out on the deeper central areas of the Hauraki Gulf.

Past research in the CPA

Seafloor type in the cable area has been mapped at a coarse scale by Carter and Eade (1980) and Manighetti and Carter (1999); and, for the inner Gulf component, at a finer scale by Morrison et al. (2003). Shears and Usmar (2006) describe bottom types at the two localised CPAs that they surveyed for fish. The seabed is relatively uniform mud from close to the beginning of the CPA at Takapuna Beach to near Kawau Island (Morrison et al. 2003). It then becomes sandy with a high proportion of calcium carbonate material with occasional low rock outcrops as the cable enters the Jellicoe Channel to the west of Little Barrier Island (Manighetti and Carter 1999, Shears and Usmar 2006). Further out on the continental shelf north of Little Barrier Island it becomes muddier again (Leathwick et al 2012).

The CPA's potential to act as a de facto marine protected area for fish populations was investigated in 2004 by Shears and Usmar (2006). The authors used baited underwater video (BUV) to estimate relative abundances of carnivorous fishes inside

and outside the CPA, in two areas. BUV has been used as a tool to monitor snapper and blue cod in several northern marine reserves since 1998 (Willis and Babcock 2000, Willis et al. 2003), and has revealed that legal-sized snapper and blue cod are usually much more abundant in marine reserves than in adjacent fished areas. In autumn and spring 2004, Shears and Usmar (2006) deployed BUV on (1) 20–30m deep mud sediments south of the Whangaparaoa Peninsula (“inner Gulf” site, 8 stations inside the CPA and 8 sites outside), and (2) 30–40m deep patch reefs, west of Little Barrier Island (“outer Gulf” site, 11 stations inside the CPA and 11 sites outside) (known as Northwest Reef). The authors found that fish including snapper were largely unaffected by the CPA, instead being much more strongly influenced by depth and bottom type. This lack of response to protection was tentatively attributed to the short time that the CPA had been in place, weak enforcement of the exclusion area before 1999, and/or unsuitable habitat. No direct work on the CPA has been published since, outside of the present study.

2.0 Methodology

2.1 Sampling design

Five sampling blocks were selected along the CPA, between 50 and 130m depth. Each block nominally extended 2.5km to each side of the CPA boundaries, and 3km along the main axis of the CPA (Figure 1). As the CPA gradually widens with distance from the shore, the outer deeper blocks were slightly wider than the shallower blocks. Four transects were assigned to each block, each starting at the block centre, and running west or east for each subsequent transect. Within a transect (west or east), four 200m long sampling 'segments' were assigned as follows (see Figure 1 for a visual representation); at 150m from the CPA centre-line, 100m before the halfway point between the CPA centre-line and the CPA boundary, 150m outside the CPA boundary, and 2300m outside the CPA boundary. The separation distance between each adjacent transect (north-south) was set at 1km (1000m) (Figure 1). As no previous data were available, no power analysis for sample size versus magnitude of detectable effect was possible.

The five survey blocks were selected to cover a range of depths and sediment types using the very limited and coarse sediment type charts for that region of the Hauraki Gulf (Leathwick et al. 2012). Survey blocks were located beyond the inner Hauraki Gulf, where all commercial seafloor-contact fishing is generally prohibited for fisheries management purposes, both inside and outside of the CPA (i.e., the mid to outer Hauraki Gulf CPA region sampled had fishing activity beyond its boundaries).

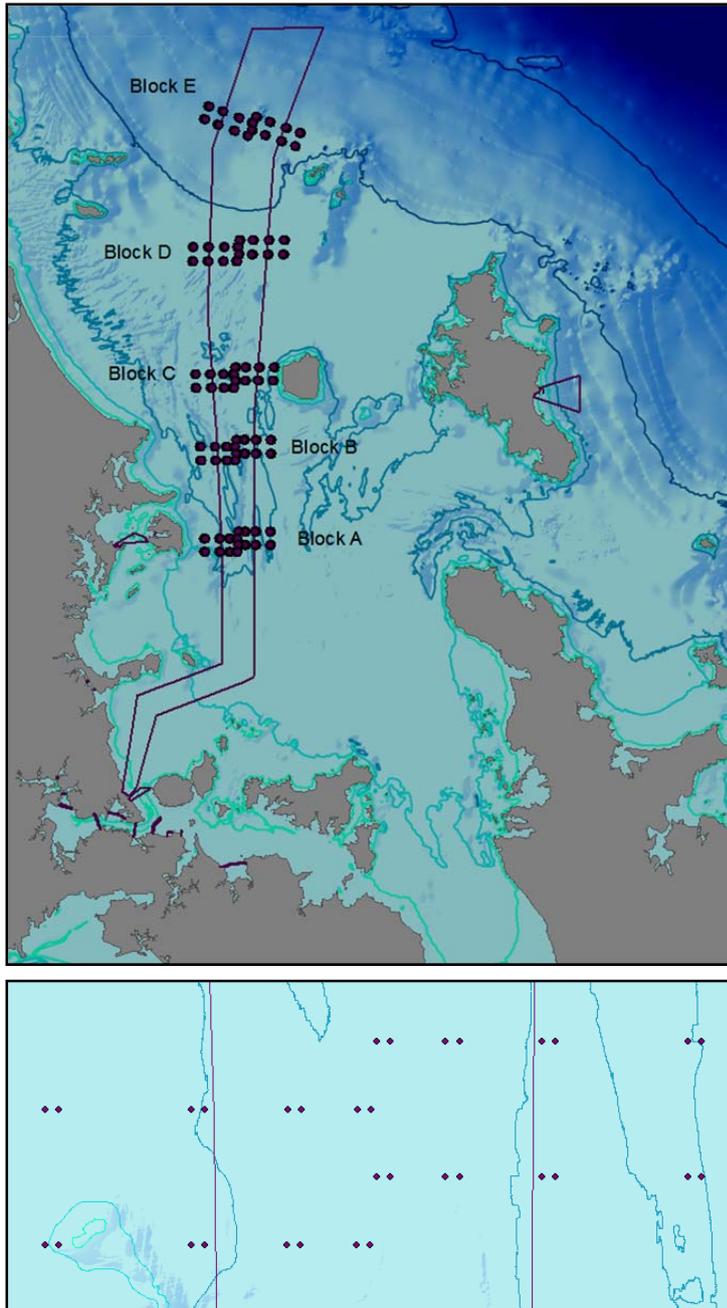


Figure 1: Top, location of the CPA in the Hauraki Gulf, the five sampling blocks, and the sampling segments (displayed as dots, each is 200m long). Bottom, close-up of Block A, showing the CPA boundary, and the start and end points of each of the 200m long sampling segments.

2.2 Sampling gear and deployment

A towed video array (CoastCam) was used to image the seafloor. This array has a forward-facing high definition video camera that provides continuous imagery, and a downward-facing stills camera that takes an image every thirty seconds. Both are

equipped with scaling lasers 20cm apart, to allow the size of the image, and any objects within it, to be estimated. A lower resolution video feed to the surface allows the camera operator to see what is happening on the seafloor, and provide instructions as required to the vessel operator. The survey was done over four nights from the 18th to the 22nd February 2015. Night-time surveys were necessary in order to quantify abundances of fish species that were active during the day and not detectable by towed camera during daylight hours (e.g. snapper, Morrison and Carbines 2006), or cryptic during the day but active on the seafloor during the night (e.g. small conger eels, Jones et al. 2010).

The towed camera was deployed once along each 200m sampling segment, at a tow speed of around 0.5–1 knot. At regular intervals the batteries were changed over, and the imagery downloaded from the two camera systems (imagery is recorded directly to the devices, rather than being remotely sent up the cable, due to data transmission size constraints).

2.3 Image processing

The video was used as the main data generation source, as it covered the greatest area of seafloor, and many of the organisms encountered were present at relatively low densities. All objects greater than 2cm were counted and identified to the best practical resolution. For some sites, small discrete ‘clumps’ of biogenic material were present (cemented shell, bryozoans, hydroids, sponges and other contributions), which were scored as ‘indeterminate biogenic clump’. All fish individuals seen were identified to species, and measured down to the nearest 5cm total length (TL). Jack mackerel (*Trachurus* spp.) were counted but excluded from formal analyses, as often they were actively following the camera/lights, and occurred up in the water column. The total area covered by each video transect was calculated as the distance towed as measured by GPS (circa 200 m) multiplied by an average transect width, as calculated from a series of estimates along the transect length. Transect widths were calculated using the known distance between the scaling lasers (20 cm). Seafloor imagery lost when the camera was too far from the seafloor, and/or the water visibility was too poor, was subtracted from this estimate, so that the final ‘area swept’ by the camera was an accurate reflection of the usable imagery and associated faunal densities.

The still imagery was used to characterise sediment type (i.e., mud, sand, dead shell) and note any patchiness at the scale of multiple images, e.g., a shell hash area surrounded by sand. Where burrows occurred, the image was scored to one of six classes (20% cover interval bins), with the default being no burrows present (0%

cover). Transect values were calculated as averages of the images. Crinoids (feather stars) were abundant in one of the deeper blocks, and for this species, which is abundant but partially transparent and so hard to count using video, counts per unit area were calculated from the stills rather than video. Animals swimming were ignored, as it was not possible to determine whether they had originated from inside the sampling transect. The scaling lasers were used to calculate each image's area. Abundances were standardised to number of individuals per 100 m².

2.4 Data for analysis

Assemblage data (a matrix of species/operational taxonomic units (OTUs) per 100 m²) were used as the response variables input. OTUs were used where the video resolution was not sufficient to confidently identify fauna down to species-level; examples included some small eel and gurnard species. Potential environmental drivers available included sediment type dominance (muddy versus sandy), depth, and burrow density (one of six classes), and the east versus west side of the CPA centre; while fishing intensity was defined as either zero (inside the CPA) or one (outside the CPA).

The fish and benthic communities were examined separately.

2.4.1 Univariate analyses

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

Univariate community measures and individual taxa/OTU densities ($\log x + 0.01$ transformed) were examined within a linear modelling framework in relation to explanatory environmental variables, allowing for an interaction between block and inside/outside the CPA. Backwards model selection with Akaike information criterion (AIC) was used to select the minimum adequate model for each response variable, with only the significant terms retained in the final linear models. Terms for water depth, burrows, and per cent mud were fitted as continuous variables, while the other terms were fitted as categorical variables. While per cent mud was fitted as a linear term, preliminary analysis suggested the effect of depth may be non-linear,

and so this term was fitted as a 3rd order polynomial (which allows a range of non-linear responses if necessary). For the analysis of the univariate fish community measures, linear explanatory terms were also included in the full model for sponges, biogenic clumps and structure (the sum of the two) density (although the structure term was never retained).

2.4.2 Multivariate analyses

Multivariate differences in community composition between the different sampling hierarchy levels examined with non-metric Multi-Dimensional Scaling (MDS) and tested with an “analysis of similarities” randomisation test (ANOSIM) (Clarke 1988). Discriminating species within each block were determined using the SIMPER routine. The relationships between the faunal communities at each site, available environmental drivers, and fishing pressure were examined using distance based linear modelling, with the DISTLM method (Anderson 2001, McArdle and Anderson 2001) within PERMANOVA+ for PRIMER (Anderson et al. 2008). DISTLM partitions variation in a data cloud, as described by a resemblance matrix, according to a multiple regression model. Importantly, it supports the use of a number of different distance measures, including the frequently used Bray-Curtis similarity measure, and can be used in backwards selection mode. While both Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA) also partition variance in a data cloud according to a multiple regression model, these two analyses are confined to the use of Euclidean and chi-square distances respectively, which are not frequently used in analyses of community data. Backwards selection from a full model (including all explanatory variables) using AIC as the model selection criterion was used to identify terms significantly contributing to explanation of variability in the community composition. Terms for water depth and per cent mud were fitted as continuous (linear) variables, while the other terms were fitted as categorical variables.

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.

3.0 Results

3.1 Species observed

Three thousand, eight hundred and sixteen invertebrates were counted, along with nine individual records of macroalgae from some of the shallower blocks. The invertebrate assemblage (aggregated across the five blocks), was dominated by the compound ascidian *Synoicum kuranui* (a sea-squirt), a range of sponges, indeterminate biogenic clumps, and carrier shells (the gastropod *Xenophora neozelanica*), followed by lesser numbers of scallops, feather stars, encrusting sponges, cup corals, shrimps, and brachiopods (lamp-shells). Some of these species are shown in Figures 2–3. The fish assemblage (776 individuals observed) was dominated by small benthic nocturnal species only seen during the hours of darkness, including silver conger and other small eel species, red bandfish (which live in burrows) and small morid cod, along with lower numbers of small gurnard species (probably scaly gurnard), flatfish (probably witch, *Arnoglossus scapha*), snapper, sea perch, jack mackerels, and red mullet. Some examples are shown in Figure 4.

Table 1: Number of fish, invertebrates and macroalgae observed. Not all species could be identified to species-level given the video resolution. Some species identified as gastropods may be empty dead shells/ occupied by hermit crabs.

Species	Latin name/comment	No.	Species	Latin name/comment	No.
Silver conger eel	<i>Gnathophis habenatus</i>	214	Ascidians (compound)	<i>Synoicum kuranui</i>	1277
Red bandfish	<i>Cepola haastii</i>	95	Sponge (Demospongiae)	(multiple species)	704
Eels sp. 2	Small and elongate	83	Indeterminate biogenic		665
Unid. small fish	Includes opalfish/triplefins	75	Carrier shell (gastropod)	<i>Xenophora neozelanica</i>	328
Small morid cod	Unknown	73	Scallop	<i>Pecten novaezelandiae</i>	197
Triglidae (gurnards)	Probably all scaly gurnard	56	Crinoidea (motile) feather star	<i>Argyrometra mortenseni</i>	119
Flatfish	(probably witch)	44	Encrusting sponges	(multiple species)	114
Snapper	<i>Pagrus auratus</i>	27	Cup coral	<i>Flabellum</i> sp.	88
Sea perch	<i>Helicolenus percoides</i>	24	Crustacean (shrimp)		77
Jack mackerel	<i>Trachurus</i> spp.	21	Brachiopods (lamp-shells)		72
Red mullet	<i>Upeneichthys lineatus</i>	20	Crustacean (Paguridae hermit crabs)		49
Red gurnard	<i>Chelidonichthys kumu</i>	12	Starfish 1	<i>Luidia australiae</i>	27
Leatherjacket	<i>Meuschenia scaber</i>	10	Starfish 2	<i>Astropecten polyacanthus</i>	19
Butterfly perch	<i>Caesioperca lepidoptera</i>	5	Anemones		18
Snake eel	<i>Ophisurus serpens</i>	4	Squid (Teuthidae)		13
Common roughy	<i>Paratrachichtys trailli</i>	3	Hydroids		11
Frostfish	<i>Lepidopus caudatus</i>	3	Echinoid (urchin)	(not kina)	7
Cucumber fish	<i>Paraulopus nigripinnis</i>	2	Mollusc (gastropod)		7
Pink maomao	<i>Caprodon longimanus</i>	1	Sabellidae (fan worm)		6
Hagfish	<i>Eptatretus cirrhatu</i>	1	Crustose coralline algae	(patch reef edge)	5
Porcupine fish	<i>Allomycterus pilatus</i>	1	Pennatulacea (sea pens)		4
Labridae (wrasses)		1	Red bladed algae		3
John dory	<i>Zeus faber</i>	1	Alcyonacea (soft coral)		2
			Large shrimp		1
Total		776	Algae (encrusting)		1
			Bryozoans		1
			Total		3816

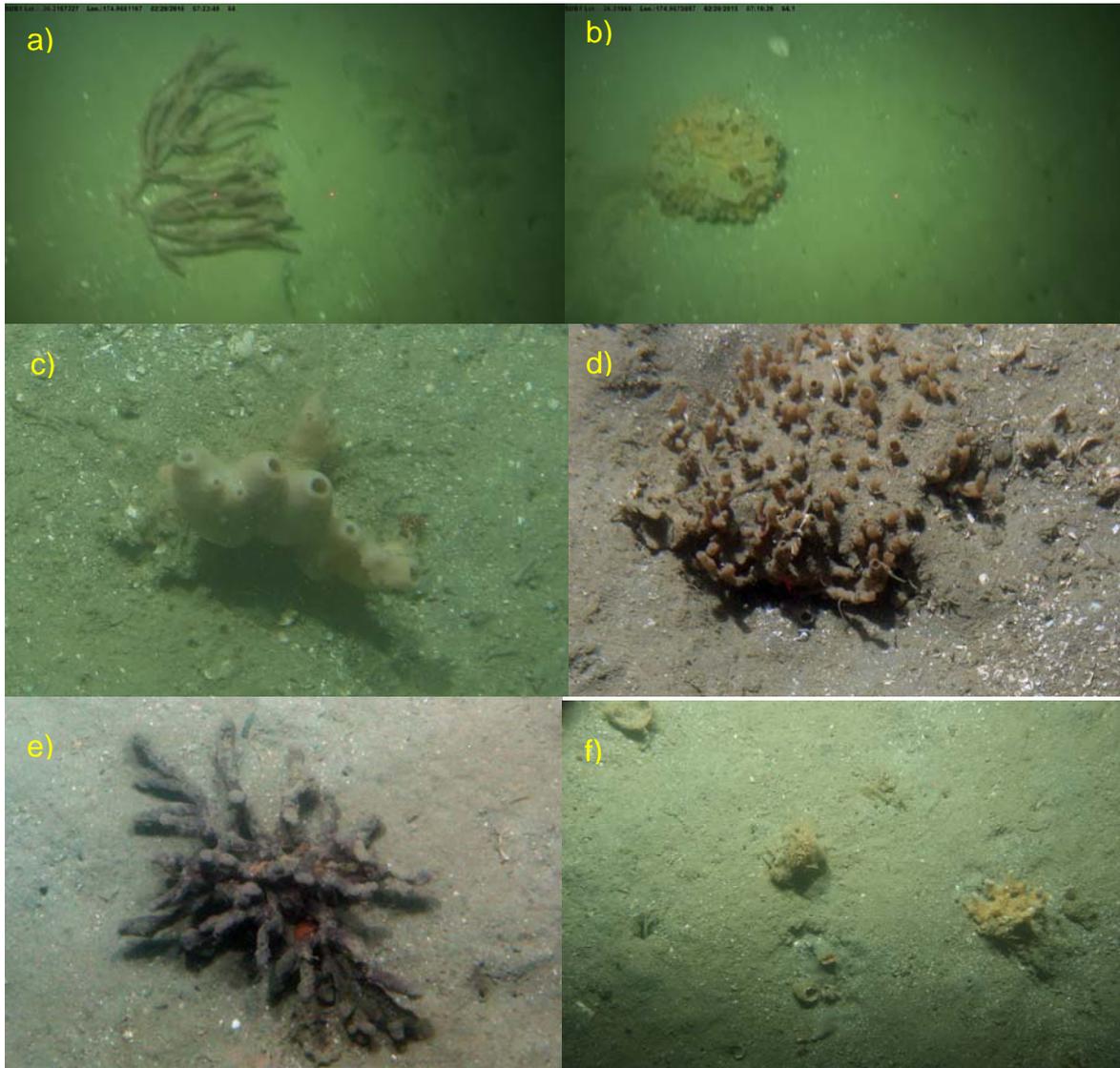


Figure 2: Examples of sponges seen: a) Axinellidae/Raspailiidae sp. indeterminate; b) Demosponge unidentified sp.; c) *Chondropsis kirkii*; d) *Adocia caminata* (?tentative); e) *Dactylia palmata*; f) *Crella incrustans*.

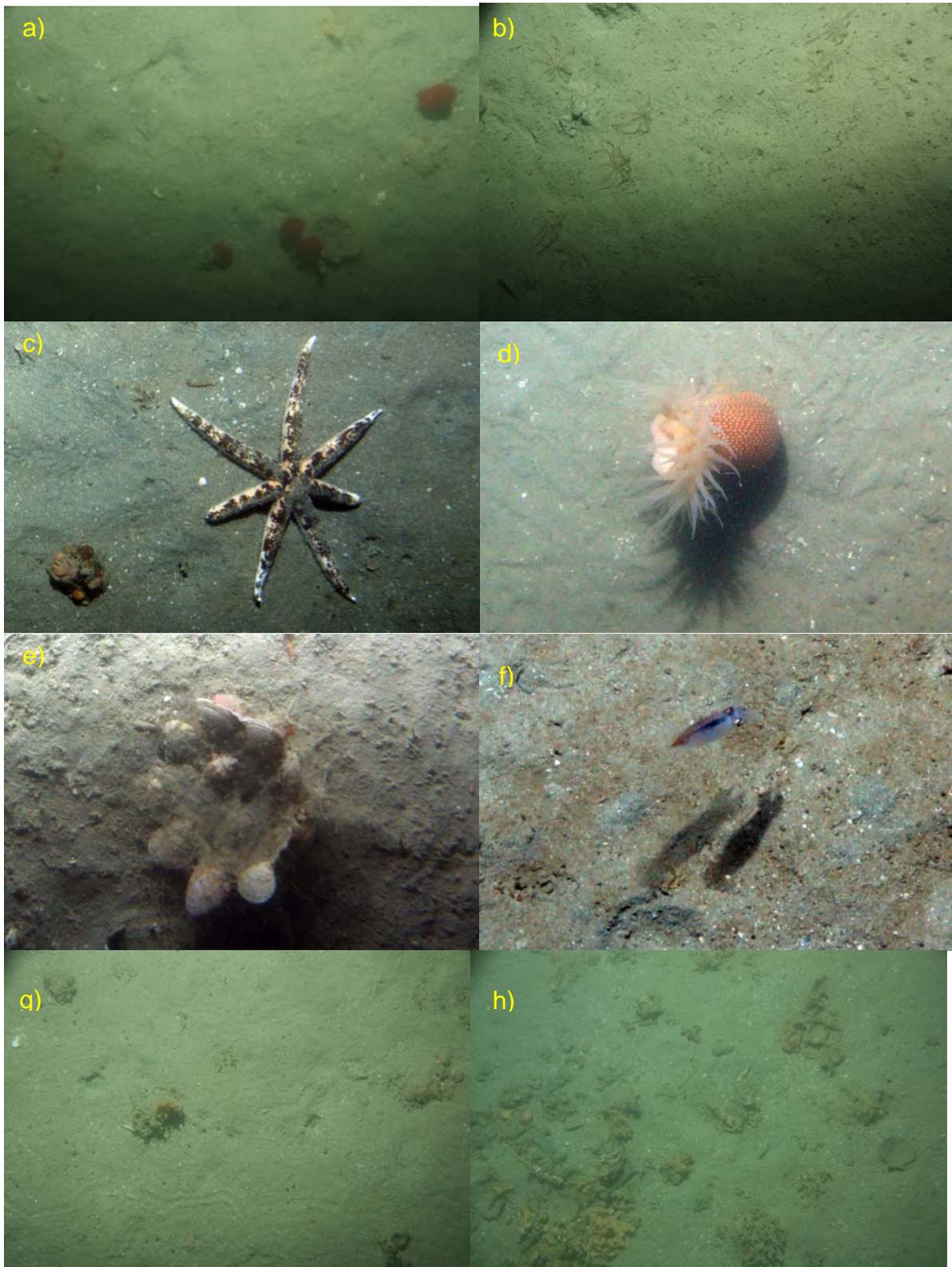


Figure 3: Examples of other invertebrates seen: a) compound ascidian *Synoicum kuranui*; b) crinoids *Argyrometra mortenseni*; c) starfish *Luidia australiae*; d) wandering anemone (unidentified sp.); e) carrier shell (gastropod *Xenophora neozelanica*) (upside down, likely to

be dead shell); f) unidentified small squid; g, h) examples of 'indeterminate biogenic clumps' and sponges.

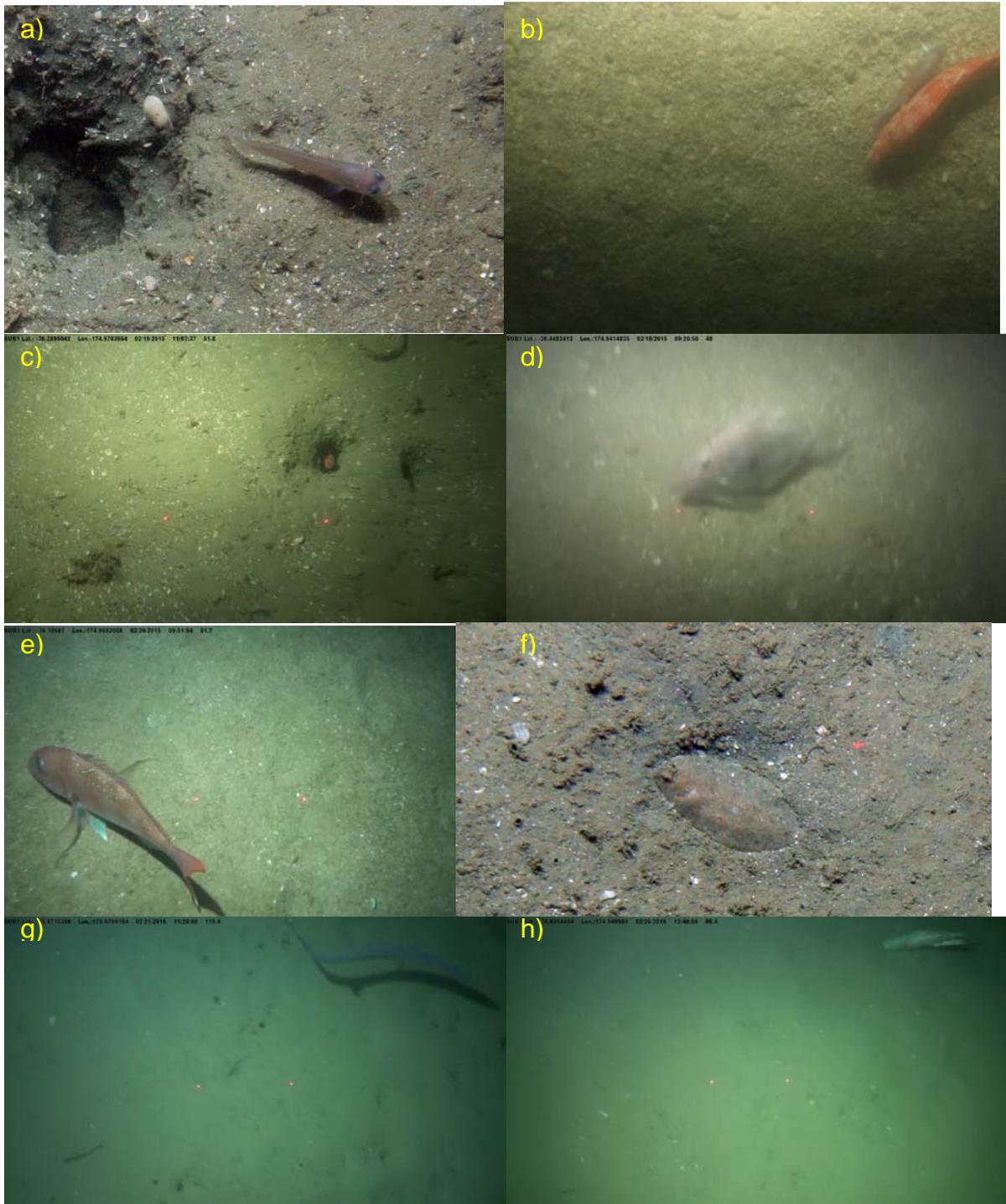


Figure 4: Example of fish seen: a) small morid cod, unidentified sp.; b) red mullet and morid cod; c) red bandfish in burrow; d) John dory; e) snapper; f) unidentified small flatfish (probably witch); g) unidentified silver eel; h) snake eel.

3.2 General description of the seafloor types

A general visual overview of the soft sediment types present is given in Appendix A. Broadly speaking, blocks A (35–54m water depth) and B (48–61 m) appeared to have a seafloor of muddy fine sands with variable but limited shell grit components. Block C (40–55 m), due west of Little Barrier Island, appeared to have a higher shell grit component, in agreement with the higher calcium carbonate sediment components recorded by Manighetti and Carter (1999) for this area. Blocks D (75–89 m) and E (119–129 m) appeared to be composed of finer muds, with evidence of trawl marks at two sampling segment stations, both outside of the CPA (see the linear depressions present in two images, Appendix A). As no bottom contact sampling was conducted, these sediment classes are based on visual observations only, but are based on experience with previous seafloor mapping projects where both visual and physical sampling was undertaken.

3.3 Univariate measures

3.3.1 Benthic invertebrate data

Species richness (the average number of species per sampling segment) was modest (Figure 5). Higher richness was seen in blocks A to C, and ranged from c. 4 to 7 species. Combined species abundances showed a similar trend, with blocks A to C having c. 0.25 to 0.75 organisms per 100 m², which dropped to less than 0.2 for blocks D and E. The other species diversity indices showed different patterns across the blocks, with species evenness slowly increasing across blocks A to D, before dropping at block E, and Shannon's H, and Hill's N1 and N2 showed a moderate parabolic response across the five blocks.

At the individual species/OTU level, the compound ascidian *S. kuranui* was present in Blocks A and B (the latter outside the CPA only), and absent from blocks C–E (Figure 6), possibly due to its need to attach to hard surfaces (e.g., dead shells). This may also explain why brachiopods were also largely confined to blocks A and B. Free-standing sponges and encrusting sponges (multiple combined species for each) were present across the blocks, but were less abundant with increasing depth and associated muddiness. Indeterminate biogenic clumps were most abundant across blocks A–C, and largely absent from the two deeper, muddier blocks. Cup corals showed a similar pattern, while carrier shells and hermit crabs were largely found in blocks B–D, and shrimps became more common in the deeper muddy blocks of D to E. Taxa largely restricted to one block included scallops in block C,

and crinoids in block E. It is useful to note that the density values (by taxa) reported are averages across the relevant 200m sampling segments; it was evident from the imagery that a number of species were patchy at finer scales (within the 200m sampling segments). However, even within these small higher density patches, densities were still relatively low.

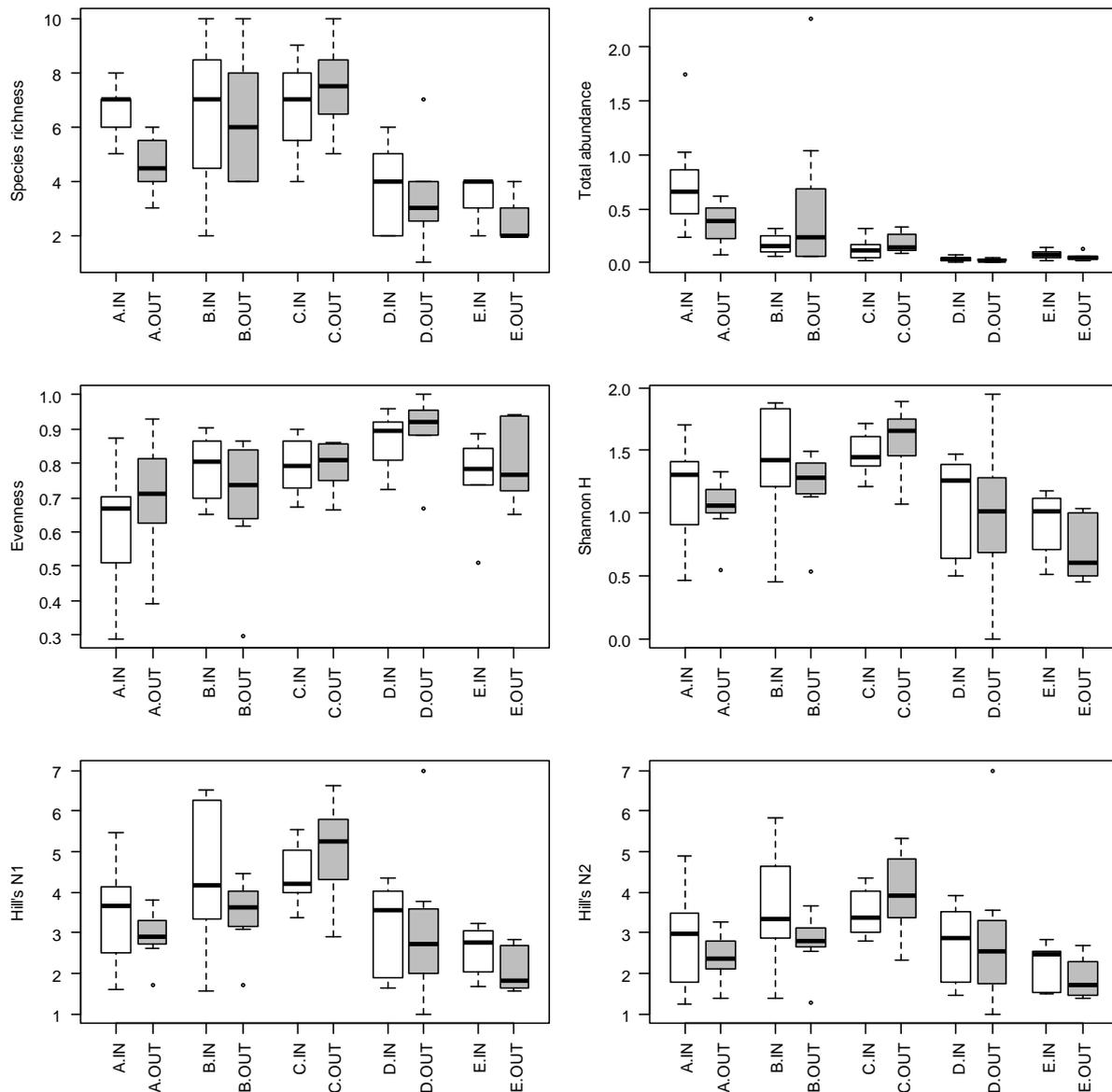


Figure 5: Boxplots of benthic invertebrate assemblage diversity and abundance measures across the five sampling blocks, divided into inside (A.IN–E.IN) and outside (A.OUT–E.OUT) the CPA. Plotted are species richness, total abundance, evenness, Shannon H, Hill's N1, and Hill's N2. Thick horizontal black lines are medians, upper and lower boxes cover the upper and lower quartiles, the error bars are upper and lower adjacent values, and the dots outliers beyond this. Clear shading, inside CPA; grey shading, outside CPA. The upper (lower) adjacent value is the largest (smallest) observation that is less (greater) than or equal to the upper (lower) quartile plus (minus) 1.5 times the interquartile range.

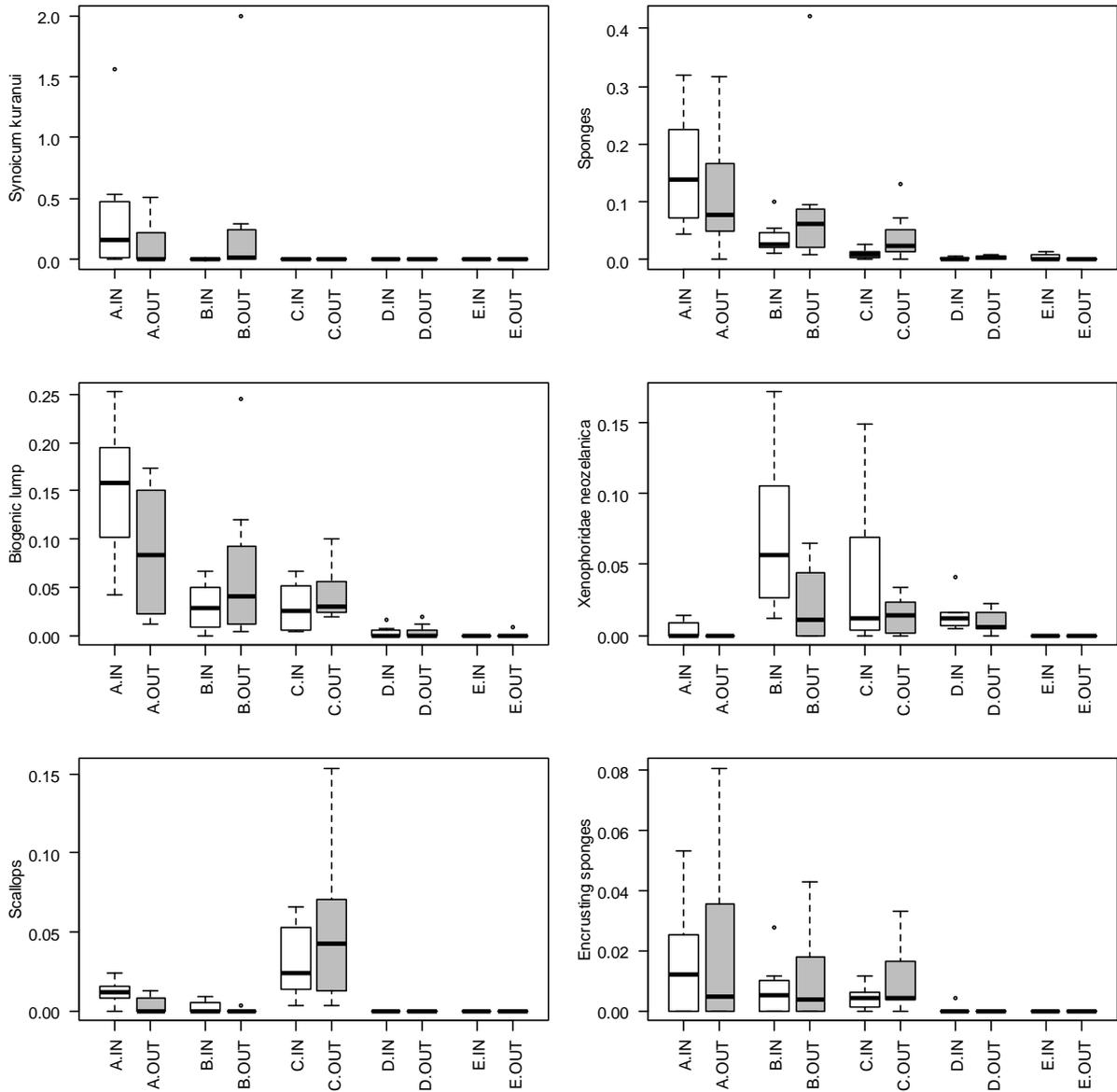


Figure 6: Individual taxa/OTU densities across the five sampling blocks, divided into inside (A.IN-E.IN) and outside (A.OUT-E.OUT) the CPA. Plotted are *Synoicum kuranui* (red compound ascidian), sponges, indeterminate biogenic clumps, the carrier shell *Xenophora neozelanica*, scallops, and encrusting sponges. Thick horizontal black lines are medians, upper and lower boxes cover the upper and lower quartiles, the error bars are the upper and lower adjacent values, and the dots outliers beyond this. Clear shading, inside CPA; grey shading, outside CPA. The upper (lower) adjacent value is the largest (smallest) observation that is less (greater) than or equal to the upper (lower) quartile plus (minus) 1.5 times the interquartile range.

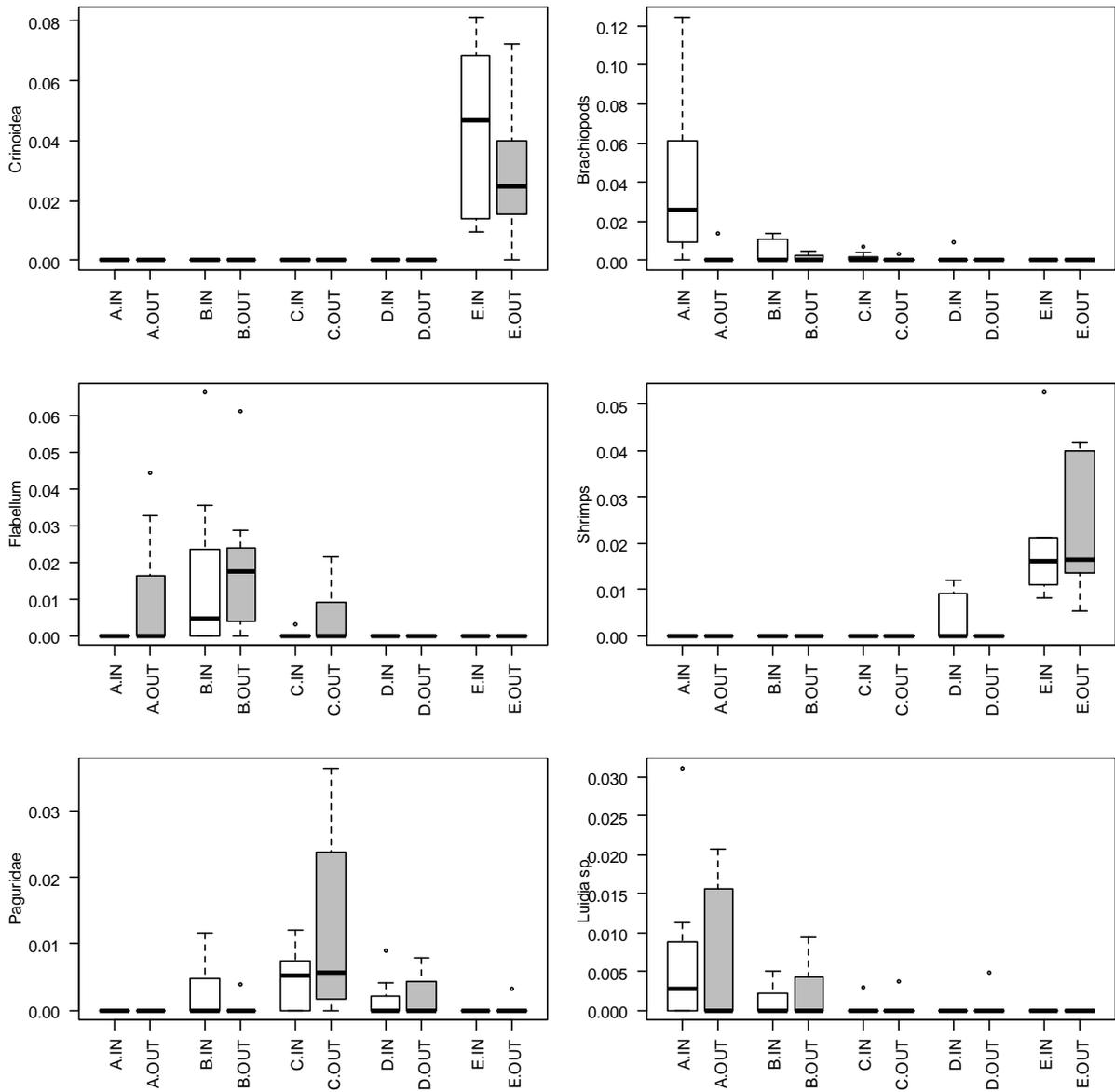


Figure 6 continued: Individual taxa/OTU densities across the five sampling blocks, divided into inside (A.IN-E.IN) and outside (A.OUT-E.OUT) the CPA. Plotted are the crinoid *Argyrometra mortenseni*, brachiopods, cup corals, shrimps, hermit crabs, and the starfish *Luidia australiae*. Thick horizontal black lines are medians, upper and lower boxes cover the upper and lower quartiles, the error bars are the upper and lower adjacent values, and the dots outliers beyond this. Clear shading, inside CPA; grey shading, outside CPA. The upper (lower) adjacent value is the largest (smallest) observation that is less (greater) than or equal to the upper (lower) quartile plus (minus) 1.5 times the interquartile range.

Linear modelling of the univariate invertebrate indices and individual taxa/OTUs revealed a range of significant influences (Table 2). Significant effects of block location and/or depth (the two are correlated) were almost universal across all of the response variables assessed, along with lesser occurrences of effect for east versus

west, burrow density, mud dominance, being inside/outside of the CPA, and interactions between subsets of these variables. Collectively, the direction and magnitude of these numerous effects are very hard to capture in a simple table (including between individual block comparisons), and so for clarity the reader is referred back to the visual boxplot representations in Figures 5 and 6.

Table 2: Significant explanatory variables from linear modelling of the invertebrate data.

Index / taxa / OTU							Explanatory variable
	Block	Depth	East/West	Burrows	Mud	Inside/outside	Interactions
Richness	✓		✓			✓	
Abundance	✓		✓		✓	✓	✓
Evenness	✓	✓		✓			
Shannon H	✓	✓	✓			✓	
Hill's N1	✓	✓	✓			✓	
Hill's N2	✓	✓					
<i>Synoicum kuranui</i>	✓	✓	✓			✓	✓
Sponge (Demospongiae)	✓	✓			✓	✓	
Indet. biogenic clump	✓	✓	✓			✓	✓
<i>Xenophora neozelanica</i>	✓				✓	✓	
Scallops (<i>Pecten</i>)	✓					✓	✓
Encrusting sponges	✓				✓		
Crinoidea		✓	✓				
Brachiopods	✓					✓	✓
Shrimps	✓	✓				✓	✓
Paguridae	✓		✓				
<i>Luidia australiae</i>		✓			✓		

3.3.2 Demersal fish data

Fish species richness (the average number of species per sampling segment) was modest (Figure 7). There was a trend of increasing fish species richness across blocks A to E with increasing water depth, which was also matched by fish abundance (although densities were relatively modest). The highest species richness, in blocks D and E, ranged from c. 5 to 7 species. Species Evenness did not show a depth-related trend, dipping in value at block C. Shannon's H, and Hill's N1

and N2 showed a moderate general increase across the block locations with increasing depth (Figure 7).

At the individual species/OTU level, silver conger eels, small benthic fishes (largely opalfish spp.), eel sp. 2, and a small unidentified morid cod species were widespread across the five sampled blocks (Figure 8). Red bandfish were more abundant in the deeper muddier blocks of D and E, along with small gurnards (probably scaly gurnard). Small flatfish (probably witch, *Arnoglossus scapha*) occurred across blocks B to E, while snapper were seen across the three shallower and less muddy blocks of A to C. Red mullet were uncommon and only seen at blocks A and C, while red gurnard occurred at very low densities across blocks A to D. Sea perch were only seen in the deepest block E, while leatherjacket were only observed at block C (Figure 8).

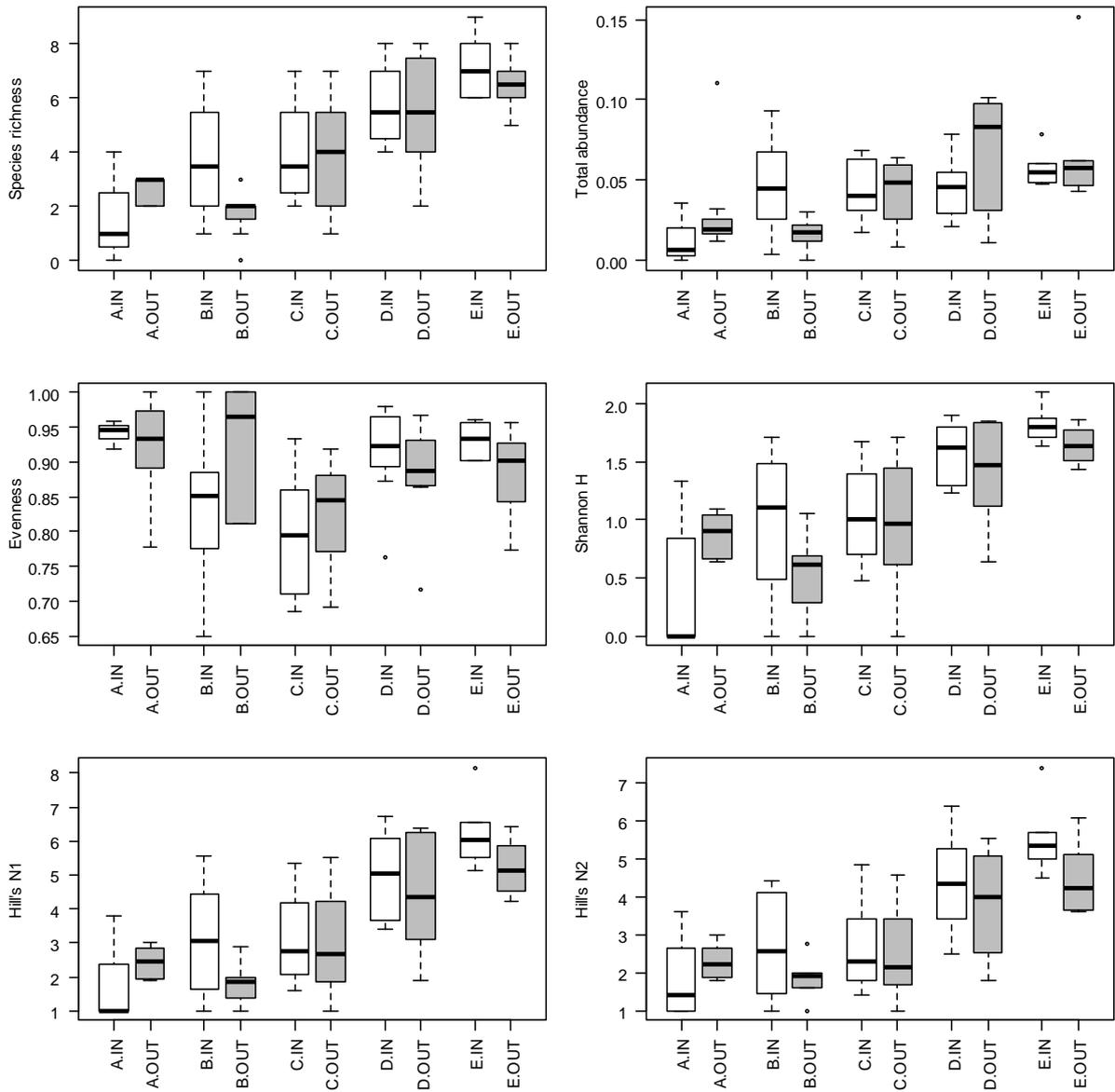


Figure 7: Boxplots of demersal fish assemblage diversity and abundance measures across the five sampling blocks, divided into inside (A.IN-E.IN) and outside (A.OUT-E.OUT) the CPA. Plotted are species richness, total abundance, evenness, Shannon H, Hill's N1, and Hill's N2. Thick horizontal black lines are medians, upper and lower boxes cover the upper and lower quartiles, the error bars are the upper and lower adjacent values, and the dots outliers beyond this. Clear shading, inside CPA; grey shading, outside CPA.

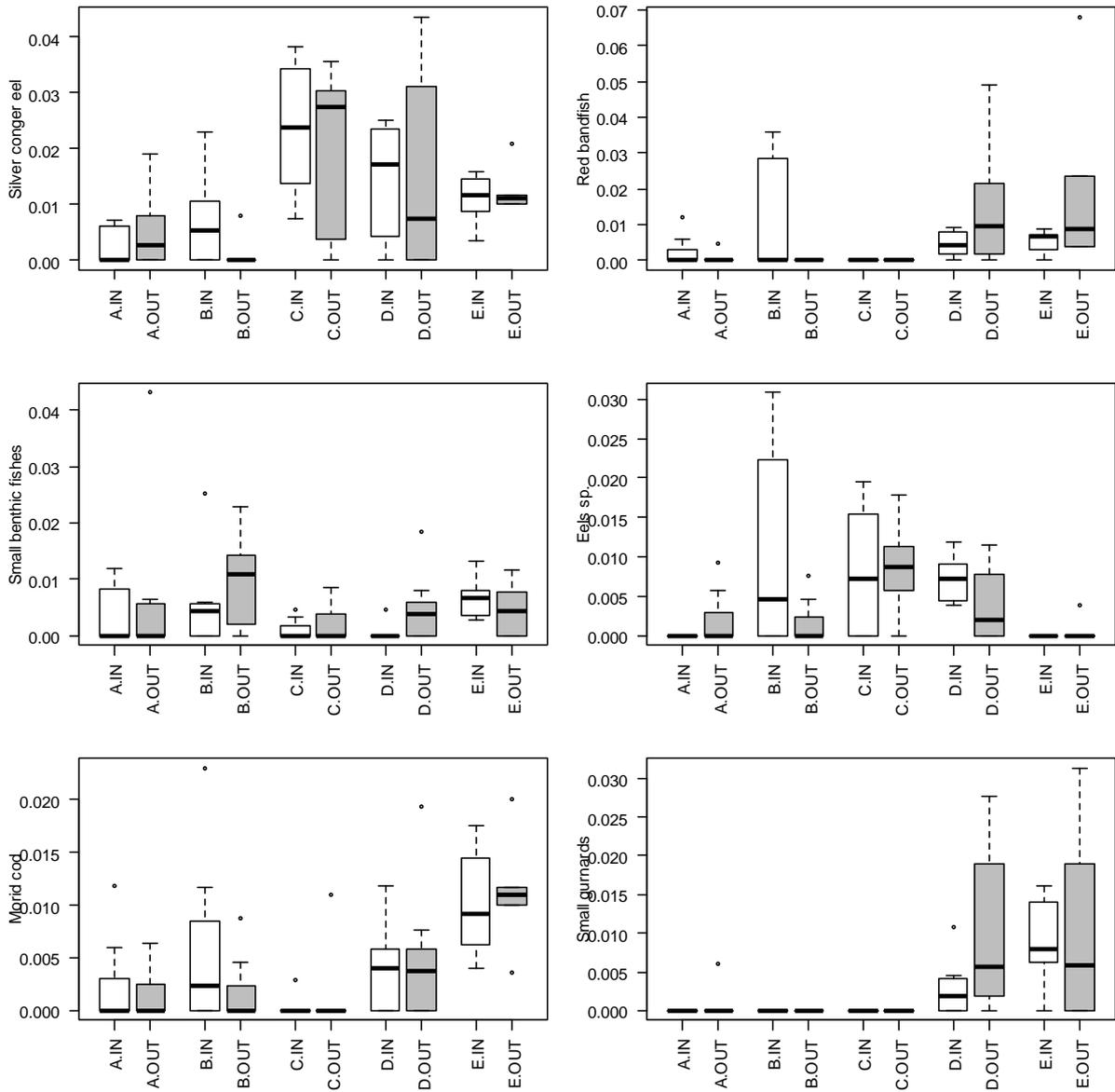


Figure 8: Individual fish taxa/OTU densities across the five sampling blocks, divided into inside (A.IN-E.IN) and outside (A.OUT-E.OUT) the CPA. Plotted are silver conger eel, red bandfish, small demersal fishes (probably mainly opalfish), eel sp., small morid cod, and small gurnards (probably scaly gurnard). Thick horizontal black lines are medians, upper and lower boxes cover the upper and lower quartiles, the error bars are the upper and lower adjacent values, and the dots outliers beyond this. Clear shading, inside CPA; grey shading, outside CPA. The upper (lower) adjacent value is the largest (smallest) observation that is less (greater) than or equal to the upper (lower) quartile plus (minus) 1.5 times the interquartile range.

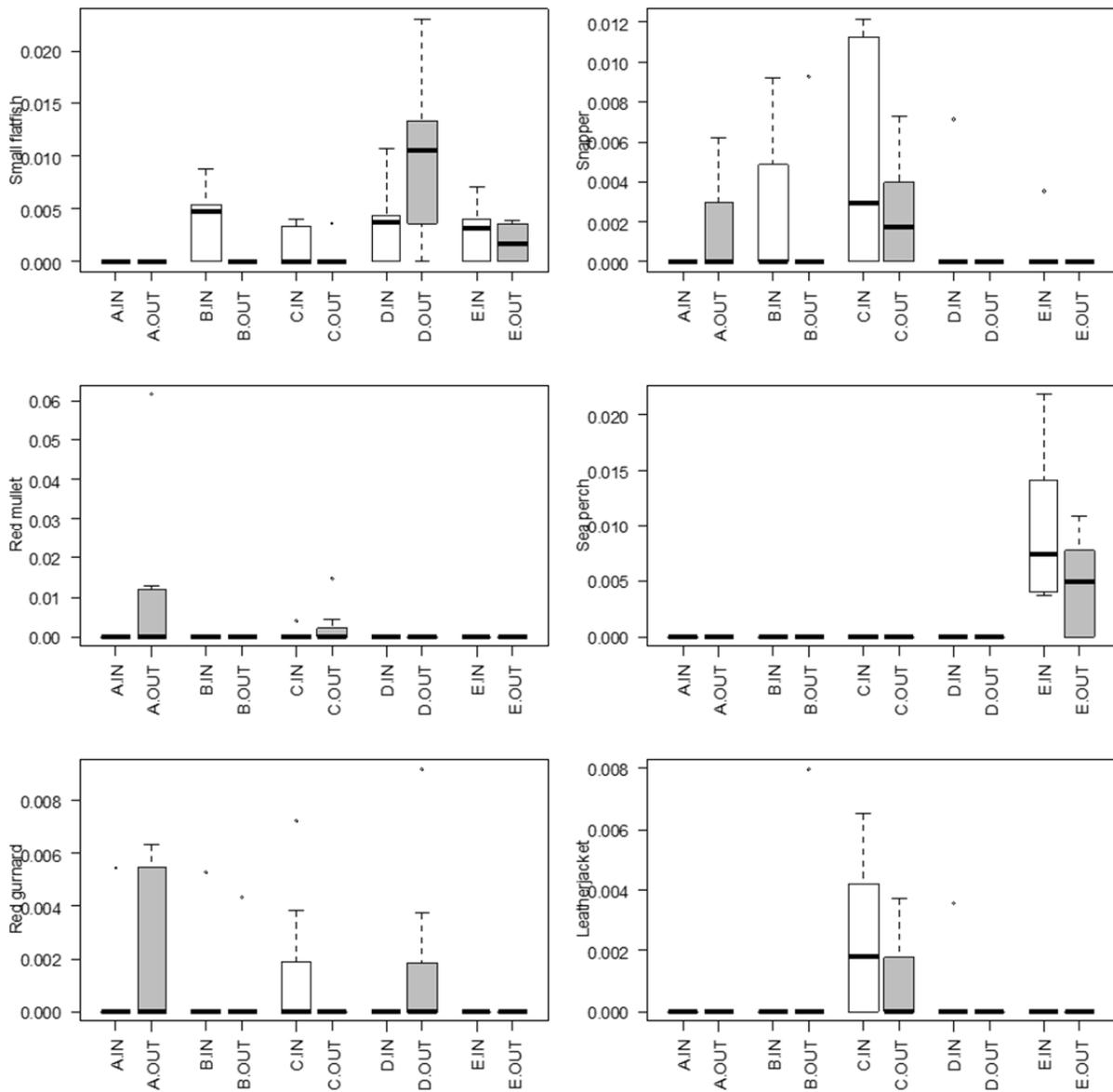


Figure 8 continued: Individual fish taxa/OTU densities across the five sampling blocks, divided into inside (A.IN-E.IN) and outside (A.OUT-E.OUT) the CPA. Plotted are small flatfish, snapper, red mullet, sea perch, red gurnard, and leatherjacket. Thick horizontal black lines are medians, upper and lower boxes cover the upper and lower quartiles, the error bars are the upper and lower adjacent values, and the dots outliers beyond this. Clear shading, inside CPA; grey shading, outside CPA. The upper (lower) adjacent value is the largest (smallest) observation that is less (greater) than or equal to the upper (lower) quartile plus (minus) 1.5 times the interquartile range.

As with the invertebrate data, linear modelling of the univariate fish indices and individual taxa/OTUs revealed a range of significant influences (Table 3). Significant effects of block identity and/or depth (the two are correlated) were almost universal across all of the response variables assessed, along with lesser occurrences of

effect for east versus west, burrow density, mud dominance, being inside/outside of the CPA, and interactions between subsets of these variables. The reader is referred to the boxplot visual representations in Figures 7 and 8.

Table 3: Significant explanatory variables from linear modelling of the fish data

Index / taxa / OTU	Block	Depth	East/West	Burrows	Mud	Bio	Sponge	Inside/outside	Explanatory variable
									Interactions
Richness		✓				✓		✓	
Abundance	✓	✓	✓					✓	✓
Evenness	✓		✓						
Shannon H	✓					✓			
Hill's N1		✓				✓		✓	
Hill's N2		✓		✓		✓		✓	
Silver conger eel	✓				✓			✓	
Red bandfish	✓							✓	✓
Small demersal fish	✓			✓	✓				
Eels sp. 2	✓		✓	✓		✓	✓	✓	✓
Morid cod		✓			✓				
Small gurnards	✓	✓		✓				✓	✓
Small flatfish	✓							✓	✓
Snapper		✓				✓		✓	
Red mullet		✓							
Sea perch	✓	✓		✓					
Leatherjacket			✓		✓				

3.4 Multivariate analyses

3.4.1 Invertebrate data

An MDS plot showed differences in invertebrate assemblages across the five sampling blocks, with blocks A and B showing the greatest overlap, followed by increasing ordination distance between blocks C, D, and E (Figure 9). For completeness, the sampling segments are displayed here as inside and outside entities, but statistical analyses are reserved for the latter DistLM/dbRDA1 approach. For all of the five blocks, between 2 and 5 taxa contributed more than 90 per cent of the within group similarity (see Table 4 for species/OTU contributions).

Benthic community

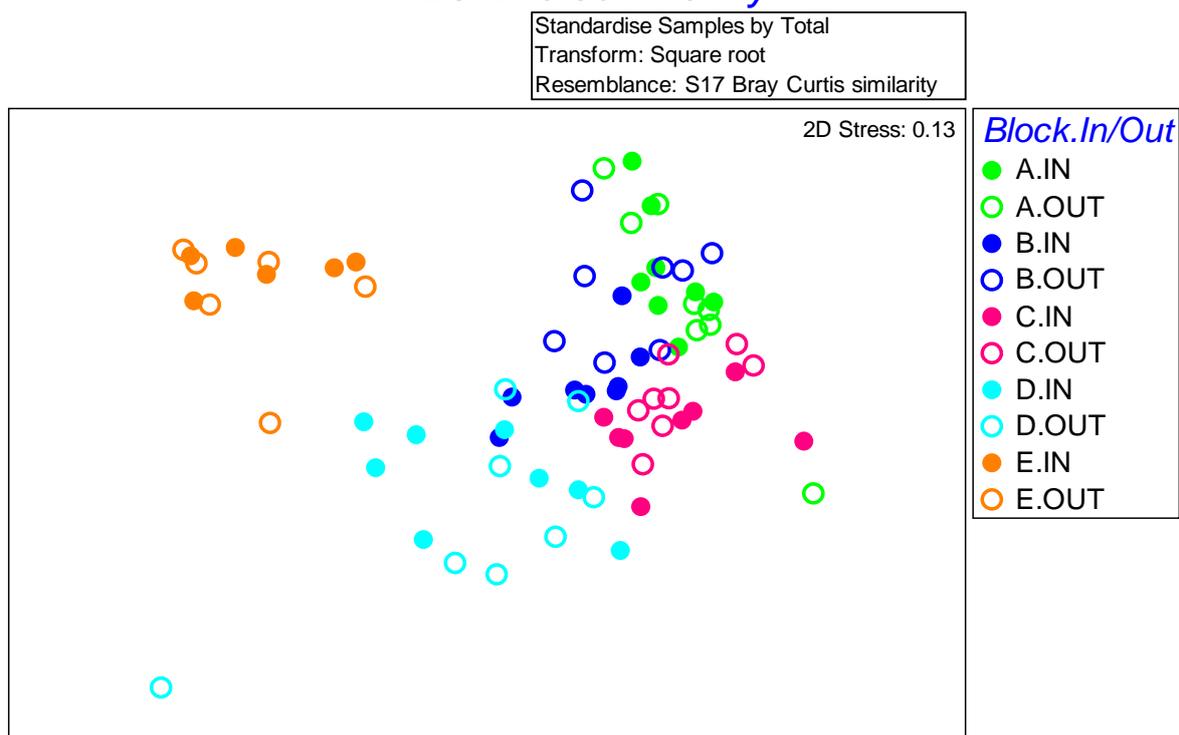


Figure 9: MDS plot of invertebrate data from the five sampling blocks and status interactions.

Table 4: Invertebrate taxa/OTU contributions to within-group similarity within each of the five sampling blocks from the SIMPER analysis. For each block, these are listed in descending level of contribution to within-group similarity. Av. Abund, average abundance across sample replicates; Av. Sim, average similarity across sample replicates; Sim/SD, similarity divided by the standard deviation across sample replicates; %Contrib., how much the individual species contributes to overall within group similarity; Cum. %; cumulative contribution of all species at this point in descending species abundances.

Taxa/OTU	Av. Abund	Av. Sim	Sim/SD	%Contrib.	Cum.%
Block A					
Indeterminate biogenic clump	4.96	18.29	2.23	33.03	33.03
Sponge (Demospongiae)	4.68	17.55	2.08	31.69	64.72
<i>Synoicum kuranui</i>	3.99	9.00	0.60	16.24	80.96
Brachiopods	1.24	3.04	0.73	5.49	86.45
Scallop (<i>Pecten</i>)	0.99	2.75	0.79	4.97	91.42
Block B					
Sponge (Demospongiae)	4.76	19.42	2.85	33.83	33.83
<i>Xenophora neozelanica</i>	4.24	14.76	1.27	25.71	59.54
Indeterminate biogenic clump	3.67	11.19	1.47	19.49	79.03
<i>Synoicum kuranui</i>	2.00	4.07	0.41	7.08	86.11
Cup coral (<i>Flabellum</i> sp.)	1.96	3.98	0.83	6.92	93.04
Block C					
Scallop (<i>Pecten</i>)	4.92	17.20	2.38	28.84	28.84
Indeterminate biogenic clump	4.75	16.41	3.47	27.52	56.37
Sponge (Demospongiae)	2.96	7.88	1.13	13.22	69.58
<i>Xenophora neozelanica</i>	3.32	7.62	0.87	12.78	82.36
Encrusting sponges	1.88	5.31	1.25	8.90	91.26
Block D					
<i>Xenophora neozelanica</i>	5.97	27.04	2.14	73.63	73.63
Echinoid (urchin)	1.79	2.25	0.29	6.14	79.77
Indeterminate biogenic clump	1.62	2.01	0.27	5.47	85.25
Sponge (Demospongiae)	1.58	1.60	0.29	4.36	89.61
Crustacean (shrimp)	1.20	1.43	0.20	3.89	93.50
Block E					
Crinoidea	6.80	33.50	1.90	50.30	50.30
Crustacean (shrimp)	5.90	30.70	3.10	46.10	96.40

A DistLM analysis showed a very clear separation of the five sampling blocks based on their invertebrate fauna, aside from some overlap between blocks B and C (Figure 10). The first axis explained 33.8 per cent of the variation, while the second axis explained a further 17.1 per cent. Most of the overall cumulative explained variance was contributed by a block effect (56.9%), followed by depth (2.4%), proportion mud (1.2%), and finally, a small CPA effect (1.3%) (Table 5). Effectively this meant that the CPA effect was very small, relative to other environmental drivers.

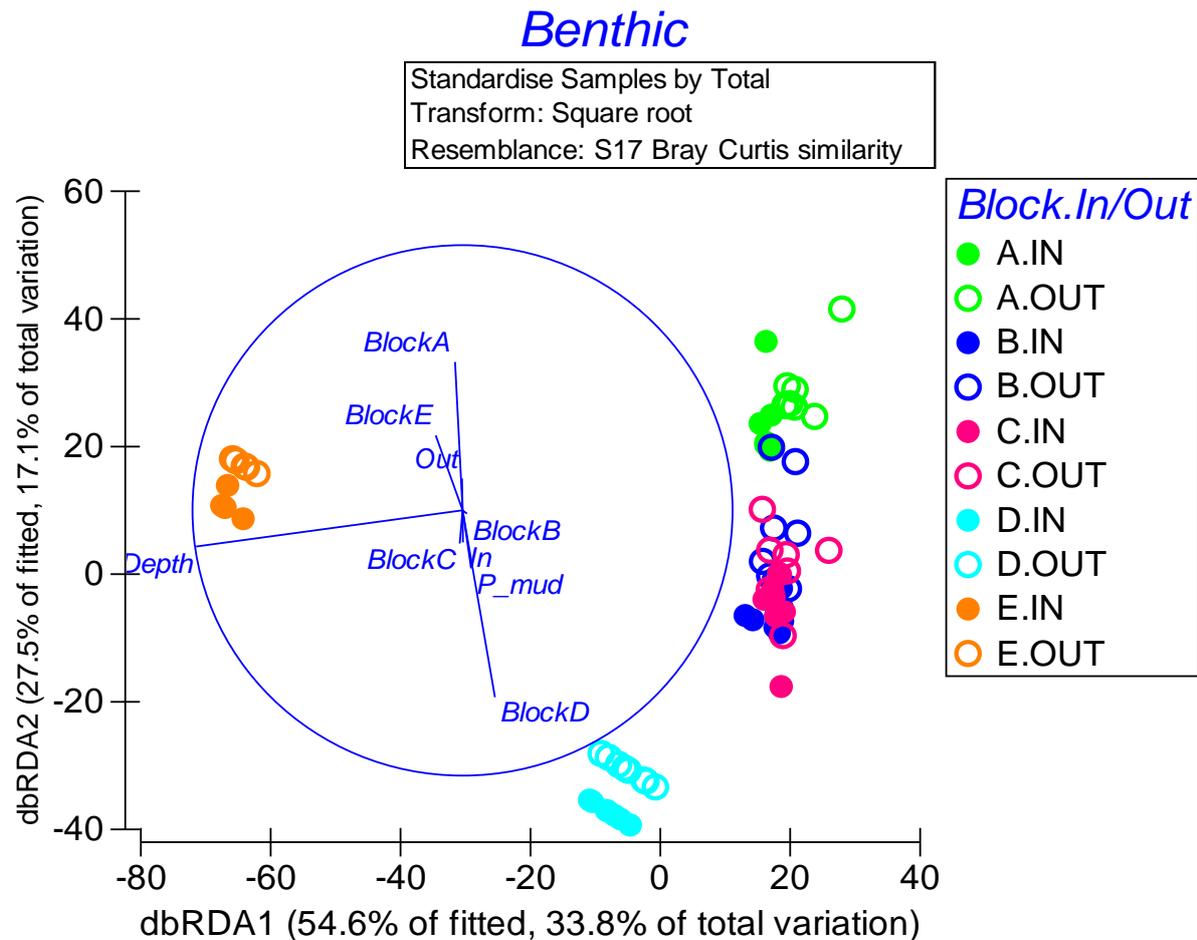


Figure 10: DistLM plot for the invertebrate assemblage data. Vectors (partial correlations) show the relative magnitude of effect for the different explanatory variables, taking into account the other variables; the direction indicates the influence of that variable with each axes and the longer the line, the greater the influence.

Table 5: Results from DISTLM analysis: marginal (when fitted on its own), partial (fitted in order in the final model) and cumulative contributions to overall variance for invertebrate assemblage data

Term	Marginal	Partial	Cumulative
Block	0.569	0.569	0.569
Depth	0.333	0.024	0.594
P mud	0.103	0.012	0.606
Protection (In/Out)	0.014	0.013	0.619

3.4.2 Fish data

An MDS plot of the fish data showed a much less ordered change across blocks than for the invertebrate data, with a large degree of overlap across the blocks, although block E showed less variability than the others (Figure 10).

For all of the five blocks, between 4 and 7 taxa contributed more than 90 per cent of the within group similarity (see Table 6 for species/OTU contributions).

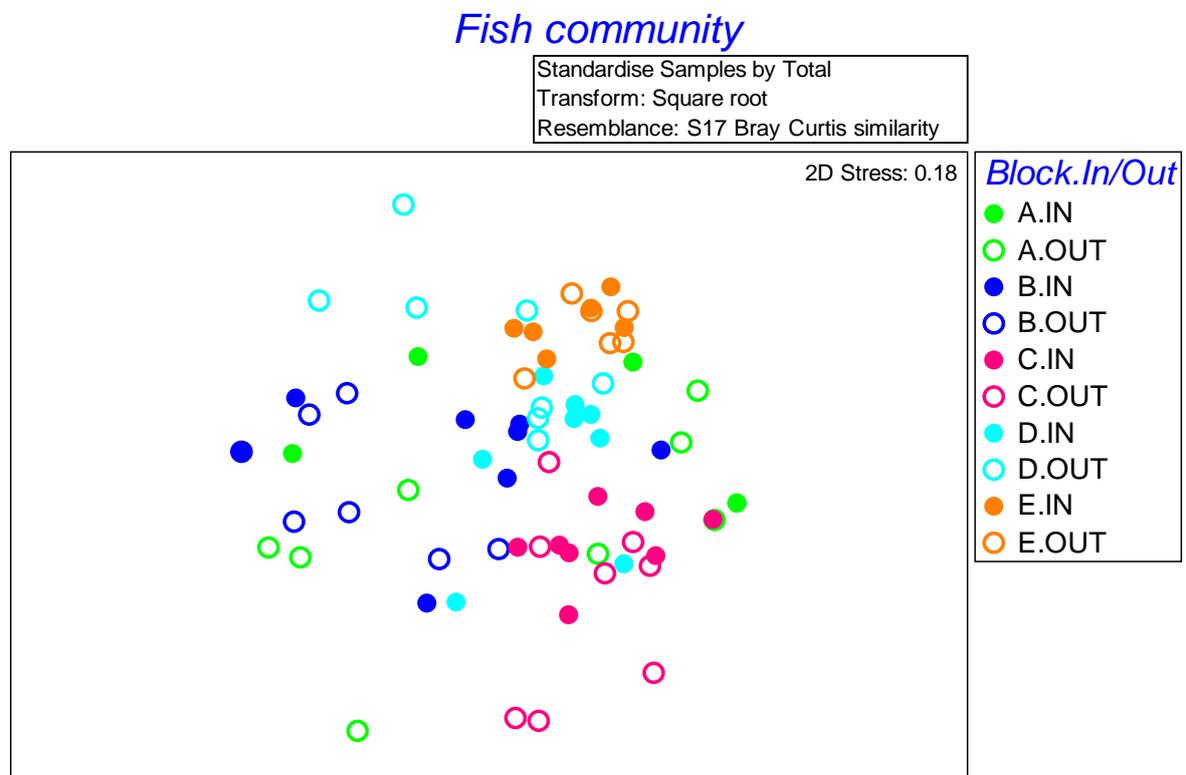


Figure 11: MDS plot of fish data from the five sampling blocks

Table 6: Fish taxa/OTU contributions to within group similarity within each of the five sampling blocks from the SIMPER analysis. For each block, these are listed in descending level of contribution to within group similarity. Av. Abund, average abundance across sample replicates; Av. Sim, average similarity across sample replicates; Sim/SD, similarity divided by the standard deviation across sample replicates; %Contrib., how much the individual species contributes to overall within group similarity; Cum. %; cumulative contribution of all species at this point to overall within group similarity.

Taxa/OTU	Av. Abund	Av. Sim	Sim/SD	%Contrib.	Cum.%
Block A					
Silver conger eel	3.69	11.18	0.43	51.13	51.13
Small demersal fish	2.92	3.74	0.33	17.11	68.24
Red mullet	1.62	2.25	0.23	10.28	78.52
Eels	0.92	1.77	0.23	8.08	86.60
Red gurnard	1.56	1.54	0.23	7.03	93.62
Block B					
Small demersal fish	4.95	16.11	0.77	48.47	48.47
Eels	2.33	4.24	0.44	12.77	61.24
Small flatfish	1.11	3.66	0.61	11.01	72.24
Red bandfish	1.28	3.64	0.40	10.96	83.21
Silver conger eel	1.87	3.19	0.44	9.59	92.80
Block C					
Silver conger eel	6.19	25.77	1.36	54.73	54.73
Eels	3.56	12.18	0.99	25.85	80.58
Leatherjacket	1.10	3.31	0.55	7.04	87.62
Snapper	1.83	2.32	0.42	4.93	92.55
Block D					
Silver conger eel	4.05	10.04	0.96	20.85	20.85
Eels	2.86	8.72	1.08	18.10	38.96
Red bandfish	3.07	7.60	0.99	15.77	54.73
Small flatfish	3.03	6.61	0.79	13.72	68.45
Carangidae (Jacks)	2.04	4.11	0.63	8.53	76.99
Small morid cod	1.99	3.63	0.68	7.54	84.53
Small gurnards	2.02	3.33	0.46	6.92	91.45
Block E					
Silver conger eel	4.38	15.51	3.90	23.45	23.45
Small morid cod	4.11	13.45	4.63	20.34	43.79
Red bandfish	3.62	11.09	1.53	16.76	60.55
Sea perch	3.16	9.71	1.55	14.68	75.23
Small gurnards	2.97	6.38	0.79	9.64	84.87
Small flatfish	1.60	4.18	0.80	6.31	91.18

A DistLM analysis showed a reasonably clear separation of the five sampling blocks based on their fish fauna (Figure 12). The first axis explained 15.8 per cent of the variation, while the second axis explained a further 10.3 per cent. Most of the overall cumulative explained variance was contributed by a block effect (30.9%), followed a proportion mud effect (2.4%). Unlike the invertebrate assemblage, there was no CPA effect on the fish assemblages.

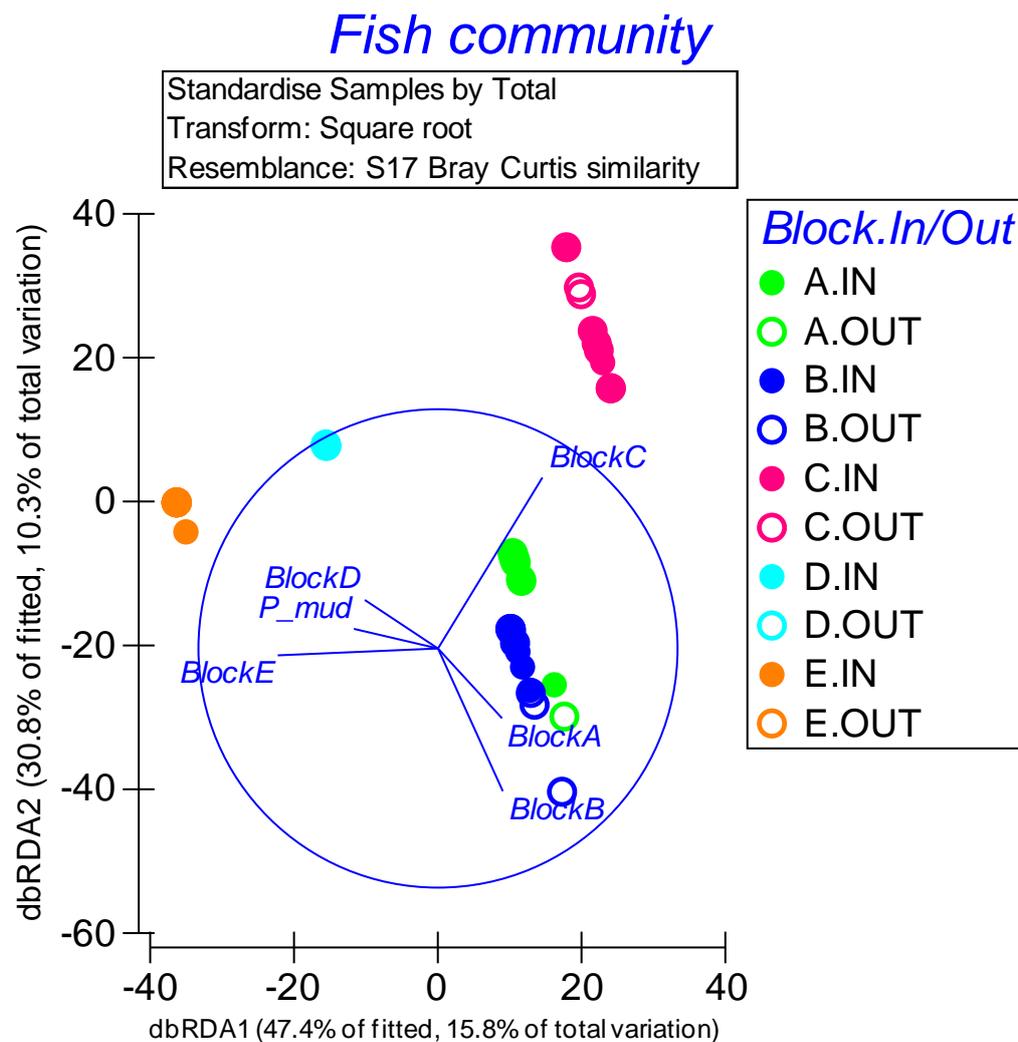


Figure 12: DistLM plot for the fish assemblage data. Vectors (partial correlations) show the relative magnitude of effect for the different explanatory variables taking into account the other variables; the direction indicates the influence of that variable with each axes and the longer the line, the greater the influence.

Table 7: Results from DISTLM analysis: marginal (when fitted on its own), partial (fitted in order in the final model) and cumulative contributions to overall variance for the fish assemblage data

Term	Marginal	Partial	Cumulative
Block	0.309	0.309	0.309
P mud	0.078	0.024	0.334

4.0 Discussion and conclusions

The invertebrate epifauna and demersal fish assemblages in and adjacent to the CPA were relatively modest (c.f., Jones et al., in review), both in terms of the number of species observed, and their relative abundances. While there was a weak effect of the CPA on the invertebrate assemblage, which explained 1.4 per cent of the variation present, its effect was ‘swamped’ by the larger effects of sampling block, water depth, and proportion of mud. There was no discernible effect of the CPA on the fish assemblages, consistent with the findings of Shears and Usmar (2006). This outcome may be due to a number of different mechanisms, but the overall conclusion is that the CPA does not presently have a significant effect on seafloor-associated species diversity and abundance. The sampling intensity was considered sufficient to detect any major changes in assemblage compositions and densities across the survey area, with generally high species and seafloor habitat homogeneity observed within any given sampling block.

The general lack of response of organisms to protection within the CPA is interesting. Past research on New Zealand marine reserves provides few clues. Although all marine reserves in mainland New Zealand include soft sediments, most are centred on shallow rocky reefs and almost all research on the effects of protection has focussed on this latter habitat. The few studies on (shallow water) soft sediments have targeted “halo effects” caused by reef-based predators like spiny lobsters (e.g., Langlois et al. 2005), rather than processes occurring wholly within the soft-sediment habitats, which are much more relevant for the CPA.

Previous research indicates that larger soft-sediment epifauna (e.g., sponges, horse mussels and bryozoans) are highly vulnerable to dredging and trawling, so it is likely that those organisms were either (1) rare in and around the CPA prior to fishing, or (2) once common but depleted by fishing or other factors, and slow to recover due to low recruitment and growth rates, or contemporary habitat change such as sedimentation. Without historical data, we cannot distinguish between these two possibilities. For example, horse mussels (*Atrina novaezelandiae*) occur across New Zealand’s continental shelf to water depths of greater than 100m (Morrison et al. 2014). None were observed across the five survey blocks, although the sediments in blocks A to C seemed to be suitable habitat (see Jones et al. b., in review). There are anecdotal historical accounts of this species being ‘conditioned’ (removed) on Hauraki Gulf and other fishing grounds through the use of towed steel hawsers and water-filled steel drums and bobbins (Jones et al. a, in review). Present day populations are still common in many shallower areas of the Hauraki Gulf such as

Omaha Bay (Taylor and Morrison 2008), Kawau Bay (M. Morrison, pers. obs.) and some areas around the inner Hauraki Gulf islands (Compton et al. 2012). Conceivably the distance from the CPA to possible larval supply/early life stage source populations might be playing a role in hindering species re-establishment, if the CPA is currently degraded. However, our poor knowledge of species distributions outside of the CPA and across the wider Hauraki Gulf, their life histories, and the dispersal/connectivity scales of relevance, makes this question problematic to address.

The apparent 'narrowness' of the CPA might prevent numbers of snapper and other fish species from building up if individuals are prone to straying across the boundaries and being removed by fishing. Although the CPA is much wider than the nearby Cape Rodney to Okakari Point (Leigh) Marine Reserve, where there have been large increases in legal-sized snapper (Willis et al. 2003), it appears that the widespread shallow rocky reef habitat inside the Leigh reserve "anchors" many individual fish to very small home ranges and reduces their losses to fishing (e.g., Parsons et al. 2003, 2010), while the lack of comparable structure in the CPA precludes a similar effect there. Broad-scale tagging of snapper populations in the Hauraki Gulf has shown that reef-associated snapper move relatively small distances, while snapper over open, relatively unstructured, soft sediments are much more mobile and move larger distances (Parsons et al. 2011, Morrison and Parsons, unpublished data). It is also not clear whether the timing of the survey (February) may have affected the densities of adult snapper, as this species undergoes large-scale migrations into shallower waters (< 50 m) during the warmest months of the year (i.e., in shallower depths than those encompassed by the survey).

Shears and Usmar (2006) tentatively attributed the lack of response of snapper to protection within the CPA in their 2004 survey to the young age of the CPA at the time (<4 years), illegal fishing within the CPA, and/or unsuitable habitat. This current survey did not cover their two areas of interest (shallow <30m muddy soft sediments south of Whangaparoa Peninsula, and the 30–50m depth patch reef complex known as North-West Reef) as they were outside the programme brief. As 11 years has elapsed since their survey, it would be useful to revisit North-West Reef, and see whether reef fishes, in particular snapper, have increased in abundance. This reef complex, along with the two small ones encountered in the current survey (as shown in Appendix B), probably represent most of the harder seafloor structure present inside the CPA. They also hold highly diverse and abundant biological assemblages, as seen from the limited available imagery. However, as non-soft sediment habitats, they were outside the survey objectives and soft sediments focus.

For the soft sediments surveyed, there are no historical data available against which to compare current day seafloor assemblages. This makes it problematic to determine how much present day assemblages differ from those existing prior to human influence, and we can only speculate on what changes humans have brought.

The presence of the 'indeterminate biogenic clumps' is of interest. As no direct physical sampling was possible, only visual estimations are possible. They appear to be a mixture of dead shell and other biogenic debris, along with some modest levels of living fauna including sponges, bryozoans, and possibly hydroids. It is not known whether these represent a stable state, or part of a trajectory of change, either increasing or decreasing over time. In Foveaux Strait, Cranfield et al. (2004) suggested a succession model of recovery after fishing ceased, in which the macrofauna (epifauna) passed through a series of compositions, each increasing in biological complexity. Its progress was dependent on both the time since fishing ceased and on the proximity of the sources of re-colonising propagules. It is possible that these indeterminate biogenic clumps represent a stage in succession, but equally they might simply represent relic material from the past, with low levels of present day fauna utilising the hard surfaces available,

The resources available for this programme only allowed counts to be made of these 'clumps', but a more robust approach in the future would be the estimation of proportion of cover, using still images. This would allow for monitoring of these features to see if they were growing in cover over time. However, the potentially very slow rate of recovery, if that is occurring, means that monitoring would need to be at the scale of decades.

A number of previously unknown species 'zones' for the outer Hauraki Gulf were revealed, including a relatively high abundance of several small eel species, red bandfish, and the crinoid *Argyrometra mortenseni* in the deeper blocks. These species have also been previously observed in abundance on the continental shelf further north, between North Cape and the Bay of Islands during the 2010 OS2020 programme (see www.OS2020.org.nz). It seems likely that they form a continuous faunal band along the upper north-eastern New Zealand continental shelf.

A suggestion for future investigation in the central to deeper Hauraki Gulf is to use sediment coring to: 1) assess the historical Sedimentation Accumulation Rate (SAR), including "Criminal Scene Investigation" (CSI) techniques to assess the influence of different land use types; and 2) the 'death assemblage' record left in the sediments. For instance, SAR work on the continental shelf adjacent to the Bay of Islands, at similar depths to this study, found sediments were accumulating at about 2 mm/yr, and suggested that the inner shelf environment was a major mud sink (Swales et al.

2010). As part of the same programme, CSI techniques focussed on the Bay of Islands proper, to assess the relative sediment contributions from different land use types, including native forest, exotic pine forests, grasslands and others (Gibbs and Olsen 2010). Such data for the Hauraki Gulf CPA would provide some fundamental knowledge on what benthic assemblages were once present in these areas, the sediment types they were associated with, and how both the sediments and associated fauna might differ from what is present today.

5.0 References

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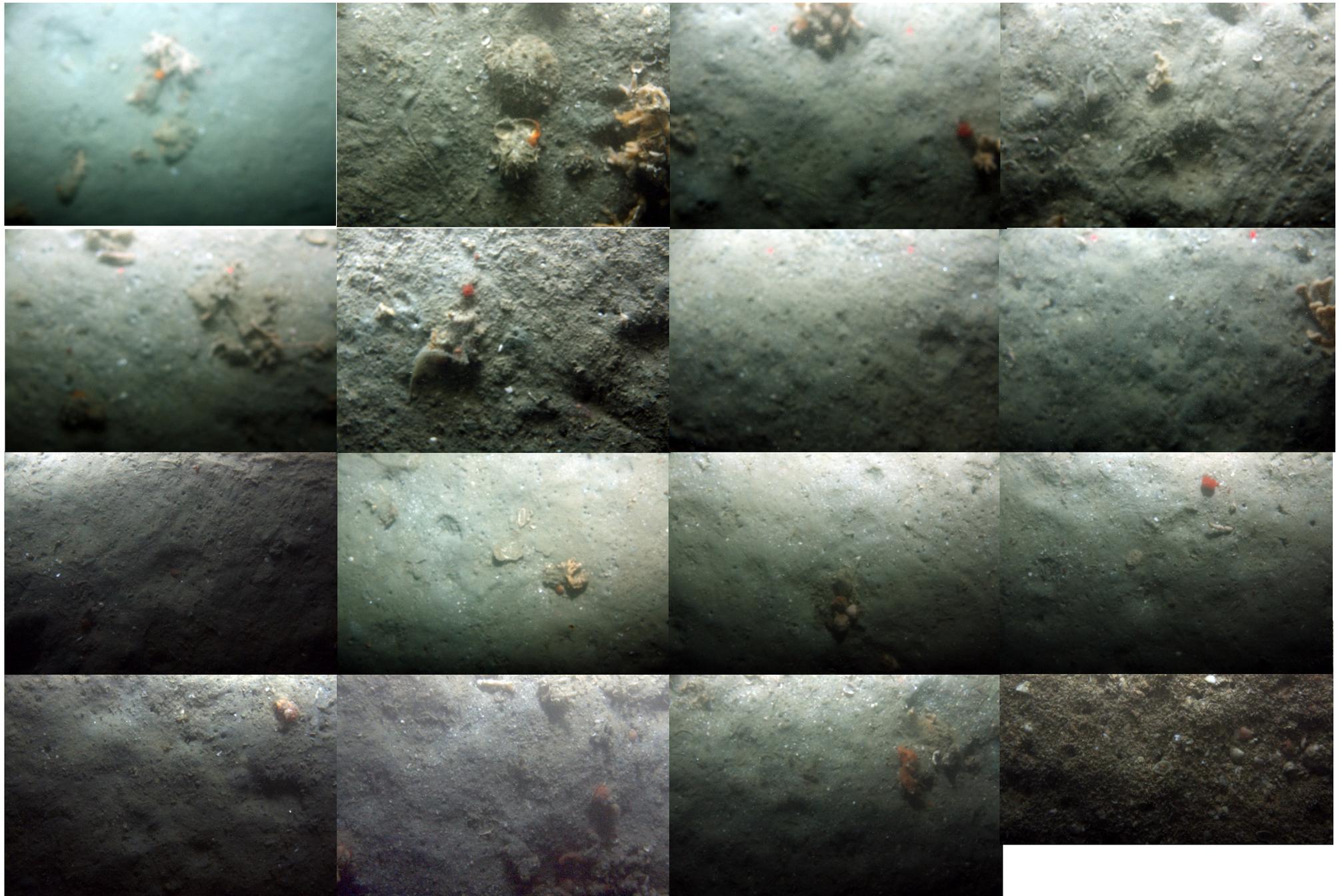
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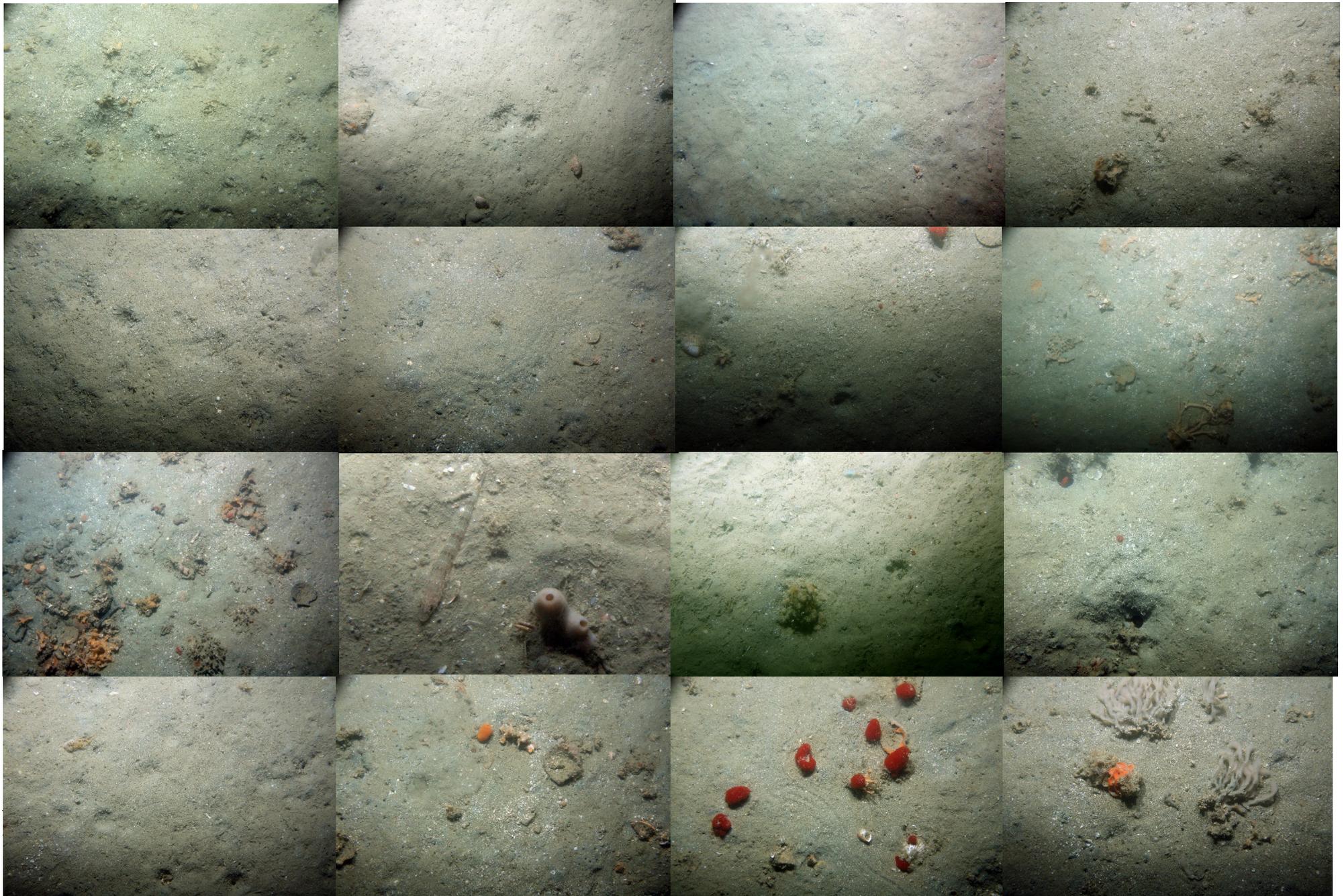
7.0 Appendix A: Representative soft sediment seafloor types

Each image represents one c 200m sampling segment, presented in the same spatial arrangement as in the block (see Figure 1). Note that while these are generic images of soft sediment type for each sampling segment, that images with epifauna present are not representative of 'average' faunal densities, as interesting images have been deliberately selected. Image scale varies: where two red laser dots are visible, these are 20cm apart.

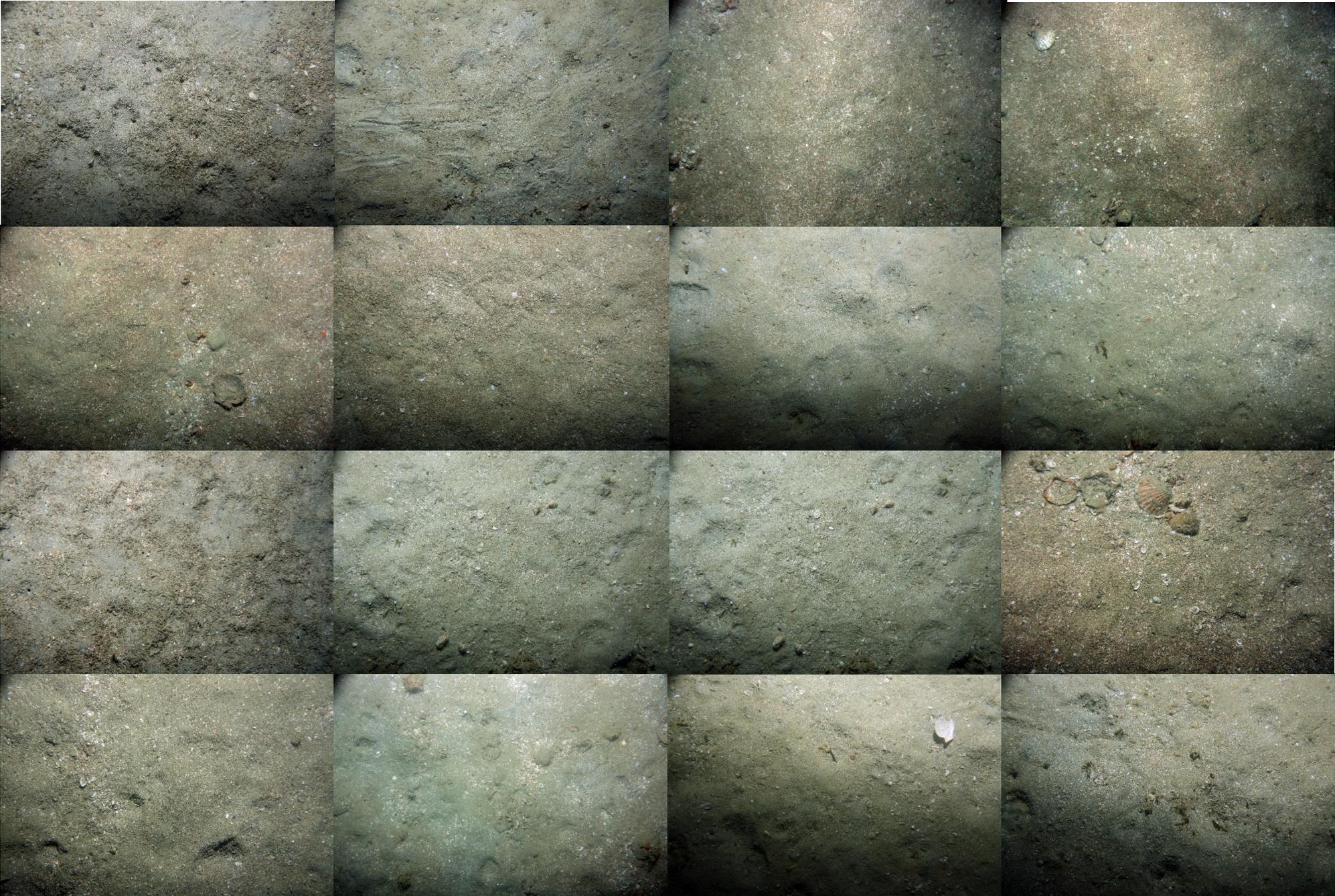
Block A



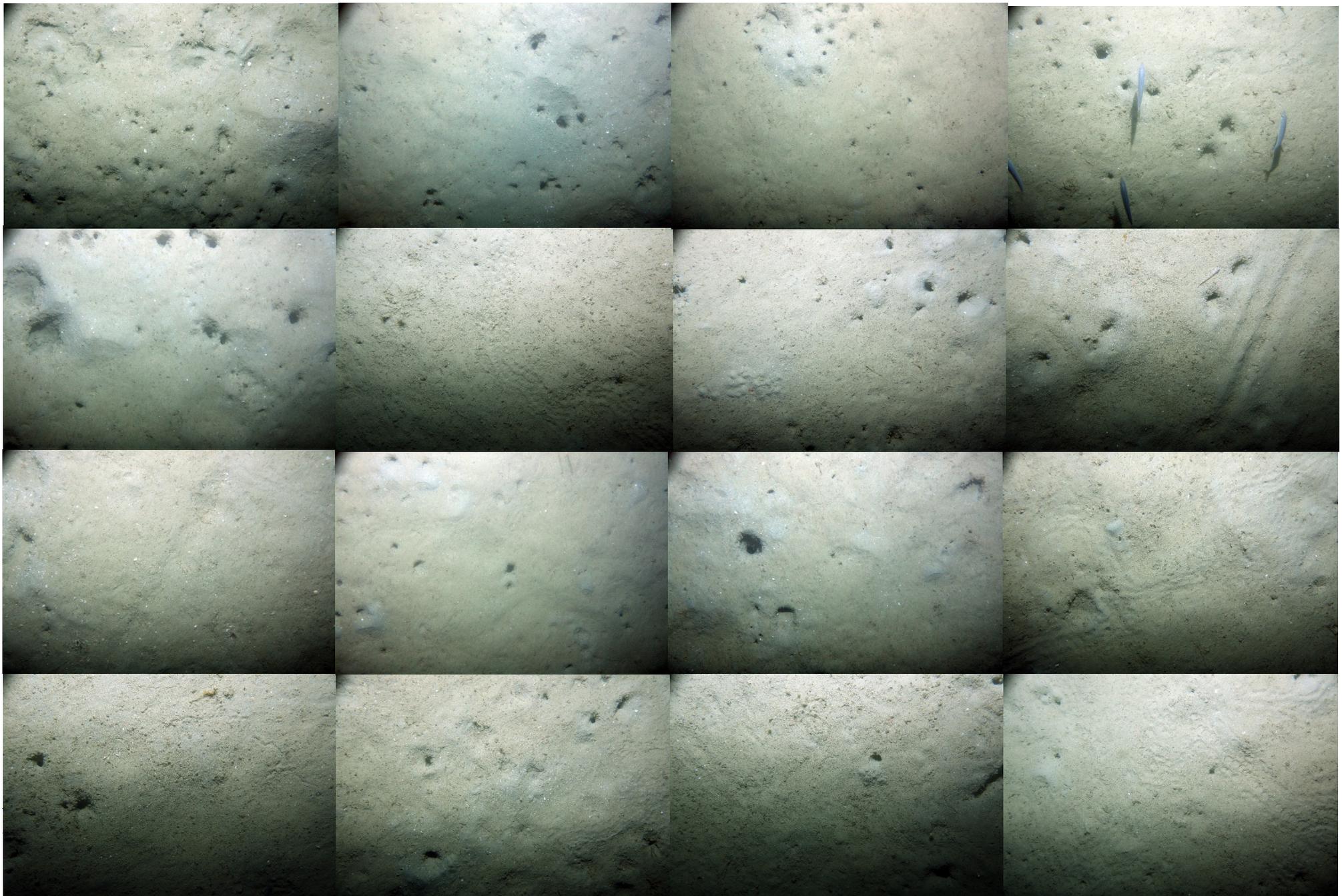
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Block C



Block D



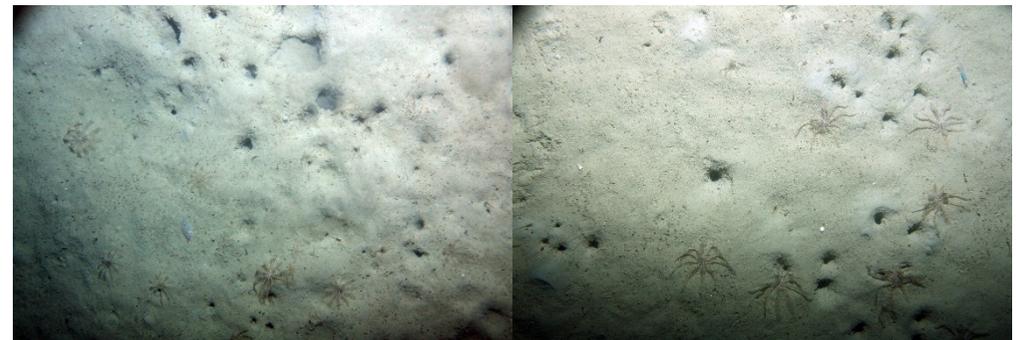
Block E



Transect not sampled



Not sampled



Still camera failed – video grabs shown



8.0 Appendix B: Reef habitats

While not part of the survey design, two areas of rocky reef were encountered during the sampling, and are included here for completeness. The first area occurred as small areas of low lying patch reef in c. 50m water depth, and held high densities of sponge species, as well as some red macroalgae and non-geniculate algae. Water clarity was high (Figure A top row). The second site was further out on the shelf, and seen on the survey vessels echo sounder outside of the transect proper. It was a much more rugged reef, rising 4–6m off the seafloor, with many steep slopes and small rides and ‘knolls’. It held a diverse fauna of sponges, and some black corals, along with abundant pink maomao (*Caprodon longimanus*) and butterfly perch (*Caesioperca lepidoptera*) (Figure A, bottom two rows). Collectively, both systems held high epifaunal biodiversity.

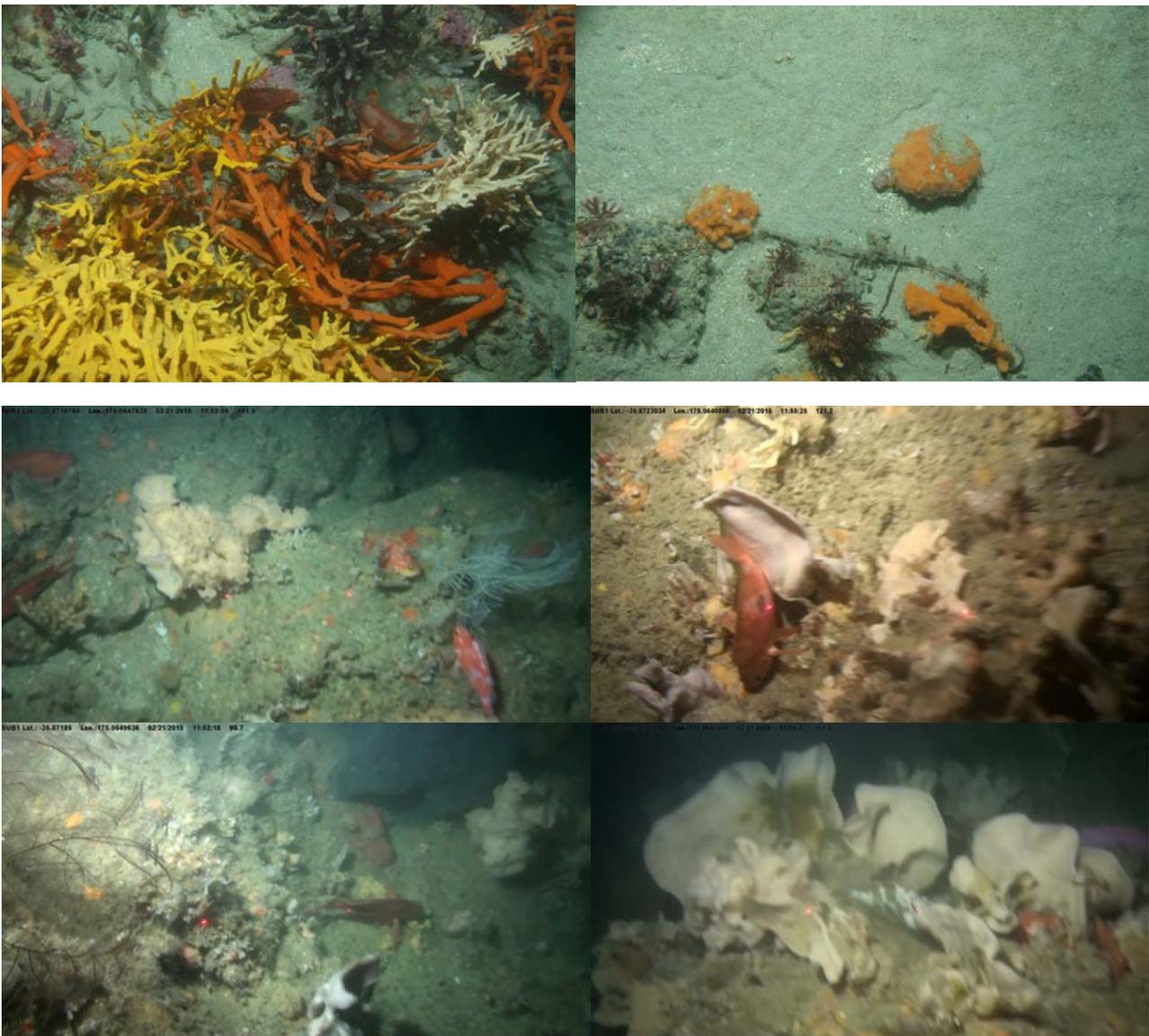


Figure A: Deep water rock reefs encountered during the survey. Top row, shallower patch reef system with a number of sponge species, and red algae (including *Rhodymenia*, *Gracilaria* or *Sarcodia*, and possibly *Callophyllis* sp.). Bottom rows, deeper reef (c. 130 m) with sponge and black coral assemblage.