Biological Monitoring of the Fiordland
(Te Moana o Atawhenua)
Marine Area
and Fiordland’s Marine Reserves – 2010

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A subtidal biological monitoring survey was carried out to collect data on indicator species (rock lobsters, blue cod, sea urchins, kelp and selected sessile invertebrates) within the Fiordland (Te Moana o Atawhenua) Marine Area (FMA) and its marine reserves. This survey is Stage 2 of a longer-term study to monitor effects of changes in management of the region on abundance and distribution of key species. We conducted a 13-day subtidal research survey across 41 sites in Fiordland (36 long term monitoring sites and 5 biosecurity spot check sites). We carried out checks on five of the manmade structures in Fiordland for eight species that have been identified as the most likely invasive speciesin this region. No invasive species was detected in the survey. At the long term monitoring sites, we collected information on the abundance and size structure of key indicator species (rock lobsters and blue cod), reef fish community structure, relative abundance of common kelps, sessile rock wall invertebrates and errant macroinvertebrates during depth stratified surveys that complemented those conducted in 2002, 2006 and 2007. In addition, data on reef fish community structure is comparable to those collected by Francis & Ling (1985) and Francis et al. (1985, 1989). A fine scale CTD survey was carried out at each site and these data complement those collected in February 2006 and 2007 in describing the physical marine environment. We measured relative abundances of seabirds and marine mammals on six opportunistic transects conducted between fjords. In this report, we provide increased scientific understanding of the Fiordland Marine Area to support conservation management. We identify changes in the size structure and abundance of key predatory and grazer species likely due to management changes in the Fiordland Marine Area, using a series of data collected since 2002 to compare trajectories of populations and communities among zones. Thus, we provide a basis for understanding the efficacy of marine reserves and commercial exclusion zones within the FMA. Using data from diver assessed quadrats and photoquadrats to quantify sessile encrusting invertebrates, mobile invertebrates and kelp we describe the community composition and diversity of different habitat types in the Fiordland Marine Area. We identify strong patterns of variation in community structure associated with depth, which differ among inner, mid and outer fjord habitats. We identify Long Sound as unique with respect to composition and stratification of these communities. We observe positive changes in rock lobster and blue cod abundances within marine reserves, but not in the other management zones. Similarly, we see evidence for changes in reef fish

community structure and composition through time in the fished areas but not in the marine reserves, indicating a basic difference in community dynamics.

1. Introduction

This report details methods, data and key analytical results from a 13 day research cruise aboard the Department of Conservation's M/V *Southern Winds*. The primary objective of this survey was to further resolve spatial patterns and temporal trends in marine biodiversity at shallow subtidal depths (0-20 m) within Marine Reserves, Commercial Exclusion Zones (areas closed to commercial fishing) and Open regions of the Fiordland (Te Moana o Atawhenua) Marine Area (FMA) (Figure 1). Specific focus was placed on collecting data sets complementary to those collected in 1985-6, (reef fish only) (Francis & Ling 1985, Francis et al. 1989), 2002 (Wing et al. 2003a), 2006 (Wing 2006) and 2007 (Wing & Jack 2008) for comparison of temporal trends and community dynamics within management zones. The cruise took place from February 3rd to 14th, 2010 starting in Doubtful Sound and finishing in Bluff. Eleven research divers and two vessel skippers contributed to the survey with a team of seven research divers working for the full extent of the trip. Thirty-nine monitoring sites (33/34 core target sites, 2 high priority sites, 1 low priority site and 3 additional sites) were surveyed (Figure 1). Analysis of these data focussed on resolving changes in abundance of key indicator species such as the rock lobster (*Jasus edwardsii*), blue cod (*Parapercis colias*), kina (*Evechinus chloroticus*) and common kelp (*Ecklonia radiata*), as well as changes in the structure and composition of the reef fish community. For this analysis the results from the 2010 research cruise were combined with those from previous Fiordland monitoring cruises, in 2006 and 2007, and with data from Fiordland-wide surveys undertaken by the University of Otago Subtidal Research Group in 2002 and 2005.

The **first focus** of the analysis contained in this report was **to characterise Fiordland marine habitats** and thus **describe patterns of spatial variation in communities of sessile rock wall invertebrates along major environmental gradients in the fjords**. This is relavent to developing balanced representation of communities within a spatial management regime. Here we collected fine scale data using photoquadrats stratified across depth and replicated among sites across the region. A detailed analysis of key species within these communities provides a description of habitat and community types within the shallow subtidal (0-20 m) across the Fiordland Marine Area. These data build on previous analyses from 2006 and 2007 and provide a basis for interpreting differences in community and habitat types across the region. In the present analysis, added resolution of the communities that lie between the low tide line and 5 m depth provides a new level of information on these communities that harbour key food resources for indicator species such as the red rock lobster (for example blue mussels). We use this information to increase our understanding of the spatial interplay between habitat types and management zones, important for interpreting later analyses.

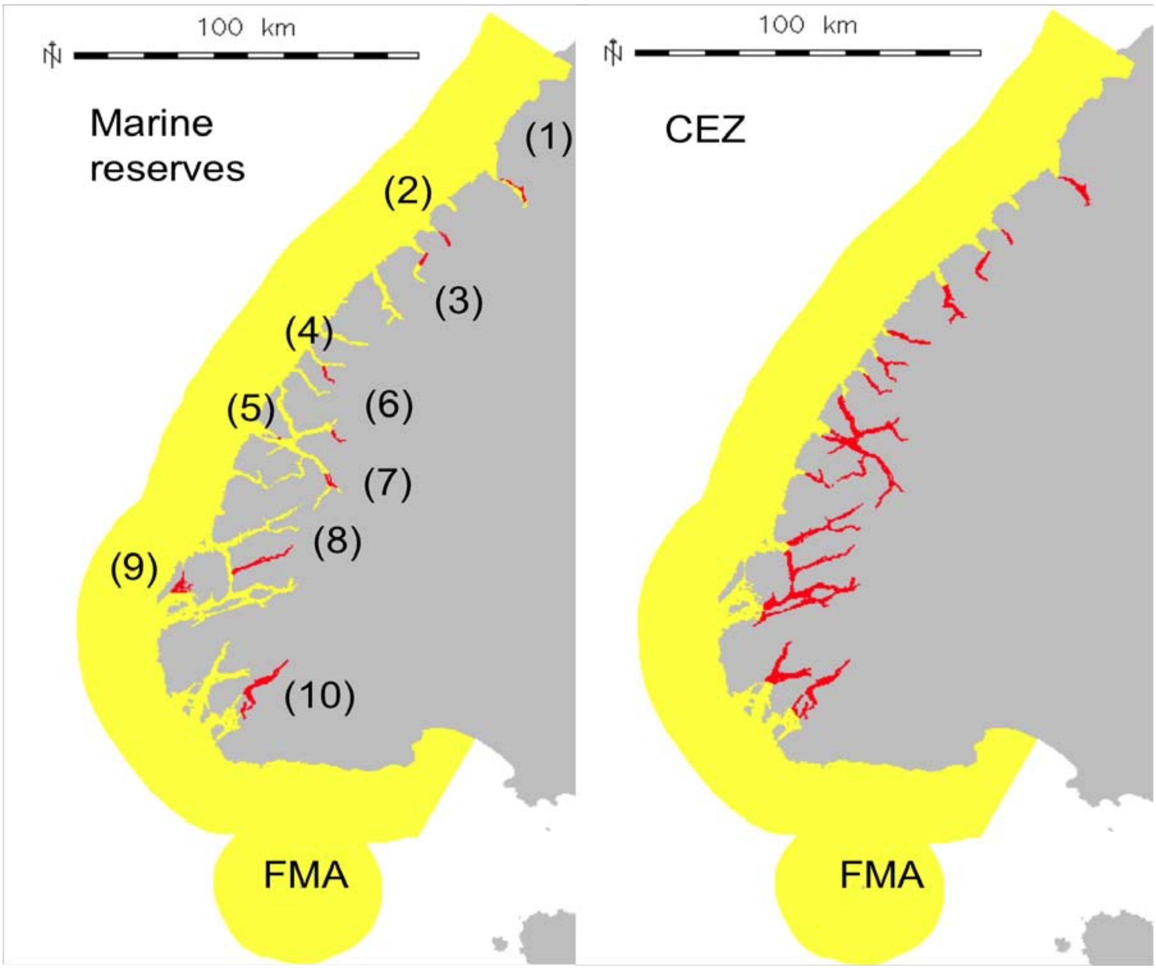

Figure 1: Marine reserves and Commerical Exclusions Zones in the Fiordland Marine Area (FMA). Marine reserves: (1) Piopiotahi (Milford Sd,), (2) Te Hapua (Sutherland Sd.) (3) Hawea (Clio Rocks), (4) Kahukura (Gold Arm), (5) Te Awaatu Channel (The Gut), (6) Kutu Parera (Gaer Arm), (7) Taipari Roa (Elizabeth Island), (8) Moana Uta (Wetjacket Arm), (9) Taumoana (Five Fingers Peninsula), (10) Te Tapuwae o Hua (Long Sound). CEZ: Commercial Exclusion Zone.

The **second** set of analyses focussed on key management questions:

1) **How much has the abundance of red rock lobster and blue cod changed in Marine Reserves relative to Commercial Exclusion Zones or Open areas?**
2) **How much has reef fish community structure and composition changed through time in these management zones and do dynamics in the exploited versus the unexploited reef fish species differ among each of these zones?**
3) **How do the dynamics between sea urchins and kelp vary among habitat zones and with abundance of predators such as the red rock lobster; and how is representation of these ecological scenarios balanced among spatial management units?**

Answers to these questions form part of the basis for interpreting the effects of habitat variability and of spatial management across the region and therefore assessing the effects of the Fiordland Marine Management Act 2005 (FMMA 2005). Because here we focus on changes in indicator species and communities within particular zones rather than comparing zones with “control” sites, we are testing effects in terms of change to individual species abundances or dynamics of community composition that are specific to those zones. Therefore the working hypotheses are based on the question: Are the dynamics or trajectory of change different among zones (rather than the approach of asking if the mean abundance differs among zones)? This approach highlights one of the key features of the Fiordland marine environment: the observed strong effects of environmental gradients and environmental heterogeneity on suitable habitat and aggregation of the indicator species in question. Each of the key indicator species is highly aggregated across the landscape and variability among habitats and across gradients is a common feature of the Fiordland environment. Because of this, it is not feasible to set up a classic impact-control study of relative abundances that has sufficient power to be useful within the time frame in question. There are clearly no controls for some of the unique habitats and zones, for example Long Sound. Instead, we make use of time series of abundances and of species composition within specific regions to test for variation in patterns of change over time, or community dynamics among management zones.

As with previous monitoring surveys, data on the physical oceanographic conditions across the Fiordland Marine Area were collected with a series of high-resolution hydrocasts that detailed water column structure in the top 50m of the water column. Data were collected at each of the 33 Department of Conservation long-term monitoring sites visited during the cruise providing information on temperature, salinity, Chl *a* and irradiance from the surface to 50m. These data augment previous surveys and provide a reference from which to assess long-term changes to the physical conditions within the region and complement biological data collected.

Because of the threat of incursion by introduced invertebrates and marine algae, most notably *Undaria pinnatifida*, a series of spot checks were carried out on man-made structures within the inner waters of the Fiordland Marine Area. Presence of invasive species was also checked across the subtidal monitoring sites by both divers undertaking active surveys, and within photoquadrats collected at each site.

During the cruise, we took advantage of the vessel's transits between fjords by collecting information on abundance and distribution of marine mammals and seabirds from a series of six 200m wide belt transects. These data provide a reference of relative abundance of species and a record of incidence for sea birds and marine mammals in the region, and a baseline from which to judge long-term trends in species occurrence**.**

Each of the data sets collected in this survey augment previous surveys and are compatible in terms of the methods used and comparible (with caveats) with the distribution of sites and habitats surveyed. Raw data are provided to DOC as a permanent record from which to assess change in the Fiordland Marine Area associated with spatial management or with anthropogenic and environmental drivers.

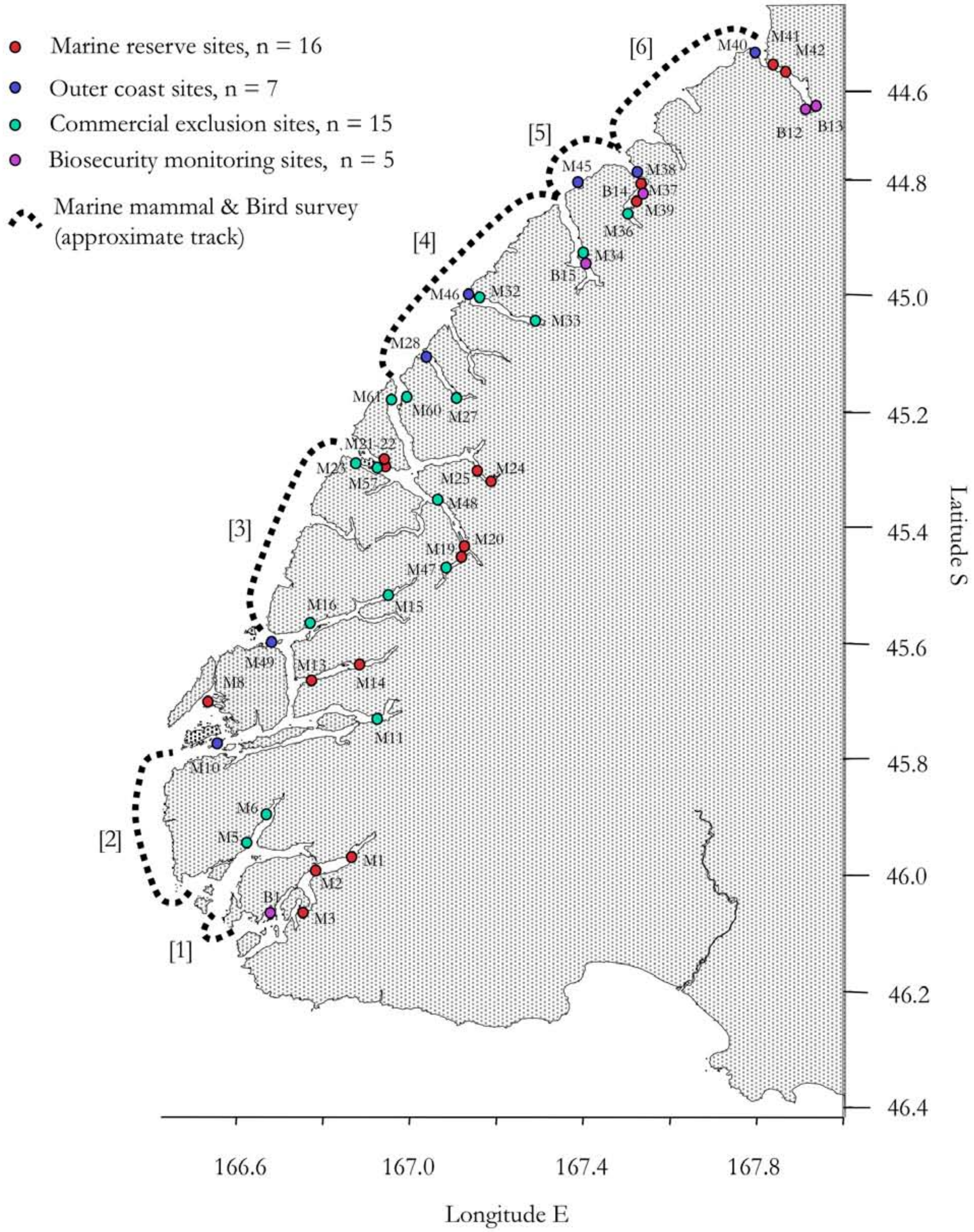

Figure 2. Fiordland. Sites and transects surveyed in 2010. M: subtidal monitoring sites, B: biosecurity sites.

2. Methods

2.1 Sites and Transects

Surveys of fish, habitat-forming species (including macroalgae and invertebrates) and oceanographic conditions were completed at 39 sites (Appendix 1). Biosecurity checks were conducted at 5 sites (Figure 2). Surveys of marine mammals and seabirds were conducted along 6 transects (Figure 2).

2.2 Community composition and diversity of different habitat types in the Fiordland Marine Area.

One diver (paired with red rock lobster videogrammetry) made a permanent record of diversity and abundance of fragile encrusting sessile invertebrates and smaller (red & coralline) algae using 10 x photoquadrats (42 x 60cm; 0.17 m^2) of the rock walls at stratified depths (0 (lowtide mark), 2.5, 5, 10, 15 and 20 m) after Wing (2006) and Wing & Jack (2008). These photographs were analysed for the communities that they contained by enumeration or by reporting incidence of 115 key species (Appendix 2). Incidence was reported for species that were colonial (some sponges and bryozoans) or for species that were difficult to enumerate accurately from photographs, including kelps, barnacles and mussel spat.

In addition, one dive pair directly enumerated mobile macroinvertebrates and macroalgae, using 6-8 paired 2 m^2 quadrats (141.4 x 141.4cm) at 5, 10 and 15 m depth at each site. This was conducted by two dive pairs after the number of divers was increased half way through the cruise, doubling the amount of replicates per site at 15 sites. This method is more suited to characterizing abundance patterns of larger, rarer invertebrates than the photoquadrats and in addition provided accurate density estimates of the major kelps especially *Ecklonia radiata.* Species identified are listed in Appendix 2.

2.3 Changes in the size structure and abundance of key predatory and grazer species in response to management changes in the Fiordland Marine Area.

2.3.1 Blue cod, other reef fish and rock lobsters

These data were collected using established videogrammetric, underwater visual census (UVC) and divers 'count-per-unit-effort' techniques from previous surveys (2006 & 2007). Fish surveys were conducted after Wing (2006) and Jack & Wing (2008) using depth stratified 50 m long x 5 m wide x 2.5 m high belt transects. 2 dive pairs conducted 2 transects at 15m depth, 1 transect at 10 m depth and 1 transect at 5 m depth at each site. Divers enumerated all fish species and rock lobsters (*Jasus edwardsii*) encountered on the transects and categorized key exploited species into 3 broad size categories using visual estimation relative to the size of their slate. Size categories for blue cod *Parapercis colias*) were <100 mm, 100 – 330 mm and >330 mm. Size categories for rock lobsters were <100 mm, 100 – 150 mm and >150 mm. Size categories for blue moki (*Latidropsis ciliaris*) were <200 mm, 200 – 400 mm and >400 mm. Size categories for trumpeter (*Latris lineata*) were <300 mm, 300 – 400 mm and >400 mm. Insufficient data were collected for blue moki and trumpeter for size distributions to be analysed statistically and so no further analysis is provided for these two species. In addition, divers conducting all tasks kept a running 'divers count-per-unit effort' (CPUE) tally of all blue cod and rock lobsters encountered. This temporal metric has been demonstrated to be more likely to detect presence of blue cod and rock lobsters and is especially useful in comparing relative abundances at sites where these species are rare (Wing & Jack 2008, Jack & Wing 2010). Size distribution and sex of rock lobsters was collected by a dedicated additional diver (paired with photoquadrat surveyor), using a non-invasive calibrated video technique (Jack & Wing 2010). The video footage was post-processed using iMovie 09 Version.8.0.6 (Apple inc) and individual images were measured using imageJ64 1.43r (National Institutes of Health USA). Although the structure of dive teams varied during the cruise, the data-recording members remained constant throughout the surveys.

2.3.2 Kina, kelp and rock lobsters

Potential variation in the spatial and temporal dynamics among kina (*Evechinus cholroticus*), common kelp (*Ecklonia radiata*) and rock lobster was investigated using data collected in 2006/7 and 2010. The kina and kelp data came from the diver-assessed quadrat pairs, and the rock lobster data came from the divers count per unit effort estimates, as outlined above.

2.3.4 Kina and päua size structure

One dive pair measured the size (max diameter) of the first 10 kina encountered during the macroinvertebrate quadrat surveys at each site. No päua (*Haliotis* spp.) were encountered during the surveys, likely either because they were distributed more shallowly than the 5m survey depth, because the surveys did not incorporate sufficient appropriate habitat or because they had been removed by fishing from suitable surveyed areas. Because insufficient data were collected to detect patterns or changes at scales relavent to that which kina are known to vary (Wing et al. 2001, Wing 2009) no further analysis of these data has been conducted.

2.4 Oceanographic characteristics of the Fiordland Marine Area

Physical and biological oceanographic characteristics of the FMA were characterized by taking a series of salinity, temperature, light and Chl*a* profiles to 50 m depth at each site, consistent with previous surveys (Wing & Jack 2007).

At completion of the cruise each of the CTD casts was post-processed using the program Sea Soft. Data were saved as raw text files in addition to bin-averaged conglomerate files. The data were used to calculate surface salinity and temperature.

Surface salinity: Surface salinity was calculated as the mean salinity in the upper two meters of the water column to be compatible with calculations from fine scale CTD surveys carried out in 1998, 1999, 2002, 2003, 2004, 2005, 2006 and 2007 (Wing et al. 2003, 2004, 2005, 2006, 2007).

Surface temperature (SST): Surface temperature was calculated as the mean temperature in the upper two meters of the water column as above.

2.5 Detection of marine invasive species new to the Fiordland Marine Area or New Zealand

Five high-risk areas within the FMA (barges, wharfs and mooring lines) were targeted for detection of invasive marine species using diver visual assessments. Particular emphasis was placed on detecting common invasive species from the Biosecurity New Zealand database. Each of the targeted sites and the monitoring sites within Objectives 1 and 2 were surveyed for invasive species and for species that have not been recorded as part of previous biodiversity monitoring.

2.6 Cetacean and seabird populations within the Fiordland Marine Area

During transit between fjords, one trained observer (SRW) recorded abundance of seabirds and marine mammals in a 200 m swath transect. Abundances were totals per transect.

2.7 Previously collected data sets

In this report, data are compiled from previous Fiordland surveys, where methods and sites are comparable, and a valuable time series is constructed. Data were sourced from comprehensive region-wide surveys undertaken in 1985-1986 (Francis & Ling 1985, Francis et al. 1989); 2002 (Wing et al. 2003a) and (Wing *unpublished data*); 2006 (Wing 2006); and 2007 (Wing & Jack 2008). Where survey methods differed (especially surveys by Francis versus surveys by Wing), after consultation between both authors to ascertain potential problems with data compatibility associated with seasonality and methodology, we transformed data into the same units and divided it into similar depth strata for comparison. When selecting sites for comparison, our 12 year research programme (refereced above) in Fiordland meant that data collected at exactly the same sites were available in most years, 2002, 2006, 2007 and 2010. These are the DOC long term monitoring sites referred to in Figure 2. For the NZOI fish surveys conducted by Francis et al. (1985, 1989), a mixture of DOC monitoring sites and additional or alternative sites were included in the analysis. Where additional sites were used in the analysis, we only included data from those sites that were in proximity with a DOC monitoring site that had not been surveyed. A full list of sites used in the analysis in given in Appendix 3, and referenced to site locals in each report (Francis et al. 1985, Francis et al. 1989, Wing et al. 2003, Wing 2006, Wing and Jack 2007).

Table 1. Summary of Reef Fish Survey Methods

Citation	Month	Year	Strata	Sample Unit	Sites
Francis et al. 1985	March	1985	0-5, 5-10, 10-15 m	Horizontal 2.5x30m for 0-5 m strata, vertical 5x10m for 5-10m and 10-15m strata	Nine sites Doubtful and Thompson's Sounds
Francis et al. 1989	May Feb	1986 1987	0-5, 5-10, 10-15 m	Horizontal 2.5x30m for 0-5 m strata, vertical 5x10m for 5-10m and 10-15m strata	45 sites throughout Fiordland
Wing et al. 2003	Oct	2002	0-5, 5-10, 10-15 m	40 m x 5 m	DoCM+ sites
Wing 2006	Feb	2006	2.5-7.5, 7.5-12.5, 12.5-17.5 m	50 m x 5 m	DoCM sites
Wing and Jack 2007	Feb	2007	2.5-7.5, 7.5-12.5, 12.5-17.5 m	50 m x 5 m	DoCM sites

2.8 Statistical Analysis

Univariate analyses were conducted in JMP 7.0 (SAS 2007). Multivariate analysis and ordinations were conducted using PERMANOVA+ routines in PRIMER-E. For further information concerning these techniques please refer to the Primer-E user guides and previous reports (Clarke & Gorley 2006, Anderson et al. 2008, Willis et al. 2009).

3. Data analysis and Results

3.1 Community composition and diversity of different habitat types in the Fiordland Marine Area.

3.1.1 Classifying habitats

Physical habitat classification was achieved across the Fiordland region using a “threshold model” that defined substratum type (rocky versus soft sediment), the division between the photic and aphotic zone, and wave-exposed and wave-sheltered regions (Wing et al. 2004). The study was limited to sites on rocky sediment in the photic zone.

Two distinct rocky reef habitats were identified using a physically defined boundary where surveys took place (Wing et al. 2003a). Mean values for orbital velocity on the bottom (U_{bot}) were derived from the SWAN wave model at 50 m resolution. A region was defined where orbital velocity flow rate exceeded 6 cm s^{-1} as this is the critical velocity below which thick diffusional boundary layers form around kelp blades and impede mass transport of nutrients, particularly nitrogen sources (Hurd et al. 1996, Hurd 2000, Stevens et al. 2003). This value was used as the theoretical limit to flow-mediated nutrient uptake of kelp and therefore as a boundary for primary productivity. Using this boundary layer, habitat types were identified as (1) Exposed reef: rocky reef with saturating flow, (2) Sheltered reef: rocky reef with quiescent flow. These separated geographically into outer (exposed) and inner (sheltered) fjord regions (see (Wing et al. 2005) for a detailed methodology).

Habitat type at each site was further defined as inner-, mid- or outer-fjord based on a Ward’s hierarchical cluster analysis that combined three biological indicators of habitat type in a GIS framework. Firstly, the mean test diameter of populations of sea urchins *Evechinus chloroticus* was sampled in 1998, 1999, 2002 and 2003 (see (Wing et al. 2001) for a detailed methodology). Mean test diameter was used as an estimate of size structure and nutritional history of each population (Wing et al. 2003b). A shift in size-structure between inner- and outer-fjord populations corresponds to dramatic shifts in diet (Wing et al. 2001), reproductive output (Wing et al. 2003b), and genetic diversity (Perrin et al. 2003, Sköld et al. 2003, Perrin et al. 2004), much of which can be attributed to the shift from sheltered to wave-exposed environmental conditions. Secondly, morphological variability among populations of the dominant kelp *Ecklonia radiata* was measured, as phenotypic plasticity takes place in response to gradients in the hydrodynamic and light environment (Wing et al. 2007). Blade morphology was used as an indicator of differences in primary productivity among sites. Thirdly, patterns in the relative abundance of populations of reef fishes identified species into two distinct guilds representative of inner- and outer-fjord habitats (Francis & Ling 1985, Francis et al. 1989). Underwater visual census of reef fishes was conducted at sites throughout Fiordland in 2002 and the data were augmented with a survey conducted throughout the region in 1985-1986 (see (Wing et al. 2004) for detailed methodology). Fish species were defined as indicative of inner- or outer-fjord physical habitat. Their relative abundance was used to indicate the ecotone boundary between the two habitat types

For each biological indicator, Ward's (Legendre & Legendre 1998) hierarchical minimum variance method was used to cluster groups of similar sites. The clusters of two (inner/outer) for each of the three indicators were then combined in geographic space to map out predicted ecotone boundaries at each fjord entrance and define a transition region between the wave-sheltered inner- and wave-exposed outer-fjord regions (see Wing et al. 2004 for a detailed methodology). The 36 sites of the current study were then defined as inner-, outer- or mid-fjord, based on their position in the above-described geographic space (Figure 3, Appendix 1).

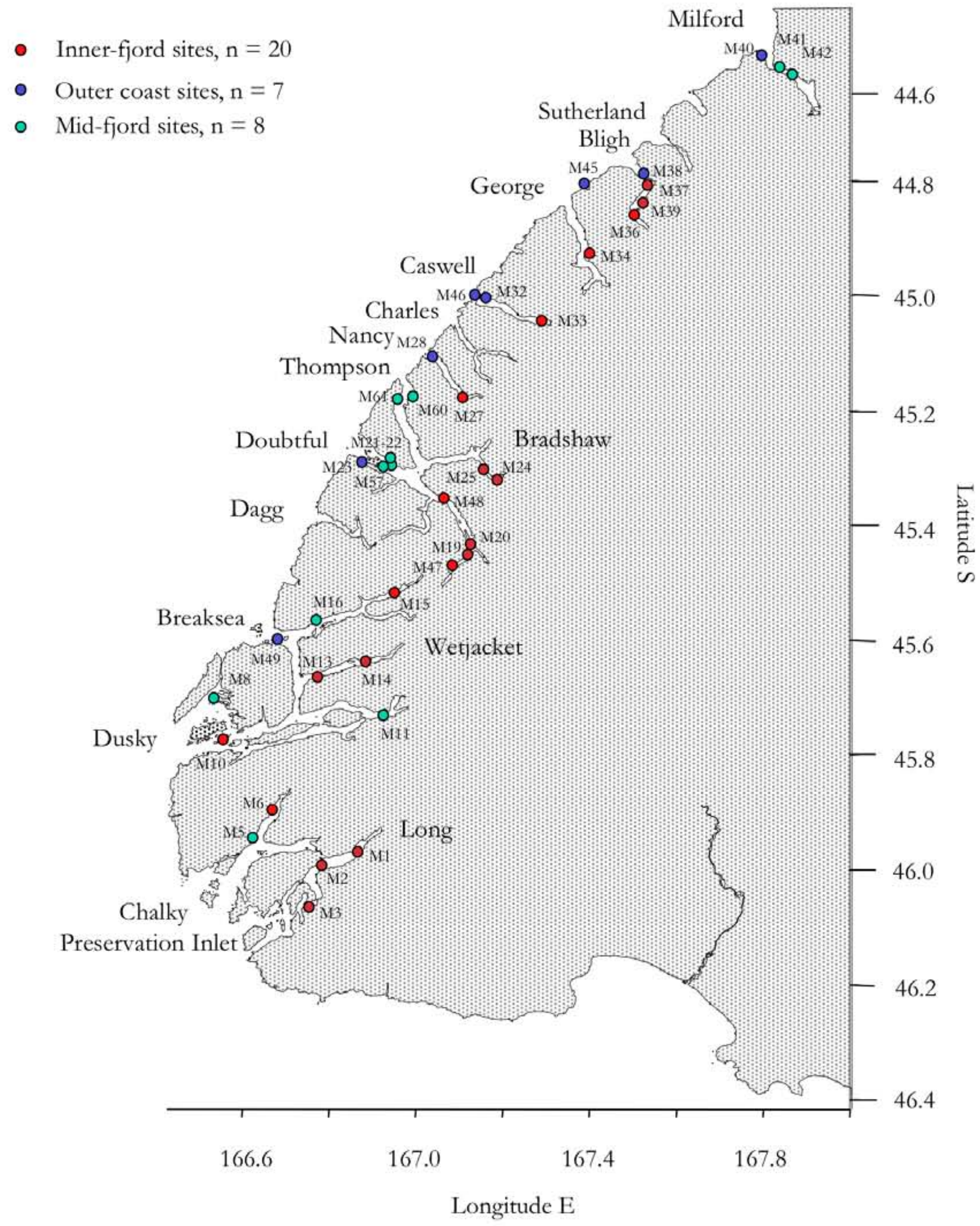

Figure 3: Survey sites habitat types (red: inner-, green: mid-, blue: outer-fjord habitat)

3.1.2 Spatial variation in invertebrate and kelp assemblages from photoquadrats

Differences in the benthic assemblages were contrasted among depth zones in the different (mid-, inner-, outer-fjord) regions using permutational multivariate analysis of variance (PERMANOVA). Because Long Sound has been recognised as distinct in its benthic assemblage (Smith 2001), it was analysed as a separate region. Data were averaged among quadrats at the site level and log (abundance+1) transformed. A PERMANOVA was conducted for the factors Depth (6 levels, fixed) and Region (4 levels, fixed), followed by post-hoc pairwise comparisons for each factor. Statistical p values were calculated using 9×10^5 permutations of residuals under a reduced model, using Type III (partial) sums of squares. The benthic community as characterized by the photoquadrats varied significantly among regions (*pseudo* $F_{3,191} = 6.64$, $p<0.01$; post-hoc pairwise comparisons: Long [A], Inner [B], Mid [C] & Outer [D]; where regions not connected by the same letter are significantly different) and among depths (*pseudo* $F_{5,191} = 7.14$, $p<0.001$) Communities within each region were more stratified at shallower depths and became more homogenous at greater depths (post-hoc pairwise comparisons: 0m [A], 2.5m [B], 5m [C], 10, 15 & 20m [D]; where regions not connected by the same letter are significantly different). The effect of depth was consistent among regions, indicated by a non-significant interaction term between factors. No dispersion effect was detected (PERMDISP $p>0.05$). Principal coordinates analysis (PCO), which works to place the points into Euclidean space, preserving the original dissimilarities as well as possible (Gower 1966), was conducted on data that were hierarchically averaged at the site level and then at the level of region/fjord to visualise these patterns (Figure 4). Shallow sites were in general characterised by a greater prevalence of *Ulva.* spp. and barnacles and high abundance of *Mytilus edulis galloprovincialis,* whilst deeper sites were characterised by greater abundances of red brachiopods (*Terebratella* spp.*)* and sea cucumbers (*Stichopus mollis)*, and higher incidence of *Codium* spp.*,* catenicellid bryozoans, and elephant ear sponges (*Axinella tricalyformes*). Long Sound was distinct due to greater abundances of the white sea urchin (*Pseudechinus huttoni*), reef tube worm (*Neovermilia sphaeropmatus*) and apricot sea star (*Sclerasterias mollis*), a deep-water emergent species usually associated with the shelf. Long Sound was also distinct due to lesser incidence of articulate coralline algae compared with the other fjords.

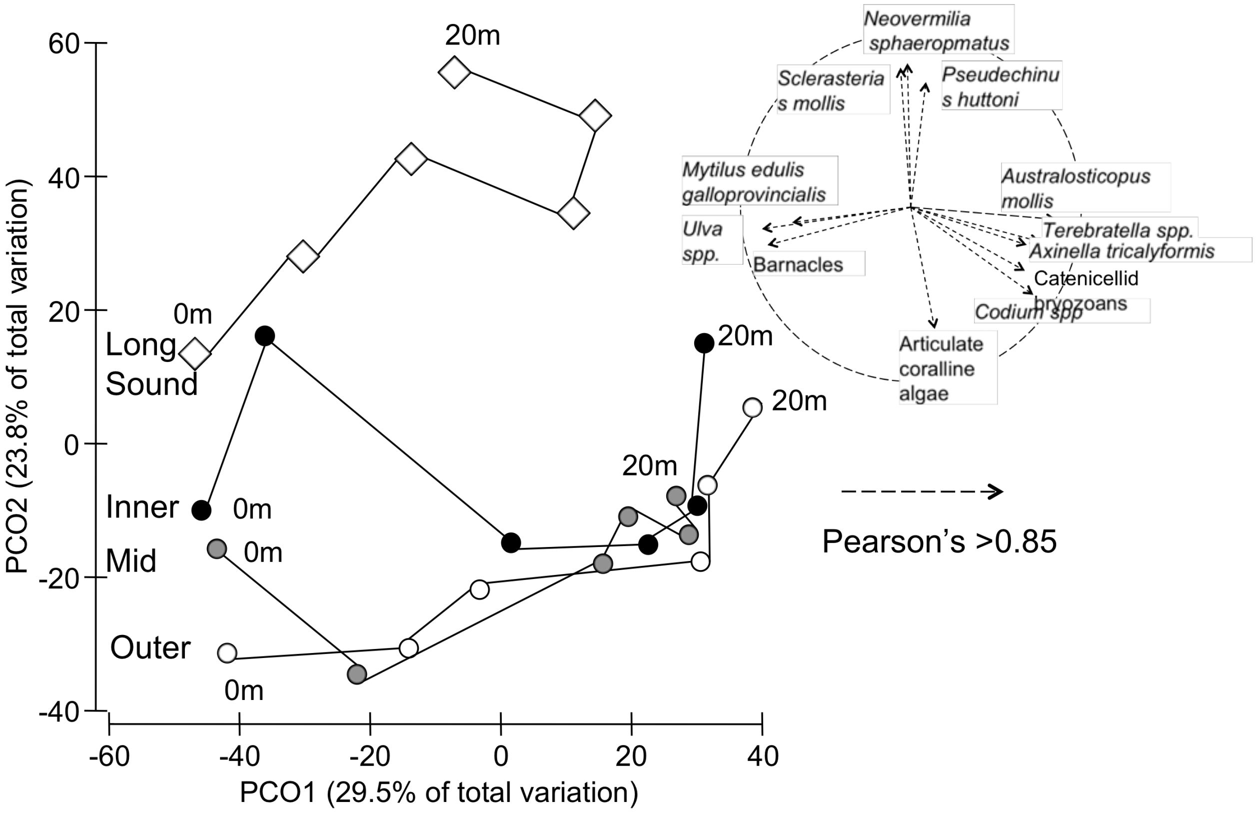

Figure 4. PCO of benthic assemblages in photoquadrats at sites in the inner- (●), mid- (●),outer-fjord (**O**) and Long Sound (◇), following log(x+1) transformation, based on the Bray-Curtis similarity index. Vectors show Pearson's correlations of individual species with axes that are R(x)>0.85. Sampling depths were: 0m, 2.5m, 5m, 10m, 15m and 20m from the low tide mark.

3.1.3 Spatial variation in invertebrate and kelp assemblages from diver-assessed quadrat-pairs

Differences in the benthic assemblages were contrasted among depth zones in the different (mid-, inner-, outer-fjord & Long Sound) regions using permutational multivariate analysis of variance (PERMANOVA). Data were averaged among quadrat-pairs at the site level and log(abundance + 1) transformed. A PERMANOVA was conducted for the factors Depth (3 levels, fixed) and Region (4 levels, fixed, as in Section 3.1.2), followed by post-hoc pairwise comparisons for each factor. p values were calculated using 9×10^5 permutations of residuals under a reduced model, using Type III (partial) sums of squares.

The benthic community, as characterized by quadrat-pairs, varied significantly among regions (*pseudo* $F_{2,104} = 10.42$, $p<0.001$; post-hoc pairwise comparisons: Long [A], Inner [B], Mid [C] & Outer [D]; where regions not connected by the same letter are significantly different) and among depths (*pseudo* $F_{5,191} = 2.03$, $p<0.01$; post-hoc pairwise comparisons: 5m [A], 10m [AB], 15m [BC]; where regions not connected by the same letter are significantly different). The effect of depth was consistent among regions, indicated by a non-significant interaction term between factors. No dispersion effect was detected (PERMDISP $p>0.05$).

To visualise these patterns, PCO was conducted on data that were hierarchically averaged at the site level and then at the level of region/fjord (Figure 5). Long Sound was highly distinct from other regions due to an abundance and richness of sea star species including *Sclerasterias mollis* (apricot sea star), *Coscinasterias muricata* (11-armed sea star), *Asterodon miliaris* (red biscuit star), *Allostichaster insignis* (3&3 sea star) and *Patiriella* spp. (cushion star). Long Sound also contained a distinct higher abundance of *Maoricolpus* spp. (turret shells) and *Pseudechinus huttoni* (white sea urchin). Outer-fjord sites were distinct from other regions due to an abundance and richness of large kelps and associated grazers including *Evechinus chloroticus* (Kina) and *Calliostoma* spp. (herbivorous top-shells). Also more abundant at outer-fjord sites were *Ophiopsammus maculata*, large scavenging and predatory snake stars, which feed on small grazers. Abundance of the sea cucumber *Australostichopus mollis* was positively associated with inner-fjord habitats and deeper strata. Of note is the similarity between communities characterized in the mid-fjord at 10m and inner-fjord at 5m, and between those in the mid-fjord at 15m and inner-fjord at 10m, suggesting a compounding effect of depth on community stratification along the fjord axis.

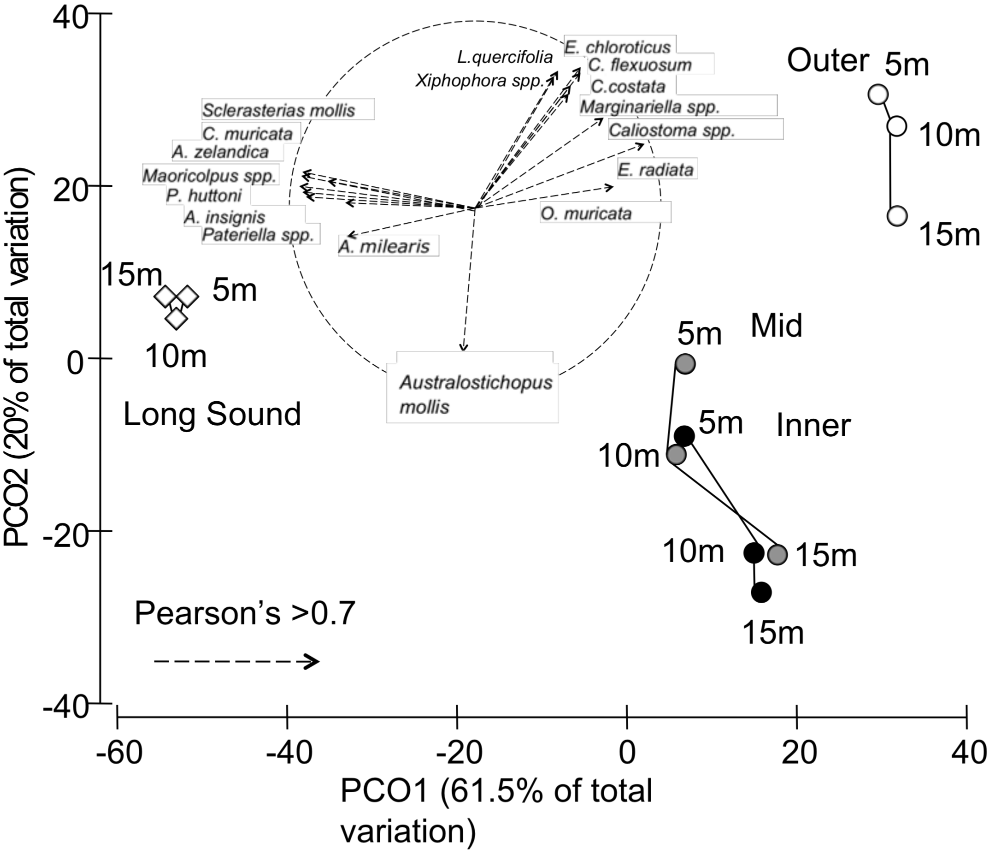

Figure 5. PCO of benthic assemblages in diver-assessed quadrat pairs at sites in the inner- (●),mid- (●),outer-fjord (O) and Long Sound (◇), following log(x+1) transformation, based on the Bray-Curtis similarity index. Vectors show Pearson's correlations of individual species with axes that are R(x) >0.7. Sampling depths were 5, 10 and 15m.

3.2 Changes in size structure and abundance of key predatory and grazer species in response to management changes in the Fiordland Marine Area.

3.2.1 Blue cod and rock lobster abundance using diver's 'count-per-unit-effort' (CPUE) tallys

CPUE tallys from surveys conducted in 2002, 2005, 2006, 2007 and 2010 were used to identify temporal trends in abundance of rock losbters and of blue cod among management regions in each of the fjords. 3 - 5 tallys (1 per diver pair) were collected at each site during each survey event. To enable maximum use of this longditudinal data set, a subset of sites were used in the analysis where data were available at least 4 of the 5 time points for sites within management zones (2 or 3 levels) in each of 9 fjords. Site was fitted as a random factor and year as a covariate using the GLM procedure in JMP 7 (SAS 2006).

Model fits are sumarized in Table 2 and 3 and graphs of each management zone within each fjord are presented in Appendix 4 & 5 for the red rock lobster and blue cod respectively. Figures 6 and 7 show the slope or change in estimates of relative abudance in (a) marine reserves, (b) commercial exclusion zones and (c) regions open to commercial fishing in each fjord for rock lobsters and blue cod respectively. Bars that fall below 0 indicate a negative slope or populations that are declining in abundance over time. Bars that fall above 0 indicate a positive slope and populations that are increasing in abundance over time. Asterix' denote regions where this change in abundance over time is statistically significant ($p < 0.05$).

Figure 6 indicates that significant positive changes in rock lobster CPUE were observed in newly established (2005) marine reserves in Bradshaw, Wetjacket, Dusky and Bligh Sounds while significant negative changes were observed in the commercial exclusion zones in Breaksea and Nancy Sound. No significant changes in abundance were observed on the open coast where abundances are generally low or in The Gut Marine Reserve where relatively high abundances have been maintained (see Appendix 4 and 5 for regional averages). Elizabeth Island Marine Reserve also showed no change with out any rock lobsters observed in the reserve during the time of study.

Figure 7 indicates that positive changes in relative abundance of blue cod were observed in newly established (2005) marine reserves in Bradshaw, Wetjacket and Long Sounds, but not in commercial exclusion zones or on the open coast, where in Dusky Sound, a marginally non-significant decline was observed.

Table 2. Rock lobster *Jasus edwardsii*. GLM of CPUE estimates of abundance; Model fit for the factor Year. **Bold:** statistically significant result

Fjord	Management Zone	r^2	df	F ratio	p
Milford	Old Marine Reserve	0.34	1,29	0.01	0.91
Bligh	Marine Reserve	0.56	1,28	6.69	**0.015**
Doubtful	Old Marine Reserve	0.11	1,34	0.02	0.90
Doubtful	Marine Reserve	0.00	1,26	0.00	1
Bradshaw	Marine Reserve	0.76	1,15	5.08	**0.042**
WetJacket	Marine Reserve	0.27	1,41	5.95	**0.019**
Dusky	Marine Reserve	0.30	1,18	7.86	**0.012**
Long	Marine Reserve	0.00	1,37	0.00	1
Milford	CEZ	0.00	1,5	0.00	1
Bligh	CEZ	0.15	1,16	51.76	0.11
George	CEZ	0.13	1,15	2.21	0.16
Caswell	CEZ	0.52	1,26	0.28	0.60
Nancy	CEZ	0.47	1,35	3.49	0.07
Doubtful	CEZ	0.53	1,32	0.83	0.37
Breaksea	CEZ	0.31	1,37	11.46	**0.0018**
Dusky	CEZ	0.39	1,21	0.21	0.64
Chalky	CEZ	0.28	1,55	0.004	0.94
Milford	Open	0.00	1,14	0.001	0.96
Bligh	Open	0.02	1,15	0.36	0.56
Doubtful	Open	0.12	1,13	1.73	0.21
Dusky	Open	0.04	1,16	0.83	0.38

Table 3. Blue cod *Parapercis colias*. GLM of CPUE estimates of abundance; Model fit for the factor Year. **Bold:** statistically significant result

Fjord	Management Zone	r^2	df	F ratio	p
Milford	Old Marine Reserve	0.02	1,29	0.00	0.96
Bligh	Marine Reserve	0.04	1,28	0.37	0.55
Doubtful	Old Marine Reserve	0.06	1,34	0.003	**0.003**
Doubtful	Marine Reserve	0.10	1,26	3.48	0.07
Bradshaw	Marine Reserve	0.79	1,15	62.49	**<0.0001**
Wetjacket	Marine Reserve	0.29	1,41	16.89	**0.0002**
Dusky	Marine Reserve	0.08	1,17	1.51	0.23
Long	Marine Reserve	0.34	1,37	4.09	**0.05**
Milford	CEZ	0.07	1,4	0.307	0.11
Bligh	CEZ	0.09	1,16	10.64	0.22
George	CEZ	0.00	1,15	0.00	0.98
Caswell	CEZ	0.25	1,26	3.05	0.09
Nancy	CEZ	0.00	1,35	0.76	0.39
Doubtful	CEZ	0.43	1,32	4.17	**0.0587**
Breaksea	CEZ	0.22	1,37	0.33	0.57
Dusky	CEZ	0.07	1,21	0.43	0.54
Chalky	CEZ	0.17	1,55	0.02	0.89
Milford	Open	0.19	1,14	3.23	0.093
Bligh	Open	0.10	1,15	1.69	0.21
Doubtful	Open	0.22	1,13	11.71	0.07
Dusky	Open	0.12	1,16	2.255	0.15

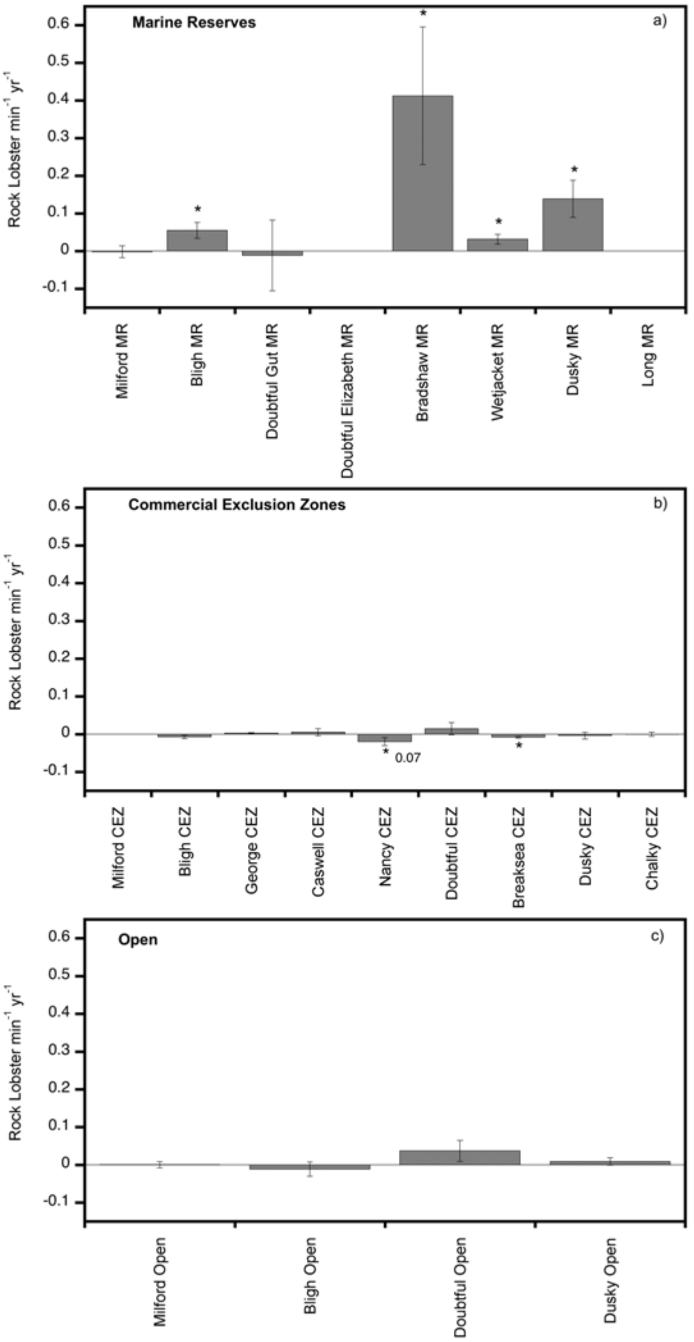

Figure 6. Rock lobster *Jasus edwardsii*. Slope of model for CPUE fitted to year for management zones within each fjord. Error bars are ±1 SE of the model fit. * Statistically significant changes in relative abundance.

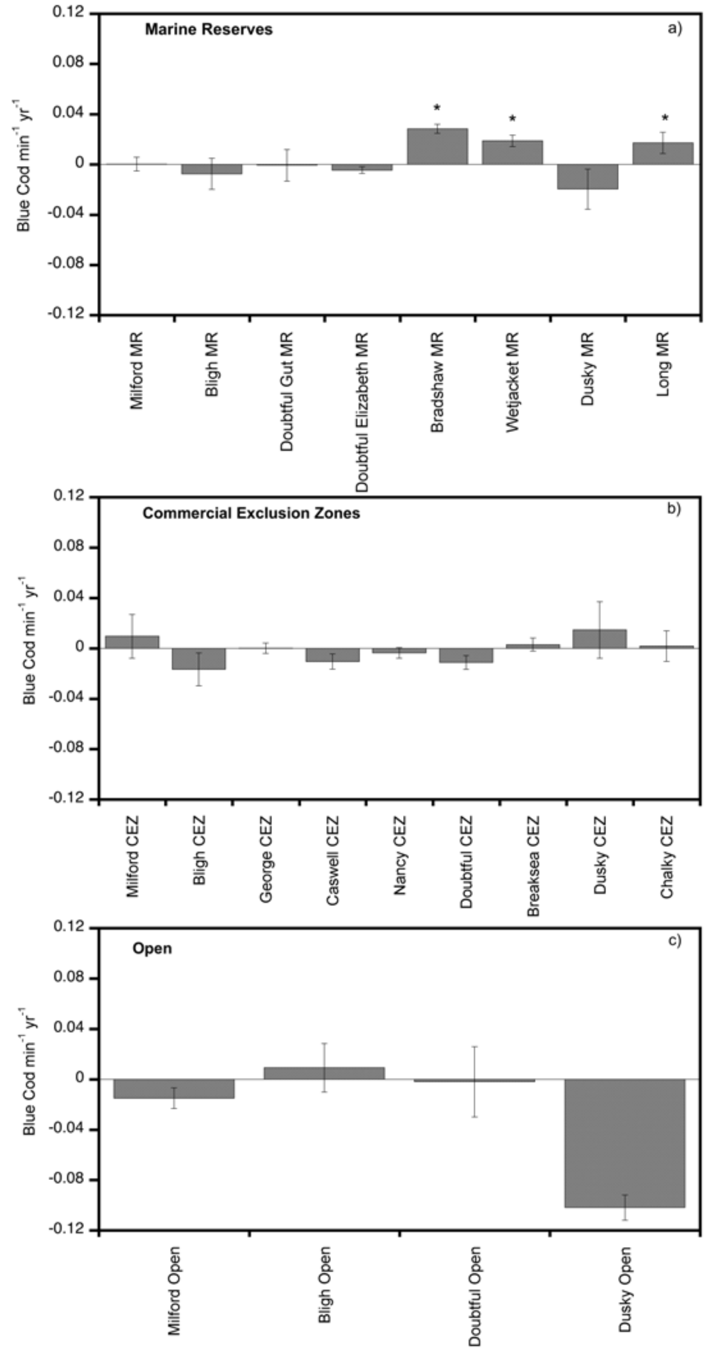

Figure 7. Blue cod *Parapercis colias*. Slope of model for CPUE fitted to year for management zones within each fjord. Error bars are ±1 SE of the model fit. * Statistically significant changes in relative abundance.

3.2.2 Rock lobster size structure

At the 18 sites where size frequency data for rock lobsters were collected by video, they were assigned to 5 mm bin size classes (between 65 mm and 180 mm) following videometric calculations and size frequency distributions were compared among the 4 management zones (CEZ, old marine reserves (established in 1993), new marine reserves (established in 2005) and open coast areas open to commercial fishing). For each management zone, we calculated the relative abundance of males and females in each size class by combining videogrammetric (size and sex) and abundance data (mean CPUE). This method assumes that when combining size and sex with CPUE data, because both are random samples of the population, the 2 data sets are compatible and represent the same population, consistent with our sampling design (Jack & Wing 2010). This assumption is valid in the present analysis because surveys were conducted for large strips of the reef (e.g. divers conducting fish surveys counted all rock lobsters from two 100 m long bands, while divers doing photoquadrates covered the same sized area, and divers counting kina and kelp closely searched the substratum). We expect that if rock lobsters were present on the reef, because they are large conspicuous invertebrates, they would be equivalently detectable by each diver group. We used PERMANOVA+ for Primer (PRIMER-E) to test for among-zone differences in the size frequency distribution. For each sex, we calculated the maximum distance (D_{max}) among cumulative size-frequency distributions where $D_{max} = \max i |y_{i1} - y_{i2}|$. Here the absolute value of $y_{i1} - y_{i2}$ reflects the observed difference in abundance for each size class. We conducted a 1-way permutational ANOVA for the factor management zone (fixed, 4 levels) in the PERMANOVA routine, using 9×10^5 unrestricted permutations of the raw data to conduct an exact test. No significant differences were found in the size frequency of males or females among management zones ($p > 0.05$). Although differences seem apparent when data are graphed at the level of management zone (Figure 8a & b), the lack of statistical difference is likely due to the high level of variability and low level of within-site replication (n=1 per site) among zones. To further investigate this observation, for sites where lobsters were observed, we conducted a one-way PERMANOVA using permutations of the residuals under a reduced model and Type III sums of squares to model the effect of sex (2 levels, fixed), zone (4 levels, fixed), and site (19 levels, random nested within zone) on Euclidean distances among individual carapace lengths. This test is equivalent to an ANOVA but can be considered robust because it uses permutations instead of modeling based on the normal distribution. Male rock lobsters were larger than females ($F_{1,28}$ = 33.349, p = 0.0001) and carapace lengths of lobsters varied significantly among sites ($F_{5,238}$ = 5.535, p = 0.0001) but not among management zones ($p > 0.05$).

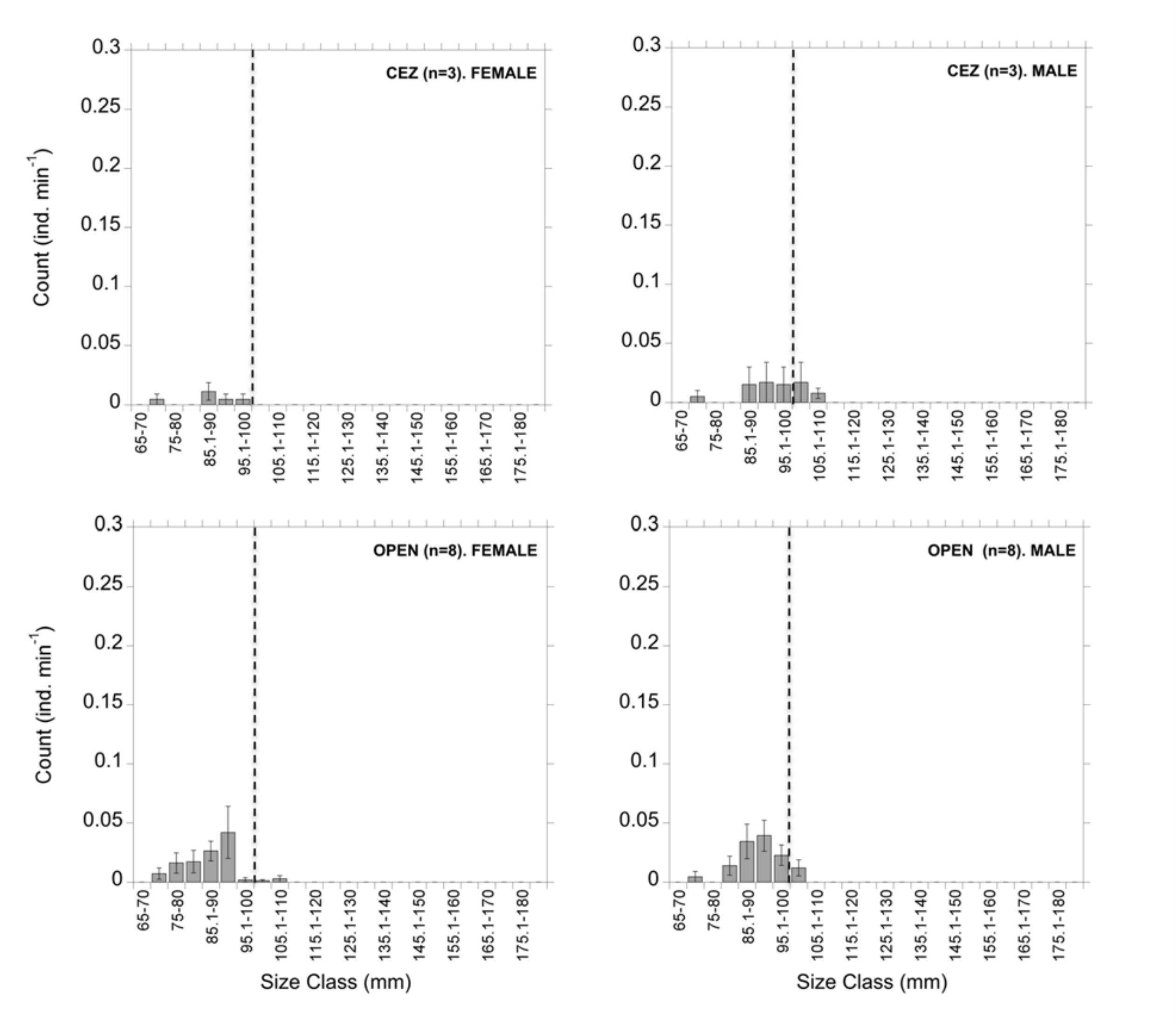

Figure 8a Rock lobster *Jasus edwardsii.* Size-frequency distributions of male and female rock lobster from videogrammetric data sites in the commercial exclusion zones and in regions open to commercial fishing. Data are averages and error bars are one standard error.

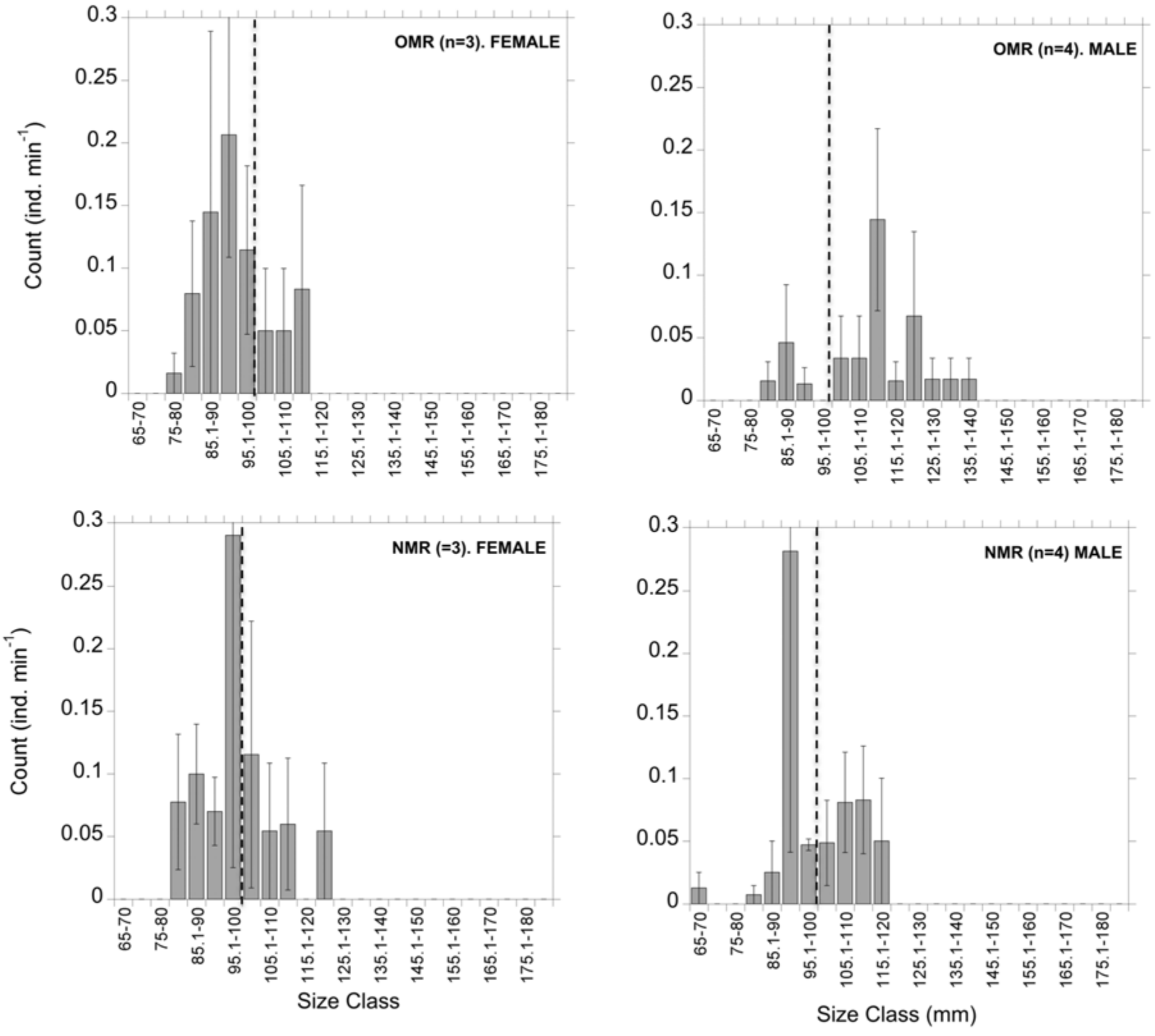

Figure 8b Rock lobster *Jasus edwardsii.* Size-frequency distributions of male and female rock lobster from videogrammetric data sites in the new marine reserves (est. 2005) (NMR) and in old marine reserves (est. 1993) (OMR). Data are averages and error bars are one standard error.

3.2.3 Reef fish community structure and composition

Data for assessing changes in reef fish community structure over time were compiled from surveys conducted in 1985-7 (Francis & Ling 1985, Francis et al. 1989), 2002 (Wing et al. 2003a), 2006-7 (Wing 2006, Wing & Jack 2008) and 2010 (Table 1). Data were selected from 37 sites that were sampled in at least three of the four time periods (Appendix 3). Data were stratified into depths of 0-7.5, 7.6-12.5, and 12.6-17.5 m and transects were summed to 250m^2 depth-stratified sample units. This summing reduces replication at the lowest level (and therefore power) but decreases the noise caused by high levels of variation among transects. The data were averaged by depth and then by site within each year to produce an average abundance of each species per sampling event (site/year). We conducted parallel analyses on square root transformed and presence/absence transformed data. Square root transformation dampens the effect of extremely prevalent species (such as schooling telescopefish and butterfly perch) in the analysis. We use these data to assess changes in overall relative abundances or community structure. Presence/absence transformation allows isolation of variation in species incidence or community composition from variation in structure driven by relative abundances for comparison. Thus we use presence/absence transformed data to assess changes in community composition. The data were divided into fished and non-target species and analyzed separately according to those groups so that, in total, four parallel analyses were carried out. Resemblances were calculated using the Bray-Curtis similarity index with a dummy variable of 0.001. To test for differences in the structure of fish communities among management zones, we conducted PERMANOVAs with the factors Management Zone (4 levels, fixed) and Year (4 levels, fixed) for both the exploited and non-exploited species (Table 4). To visualize the differences in community structure among management zones we calculated the distance to the group centroids (equivalent to a multivariate averaging procedure) for each management zone in each year (16 levels), which were plotted using principle coordinate analysis (PCO). Because management zones are spatially confounded within habitat types, environmental forcing likely drives differences in fish community structure among them. With this analysis, we aim to describe the changes in community composition and structure over time within management zones. For clarity, we show each PCO as 4 plots, derived from the same ordination but each only showing the results for one management zone (Figures 9-12).

We tested for differences in the reef fish community among years within each management zone using PERMANOVAs for the factor Year (4 levels, fixed).

The results of the main test PERMANOVA models indicate that the structure of the exploited reef fish community varied significantly among years and among management zones (Table 4) as did the composition of the exploited reef fish community, as represented by Presence/absence data (Table 4). Similarly, the structure of the non-targeted reef fish community varied significantly among years and among management zones (Table 4). However, the composition of the non-targeted reef fish community differed among management zones but not among years (Table 4).

Table 4. Main PERMANOVA tests for the effect of Year and Management Zone (Man) on exploited and non-target members of the reef fish community using square root transformed and presence/absence (PA) data. p values in bold denote statistically significant results.

Fish Community	**Source**	**df**	**Pseudo F**	**p**
Exploited	Management	3,106	2.38	**.0047**
	Year	3,106	3.28	**.0001**
	Man * Year	9,106	1.03	.4293
Exploited PA	Management	3,106	2.23	**.006**
	Year	3,106	3.43	**.0001**
	Man * Year	9,106	1.25	.1409
Non Target	Management	3,106	15.69	**.0001**
	Year	3,106	2.66	**.006**
	Man * Year	9,106	0.773	.8082
Non Target PA	Management	3,106	12.57	**.0001**
	Year	3,106	1.78	.0807
	Man * Year	9,106	0.48	.9766

Using pairwise post-hoc tests of differences among years within management zones, we found that the structure of the exploited fish community did not change over time in old marine reserves or in new marine reserves (Table 5 & 6). In the ordination plots for both these management zones, we observed a change in the fish community whereby a large difference is observed between 1985-7 and 2002. However, after the implementation of the FMMA (2005), this change is somewhat reversed and the communities measured in 2010 appear to begin to converge with those from 1985, with increases in abundance of blue moki, greenbone (*Odax pullus*) and trumpeter (Figure 9a & b). It should be noted, however, that this increase occurred over both the newer marine reserves established in 2005 and the older reserves that had been in place for some time. In contrast, we found the structure of the exploited reef fish community in both commercial exclusion zones and regions open to commercial fishing to vary significantly among years, indicated by significant differences among three of the six pairs of years tested (Figure 9c & d, Table 7 & 8). In both of these management zones, the trajectory of community structure remains distant to those observed in 1985 with an overall increase in sea perch and decrease in blue cod in commercial exclusion zones and no clear pattern on the open coast.

These patterns are mirrored and the effects are somewhat clearer in the analysis of changes in the exploited reef fish community composition. The composition of the exploited reef fish community did not vary significantly among years in old marine reserves (est. 1993) or new marine reserves (est. 2005) (Table 9 & 10). In both management zones, the trajectory of the reef fish community composition is convergent towards its origin in 1985, with increased incidence of greenbone and blue moki (Figure 9a and b). Conversely, the composition of the exploited reef fish community varied significantly among years at sites in commercial exclusion zones and on the open coast, indicated by significant differences among 4/6 pairs and 5/6 pairs of years in commercial exclusion zones and open regions respectively, tested in the PERMANOVA pairwise tests (Table 11 and 12, Figure 10c and d). These results indicate a strong effect of management zone on the dynamics of the exploited reef fish community, both in structure and composition. We compared this result with a parallel analysis for non-targeted reef fishes. Our working hypothesis was that changes in relative abundance of large picivorous fish (the exploited group) may affect the overall abundances of their prey (non-target reef fishes), but would likely not affect their relative abundance (non-target fish community composition).

Using pairwise post-hoc tests of differences among years within management zones, we found that the structure of the non-target fish community did not change over time in old marine reserves or in new marine reserves (Table 13 & 14, Figure 11a & b). In old marine reserves we observed a similar U-shaped trajectory in community composition over time as seen for exploited fish species (Figure 11a), with a decrease in abundance of wrasse species, marblefish, telescopefish and butterfly perch. However, non-target reef fish community structure did vary among years at sites within commercial exclusion zones and in areas open to commercial fishing. Three out of six and four out of six significant differences were found between pairs of years in commercial exclusion zones and in open areas respectively, with a decrease in wrasses, butterfly perch, marblefish and telescopefish at sites in commercial exclusion zones over time and an increase and subsequent decrease in spotties over time in areas open to commercial fishing (Table 15 & 16, Figure 11c & d).

Composition of the non-target fish community did not vary among years in old or new marine reserves (i.e. the same species were seen among years in the two regions) (Table 17 & 18, Figures 12a & b). Composition of the non-target fish community also did not vary among years in commercial exclusion zones or at sites on the open coast indicated by mostly non-significant results for pairwise tests (Table 19 & 20, Figures 12c & d).

These results indicate that the structure of the non-target fish community (relative abundances) changed over time in commercial exclusion zones and on the open coast, but was stable in marine protected areas. Conversely, the composition of the non-target fish community was stable over the time monitored in all management zones.

Table 5. Exploited reef fish in old marine reserves (est. 1993) pair-wise PERMANOVA results

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.98177	0.4058	15	0.4224
2002, 2010	1.4793	0.0659	15	0.1653
2002, 1985	0.7948	1	3	0.601
2006, 2010	1.1012	0.3462	35	0.3277
2006, 1985	1.2537	0.2036	15	0.2467
2010, 1985	0.99235	0.5869	15	0.4158

Table 6. Exploited reef fish in new marine reserves (est. 2005) pair-wise PERMANOVA results

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.97389	0.4679	6830	0.445
2002, 2010	0.59291	0.9142	6857	0.8157
2002, 1985	0.86103	0.5342	1710	0.5079
2006, 2010	0.89438	0.5707	9756	0.5369
2006, 1985	1.1995	0.2188	8545	0.2289
2010, 1985	0.87117	0.5653	8576	0.5304

Table 7. Exploited reef fish in Commercial Exclusion Zones (est. 2005) pair-wise PERMANOVA results. p values in bold denote statistically significant results.

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	1.0711	0.3392	9854	0.3422
2002, 2010	0.87154	0.6036	9890	0.5358
2002, 1985	1.6374	**0.024**	9744	**0.0391**
2006, 2010	1.3112	0.1659	9901	0.1719
2006, 1985	1.8111	**0.0286**	9839	**0.029**
2010, 1985	1.9956	**0.0171**	9880	**0.0201**
2002, 2006	1.0711	0.3392	9854	0.3422

Table 8. Exploited reef fish in open regions pairwise PERMANOVA results. p values in bold denote statistically significant results.

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	1.297	0.1895	385	0.1838
2002, 2010	0.79168	0.6586	715	0.6174
2002, 1985	2.1435	**0.0172**	255	**0.0119**
2006, 2010	1.6708	**0.017**	6221	**0.0351**
2006, 1985	1.3743	0.1379	1780	0.1361
2010, 1985	2.2218	**0.0001**	6272	**0.0025**

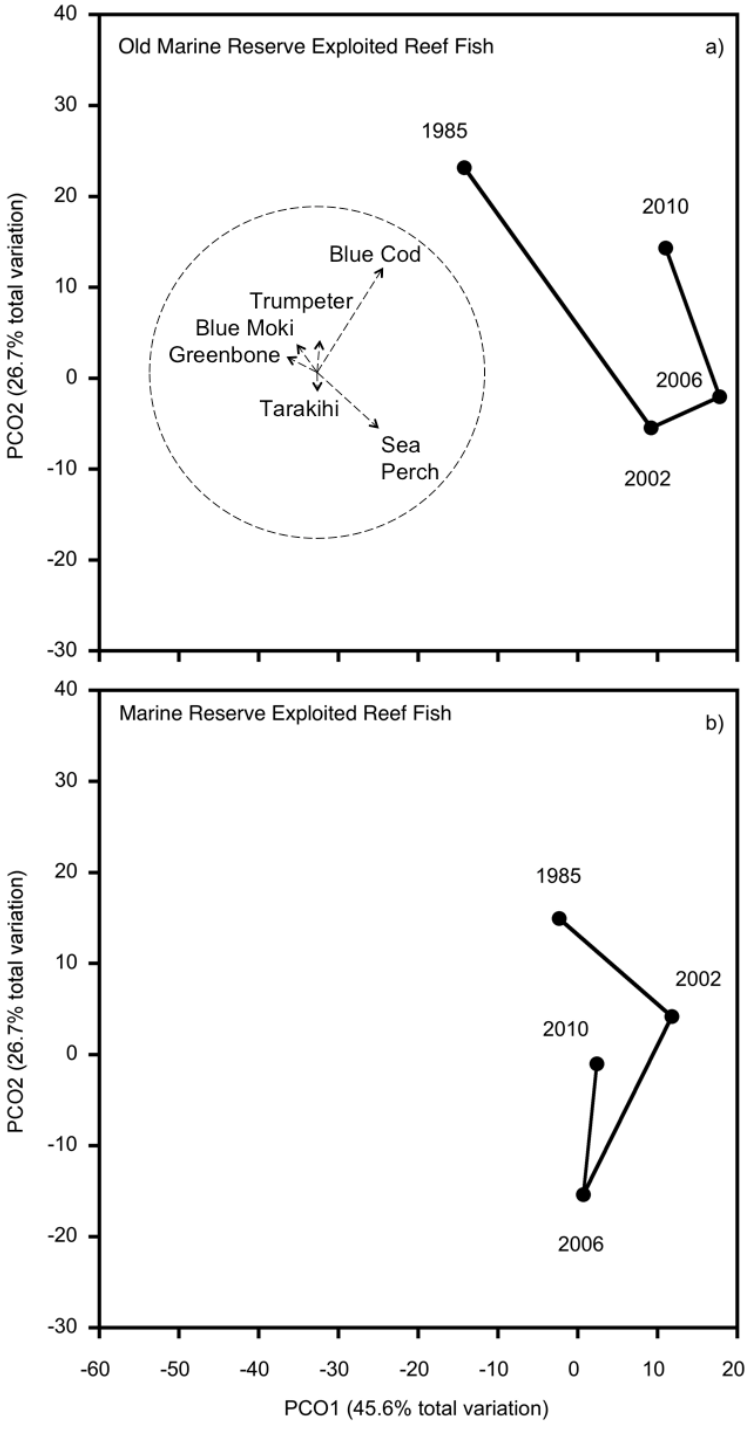

Figure 9.ab. Exploited reef fish community structure at sites in (a) old marine reserves (est. 1993) and (b) marine reserves (est. 2005). Points shown are group centroids. Vectors are Pearson’s correlations.

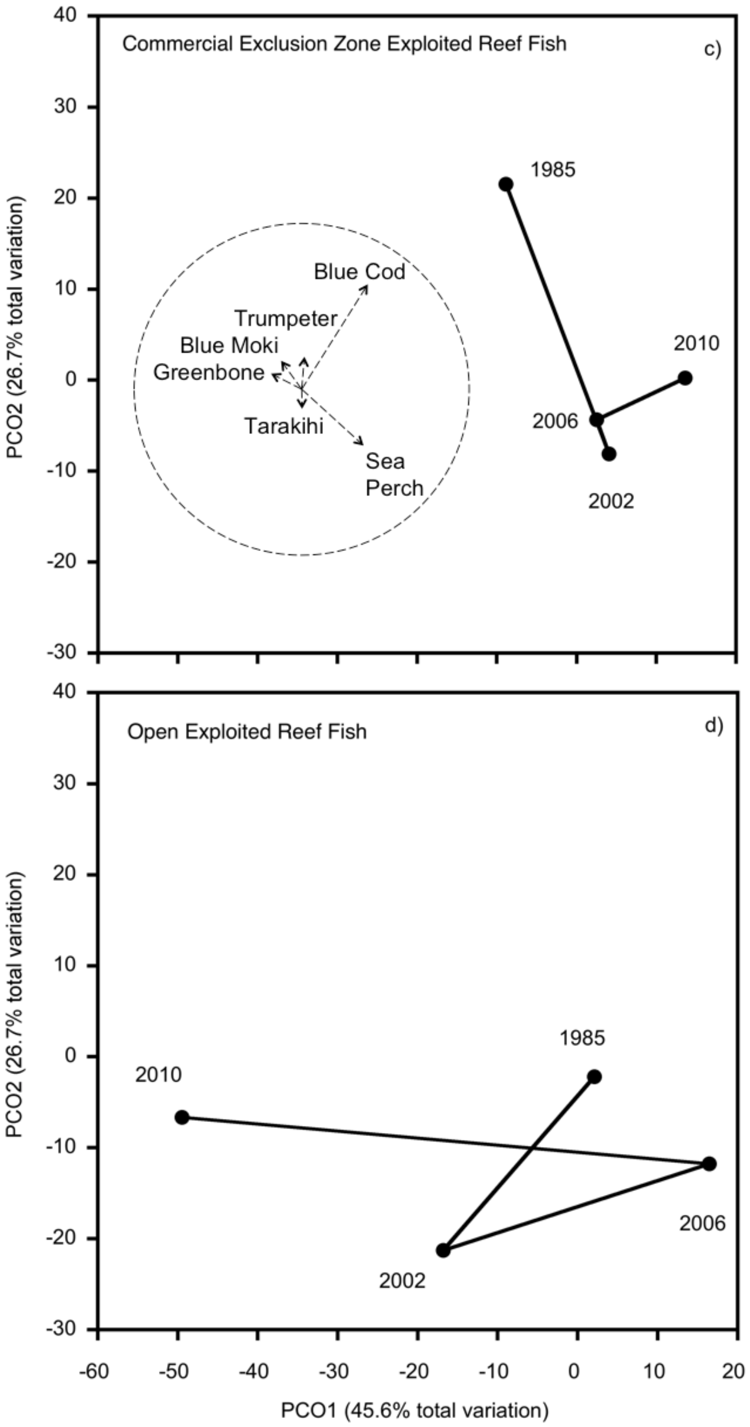

Figure 9.cd. Exploited reef fish community structure at sites in (c) commercial exclusion zones (est. 2005) and (d) regions open to commercial fishing. Points shown are group centroids. Vectors are Pearson’s correlations.

Table 9. Exploited reef fish presence/absence in old marine reserves (est. 1993) pair-wise PERMANOVA results

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.9759	0.7363	3	0.4017
2002, 2010	1.2553	0.3302	5	0.2466
2002, 1985	0.44721	1	2	0.8498
2006, 2010	1.3416	0.4298	2	0.1948
2006, 1985	1.1547	0.3378	4	0.3072
2010, 1985	1.1547	0.3377	6	0.2999

Table 10. Exploited reef fish presence/absence in new marine reserves (est. 2005) pair-wise PERMANOVA results

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	1.107	0.292	102	0.2961
2002, 2010	0.49036	0.967	120	0.92
2002, 1985	1.157	0.2571	101	0.2563
2006, 2010	1.026	0.4395	21	0.3786
2006, 1985	1.0244	0.3467	126	0.3692
2010, 1985	0.92818	0.5086	124	0.4891

Table 11. Exploited reef fish presence/absence in Commercial Exclusion Zones (est. 2005) pair-wise PERMANOVA results. p values in bold denote statistically significant results.

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	1.008	0.4051	291	0.3943
2002, 2010	1.4202	0.1051	204	0.1179
2002, 1985	1.8084	**0.0182**	330	**0.0197**
2006, 2010	1.9716	**0.0112**	18	**0.0133**
2006, 1985	2.2737	**0.0015**	205	**0.0032**
2010, 1985	1.7337	**0.0298**	140	**0.0364**

Table 12. Exploited reef fish presence/absence in open regions pair-wise PERMANOVA results. p values in bold denote statistically significant results. Italicized p values denote marginally non-significant results.

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	1.4822	*0.0761*	72	*0.0901*
2002, 2010	0.82347	0.6927	82	0.6158
2002, 1985	2.0953	**0.0024**	33	**0.0062**
2006, 2010	1.777	**0.0167**	24	**0.0218**
2006, 1985	1.4318	*0.0836*	238	*0.0993*
2010, 1985	1.9899	**0.0009**	287	**0.0067**

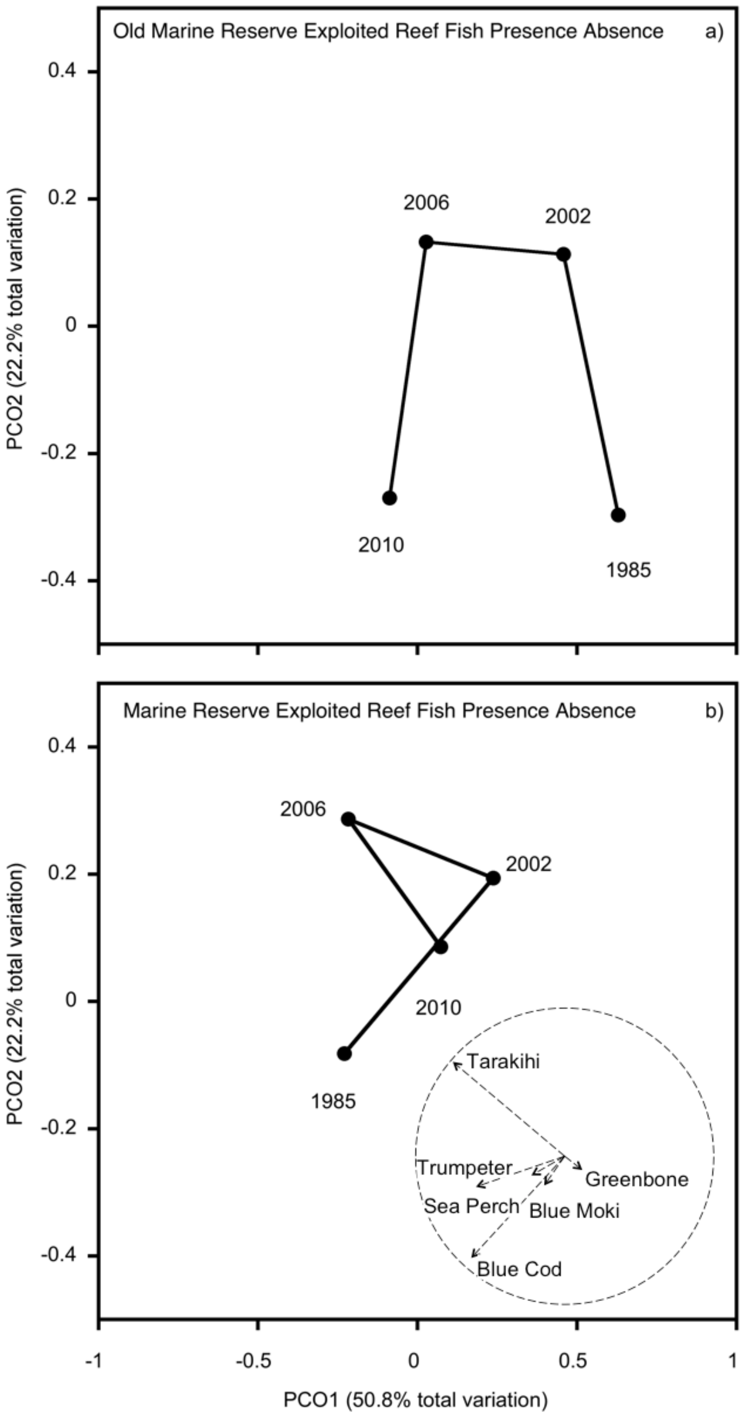

Figure 10.ab. Exploited reef fish community composition at sites in (a) old marine reserves (est. 1993) and (b) marine reserves (est. 2005). Points shown are group centroids. Vectors are Pearson's correlations.

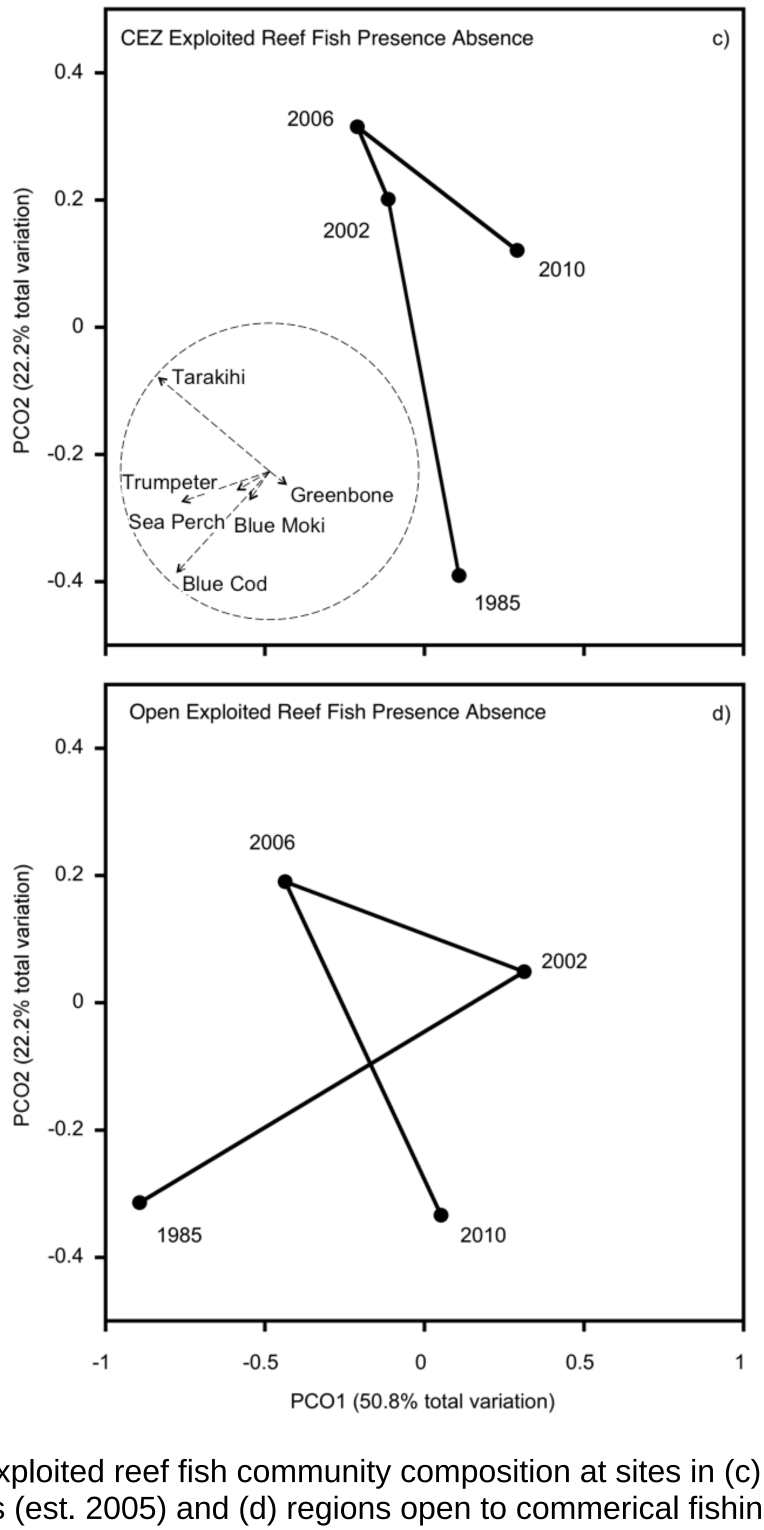

Figure 10.cd. Exploited reef fish community composition at sites in (c) commercial exclusion zones (est. 2005) and (d) regions open to commerical fishing. Points shown are group centroids. Vectors are Pearson's correlations.

Table 13. Non-Target reef fish in old marine reserves (est. 1993) pair-wise PERMANOVA results

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.56087	0.8616	15	0.737
2002, 2010	0.72802	0.7327	15	0.6735
2002, 1985	0.83166	0.6644	3	0.5548
2006, 2010	1.2621	0.1978	35	0.213
2006, 1985	1.3152	0.2697	15	0.2144
2010, 1985	0.60471	0.9334	15	0.7572

Table 14. Non-Target reef fish in new marine reserves (est. 2005) pair-wise PERMANOVA results

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.92558	0.4355	6822	0.4328
2002, 2010	0.96848	0.402	6839	0.4006
2002, 1985	0.80244	0.5257	1707	0.5399
2006, 2010	No-test			
2006, 1985	1.3074	0.1692	8491	0.1704
2010, 1985	1.2389	0.1885	8613	0.1973

Table 15. Non-Target reef fish in Commercial Exclusion Zones (est. 2005) pair-wise PERMANOVA results. p values in bold denote statistically significant results.

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.91721	0.4527	9900	0.4472
2002, 2010	0.94612	0.4183	9919	0.4183
2002, 1985	1.7423	**0.0345**	9829	**0.0428**
2006, 2010	1.0243	0.3302	9893	0.3463
2006, 1985	1.7972	**0.023**	9881	**0.026**
2010, 1985	1.6555	**0.0463**	9880	**0.0533**

Table 16. Non-Target reef fish in open regions pair-wise PERMANOVA results. p values in bold denote statistically significant results. Italicized p values denote marginally non-significant results.

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	1.4512	*0.065*	715	*0.0921*
2002, 2010	1.9262	**0.0168**	715	**0.0194**
2002, 1985	1.6914	**0.0548**	494	**0.0585**
2006, 2010	1.5256	**0.0544**	8150	*0.0692*
2006, 1985	2.3702	**0.0004**	8108	**0.0016**
2010, 1985	2.0309	**0.003**	8116	**0.0083**

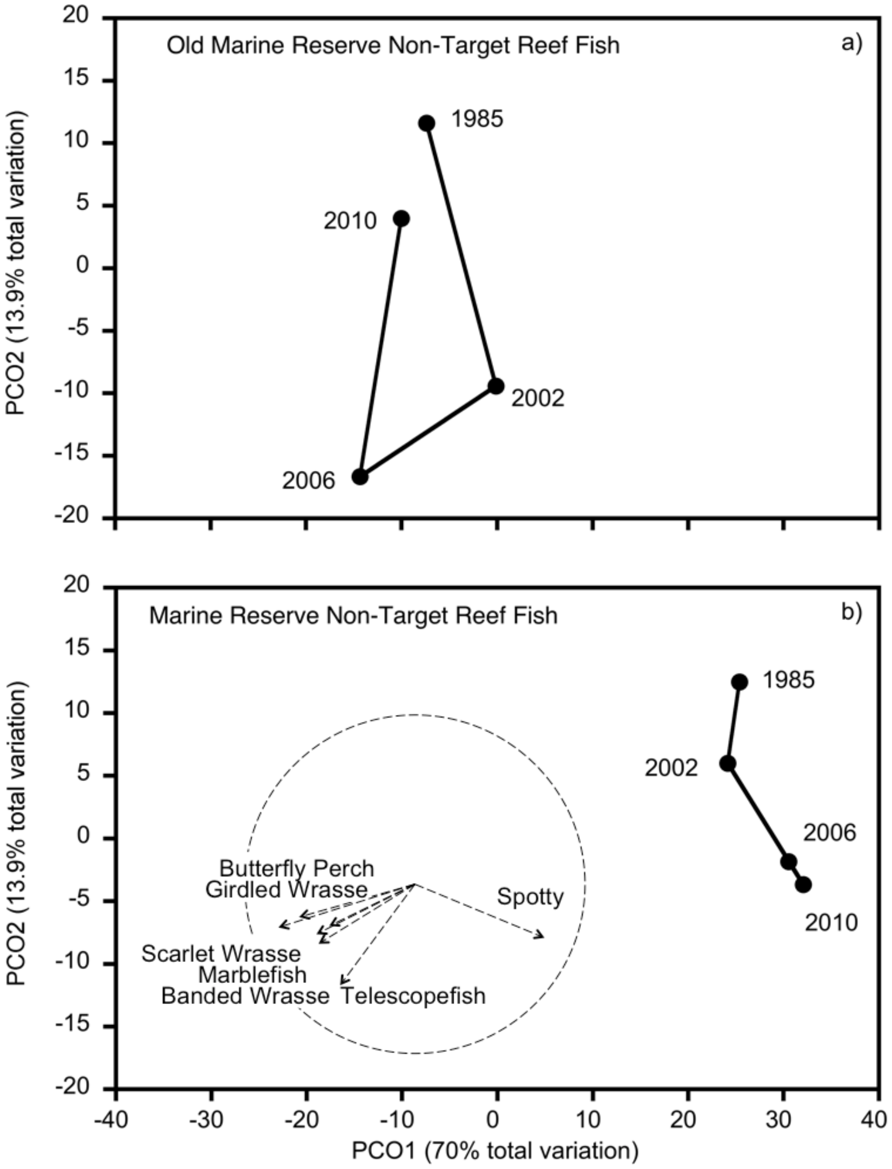

Figure 11.ab. Non-target reef fish community structure at sites in (a) old marine reserves (est. 1993) and (b) marine reserves (est. 2005). Points shown are group centroids. Vectors are Pearson’s correlations >0.5.

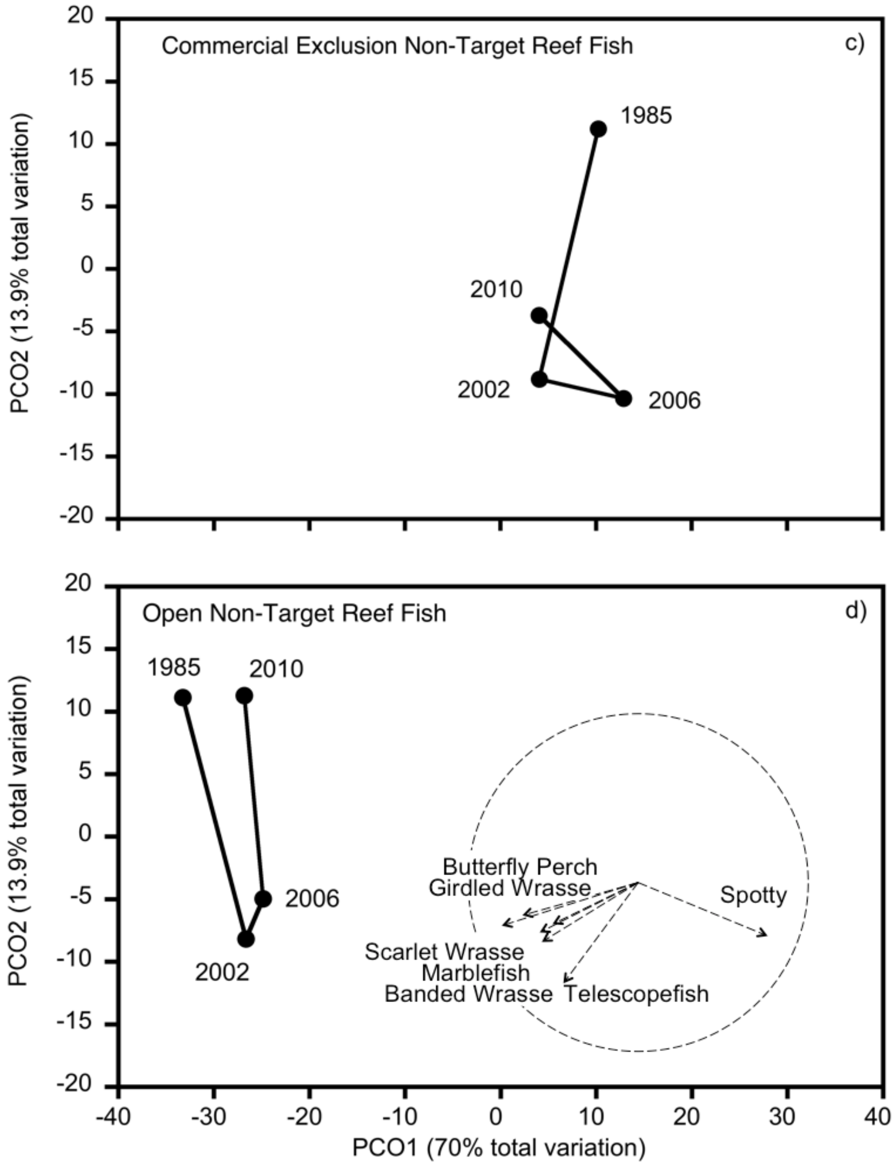

Figure11.cd. Non-target reef fish community structure at sites in (c) commerical exclusion zones (est. 2005) and (b) areas open to commercial fishing. Points shown are group centroids. Vectors are Pearson's correlations >0.5.

Table 17. Non-Target reef fish presence/absence in old marine reserves (est. 1993) pair-wise PERMANOVA results

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.94614	0.6019	15	0.4545
2002, 2010	1.182	0.3272	15	0.3006
2002, 1985	0.35972	1	3	0.8845
2006, 2010	0.8732	0.6031	35	0.5028
2006, 1985	1.0848	0.2721	15	0.3493
2010, 1985	0.99338	0.5333	9	0.406

Table 18. Non-Target reef fish presence/absence in new marine reserves (est. 2005) pair-wise PERMANOVA results

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.29228	0.9051	3269	0.9008
2002, 2010	0.65935	0.7352	4965	0.7019
2002, 1985	1.317	0.2106	363	0.2151
2006, 2010	0.32667	0.9263	9461	0.9237
2006, 1985	1.3596	0.1643	4323	0.1679
2010, 1985	1.1135	0.3084	5548	0.2992

Table 19. Non-Target reef fish presence/absence in Commercial Exclusion Zones pair-wise PERMANOVA results. p values in bold denote statistically significant results.

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.99252	0.4173	9863	0.4096
2002, 2010	0.81226	0.5875	9888	0.5626
2002, 1985	0.92365	0.4977	9273	0.4616
2006, 2010	1.1968	0.2346	9917	0.2371
2006, 1985	1.2761	0.1914	9067	0.1809
2010, 1985	1.8824	0.0209	9788	**0.0305**

Table 20. Non-Target reef fish presence/absence in open regions pair-wise PERMANOVA results. p values in bold denote statistically significant results.

Groups	**t**	**P(perm)**	**Unique perms**	**P(MC)**
2002, 2006	0.83388	0.5641	715	0.5449
2002, 2010	1.2345	0.2731	550	0.2469
2002, 1985	1.1226	0.3065	283	0.2976
2006, 2010	1.2783	0.2088	8197	0.2072
2006, 1985	1.3534	0.1814	6489	0.1705
2010, 1985	2.3837	0.0025	6601	**0.0062**

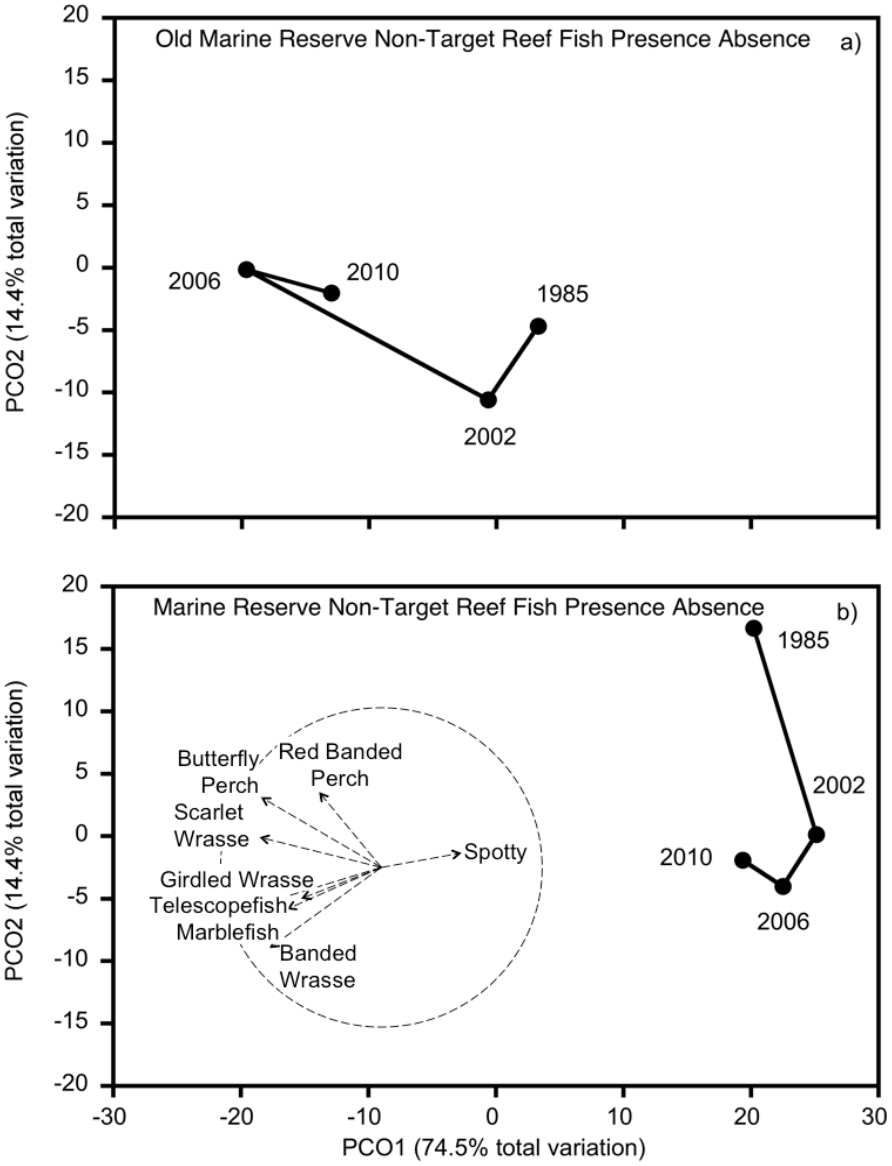

Figure 12.ab. Non-target reef fish community composition at sites in (a) old marine reserves (est. 1993) and (b) marine reserves (est. 2005). Points shown are group centroids. Vectors are Pearson’s correlations >0.5.

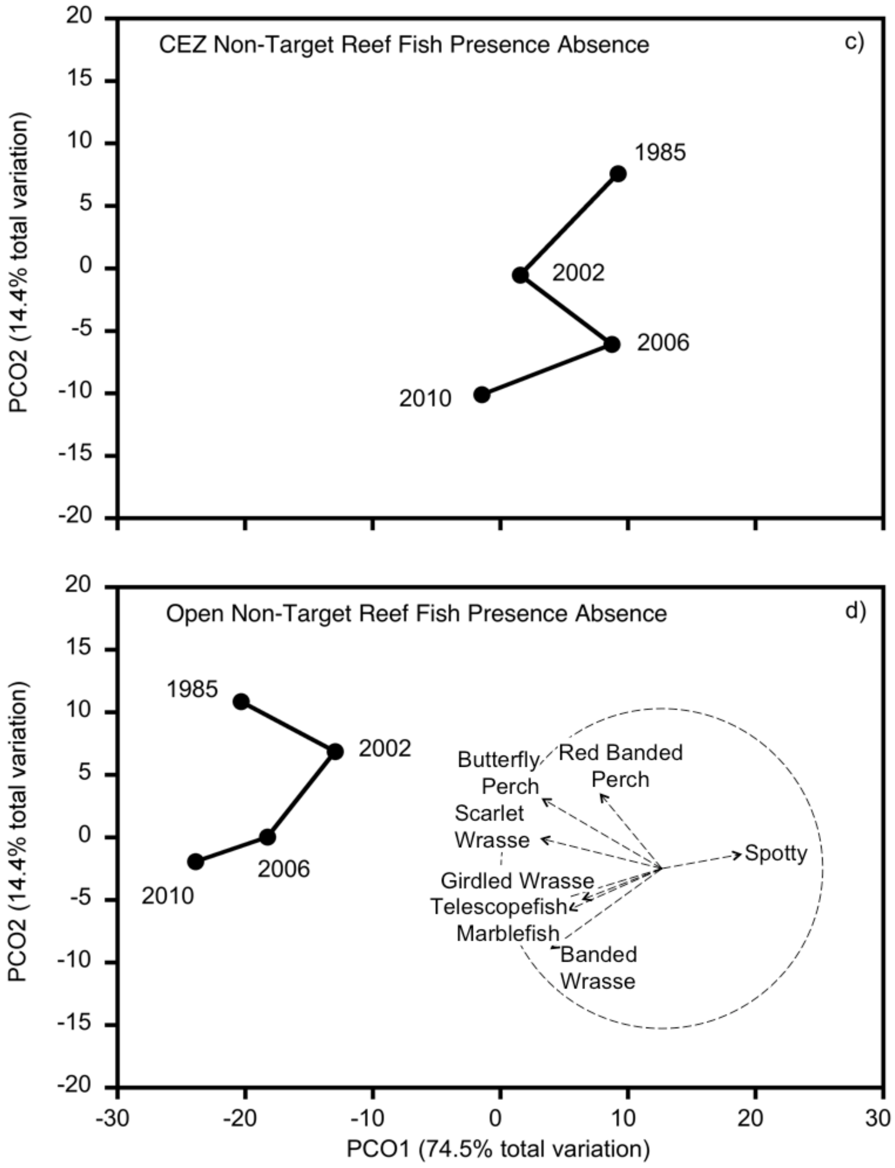

Figure 12.cd. Non-target reef fish community composition at sites in (c) commerical exclusion zones (est. 2005) and (b) areas open to commercial fishing. Points shown are group centroids. Vectors are Pearson’s correlations >0.5.

3.2.4 Kina, kelp and rock lobsters spatio-temporal dynamics

Data from all sites (n= 29) monitored during the 2006-7 (pooled) and 2010 survey periods were used to assess the relationship between the dominant canopy forming kelp, *Ecklonia radiata* and a key grazer, kina (*Evechinus chloroticus*). Quadrat-pairs were heirarchically averaged by depth and site to make site averages for each year which were square root transformed. A resemblance matrix of kina and kelp abundances was calculated using the Bary-Curtis similarity index and a dummy variable of 0.0001 used to account for zero values in the data. This resemblance matrix encapsulates the kina-kelp dynamic at each of the study sites by emphasizing the relative abundances of the two species. Spatio-temporal differences in this dynamic were tested using a PERMANOVA with the factors Year (2 levels, fixed), Management Zone (4 levels, fixed) and Habitat (3 levels, fixed). The effect of the covariate Rock Lobster Abundance was tested by fitting the average yearly CPUE values for each site to the model. No significant effects of Year or Management Zone (p >0.05) were detected and so these factors were pooled with the residuals in the final model. Pairwise post-hoc tests and tests for differences in dispersion (Perm Disp) were conducted for the factor Habitat.

The kina-kelp dynamic was relatively stable for the time period studied as evidenced by the non-significant effect of Year (p >0.05). This is consistent with studies of kina population variability, which occurs on a ten-year time scale (Wing 2009). The relationship between kina and kelp abundance was strongly driven by Habitat (Table 21). This result reinforces studies directed at understanding physical drivers of variability in kelp productivity (Wing et al. 2007), and in kina population dynamics (Wing 2009), which indicate strong physical influences on the gradient in benthic productivity and sea urchin population dynamics in the Fiordland region. We found significant differences in the relative abundances of kina and kelp among inner-, mid- and outer-fjord sites (Pairwise posthoc tests inner [A], mid [B], outer [C]) and these differences are likely based in differences in dispersion, or the range of relative abundances found within habitats (PermDisp: $F_{1, 55} = 24.56$, $p<0.001$). At outer-fjord sites, abundances of both kina and kelp were high (Figure 15). In mid-fjord sites, kina abundances were high, but kelp density varied, whilst at inner-fjord sites, abundances of both kina and kelp were found to vary (Figure 15).

The significant correlation between rock lobster abundance and the kina-kelp dynamic is indicative either of (a) a trophic interaction or (b) a correlation in habitat use between rock lobster abundance and patterns in kelp and kina abundance. The dominant source of variability in the current analysis is due to commonality of habitat use by rock lobsters and sea urchins and kelp. In this case we see high abundance of kina, kelp and rock lobsters at outer coast, kelp forest dominated sites. A secondary source of variability in the relationship is contained by two sites: Doubtful, The Gut South (M22) and Bradshaw, Green’s Cave (M25). At those sites we found high abundances of rock lobsters and low abundances of kina. Here it is possible that sea urchin populations have been depressed by high predation by rock lobsters. However, at least in the case of Green’s Cave there is no resulting increase in kelp density (a typical trophic cascade) because the physical habitat (low light, low wave action) is not conducive to kelp growth.

Table 21. Main PERMANOVA test for the effect of Habitat and Rock Lobster Abundance on the distribution of kina and kelp

Variable	df	Pseudo F	p
Habitat	2,55	5.356	**0.0004**
Rock Lobster	1,57	2.797	**0.0503**

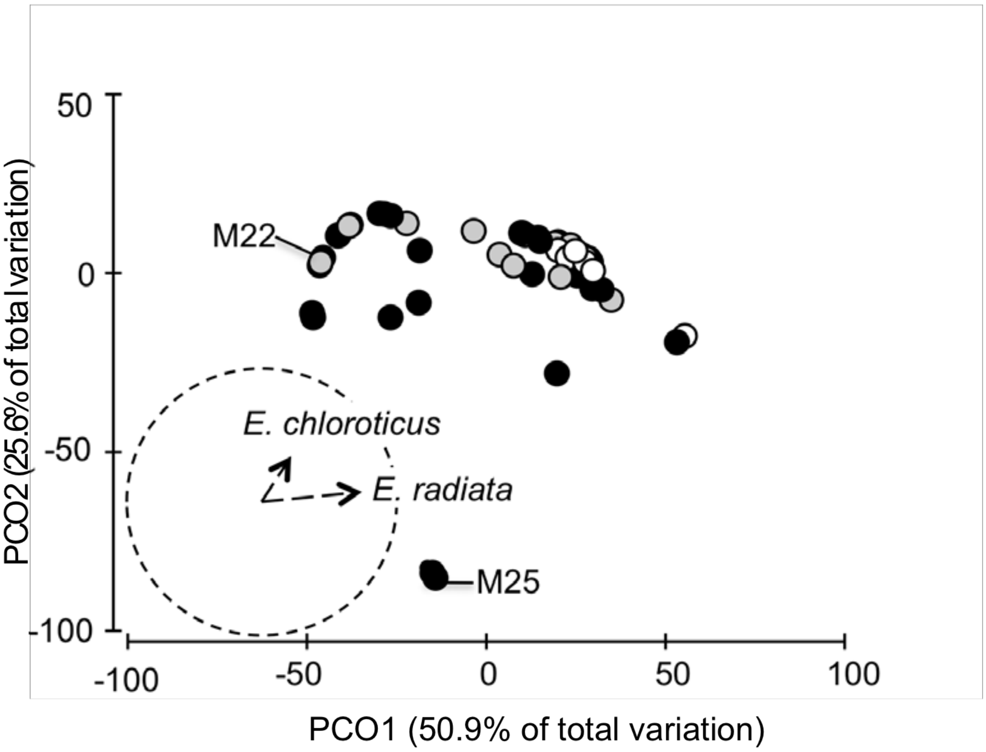

Figure 13. The relationship between kina and kelp at inner- (●), mid- (●) and outer-fjord (O) sites. Vectors show Pearson’s correlations.

3.2.5 Diver-assessed size structure of blue cod and red rock lobsters 2007 versus 2010.

We assessed possible changes in size structure of blue cod and red rock lobsters between 2007 and 2010 surveys. Data were restricted to the 15 m stratum where we had data from both time periods. Averaging at the level of DOC monitoring site and fjord provided comparitive size distributions (3 size classes for each species) for each of the four management regions for each of the two years. Data were standardised and used to make a D_{max} based resemblance matrix and tested using a PERMANOVA design with Year (2 levels, fixed) and Mangement Zone (4 levels, fixed) as factors. No significant differences were found among time periods or management zones for standardised data. These data have a low resolution for size classes and are based on diver estimates that can be quite variable among data collectors, so results should be viewed with some caution (e.g. Jack and Wing 2010).

3.3 Oceanographic characteristics of the Fiordland Marine Area.

Each of the CTD (Conductivity, Temperature, Depth) casts was post-processed using the program Sea Soft. Data were saved as raw text files. The data were used to calculate surface salinity and temperature. Calculation of these stationary indicators of the structure of the low salinity layer was carried out according to previous studies associated with development of the Fiordland GIS (Wing et al. 2003a, Wing et al. 2004, 2005). No further analysis was undertaken with these data. Raw data files accompany this report as a permanent record of physical conditions across the FMA.

3.4 Detection of marine invasive species new to the Fiordland Marine Area or New Zealand.

Surveys were conducted of three manmade structures that had previously been surveyed and two new structures (B14 & 15) (Table 22, Figure 2). None of the targeted species was detected.

Table 22. Biosecurity Survey Sites

Site	**Site #**	**Site position**	
Milford , Freshwater Basin	B12	167.92689	-44.667574
Milford , Deep water Basin	B13	167.920613	-44.677148
The Barge, Weka Island	B1	166.693518	-46.093692
Bligh, Clio Rock	B14	167.52385	-44.828907
George, Anchorage Cove	B15	167.382701	-44.933235

3.5 Cetacean and seabird populations within the Fiordland Marine Area

During 6 transects (Figure 3), 13 species of seabird, four species of marine mammal and one species of shark were observed and estimates of their relative abundances recorded. We report these raw estimates of relative abundance for each transect in Table 23. As transects were conducted on different days, with differing weather conditions, no comparisons can be drawn among the transects. No further analysis was conducted using these data.

Table 23. Raw estimates of relative abundances of seabirds, marine mammals and sharks observed during six opportunistic transects aboard the Southern Winds

Transect	**[6] Milford-Bligh**	**[5] Bligh-George**	**[4] George-Doubtful**	**[3] Doubtful-Breaksea**	**[2] Chalky-Dusky**	**[1] Long-Chalky**
Birds						
Sooty Shearwater (muttonbird)	255	52	1416	452	995	10
Buller's Shearwater	41	0	15	12	127	0
White-capped Mollymawk	41	5	41	35	21	4
Buller's Mollymawk	0	0	3	17	35	0
S. Royal Albatross	0	0	0	1	2	0
Australasian Gannet	4	0	8	2	1	0
Westland Petrel	0	0	0	1	0	0
Arctic Skua	3	0	0	0	0	0
Black Backed Gull	6	0	4	3	8	0
Red Billed Gull	2	0	8	7	6	5
White Fronted Tern	332	0	46	21	201	1
Black Shag	0	0	1	6	1	0
Cape Pigeon	0	0	0	0	1	0
Marine Mammals						
Bottlenosed Dolphin	0	21	23	12	0	0
Orca	0	0	0	0	0	7
Elephant Seal	0	0	0	0	0	1
New Zealand Fur Seal	0	0	2	1	0	0
Sharks						
Blue Shark	0	0	0	2	1	0

4 Discussion

The data and analyses contained in this report present an effective platform for informing management decision making in the Fiordland Marine Area. Information collected during the 2010 Fiordland-wide research cruise is directly comparable in terms of study sites and methods to previous research surveys carried out in 2002, 2006 and 2007 thereby providing a valuable time series for biological indicators (rock lobsters, blue cod, sea urchins, kelp, reef fish communities and sessile suspension-feeding invertebrate communities). These data may then be considered relative to management changes in the region instigated as part of the Fiordland Marine Management Act 2005 and associated fisheries legislation.

These data and analyses are divided into distinct objectives. The **first** major objective for the project was **to characterise Fiordland marine habitats** and thus **describe patterns of spatial variation in communities of sessile rock wall invertebrates along major environmental gradients** in the Fiordland Marine Area. These data provide a valuable backdrop for ecological study of communities and habitats in the region for the shallow subtidal rock wall areas and can be used to assess the balance of habitat types represented in the FMA zones.

We used the Fiordland GIS and previously collected data on size structure of kina and kelp to define 3 major habitat types by which to categorize sites. We conducted large-scale diver-assessed quadrat surveys of macroinvertebrates consistent with earlier surveys. In addition, we collected fine scale data on the suspension feeding community on rock walls using depth-stratified photoquadrats. Analyses of these data highlight three important sources of variability in the biological communities in Fiordland. The first is the variability observed among basins. This is exemplified by the striking difference in the community in Long Sound from the other fjords, a result consistent with observations by Smith (2001). A second source of variability is among major habitat divisions along the fjord axis, which correspond to strong gradients in light, wave exposure and salinity (Wing et al. 2007). A third major source of variability in communities occurs with depth and here is well resolved by the fine scale sampling through the surface low salinity layer, represented by samples taken at mean low tide, 2.5, and 5 m depth. Here we report an interaction between changes in the community with depth and position along the axis of each fjord. The analysis clearly shows enhanced stratification of communities in the inner- and mid-fjord habitats, indicating a graduated effect of the low salinity layer on the structure of the sessile invertebrate community on rock walls from inner to outer fjord.

The **second** overall objective was to assess evidence for changes in indicator taxa and communities associated with management zones in the region. To meet this objective we considered several available data sets and focussed on providing the best time series available to resolve changes in abundance, community structure and community composition within the region. We focussed on key management questions addressed below:

1) **How much has the abundance of rock rock lobster and blue cod changed in Marine Reserves relative to Commercial Exclusion Zones or Open areas?**

The first data set we considered was an index of relative abundance for rock rock lobsters and for blue cod. These data provide the most sensitive index and longest time series of rock lobster and blue cod relative abundance at our long-term monitoring sites. Because dive teams have been similarly structured in terms of tasks among time periods, one fish community survey team, one to two kina kelp quadrat survey team (s) and a sessile invertebrate photoquadrat team, the data are comparable in terms of diver effort and team makeup among time periods. For this analysis we combined data collected in the 2002: (Wing et al. 2003a) and (Wing *unpublished data*); 2005: (Wing et al. 2005) and (Wing *unpublished data*); 2006: (Wing 2006); 2007: (Wing & Jack 2008) and 2010 surveys by study site and region. We then developed a general linear model that accounted for site level variability to provide the best estimate of changes in abundance with time. These data were then considered across the different management regions at the level of fjord.

The patterns in change in abundance of **rock lobsters** indicated that, within the old marine reserves (established 1993), populations were relatively stable and maintained a relatively high abundance over the time period considered. In the new marine reserves, put in place in 2005 as part of the Fiordland Marine Management Act, there were a variety of changes in rock lobster abundance. The reserves at Elizabeth Island and Long Sound showed no changes over time and no detectable populations of rock lobsters during the study period. For the Elizabeth Island reserve this has been linked directly to a change in food supply in the region due to influences of the Manapouri Hydroelectric Power station. Pervious studies have shown a decline in the abundance of bivalve and infaunal prey directly linked to changes in the salinity regime due to the HEP tailrace (Rutger & Wing 2006, McLeod & Wing 2008, McLeod et al. 2010). No rock lobsters have been sighted during surveys of Elizabeth Island marine reserve, but studies of the diet of lobsters caught closest to the reserve (in Hall Arm) have shown that lobsters living near the degraded habitat adjacent to the tailrace do not feed on their usual diet of filter feeders (most likely mussels) and have switched to feeding on chaemoautotrophic clams. These clams occur at low density deep in the mud, contain high concentrations of sulfur and are likely a low quality food resource. Thus the lack of lobsters in Elizabeth Island marine reserve is likely due to the lack of sufficient high quality food due to the degraded nature of the habitat (Jack et al. 2009). Because the lack of lobsters is likely driven by environmental factors and not fishing pressure, it is unlikely that there will be an increase in rock lobster abundance as an effect of Elizabeth Island marine reserve over time. The remaining marine reserves that we considered showed significant positive changes in rock lobster abundance over the time period considered. This was most pronounced in the Clio Rocks Marine Reserve (Bligh Sound) and the Five Fingers Peninsula Marine Reserve (Dusky Sound). Changes in abundance in the commercial exclusion zones were mostly non-significant and also reflected relatively low population numbers in most cases. Exceptions to this were in the Nancy Sound and Breaksea Sound commercial exclusion zones where there were significant declines in rock lobster abundance over the time periods considered. There were no significant changes in relative abundance of rock lobsters in the four open regions considered. Taken as a whole, these data suggest that there has been a significant positive change in rock lobster numbers in several of the new marine reserves but that the reserves at Elizabeth Island and Long Sound do not support suitable rock lobster habitat to support such a build up in numbers. We cannot attach causality to the observed decreases in Nancy and Breaksea Sound as they are potentially consistent with natural phenomina but we also cannot exclude effects of recreational fishing as a root cause for the declines.

A parallel analysis was carried out for **blue cod** abundance and similar general results were obtained. In this case there were no apparent changes in the relatively high population abundances of blue cod in the old marine reserves, while among the group of new marine reserves there were significant increases in three of the five reserves. Notably, the Elizabeth Island Marine Reserve showed no change in very low numbers of blue cod, while the Long Sound Marine Reserve showed significant increases in relative abundance. Significant increases were also seen in the Gaer Arm and Wetjacket Arm Marine Reserves. There were no significant changes in relative abundance of blue cod in the commercial exclusion zones though the trend tended to be negative and there was a significant decline in the Dusky Sound open area, while the other open areas showed no apparent changes in abundance. These results indicate that areas of increase for blue cod tend to be in new marine reserves with appropriate habitat, notably the Long Sound Marine Reserve and the Gaer Arm Marine Reserve.

Our data also support an analysis of the patterns in rock lobster size structure and abundance across the region. These data provide information on the sex ratio of rock lobster and can be used to estimate egg production for a particular habitat or region of the fjords (Jack & Wing 2010). From this data we see evidence for mature size structure of rock lobsters in some of the old marine reserves sites that indicate a large & valuable contribution of eggs and larvae to reproduction of the stock.

2) **How much has reef fish community structure and composition changed through time in these management zones and do dynamics in the exploited versus the unexploited reef fish species differ among each of these zones?**

For this analysis, we considered changes to the whole reef fish community as indicated by data collected during Fiordland-wide research surveys in 1985-6 (Francis & Ling 1985, Francis et al. 1989), 2002 (Wing et al. 2003a), 2006 (Wing 2006), 2007 (Wing & Jack 2008) and the present survey. We divided the type of data we considered into two general categories. The first concerned the **structure** of the reef fish community that included species lists and relative abundances collected during reef fish surveys; the second was information only on the **composition** of the reef fish community as indicated by presence/absence data. The distinction between these two types of data is important. The first provides a measure of how species distributions and their relative abundances change over time. These types of data are sensitive to shifts in abundance that might be associated with competition, predation or other influences on mortality and recruitment in communities. The second type of data, (reef fish species composition), are sensitive to shifts in the types of species that make up a community. These types of shifts are associated with severe changes in mortality or recruitment that result in local or regional losses of a species or groups of species.

The data we considered in this analysis come from several sources. While the methods, time of year and depth strata surveyed are comparable for the 2002, 2006, 2007 and 2010 surveys, those collected in the New Zealand Oceanographic Institute survey in 1985-7 followed a different protocol and occurred during the austral fall rather than the summer time period. While we are still able to derive depth stratified abundance estimates from these data, several caveats are needed when making direct comparisons of abundances or community composition. To avoid these methodological problems and to focus on change in community composition we used an analysis of community similarity among time periods stratified by management region. In this case we are considering only how communities differ in time, within management zones, and then comparing groups of fish within zones. This type of comparative analysis of time series is therefore relatively robust to differences in sampling method.

First a data set was developed that contained all the overlapping sites for the 1985-7, 2002, 2006-7 and 2010 survey periods. Then these sites were divided into those within old marine reserves, new marine reserves, commercial exclusion zones and open areas. Then the fish community was divided into exploited species, and non-target species.

We could then ask the question: **how much has the exploited reef fish community changed in each one of the management zones over time?**

Within the old marine reserves and the new marine reserves we found no significant differences in structure or composition of the exploited/ non-target fish communities. Here we found evidence of a relatively stable community. In the open areas and in the commercial exclusion zones we saw a very different result. For the exploited reef fish in fished zones we found significant changes in both the structure and composition of the communities. This likely indicates the direct effects of fishing on these communities. For the non-target species, (which include several species that are caught and used as bait or discarded during fishing practices e.g. spotties, banded wrasse), we found significant changes in the community structure, but only slight changes in composition over time. This suggests a less severe (though significant) influence on these non-target communities within the fished zones. Though we cannot determine exactly what this influence might be, the data are consistent with either direct effects of fishing on the non-target species or effects of changes in predation and competition brought out by the large changes to the exploited reef fish community observed in these regions.

3) **How do the dynamics between sea urchins and kelp vary among habitat zones and with abundance of predators such as the red rock lobster; and how is representation of these ecological scenarios balanced among spatial management units?**

In order to assess the effects of physical habitat gradients on benthic productivity and resulting trophic interactions within the benthic community, we undertook an analysis of abundances of sea urchins and common kelp collected during the Fiordland-wide research cruises in 2006-7 and in 2010. These data are directly comparable with each other and provide a metric for kelp bed dynamics linked to grazing by sea urchins and potentially the interactions of sea urchin populations with predators such as rock lobsters.

We asked the question: **Do the dynamics between kina and kelp vary at the site level, among habitats or in relation to trophic influences such as predation by rock lobsters, as indicated by relative abundance.**

In these analyses, we first focussed on a combined metric for kina-kelp dynamics based on the differences in abundances for both species on a site-by-site basis. This enabled us to measure how similar sites are in terms of relative abundances of both species simultaneously. The results indicate that the dominant source of variability for abundance of kina and kelp in the system was habitat type, consistent with previous studies of these two species. The abundance of kelp and kina are both influenced by the gradient in light and wave exposure along the axis of the fjords and are positively correlated at the site level. That is, the highest abundances of both kina and kelp occur in kelp forest habitat towards the entrances of the fjords. Interestingly this is also where the highest abundances of rock lobsters occur. So in this system there is evidence that kina-kelp-rock lobster dynamics are dominated by physical or “bottom up” influences. This feature emphasises the importance of including representation of each dominant habitat type, particularly productive outer coastal habitats in spatial management of the region.

In addition to these analyses, we collected baseline information on the **physical oceanographic conditions** at the monitoring sites. These data add to an important database, which offers the only information on climatology of surface oceanographic conditions in Fiordland. This serves two important functions in the context of monitoring conditions within the Fiordland Marine Area. The first is to provide a physical basis for interpreting the patterns that we have resolved in biological communities. The second is to provide a baseline from which to interpret climatological changes that may occur on time scales of 10 to 50 years. In a similar way our records of **seabird and marine mammal sightings** along inter-fjord transects provide a valuable baseline for seabird species composition and relative abundance in the region as well as the occurrence of marine mammals.

Together these data provide a basis for identifying key habitats and their relative representation in the FMA; and for interpreting the effects of physical gradients on biological communities including suspension-feeding invertebrates, errant invertebrates and the relative abundances of sea urchins and kelp (critical species determining patterns of benthic productivity and habitat structure in subtidal systems). The data and analysis presented here provide evidence for the positive effects of spatial management in the Fiordland Marine Area both in terms of relative abundances of indicator species, red rock lobsters and blue cod, and in terms of in the reef fish community. The data and results also emphasize the strong along-fjord gradients in Fiordland that lead to patterns in biodiversity between the quiescent inner fjord habitats and the more productive outer coast and entrance sites. At these wave-washed entrance sites, though under-represented in the FMA, we see the largest gains in terms of population increases in blue cod and rock lobsters. Here also, we observe distinct communities in terms of sessile invertebrates and in rocky reef trophic interactions, as indicated by the relationships among sea urchin, kelp and rock lobster populations. This study provides evidence for positive effects of spatial management in suitable habitats in the FMA. These observations also highlight the importance of productive wave-exposed habitats at the fjord entrances as hotspots for biodiversity and in harbouring high abundances of key fauna.

5 Acknowledgements

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Appendix 1: Sites surveyed in 2010.

Long-term monitoring site	Zone	Habitat	Site position
M1 Only Islands, Long Sound	MR	inner	166.869873, -45.96029
M2 Trevacoon Head, Long Sound	MR	inner	166.778142, -45.990256
M3 The Narrows, Long Sound	MR	inner	166.73616, -46.06488
M5 Station Head, Chalky Inlet	CEZ	mid	166.633319, -45.93232
M6 Edwardson Inner, Chalky Inlet	CEZ	inner	166.665033, -45.903722
M8 Parrot Island, Dusky Sound	MR	mid	166.534184, -45.702031
M10 Anchor Island, Dusky Sound	OC	inner	166.536673, -45.760954
M11 Girlie Island, Dusky Sound	CEZ	mid	166.929156, -45.726417
M13 Inner S. Wall, Wet Jacket Arm	MR	inner	166.767499, -45.663927
M14 The Hook, Wet Jacket Arm	MR	inner	166.895194, -45.63239
M15 Vancouver Arm, Breaksea Sound	CEZ	inner	166.925814, -45.521239
M16 First Cove, Breaksea Sound	CEZ	mid	166.771023, -45.568006
M19 Rolla Island, Doubtful Sound	MR	inner	167.13207, -45.440489
M20 Elizabeth Island, Doubtful Sound	MR	inner	167.126759, -45.429679
M21 The Gut North, Doubtful Sound	OMR	mid	167.151585, -45.460418
M22 The Gut South, Doubtful Sound	OMR	mid	166.943452, -45.293654
M23 Corset Cove, Doubtful Sound	OC	outer	166.896138, -45.280227
M24 Nicole’s Nook, Bradshaw Sound	MR	inner	167.158206, -45.303154
M25 Green’s Cave, Bradshaw Sound	MR	inner	167.145385, -45.292329
M27 Heel Point, Nancy Sound	CEZ	inner	167.106616, -45.177171
M28 Burnett Point, Nancy Sound	CEZ	outer	167.030994, -45.103126
M32 Hansard Point, Caswell Sound	OC	outer	167.150808, -45.009484
M33 Inner Caswell Sound	CEZ	inner	167.288389, -45.044777
M34 Anchorage Cove, George Sound	CEZ	inner	167.382701, -44.933235
M36 Evening Point, Bligh Sound	CEZ	inner	167.499527, -44.852784
M37 Turn Round Point, Bligh Sound	MR	inner	167.537368, -44.803126
M38 Cloudy Pass Point, Bligh Sound	OC	outer	167.531413, -44.79523
M39 Clio Rock, Bligh Sound	MR	inner	167.52385, -44.828907
M40 Post Office Rock, Milford Sound	OC	outer	167.789517, -44.580578
M41 Dale Point, Milford Sound	OMR	mid	167.823603, -44.600871
M42 North side inner, Milford Sound	OMR	mid	167.880605, -44.619566
M45 Cat’s Eye Bay	OC	outer	167.3965, -44.8002
M46 Caswell Outer Coast	OC	outer	167.1433, -45.006
M47 Angelhair Cave, Doubtful Sound	CEZ	inner	167.085133, -45.46736
M48 Tricky Cove, Doubtful Sound	CEZ	inner	167.0525, -45.35
M49 Gilbert Islands, Breaksea Sound	OC	outer	166.6783, -44.5983
M57 Doubtful, Bausa South	CEZ	mid	166.9383, -45.300
M60 Thompson, Penguin Cave	CEZ	mid	166.9835, -45.153
M61 Thompson, Pepper Patch	CEZ	mid	166.7708, -45.156

Appendix 2: Species identified in diver-assessed quadrats (D) and in photoquadrats (P)

Taxa	**Species**	**Common name**	**Survey**
Algae			
Green	*Caulerpa* spp.		P
	Codium spp.		P/D
	Hormisira banksii		P
	Ulva spp.		P
Brown	Articulate corralines		P
	Carpohyllum spp.		P/D
	Carpomitra costata		P/D
	Cystophora retroflexa		P/D
	Dictyota kunthii		P
	Ecklonia radiata		P/D
	Landsburgia quercifolia		P/D
	Lessonia variegata		P/D
	Macrocystis pyrifera		P/D
	Marginariella spp.		P/D
	Sargassum sp.		D
	Xiphophora gladiata		P/D
	Zonaria sp.		D
Red	*Asparagopsis armata*		
Misc		Algal turf	P
		Benthic diatoms	P
Brachiopods			
	Liothyrella neozelandica	White Brachiopod	P
	Notosaria nigricans	Black Brachipod	P
	Terebratella inconspicta	Red Smooth Brachiopod	P
	Terebratella sanguinea	Red Ribbed Brachiopod	P
Cnidarians			
Corals/ Gorgonians	*Antipathes fiordensis*	Black Coral	P
	Errina novazelandiae	Red Coral	P
	Errina sp.	White Coral	P
		Gorgonian sea fan	P
Zooanthids/ Anemones	*Anthothoe albocinta*	White Striped Anemone	P
	Bunodactis crysobathys	Apricot Anemone	P
	Carpophyllia profunda	Cup Coral	P
	Cassiopea spp.	Benthic Jelly	P
	Cerianthus bollunsi	Tube Anemone	P
	Corynactic Haddoni	Jewel Anemone	P
	Edwardsia sp.	Red Striped Anemone	P
	Mimtridium criptum	White Anemone	P
	Parazoanthus spp.	Yellow Zooanthids	P
	Phyltenactis tuberculosa	Wandering anemone	P
	Phlyctenactis tuberculosa	Wandering Anemone	P
		White Zooanthids	P

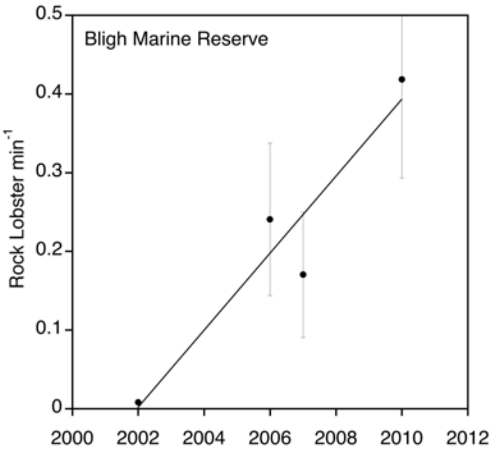
Taxa	**Species**	**Common name**	**Survey**
Annelida			
	Galeolaria hystrix	Red Tube Worm	P
	Neovermilia sphaeropmatus	Reef Tube Worm	P
	Protula bispiralis	Spiral Tube Worm	P
	Sabella sp.	Red Fan Worm	P
		Blue/Black Tube Worm	P
Molluscs			
Barnacles		Barnacles	
Bivalves	*Anomidae*	Rock jingle	P/D
	Atrina zelandica	Horse Mussel	P/D
	Aulacomya atra maoriana	Ribbed Mussel	P
	Lima colorata	Fringed Mussel	P
	Modiolarca impacta	Nesting Mussel	P
	Mytilus edulis galloprovincialis	Blue Mussel	P
	Perna canaliculus	Green Mussel	P
		Spat	P
Chitons/ limpets	*Cryptochoncus porosus*	Butterfly Chiton	P/D
	Eudoxochiton noblis	Noble Chiton	P/D
	Notoplaxus violacea	Violet chiton	P/D
	Scutus breviculus	Dusk's bill limpet	P
	S. pelliserpentis	Snake Skin Chiton	P
		Sessile Limpet spp.	P
Snails	*Argobuccinum p. tumidum*	Smooth Whelk	P/D
	Astraea heiotropium	Circular Saw shell	P/D
	Buccinulum linea	Lined Drill	P/D
	Bucinidea spp.	Whelk misc	P/D
	Calliostoma granti	Grant's Top Shell	P/D
	Calliostome trigris	Tiger Snail	P/D
	Cookia sulcata	Cook's Turban	P/D
	Dicathais orbita	White rock shell	P
	Dipthais sp.	Predatory welk	P
	Maoricolpus roseum	Turret Shell	P
	Modelia granosa	Southern Cat's eye	D
	Neoguraleus		D
	Sigapatella novazelandiae	Circular slipper shell	P
	Stuthiolaria papulosa	Large Ostrichfoot	P/D
	Turbo smaragdus	Cat's eye	P
	Xymene ambiguus	Large Trophon	P/D
Nudibranchs	*Aphelodoris luctuosa*	Smooth light seaslug	P
	Archidoris wellingtonensis	Giant green nudibranch	D
	Jason mirablis	Miraculous nudibranch	P/D
	Lamellaria cerebroides	Bumpy Seaslug	P/D
Paua	*Haliotis australis*	Yellow footed paua	D
	Haliotis iris	Black footed paua	P/D

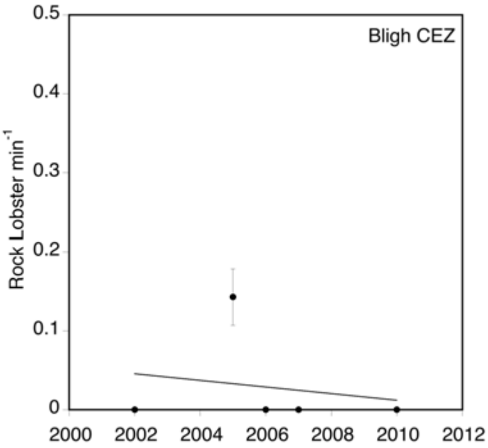
Taxa	**Species**	**Common name**	**Survey**
Sponges & Ascidians			
	Axinella tricalyformis	Elephant ear sponge	P
	Cnemidocarpa sp.	Solitary Ascidian	P
	Leucettusa lancifer	Vase Sponge	P
Bryozoans			
	Adeonellopsis sp.	Purple Bryozoan	P
	Catenicellid bryozoan	Moss Bryozoan	P
	Cinctipora elegans	Elegant lace Coral	P
	Hornera foliacea	Lacy Bryozoan	P
Echinoderms			
Sea Stars	*Allostichaster insignis*	3 & 3 Armed Sea Star	P/D
	Allostichaster polyplax	4 & 4 Sea Star	P/D
	Apteraster sp.	Slimy Sea Star	P/D
	Asterodon milearis	Red Biscuit Star	P/D
	Asterostole scabra	7 armed sea star	P/D
	Coscinasteria muricata	11 Armed Sea Star	P/D
	Henricia sp.	Pencil sea star	P/D
	Patiriella regularis/ mortenseni	Cusion Star	P/D
	Pentagonaster pulchellus	Biscuit Star	P/D
	Sclerasterias mollis	Apricot Sea Star	P/D
	Stichaster australis	Reef Star	P
	Stignaster inflatus	Ambush Star	D
Snake Stars/ Brittle Stars	*Astrobrachion constrictum*	Black Coral Snake Star	P/D
	Astroceras elegans	Gorgonian snake star	P
	Ophionereis fasiata	Variable Brittle Star	P
	Ophiosammus maculata	Snake Tail Star	P/D
	Oxycomanthus plectrophorum	Feather Star	P
Sea cucumbers	*Ocnus brevidentis*	Burrowing Sea Cucumber	P
	Ocnus spp.	Strawberry Holothurian	P
	Australostichopus mollis	Sea Cucumber	P/D
Sea Urchins	*Evechinus chloroticus*	Kina	P/D
	Pseudechinus huttoni	White Sea Urchin	P/D
Arthropods			
Crustacean	*Jasus edwardsii*	Rock Lobster	P
Pycnogonid	*Pycnogonid* spp.	Sea Spider	P/D

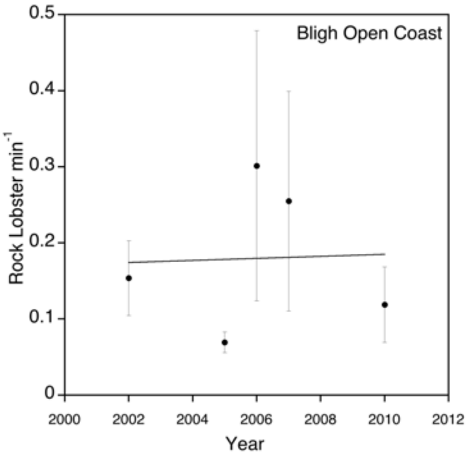
Appendix 3: Site locations used for fish community analysis. DOCM (prox): DOC monitoring site closest to site samples by Francis in 1985

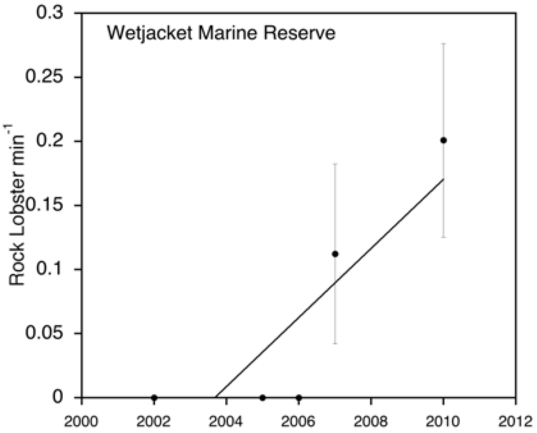
	1985		**2002**	**2006**	**2007**	**2010**		
FJORD	**DOCM (Prox)**	**Site Name (Francis)**	**DOCM**	**DOCM**	**DOCM**	**DOCM**	**Site Name (DoCM)**	**Zone**
Long	*1*	Long inner	1	1	1	1	Only Islands	MR
Long	*2*	Long Trevaccoon	2	2	2	2	Trevaccoon Head	MR
Long	*3*	Long Channel	3	3	3	3	The Narrows	MR
Chalky			5	5	5	5	Station Head	CEZ
Chalky	*6*	Chalk Edwardson	6	6	6	6	Edwardson	CEZ
Dusky				8	8	8	Parrot Island	MR
Dusky	*10*	Dusk Anchor	10	10	10	10	Anchor Island	Open
Dusky	*11*	Dusk 9 fm pass	11	11		11	Girlie Island	CEZ
Wetjacket	*13*	WJ out	13	13	13	13	South Wall	MR
Wetjacket	*14*	WJ in	14	14	14	14	The Hook	MR
Breaksea	*15*	BS Chathum pt	15	15		15	Vancouver Arm	CEZ
Breaksea	*16*	BS 2nd Cove	16	16	16	16	First Cove	CEZ
Doubtful	*19*	Doubt Eliz		19		19	Rolla Island	MR
Doubtful	*20*	Doubt Eliz		20		20	Elizabeth Island	MR
Doubtful	*21*	Bauza	21	21	21	21	The Gut North	MR
Doubtful	*22*	Bauza inner		22	22	22	The Gut South	MR
Doubtful	*23*	Doubt Out		23		23	Corset Cove	Open
Thom-Bradshaw				24	24	24	Nicole's Nook	MR
Thom-Bradshaw				25	25	25	Green's Cave	MR
Doubtful			26	26			Ransom Head	CEZ
Nancy	*27*	Nancy in	27	27	27	27	Heel Pt.	CEZ
Nancy	*28*	Nancy out	28	28	28	28	Burnett Pt	Open
Caswell	*32*	Caswell out	32	32	32	32	Hansard Point	Open
Caswell	*33*	Caswell inner	33	33	33	33	The Knob	CEZ
George	*34*	George inner	34	34		34	Anchorage Cove	CEZ
Bligh	*36*	Bligh inner	36	36	36	36	Evening Point	CEZ
Bligh	*37*	Bligh mid	37	37	37	37	Turn Round Point	MR
Bligh	*38*	Bligh out		38	38	38	Bligh outer	Open
Milford	*40*	Milford outer	40	40	40	40	Post Office Rock	Open
Milford				41	41	41	Dale Point	MR
Milford	*42*	Milford inner	42	42	42	42	Sterling Falls	MR
Outer Coast	*45*	Out Coast 3			45	45	Cat's Eye	Open
Caswell					46	46	Caswell Outer	Open
Doubtful	*47*	Doubt Deep C			47	47	Angelhair Cave	CEZ
Doubtful					48	48	Tricky Cove	CEZ
Breaksea	*49*	BS Entry			49	49	Gilbert Islands	Open
Doubtful	*56*	Bauza Island	56			56	Bauza South	CEZ

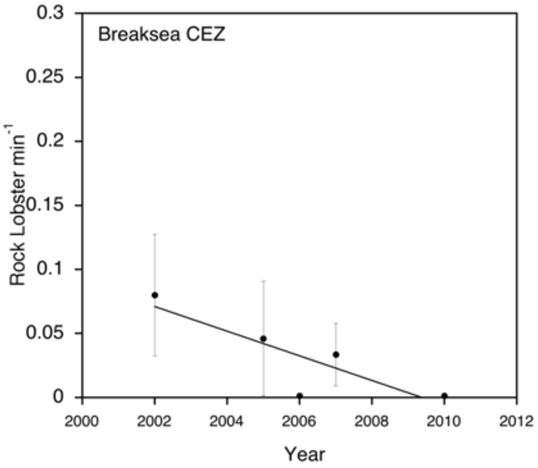
Appendix 4: *Jasus edwardsii.* Time series of CPUE estimates of abundance by management zone in each fjord

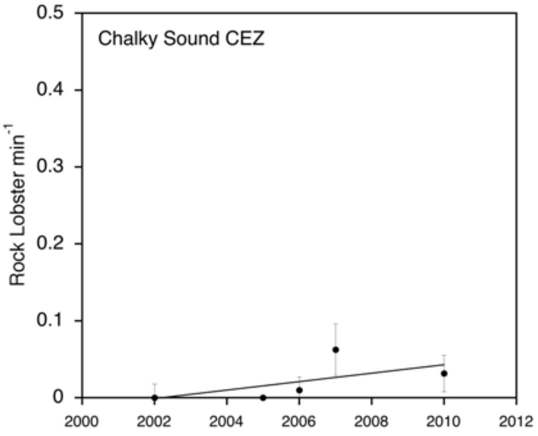







Wetjacket Marine Reserve
Rock Lobster min^{-1}
0.3
0.25
0.2
0.15
0.1
0.05
0
2000
2002
2004
2006
2008
2010
2012


Breaksea CEZ
Rock Lobster min^{-1}
0.3
0.25
0.2
0.15
0.1
0.05
0
2000
2002
2004
2006
2008
2010
2012
Year


Chalky Sound CEZ
Rock Lobster min^{-1}
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0.4
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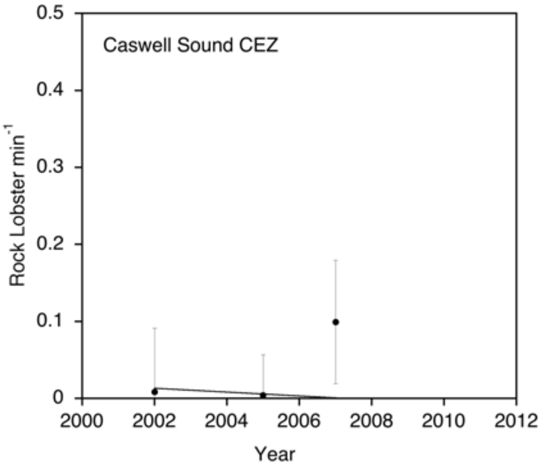
0.2
0.1
0
2000
2002
2004
2006
2008
2010
2012


Caswell Sound CEZ
Rock Lobster min^{-1}
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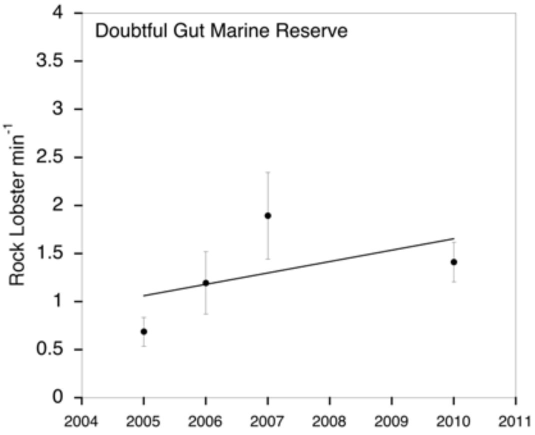
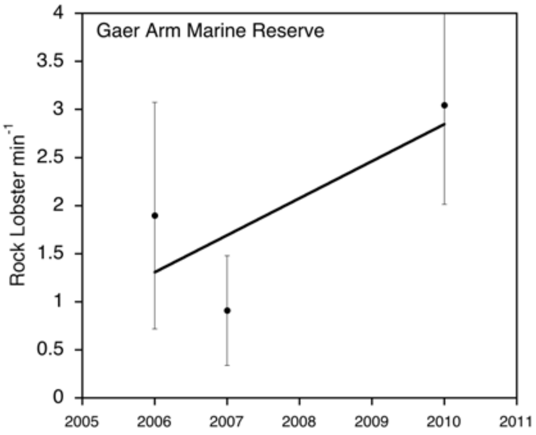
0.4
0.3
0.2
0.1
0
2000
2002
2004
2006
2008
2010
2012
Year


Doubtful Gut Marine Reserve
Rock Lobster min^{-1}
0
0.5
1
1.5
2
2.5
3
3.5
4
2004
2005
2006
2007
2008
2009
2010
2011


Gaer Arm Marine Reserve
Rock Lobster min^{-1}
0
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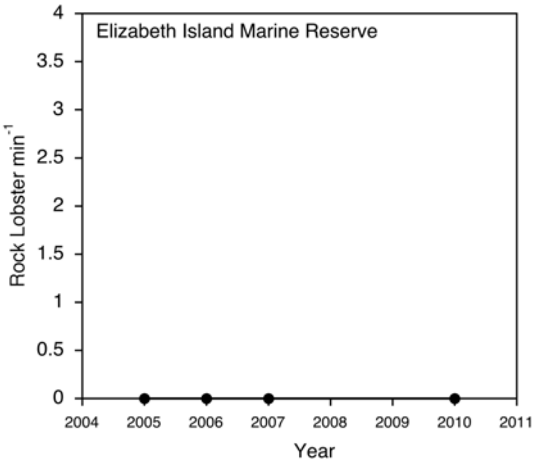
1
1.5
2
2.5
3
3.5
4
2005
2006
2007
2008
2009
2010
2011


Elizabeth Island Marine Reserve
Rock Lobster min^{-1}
0
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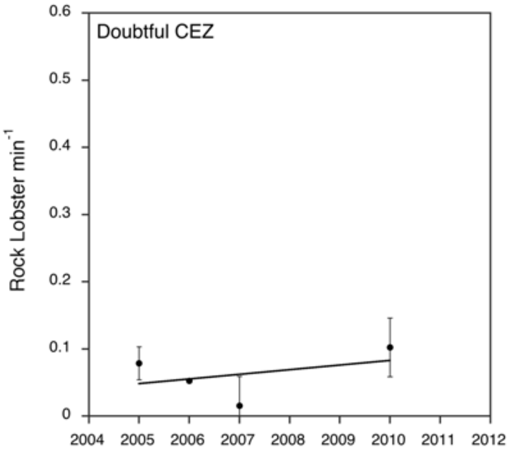
1
1.5
2
2.5
3
3.5
4
2004
2005
2006
2007
2008
2009
2010
2011
Year


Doubtful CEZ
Rock Lobster min^{-1}
0.6
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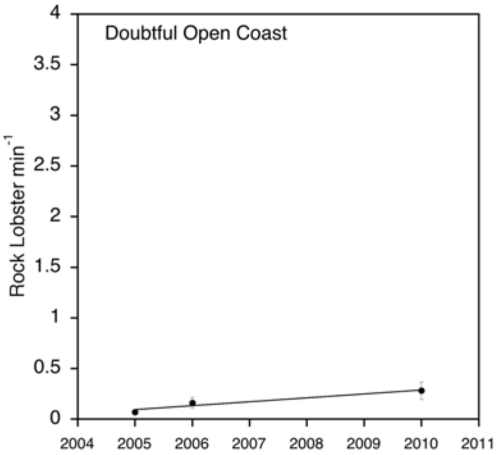
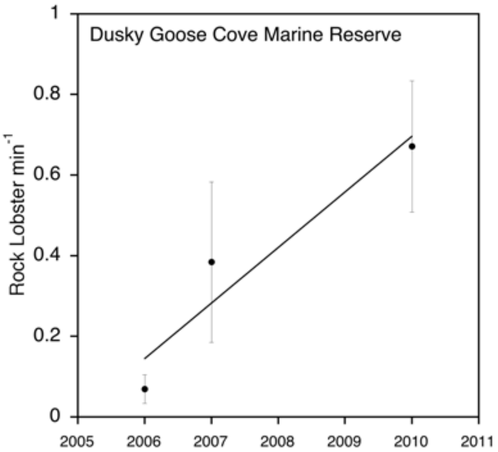
0.4
0.3
0.2
0.1
0
2004
2005
2006
2007
2008
2009
2010
2011
2012


Doubtful Open Coast
Rock Lobster min^{-1}
4
3.5
3
2.5
2
1.5
1
0.5
0
2004
2005
2006
2007
2008
2009
2010
2011


Dusky Goose Cove Marine Reserve
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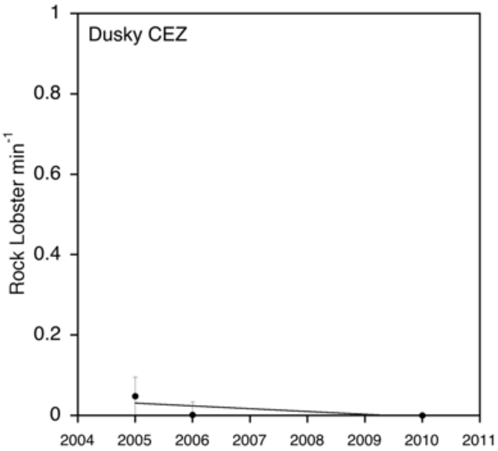
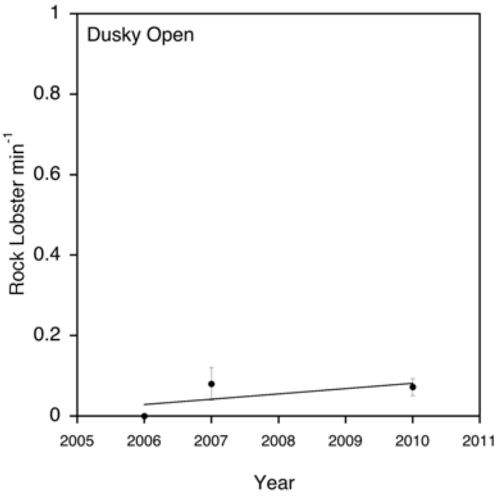
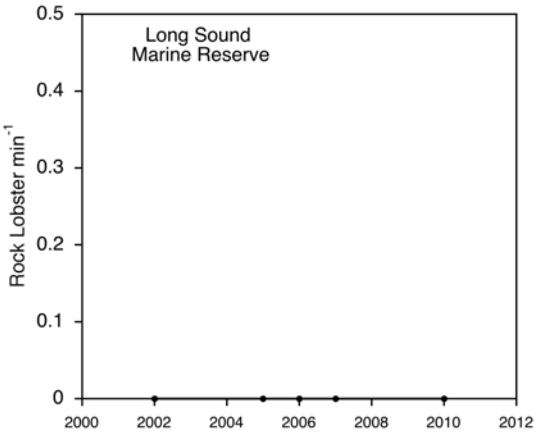
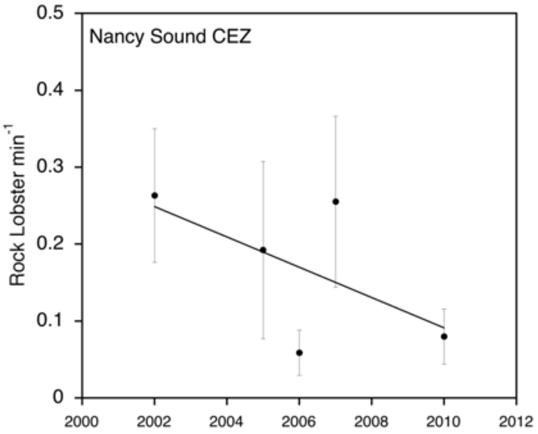
1
0.8
0.6
0.4
0.2
0
2005
2006
2007
2008
2009
2010
2011


Dusky CEZ
Rock Lobster min^{-1}
1
0.8
0.6
0.4
0.2
0
2004
2005
2006
2007
2008
2009
2010
2011


Dusky Open
Rock Lobster min^{-1}
1
0.8
0.6
0.4
0.2
0
2005
2006
2007
2008
2009
2010
2011
Year


Long Sound
Marine Reserve
Rock Lobster min^{-1}
0.5
0.4
0.3
0.2
0.1
0
2000
2002
2004
2006
2008
2010
2012


Nancy Sound CEZ
Rock Lobster min^{-1}
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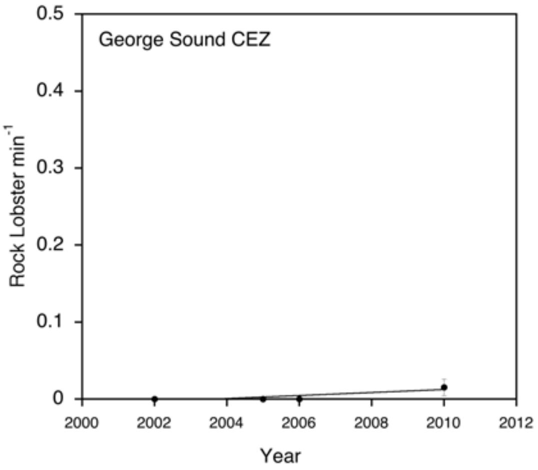
0.3
0.2
0.1
0
2000
2002
2004
2006
2008
2010
2012


George Sound CEZ
Rock Lobster min^{-1}
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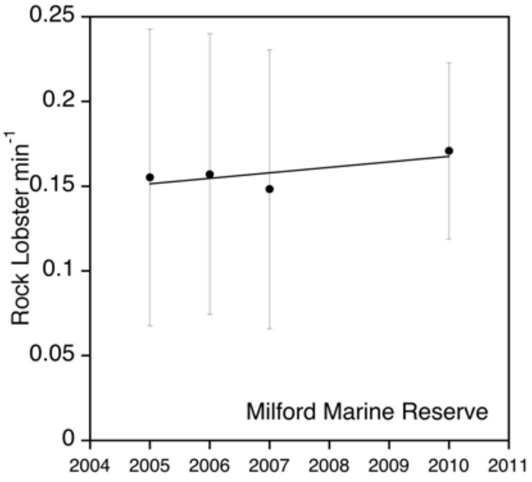
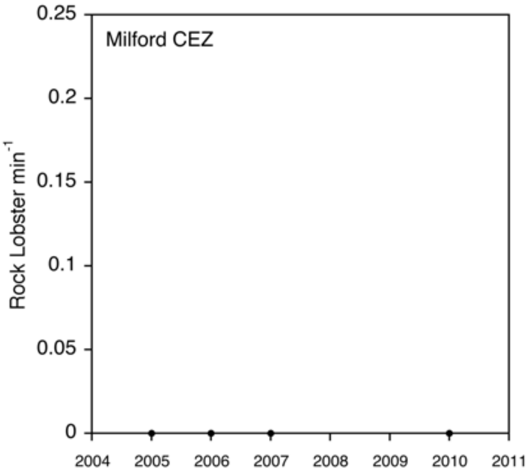
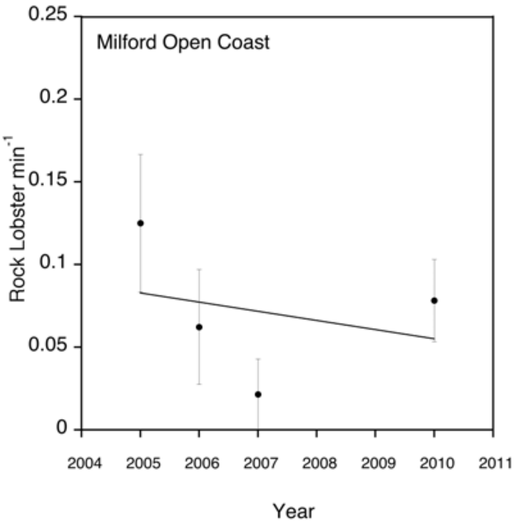
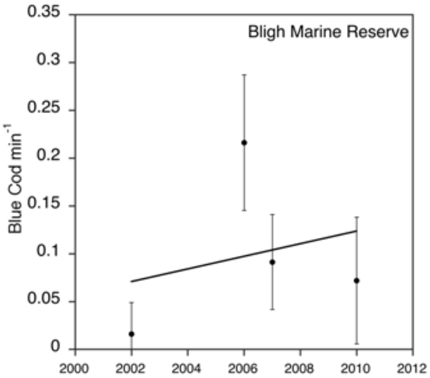
0.3
0.2
0.1
0
2000
2002
2004
2006
2008
2010
2012
Year

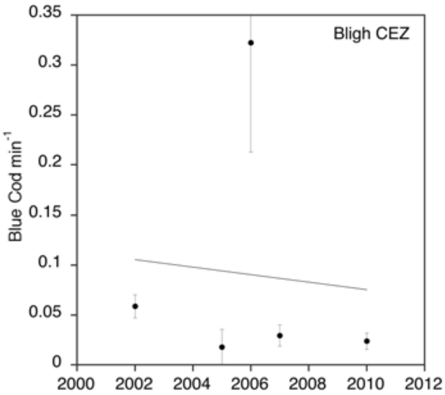

0.25
0.2
0.15
0.1
0.05
0
Rock Lobster min^{-1}
Milford Marine Reserve
2004
2005
2006
2007
2008
2009
2010
2011

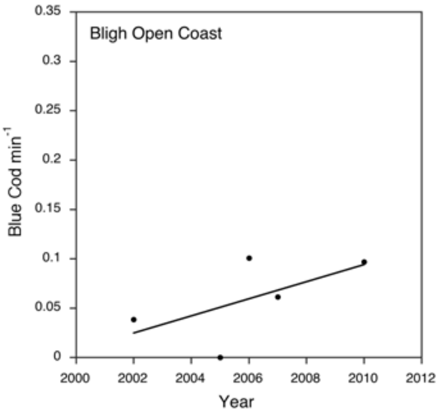

0.25
0.2
0.15
0.1
0.05
0
Rock Lobster min^{-1}
Milford CEZ
2004
2005
2006
2007
2008
2009
2010
2011

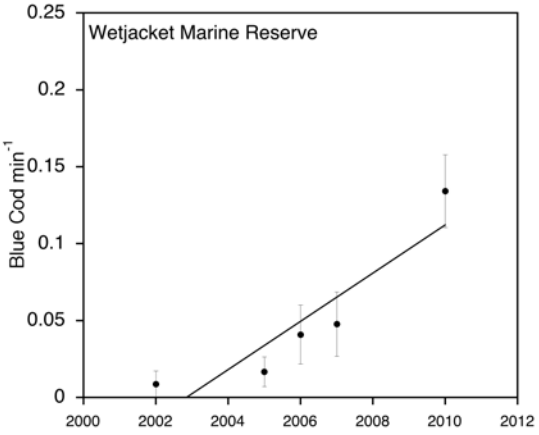

0.25
0.2
0.15
0.1
0.05
0
Rock Lobster min^{-1}
Milford Open Coast
2004
2005
2006
2007
2008
2009
2010
2011
Year

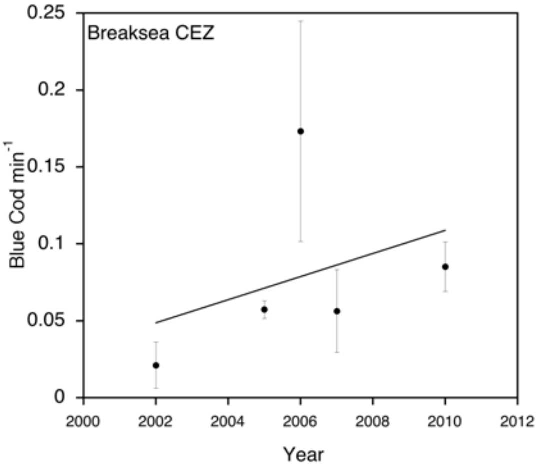
Appendix 5: *Parapercis colias.* Time series of CPUE estimates of abundance by management zone in each fjord

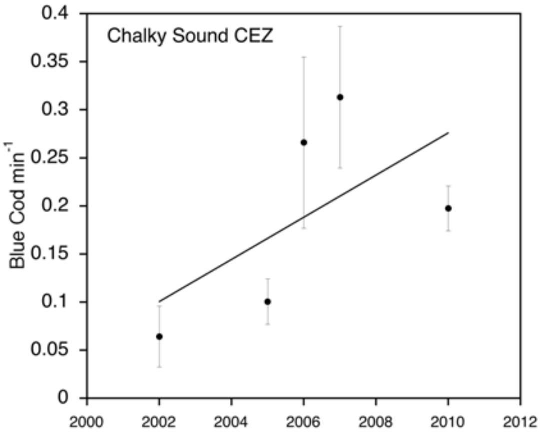


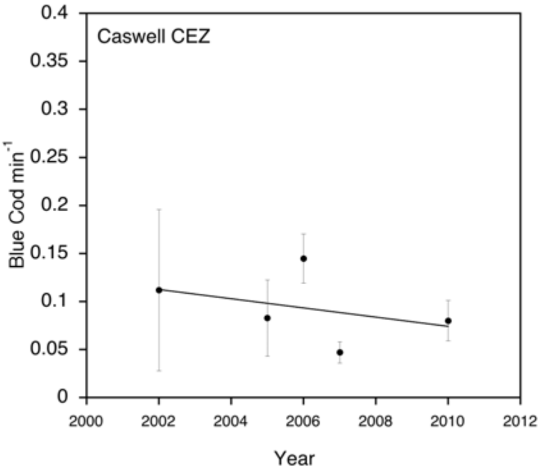


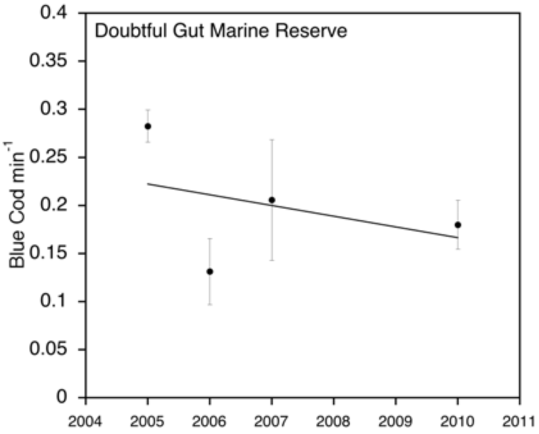


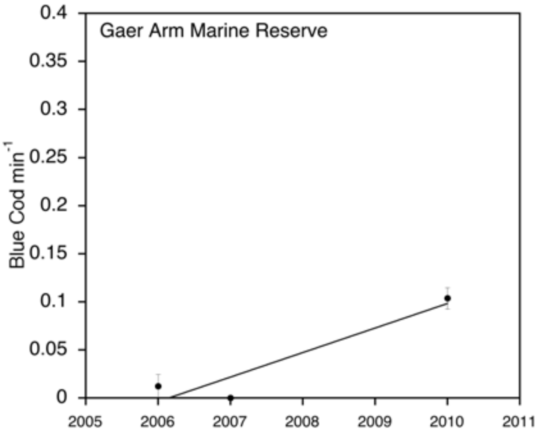

Wetjacket Marine Reserve
Blue Cod min^{-1}
0.25
0.2
0.15
0.1
0.05
0
2000
2002
2004
2006
2008
2010
2012

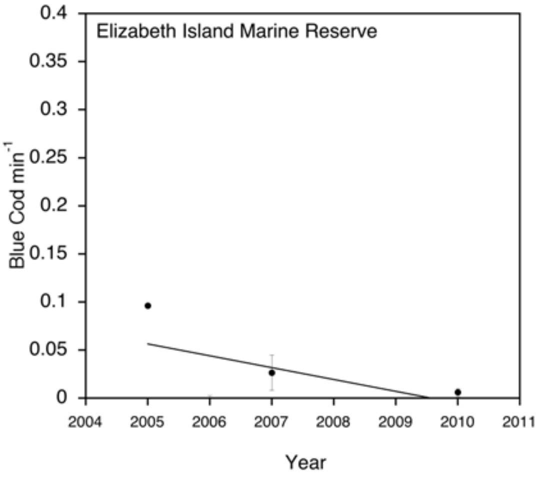

Breaksea CEZ
Blue Cod min^{-1}
0.25
0.2
0.15
0.1
0.05
0
2000
2002
2004
2006
2008
2010
2012
Year

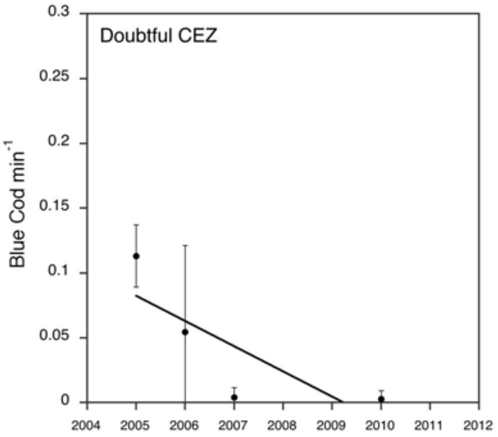

Chalky Sound CEZ
Blue Cod min^{-1}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2000
2002
2004
2006
2008
2010
2012

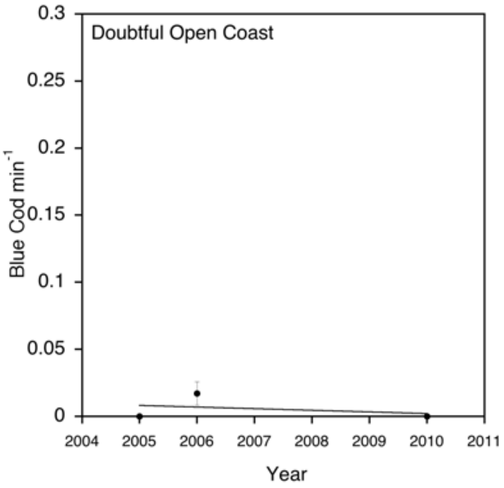

Caswell CEZ
Blue Cod min^{-1}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2000
2002
2004
2006
2008
2010
2012
Year

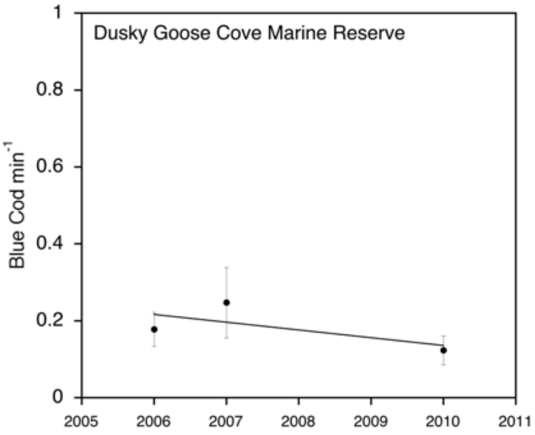

Doubtful Gut Marine Reserve
Blue Cod min^{-1}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2004
2005
2006
2007
2008
2009
2010
2011

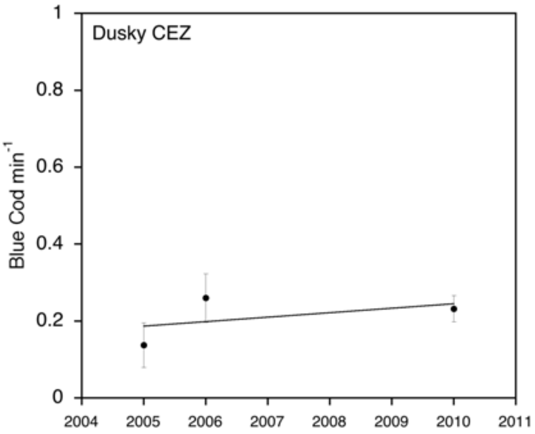

Gaer Arm Marine Reserve
Blue Cod min^{-1}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2005
2006
2007
2008
2009
2010
2011

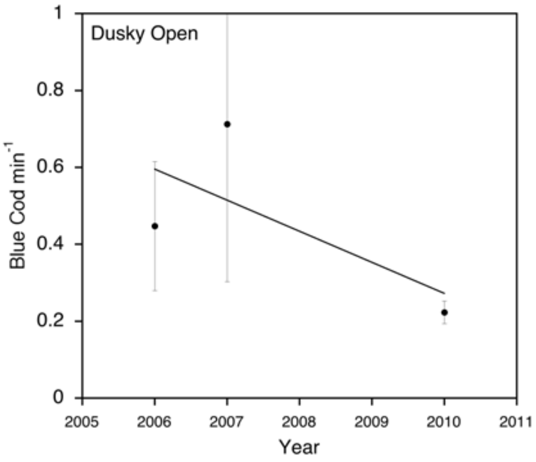

Elizabeth Island Marine Reserve
Blue Cod min^{-1}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2004
2005
2006
2007
2008
2009
2010
2011
Year

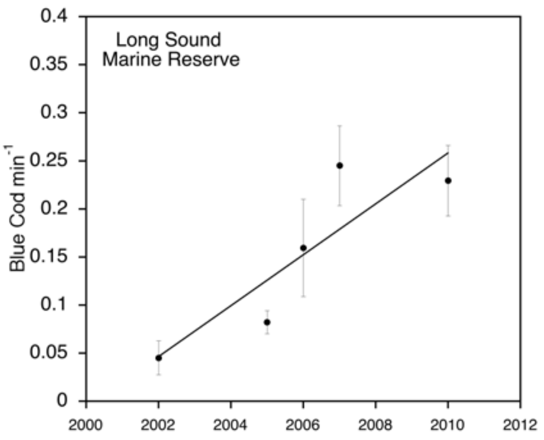

Doubtful CEZ
Blue Cod min^{-1}
0.3
0.25
0.2
0.15
0.1
0.05
0
2004
2005
2006
2007
2008
2009
2010
2011
2012

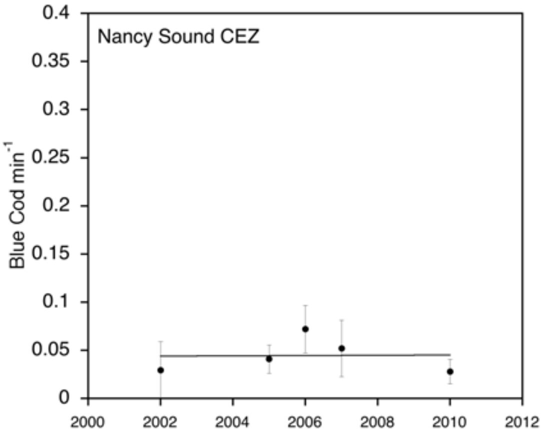

Doubtful Open Coast
Blue Cod min^{-1}
0.3
0.25
0.2
0.15
0.1
0.05
0
2004
2005
2006
2007
2008
2009
2010
2011
Year

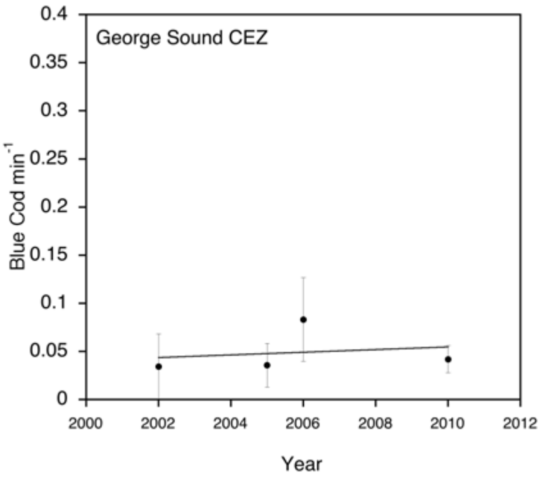

Dusky Goose Cove Marine Reserve
Blue Cod min^{-1}
0
0.2
0.4
0.6
0.8
1
2005
2006
2007
2008
2009
2010
2011

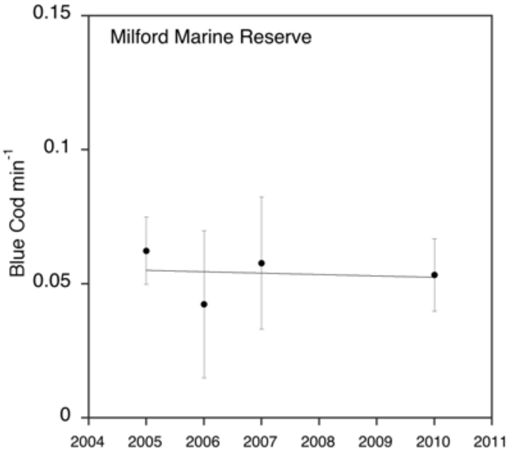

Dusky CEZ
Blue Cod min^{-1}
0
0.2
0.4
0.6
0.8
1
2004
2005
2006
2007
2008
2009
2010
2011

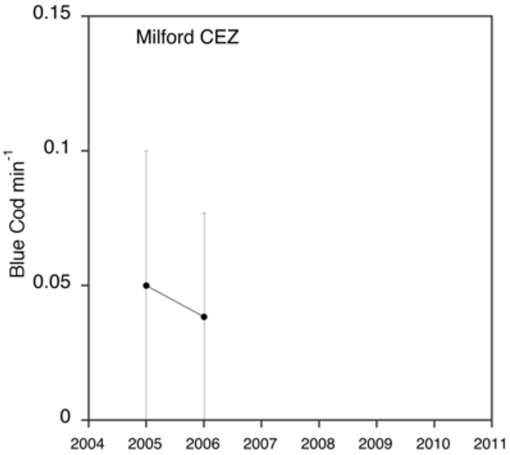

Dusky Open
Blue Cod min^{-1}
0
0.2
0.4
0.6
0.8
1
2005
2006
2007
2008
2009
2010
2011
Year

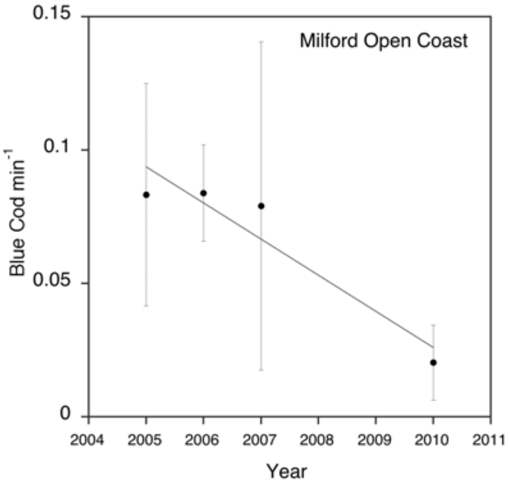

Long Sound
Marine Reserve
Blue Cod min^{-1}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2000
2002
2004
2006
2008
2010
2012


Nancy Sound CEZ
Blue Cod min^{-1}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2000
2002
2004
2006
2008
2010
2012


George Sound CEZ
Blue Cod min^{-1}
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
2000
2002
2004
2006
2008
2010
2012
Year


Milford Marine Reserve
Blue Cod min^{-1}
0.15
0.1
0.05
0
2004
2005
2006
2007
2008
2009
2010
2011


Milford CEZ
Blue Cod min^{-1}
0.15
0.1
0.05
0
2004
2005
2006
2007
2008
2009
2010
2011


Milford Open Coast
Blue Cod min^{-1}
0.15
0.1
0.05
0
2004
2005
2006
2007
2008
2009
2010
2011
Year