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Marine Environment Classification: Physical Influences on Rocky Reef Assemblages in the Hauraki Gulf*

FINAL REPORT: PHASE I

Rocky Reef Surveys, Preliminary Modelling and Spatial Predictions

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Overview

One of the challenges for managing biodiversity on regional scales is being able to use limited biological information to characterise areas with little or no quantitative biological information. The development of the New Zealand Marine Environment Classification (MEC) aims to use multiple physical environmental factors as a proxy for biodiversity patterns in the sea. A statistical validation process is used to establish empirical relationships between biological patterns and physical variables, supporting the construction of the classification to contain physical information most relevant to the observed biological patterns.

The development of a regional-scale MEC in the Hauraki Gulf, with a maximum resolution of 250 m, provides a test scenario where strong physical gradients in several physical environmental parameters occur over relatively short distances (e.g. wave exposure, salinity), while other physical parameters vary more gradually across the environmental domain (e.g. sea surface temperature). Work conducted by the National Institute of Water and Atmospheric Research, Ltd. (NIWA) to evaluate the relative importance on physical environmental variables has been limited to information available of phyto- and zooplankton concentrations, soft-sediment biological assemblages, and trawl surveys for demersal fish. As there was a lack of broad-scale information pertaining to biological assemblages of shallow rocky reefs in the Gulf, the aim of this study was to obtain the information necessary and conduct a preliminary statistical modelling against physical environmental variables. This report summarises results from the survey of 38 rocky reefs at ~15 m depth throughout the Hauraki Gulf conducted between May 2002 and February 2003 and reports on statistical relationships established between biological data and physical environmental variables.

Epifaunal invertebrates showed a pattern of increasing species density (numbers of species per 0.25 m² quadrat) and species richness (measured as the observed number of species along a transect and as the estimated number of species using the Chao 2 index) from inner to outer Gulf. Patterns of turnover diversity (i.e. changes of species composition along a transect) showed a similar increasing trend from inner to outer Gulf, but showed considerable variation in outer Gulf regions. Analysis of species rarity at individual rocky reefs (measured as the number of species occurring once or twice along a transect) showed between 36 and 46 % of the total species richness was made up of rare species.

The abundance of cryptic fishes and macroinvertebrate consumers showed several different spatial patterns within the Gulf, with some species having higher abundance offshore (e.g. the yellow-black triplefin, *Fosterygion flavonigrum* and the sea urchin, *Evechinus*

chloroticus), while other species showed higher abundances in the inner Gulf regions (e.g. the common triplefin, *Fosterygion lapillum*, and the sea cucumber, *Stichopus mollis*). There were several species that had a much more variable spatial pattern (e.g. Cook's turbin, *Cookia sulcata*), while others showed restricted areas of high abundance (e.g. the scorpion fish, *Scorpaena papillosus*).

Statistical validation using a multiple regression approach identified several physical variables related to observed biological patterns. Aspects of epifaunal species diversity were related to aspects of Sea Surface Temperature (SST) and bottom topography, while the abundance of cryptic fishes and invertebrate consumers were related to extreme wave exposure, bottom topography, and, in some cases, aspects of SST. There were several biological variables that did not have any significant statistical relationships, including the spectacled triplefin *Ruanoho whero*, the variable triplefin *Fosterygion varium*, the chiton *Cryptochonchus porosus*, and the small whelk *Axymene corticatus*.

These relationships were used to create predictive surfaces of the distribution and abundance of epifaunal invertebrates, cryptic fishes, and macroinvertebrate consumers based on the physical environmental layers. Although these predictions are only valid for rocky reefs in depths of 10 – 15 m, they provide a tool to be able to understand regional scale variation of biological patterns in the Hauraki Gulf. The discussion of the potential utility and limitations of these predictions are discussed in the context of the development of the regional scale Marine Environmental Classification.

Introduction

A lack of comprehensive biodiversity information on regional scales has prompted the search for methods that can assist in achieving regional-scale conservation and management goals. Establishing the relationship of biological attributes to physical environmental parameters provides a basis to use physical variables, which are available over broader spatial extents and more often continuous in space, to develop a classification of environmental types that reflect aspects of biological assemblages (Belbin 1993). Several approaches exist for developing and testing such environmental classification systems for terrestrial systems (e.g. Scott et al. 1987, Yee and Mitchell 1991, Bojórquez-Tapia, et al. 1995, Leathwick, et al. 2003), while there are relatively fewer examples from marine systems (e.g. Emanuel, et al. 1992, Ward et al. 1999, O'Hara 2001, Roff, et al. 2003). The lack of precedents in developing environmental classifications for marine ecosystems creates difficulty in knowing the most appropriate physical and biological constructs and the appropriate scale at which these relationships between the biological patterns and physical variables are relevant. It follows that the development of classifications for marine ecosystems and their utility as a management tools will largely depend on (1) the base physical layers, (2) empirical data to test the validity of their predictions, both within and across geographic regions, and (3) the spatial scale of resolution.

The Hauraki Gulf provides an excellent opportunity to develop and test approaches for relating physical and biological parameters in the marine environment, due to the presence of strong physical gradients for several key parameters (e.g. current flow, wave exposure, salinity) that occur over relatively short geographic distances, while other factors (e.g. sea surface temperature, stratification) change on a more continuous manner across the region. This scenario provides a quantitative basis to evaluate relationships of physical variables with different biological patterns. The development of seabed and oceanographic information layers for the Hauraki Gulf having a maximum resolution of 250 m and mapped continuously for 100's of kilometres (Hadfield, et al. 2002), and analyses of phyto- and zooplankton concentrations, soft-sediment biological assemblages, and trawl surveys for demersal fish (Hewitt and Snelder 2002) serves as a basis for developing and testing a regional marine classification model.

The development of the New Zealand Marine Environment Classification (MEC) includes the construction of base physical layers and a "validation" process against biological patterns that determines the final selection of physical variables to be used as constructs for the classification (Snelder 2000). Here it is important to note that in order to maximise the

relevance of the classification to the biodiversity intended to be managed, it is not only important to understand *which* physical environmental factors are important but *how* they relate to observed biological patterns. Draft results of the statistical validation of environmental drivers for phyto- and zooplankton concentrations, macro-invertebrates of soft-sediment habitats, and fish assemblages have been compiled in Hewitt and Snelder (2002). Although this work has established relationships between physical environmental parameters and biological assemblages associated with soft-bottom habitats, there were no comparable data available to evaluate the importance of similar physical variables for determining biological patterns of rocky bottom habitats in the region. In addition, the relevance of the MEC to near shore biological patterns had not been adequately addressed.

Shallow rocky reefs of the Hauraki Gulf represent important physical habitats for juvenile and adult fishes, rock lobster, and other mobile invertebrates, such as sea urchins and gastropods (e.g. Andrew and MacDiarmid 1991, Jones and Andrew 1993 and references therein), as well as providing hard substratum for the attachment and growth of large macroalgae, such as kelp (e.g. *Ecklonia radiata*) that form habitat structure for other organisms. These rocky reefs also support assemblages of sessile invertebrates, such as bivalves, corals and sponges, collectively termed “epifauna”, which represent a diverse multi-phyletic assemblage of organisms that interact directly (e.g. through spatial competition) and occupy similar ecological niches as suspension-feeders. As these organisms largely depend on water motion for feeding, reproduction and dispersal, they serve as a link between water column processes and the benthos (e.g. Muschenheim 1987, Gili and Coma 1998). These assemblages have also been recognised as important in the recycling of energy and materials, through the consumption and production of detrital sources in both estuarine and marine food webs (e.g. Duggins et al. 1989). In addition to being key locations for species interactions and indicators of ecological processes in the marine environment, rocky reefs have also been regarded as harbouring a significant proportion of New Zealand’s indigenous and endemic marine flora and fauna (Nelson and Gordon 1997).

Management issues surrounding rocky reefs are also somewhat distinct from that of soft-sediment habitats. Rocky reefs are a focus of numerous human activities (e.g. recreational fishing and diving) and are susceptible to damage incurred from changes in organic or inorganic sedimentation regimes (such as through aquaculture developments and dredge spoil disposal). Rocky reefs have also been implicated as indicators of trophic shifts due to the elimination of key predators due to fishing pressure (Babcock, et al. 1999, Shears and Babcock 2003). Another aspect of shallow rocky reefs in the Hauraki Gulf that makes

them a challenging system to properly manage is that individual reefs can be viewed as isolated habitat islands, separated from each other by sedimentary basins and channels. This has implications for the recovery of reef assemblages after disturbance events, connectivity and sustainable management of reef species, and the design of marine protected areas.

There is little published information available on regional-scale patterns of rocky reef communities in the Hauraki Gulf. Studies describing general community structure and gross patterns of zonation have indicated the importance of water clarity and wave exposure in determining vertical zonation patterns from the inner regions of the Hauraki Gulf to offshore island conditions (e.g. Grace 1983). Similar studies of zonation patterns of benthic communities of the Mercury Islands also suggest that there are important relationships between wave exposure and the grazing influences of sea urchins in the region (Grace 1972). In contrast to the sparse amount of information of rocky reef assemblages across the Hauraki Gulf, there is a considerable amount of information on community characteristics and habitat types in the vicinity of the Leigh Marine Laboratory (e.g. Ayling 1978, Ayling 1981). Although these studies have identified a number of key biological patterns and structuring processes, many of these investigations have been oriented towards evaluating the biological responses to protection by no-take marine reserves (e.g. Cole, et al. 1990, Cole, et al. 1992, Babcock et al. 1999, Shears and Babcock 2003). It is unclear how these studies and the understanding of the shallow water ecology of this locality can be extrapolated to explain patterns and processes operating on larger spatial scales, particularly where the “impact” or present level of human modification and the ecological response to such changes is largely unknown against a background of natural environmental variability and change. Moreover, because the focus of these studies has been on local-scale biological interactions, the relative importance of physical environmental variables in determining biological characteristics over 100's of km has yet to be examined.

Overall these studies indicate that along a gradient of increasing shelter and water turbidity inside the Gulf and vertical zonation patterns are compressed, shallow areas are dominated by mixed algal assemblages, sparse kelp forests, and some elements of deeper assemblages characterised by sponges, hydroids and ascidians. Along a gradient of increasing exposure and decreasing turbidity, there is a widening of the basic vertical zones, with more extensive kelp forest and more abundant sponge assemblages with increasing depth (e.g. Grace 1983). The importance of the sea urchin, *Evechinus chloroticus*, as a biological structuring agent for rocky reef communities has also been stressed in numerous studies (e.g. Ayling 1981, Babcock et al. 1999). Although this gives an overview of zonation patterns,

general reef characteristics, and key interacting species, there is little quantitative information available to statistically relate patterns of species abundance and diversity of rocky reefs throughout the Hauraki Gulf region.

One of the few published studies of diversity patterns of rocky reef epifaunal assemblages of offshore islands in the northeast of New Zealand indicated a trend of decreasing diversity with depth and slight differences in diversity across the region (Grange 1986). This study showed that for all sites, the area of the highest relative diversity (measured as $H'/0.25 \text{ m}^2$) was in the northernmost and southernmost parts of the study region (i.e. the Poor Knights and Aldermen Islands) with comparatively lower diversity in the centre part of the study region (i.e. Mokohinau Islands, Great Barrier Island). Vertical patterns of diversity within sites showed relatively lower diversity at shallow depths (i.e. 5-15 m) and higher diversity at depths between 20 and 30 m. Some sites (e.g. Poor Knights and Great Barrier Island) had relatively high diversity from 10 m to 35-45 m. How these patterns reflect gradients physical environmental factors along latitudinal and/or depth-stratified gradients is largely unknown. As Grange (1988) focused primarily on offshore islands of the Gulf, it is also uncertain how patterns of diversity may vary from inner to outer Gulf.

In order to resolve these regional-scale patterns and quantify relationships between physical factors and observed community patterns, there was a need to sample rocky reefs along both latitudinal and longitudinal gradients. This report contains the results of benthic surveys of 38 rocky reef sites throughout the Hauraki Gulf and a preliminary analysis of statistical relationships to physical variables of the MEC. Reef surveys were conducted primarily to quantify aspects of epifaunal invertebrate assemblages, however information on cryptic benthic fishes and mobile invertebrate consumers was also collected concurrently. Extraction of data from physical environmental layers at sampling sites was used as a basis for establishing statistical relationships between physical (i.e. predictor) variables and biological patterns (i.e. responses). Although this report focuses on the results from the epifaunal assemblages, other data sets were explored to evaluate the generalisation of the statistical modelling and to serve as a basis for future ecological work in the area. This report is complimentary to work on the development of a regional marine environment classification for the Hauraki Gulf being undertaken by NIWA.

Methods

Sampling Locations. Surveys were conducted in areas delimited by regions of contrasting wave exposure gradients indicated by NIWA wave climatology for the Hauraki Gulf

(Hadfield, et al. 2002). Sites with steeply sloping reef faces at the appropriate depth (i.e. 10 –15 m) were identified using a combination of navigational charts depth sounder and local knowledge of the boat skipper and crew. More exact locations of individual transect locations were noted and described after each dive, including general morphological characteristics of the sites and reef formations (Appendix I). Positions of transect sites were recorded by GPS (WGS 84) from the entry point of each dive and later converted to New Zeland Map Grid (NZMG) for integration into a Geographical Information System (GIS).

Location of sites and positions of sites are provided in Figure 1 and Table 1. Sites 1 – 19 were sampled between 29 April and 8 May 2002, sites 20 – 33 were sampled between 25 – 29 November 2002, and sites 34 – 38 were sampled between 29 - 30 January 2003. In addition to the rocky reefs sampled in this report, searches for rocky reefs were conducted as far south as Second Bay, Ponui Island and also in tidal channels surrounding Waiheke Island and from Deadman's Point, western Coromandel Peninsula, and channels to the north, in the vicinity of Coromandel Harbour. No suitable reef habitat was found at the required depth at these locations.

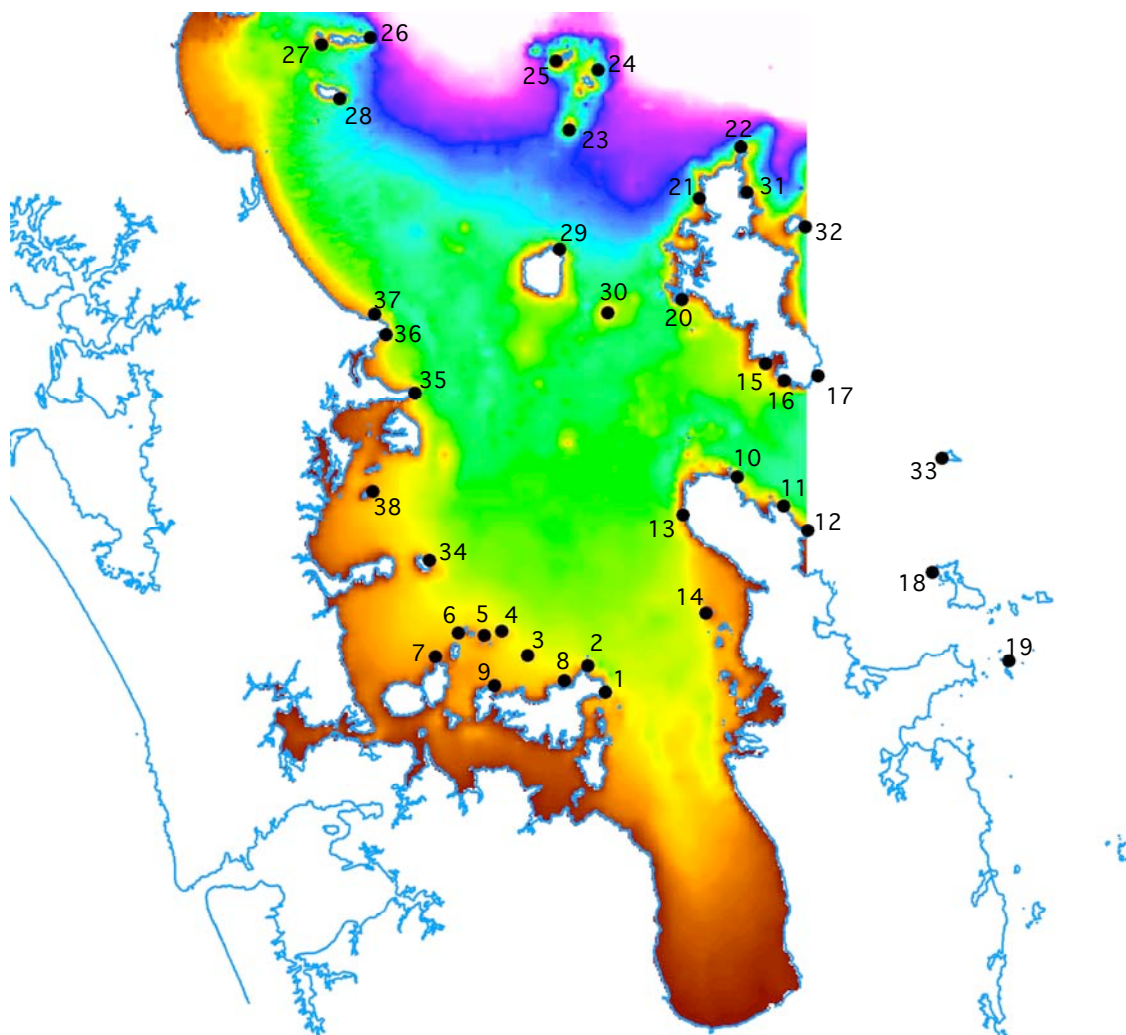


Figure 1. Location of survey sites in the Hauraki Gulf, superimposed on the NIWA bathymetry model, with shallow areas represented in red, while magenta-white areas represent deeper areas. Site numbers refer to the location names in Table 1. Note that three sampling sites (18, 19 and 33) were located outside the bathymetry grid, and three additional sites (12, 17, 32) were located on the boundary.

Table 1. List of site numbers, names, codes and positions of sampling sites for rocky reef surveys. The last column refers to the number of photoquadrats analysed for calculating diversity measures for the epifaunal assemblages.

Site_ID	Site_Name	Site_Code	Northing	Easting	N
1	Kauri Point	KauriP	6489866	2707050	15
2	Thumb Point	ThumbP	6493892	2704382	13
3	D'Urville Rock	DurviR	6495425	2695305	13
4	Ahaaha Rock	AhaahR	6499139	2691391	13
5	David Rock	DavidR	6498519	2688809	11
6	Orarapa/Motohurupapa	Orarap	6498886	2684869	14
7	Billy Goat Point	BGoatP	6495243	2681481	10
8	Splash Rock	Splash	6491646	2700887	13
9	Hakaimango Point	HakaiP	6490862	2690330	11
10	Poley Bay (the "Pinnacles")	PoleyB	6522498	2726952	10
11	Port Charles Lighthouse	PtChas	6518161	2733886	13
12	Te Anaputa Point	TeAnaP	6514448	2737551	10
13	Fantail Bay Reef	Fantai	6516762	2718716	12
14	Happy Jack Island "Motokahaua"	HJackI	6501905	2722199	12
15	Modeo Rock "Tryphena Bay Pinnacles"	Tryphe	6539514	2731206	11
16	Dolphin Bay Point	DolphB	6536974	2734040	11
17	Rosalie Bay	Rosali	6537737	2739063	10
18	Bookcase (Great Mercury Island)	Bkcase	6508078	2756352	12
19	Flat Island (Mercury Islands)	FlatIs	6494594	2767854	13
20	Junction Island	JunctI	6549164	2718538	11
21	Ahuriri Point	Ahurir	6564451	2721177	13
22	Needles Point	NeedPt	6572145	2727468	12
23	Simpsons Rock	SimpRk	6574789	2701637	12
24	Mauri Rocks	MaoriR	6583879	2705920	14
25	Stack 'H'	StackH	6585200	2699557	13
26	Copper Mine Point	Copper	6588714	2671674	11
27	Mauitaha Island	Mauiha	6587693	2664288	13
28	The Pinnacles	Pinnac	6579461	2667026	13
29	Ngatamahine Point	LBarri	6556786	2700166	10
30	Horn Rock	HornRk	6547136	2707411	12
31	Donna's Bay	DonnaB	6565311	2728379	13
32	Flat Top Island	FlatRk	6560199	2737185	11
33	Cuvier Island	Cuvier	6525318	2757782	12
34	Shag Rock	ShagRk	6509832	2680495	12
35	Elephant Point	Takatu	6535083	2678354	13
36	The Watchman	Watchm	6543896	2673971	12
37	Goat Island	GoatIs	6546973	2672309	13
38	Motuora Island	MotuIs	6520304	2671996	13

Rocky Reef Epifaunal Communities. Photographic quadrats of 0.25 m² were sampled along 50 m transects following reef contours at depths of 15 to 20 m. Individual quadrats were taken at 5 m intervals from a haphazard starting point, with slight deviations in placement dictated by reef morphology. The regular spacing of quadrats was adopted to be able to correlate changes in the epifaunal communities with data on consumer abundances taken along the transect, including densities of cryptic fish and mobile invertebrates. In most instances, quadrats were taken on surfaces from near vertical to 45° angles, however in some areas of sand channels and broken reef habitats, quadrats were taken on gently sloping bottoms. Along transects, additional replicates were haphazardly taken where possible. The number of replicates within transects varied between 10 and 15 quadrats (Table 1).

The photographic quadrat system consisted of a Nikonos V camera fitted with a 15 mm lens and two strobes fixed to a rigid framer, providing a high-resolution slide image able to identify organisms > 2-3 mm in size (Witman 1985). Although this methodology was developed for sampling the majority of epifaunal invertebrates present on most rocky reefs, it is impractical for sampling a few species of more widely dispersed megafauna (e.g. barrel sponges and some gorgonians). These species are therefore generally under represented in these analyses. To aid species identifications, voucher specimens were collected outside transects. General description of dominant organisms and life forms are provided in the site descriptions (Appendix I). Information on some algal species and functional groups can also be obtained from the quadrat images, although for the purposes of this study, they were not included.

Analysis of the photoquadrat images provided quantitative information on species diversity and benthic community attributes for reef locations. Images were projected onto a viewing screen to count species identified to the lowest taxonomic level possible. Species without positive identification were given a field name that was kept consistent throughout the image analysis process and/or referred to a voucher specimen. This approach provided a conservative estimate of species diversity for these assemblages and established a basis for increasing knowledge of the benthic fauna, which can be improved with further survey work and focused species collections and inventories for the region. It should be noted that this taxonomic uncertainty would not change the general results presented in this report, however subsequent analysis of community composition will require more detailed taxonomic information.

Species counts from the quadrat images provided several different measures of diversity and community composition that were used for modelling against physical

environmental variables. Species density, which refers to the number of species per 0.25 m² quadrat, provides a measure of diversity where smaller scale interactions, such as spatial competition, are likely to be important (Connell 1961, Jackson 1977). The variation around the mean species density (e.g. standard deviation) can be viewed as an indication of the “patchiness” of the epifaunal assemblages and the expected variation in the strength of species interactions at the scale of individual quadrats. The change in community composition from one quadrat to another provides an additional measure of diversity, which characterises the “turnover” of species along a transect. This index of diversity, often referred to as beta-diversity, was calculated using Routledge’s β_1 , which takes into account species incidence (i.e. the frequency of occurrence) and richness (i.e. the number of species) (Magurran 1988). This measure can be regarded as a measure of diversity at a scale relevant to species interactions over the scales of metres, such as seston-depletion, which can occur among suspension feeders in aggregations (e.g. Peterson and Black 1987, Lesser et al. 1992).

Species richness represents the total number of species observed along a transect (i.e. S_{obs}). Because some sites had different numbers of replicates, estimates of species richness were calculated with the Chao 2 incidence-based estimator (Colwell and Coddington 1994) using the program EstimateS (Version 5.0, R.K. Colwell). In the calculation of the species richness estimator, the accumulation of species as a function of sampling effort (i.e. the number of quadrats) provides an indication of the adequacy of sampling at individual sites. These species accumulation functions can be used to compare the relative number of species observed (S_{obs}) to the estimated species richness according to the Chao 2 estimator (Appendix II). The species accumulation functions of the observed species and the Chao 2 estimator tend to converge at most sites in the inner Gulf, indicating a representative sample of the species present at those sites, however in areas of the outer Gulf, there was a tendency to underestimate the number of species present (Colwell and Coddington 1994). These two measures of species diversity provide information of the community at a relevant scale to which species are incorporated at the local level, such as recruitment of these organisms into a given reef system (e.g. Bingham 1992, Smith and Witman 1999).

A summary table of these diversity measures calculated with the data on the incidence of epifaunal species and their ecological interpretation are provided in Table 2.

Table 2. List of response variables, description and common names and/or indicators of ecological pattern.

Variable	Description	Common Name & Indicator
Density	species density/0.25 m ²	Measure of diversity at the scale of individual quadrat, indicates the relative potential of species interactions
StdevD	Standard deviation of species density/0.25 m ²	Measure of variation in species density, indicating the relative patchiness the species aggregations at a site
RoutBi	Routledge's β_1 diversity index	Measure of turnover diversity, indicator of variation in species composition among quadrats (i.e. the smaller the index, the more homogeneous the community composition within a site)
Sobs	Observed species richness	Number of species observed at an individual site, a diversity measure relevant to the scale at which species are incorporated over 10's of metres
Chao2	Chao 2 Richness Estimator	Estimated number of species observed according to the Chao 2 index, approximates the true number of species with limited sampling, an additional measure of diversity at the scale of 10's of metres.
TRW	<i>Ruanoho whero</i>	Spectacled triplefin, broad diet of crustaceans, males defend territories, biology otherwise poorly known. New Zealand endemic.
TNS	<i>Notoclinops segmentatus</i>	Blue-eyed triplefin, predator of small crustaceans, preferred habitat as broken rock, steep rock faces and overhangs with cover dominated by crustose coralline algae, New Zealand endemic
TFM	<i>Fosterygion malcolmi</i>	Mottled triplefin, consumer of small mollusks, crustaceans and brittle stars, preferred habitat with overhangs and holes containing sponges and bryozoans, reportedly more common below 10 m depth. New Zealand endemic.
TFV	<i>Fosterygion varium</i>	Variable triplefin, one of the most common triplefins around New Zealand, predators of crustaceans and other invertebrates.
TFF	<i>Fosterygion flavonigrum</i>	Yellow-black triplefin, biology poorly known. New Zealand endemic.
TOE	<i>Optivus elongatus</i>	Slender roughy, predominately northern distribution, considered nocturnal, sheltering beneath overhangs or in caves, diet consists of planktonic invertebrates. New Zealand endemic.
SSP	<i>Scorpaena papillosus</i>	Scorpion fish, reportedly nocturnal, strongly territorial, diet consists of a wide variety of invertebrates and fishes, predominately sedentary.
BPL	<i>Parablennius laticlavus</i>	Crested blenny, principally northern species, predominately in habitats of broken rock and crevices, diet of eggs, mollusks, crustaceans, hydroids and algae. New Zealand endemic.
TFL	<i>Fosterygion lapillum</i>	Common triplefin, predator of small crustaceans, small gastropods and polychaetes, males territorial, reportedly the most abundant and wide-spread triplefins in New Zealand. New Zealand endemic
EEC	<i>Evechinus chloroticus</i>	Sea urchin or kina, key consumer of algae and sessile invertebrates in the shallow subtidal, largest sea urchin the world. New Zealand endemic.
TCS	<i>Cookia sulcata</i>	Cook's turbin, a reputed algal browser.
CDO	<i>Dicathais orbita</i>	Ribbed rock shell, reputed predator of mussels and other invertebrates in shallow subtidal areas.

SSM	<i>Stichopus mollis</i>	Sea cucumber, detritivore, reputedly more common in sheltered habitats and with increasing depth.
PHC	Hermit crabs	Collection of unidentified species, key prey items for lobster + some fish.
TMP	<i>Calliostoma (Maurea) punctulatum</i>	Carnivorous topshell, reputedly grazers of sponges such as <i>Tedania</i> and <i>Anchorina</i> . New Zealand endemic.
CCA	<i>Ceratosoma amoena</i>	Clown nudibranch, likely predator of bryozoans and hydroids.
ACP	<i>Cryptochonchus porosus</i>	Butterfly chiton, reputed browsing omnivore. New Zealand endemic.
TTV	<i>Trochus viridis</i>	small grazing gastropod. New Zealand endemic.
BAC	<i>Axymene corticatus</i>	small whelk, ecological role little known.

Cryptic Fishes. The abundance of small fishes associated with the rocky reefs, primarily composed of triplefins and blennies (hereafter referred to as “cryptic fishes”), were quantified in ten contiguous 5 m² quadrats along a 50 m transect, counting in a 1 m swath along the length of the transect. Counts were made *in situ* with the aid of a underwater torch to ensure adequate light for thorough searching and species identification. Raw species abundance for individual 5 m² quadrats was used to calculate average densities for sampling sites. In addition, data were also kept with spatial reference along the transect for future analyses of the relationship between fish abundance and other biological attributes.

The species used in the modelling against physical environmental parameters and their ecological attributes are listed in Table 2. A complete list of species encountered in the surveys is provided in Appendix IIIa.

Mobile Invertebrate Consumers. The abundance of mobile invertebrate consumers >50 mm, such as including gastropods, echinoderms and crustaceans, were quantified in twenty contiguous 5 m² blocks along the 50 m transect, counting in a 1 m swath on either side of the transect. Raw species abundance for individual 5 m² quadrats was used to calculate average densities for individual sites. Spatial information of species abundance was also maintained for future analyses in relation to biological habitat characteristics. Species used in the modelling against physical environmental parameters and their ecological attributes are listed in Table 2. A list of species recorded during in the surveys is provided in Appendix IIIb.

Small Invertebrate Consumers. The sampling of larger mobile invertebrates was unable to adequately sample small gastropods and hermit crabs (i.e. with a shell length of 20-30 mm). Complimentary sampling of these smaller consumers was conducted using 0.25 m² quadrats placed every 5 m along the transect (i.e. 10 replicates per transect). All small gastropods and

hermit crabs within the 0.25 m² quadrat were collected in individual sampling bags and sorted on the surface. Searches for animals were not made underneath rocks or boulders. Species without positive identification (e.g. many of the hermit crabs) were given field names and referred to voucher specimens. Average densities per 0.25 m² for individual sites were calculated from the replicate samples. For the purposes of establishing relationships of species abundance with physical environmental factors, two species were modelled, *Axymene corticatus* and *Trochus viridis* (Table 2). A summary of species positively identified in the surveys is provided in Appendix IIIc.

Physical Environmental Variables. Physical environmental data for the sampling locations was obtained from the NIWA regional-scale classification of Hauraki Gulf. A total of 20 individual physical layers were developed and incorporated as raster layers in ArcInfo GIS software with a maximum resolution of 250 m. Data layers include aspects of bathymetry, wave climate, tidal currents, degree of freshwater influence, sediment types, aspects of Sea Surface Temperature (SST), and sea floor curvature and slope. A detailed description of the information content of individual physical layers and relevance for the marine environment are provided in Hadfield, et al. (2002).

Circular buffers of 500 m and 1000 m radius were constructed around each sampling location and trimmed to the coastline in ArcInfo. Information from the data layers of physical environmental variables were extracted from within these buffers, providing means, standard deviations, minimum and maximum values, and other summary statistics for the areas surrounding sampling sites. As some of the resultant layers of wave characteristics were at a slightly coarser scale (i.e. 750 m) than the majority of physical layers (i.e. resolution of 250 m), data of the physical parameters from both the 500 m and 1000 m buffers were compared in order to evaluate the optimum buffer size to obtain physical information from individual sites. As the correlations between the physical data of extractions from 500 and 1000 buffers were similar (Pearson Product-Moment correlations $r = 0.774 - 0.992$), it was decided to use the values from the 1000 m buffers for statistical modelling. Values from the 500 m buffers are also available for data exploration purposes. Information from the sediment layers was not included for the statistical validation.

The matrix of physical environmental variables extracted from each site was screened to identify variables that were strongly correlated with each other by plotting correlations between individual variables. Variables such as the maximum value, standard deviations, *et cetera* were found to have correlation values ranging from $r = -0.559$ to 0.989. This process

narrowed the final selection of predictor variables to a matrix of mean values of the 1000 m buffers to characterise aspects of the physical environment. Physical data were not transformed prior to analysis in order to be consistent with the statistical validation work conducted by NIWA.

Sites 18, 19, and 38 were outside of the classification grid of the Hauraki MEC, and sites 12, 17, and 32 were located on the boundary of the environmental layers (Figure 1). Biological information from these sites is presented in the appropriate results section, however these sites were omitted from analysis of relationships to physical environmental factors.

Statistical Approach and Validation Process. Measures of epifaunal diversity and the distribution and abundance of cryptic fishes, mobile invertebrates were used to make statistical relationships against a matrix of physical environmental variables (i.e. predictor variables) described in Hadfield et al. 2002. Statistical methods followed an approach using the GRASP (Generalised Regression And Spatial Prediction) routine, developed by Landcare Research (Lehmann, et al. 2002). This method uses a multiple regression technique to establish statistical relationships between species abundance and environmental variables using a Generalized Additive Model (GAM) (Hastie and Tibshirani 1990). All models were run with a gaussian link function (for numerical abundance data with Poisson error structure) and 3 degrees of freedom.

As these models were intended to identify key physical environmental variables for further supporting the development of the MEC, detailed presentation of the model results, including the cross-validation, are provided in Appendix IV. The cross-validation involves an analysis based on subsets of the entire data set with groups being dropped from the model, recalculated, predicted, and compared with the observed data (Lehmann, et al. 2001). Additional analysis of the “drop” and “alone” contributions of individual factor are not included in this report., future fine-tuning of the models can be made. These relationships were then used to predict the species abundance from the environmental surfaces to indicate patterns of species abundance throughout the Gulf (Lehmann, et al. 2002).

Results

Patterns of Rocky Reef Epifaunal Diversity. Species density across all sites sampled showed an overall mean of 14.11 ± 4.36 SD species/0.25 m² (Figure 2A). Sites with highest species density occurred in the outer Gulf (i.e. North of Takatu Point, Cuvier and Mercury Islands),

while sites with lower species density tended to occur in the inner Gulf (i.e. south of Takatu Point)(Figure 3A). One site in the outer Gulf (site 17, Rosalie Bay) had exceptionally low species density (i.e. 5.6 species/0.25 m²). The general trend in species density indicates that sites in the inner Gulf are approximately 1 standard deviation below the overall mean species density, while sites in the northern and outer Gulf are approximately 1 standard deviation above the overall mean (Figure 4A). Sites along the northeast of the Coromandel Peninsula had relatively low species density, comparable to sites within the Gulf.

The standard deviation of the number of species per 0.25 m² quadrat had an overall mean of 4.00 ± 1.22 SD and was not strongly correlated with species density (Pearson product-moment correlation coefficient, r = 0.262). Sites with particularly low variation of species density included site 4 (Ahaaha Rock) and site 17 (Rosalie Bay), while other sites were of relatively high variation of species density, including sites 13 (Fantail Bay), 25 (Stack “H”), 29 (Little Barrier), and 35 (Takatu Point)(Figure 2A and 3B).

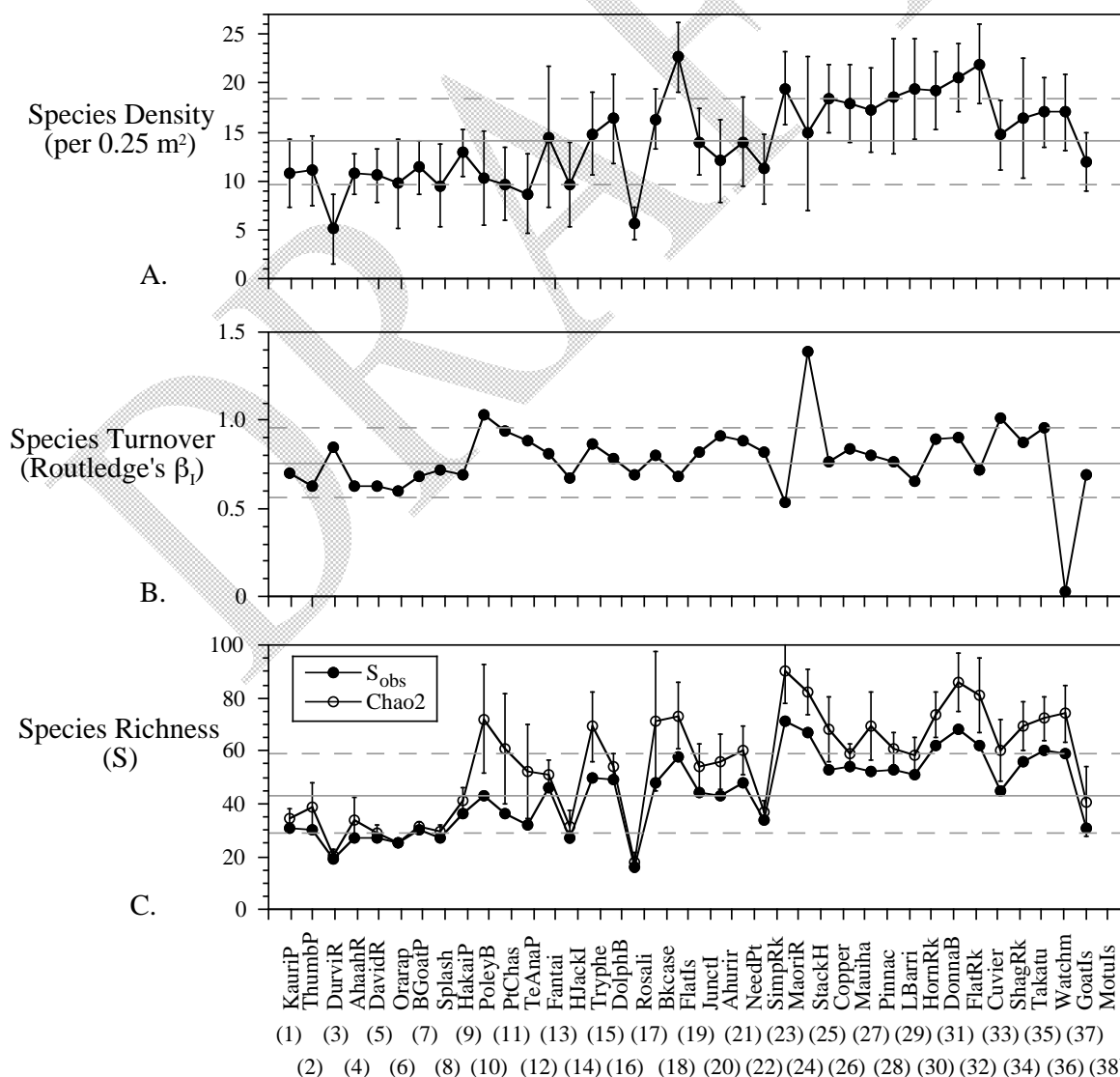


Figure 2. Patterns of epifaunal invertebrate diversity for the Hauraki Gulf. (A) species density per 0.25 m² quadrat and standard deviations. (B) turnover diversity of Routledge's β_1 (C) observed and estimated species richness (Chao 2) with the standard deviation of the 50 randomisations for calculating the Chao 2 index. In each graph, solid grey lines indicate the overall means and dashed grey lines indicate the standard deviation of the overall means.

Turnover diversity within a site, measured as Routledge's β_1 , had an overall mean of 0.77 ± 0.20 SD (Figure 2B). The site with the highest turnover diversity was 25 (Stack "H", $\beta_1 = 1.39$), and the lowest turnover diversity occurred at site 37 (Goat Island $\beta_1 = 0.31$) (Figure 2B). Turnover diversity tended to be lower in the inner Gulf, with higher and more variable values recorded in the outer Gulf (Figure 2B and 4). Sites on the northeast of the Coromandel Peninsula and sties around Great Barrier Island had consistently high turnover diversity, while notable "outliers" to this pattern occurred in the Mokohinau Islands (e.g. site 25), the coastline north of the Port of Auckland (e.g. sites 34 and 36), and one site north of Waiheke Island (i.e. site 3). Routledge's β_1 was not strongly correlated with either species density or the variation of species density (i.e. standard deviation) (i.e. Pearson product-moment correlation coefficients $r = -0.033$ and $r = 0.397$, respectively).

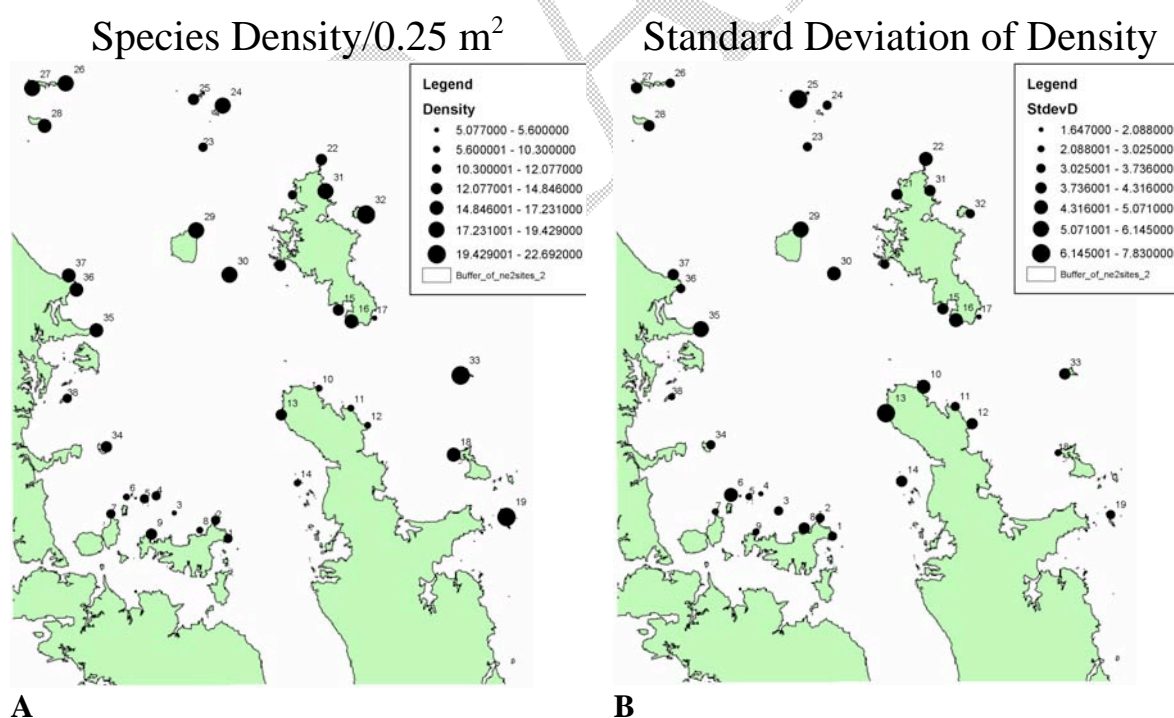


Figure 3. (A) Spatial patterns of species density and (B) the variation of species density, expressed as the standard deviation per 0.25 m² across the Hauraki Gulf.

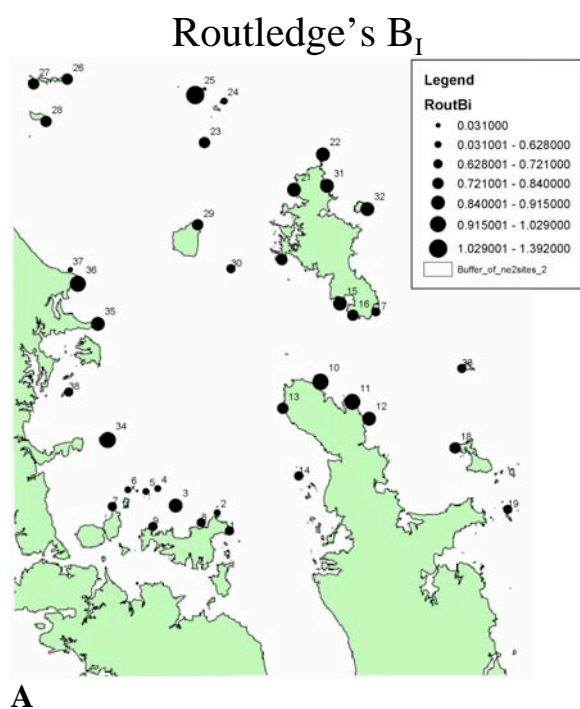


Figure 4. Spatial patterns of turnover diversity, measured as Routledge's β_I across the Hauraki Gulf.

Overall mean species richness of epifaunal assemblages was 43.95 ± 14.52 SD, and mean estimated species richness (i.e. Chao 2) was 54.99 ± 19.61 SD (Figure 2C). Both S_{obs} and Chao 2 were highly correlated (Pearson product-moment correlation coefficient $r = 0.949$). Notable differences in the two measures occurred at sites 10, 11, 12, 15 and 19. In regions of the outer Gulf, there were relatively larger deviations (e.g. sites 24–37) possibly due to under sampling at these sites (Appendix II). As these patterns were strongly correlated and the randomisations of EstimateS suggested was slight undersampling at outer Gulf sites, the patterns of Chao 2 diversity are likely to be more representative of species diversity patterns throughout the Gulf (Figure 2C).

Species richness showed a gradient from inner to outer Gulf, with comparatively low values of Chao 2 at sites north of Waiheke Island (Figure 5B). The pattern of low species richness appears to change in the middle regions of the Gulf, around sites 13, 29, 30, and 35. Sites with the highest species richness occurred in regions of the outer Gulf, where sites 24, 25, 32 and 33 all had an estimated richness greater than 74.6 species (i.e. greater than 1 standard deviation from the overall mean estimated richness).

A number of sites had over 60 species estimated, including Poley Bay (10), Port Charles Lighthouse (11), Tryphena Harbour (15), the Bookcase (18), Flat Island (19), Needles Point (22), Coppermine Point (26), the Pinnacles (28), Little Barrier (29), Donna's Bay (31),

Shag Rock (34), Takatu Point (35), the Watchman (36) and Goat Island (37). Chao 2 estimations of species richness and species density (i.e. numbers of species per 0.25 m² quadrat) were positively correlated (Pearson product-moment correlation coefficient $r = 0.808$), while correlations with the variation of species density and turnover diversity were weakly correlated ($r = 0.374$ and 0.239 , respectively).

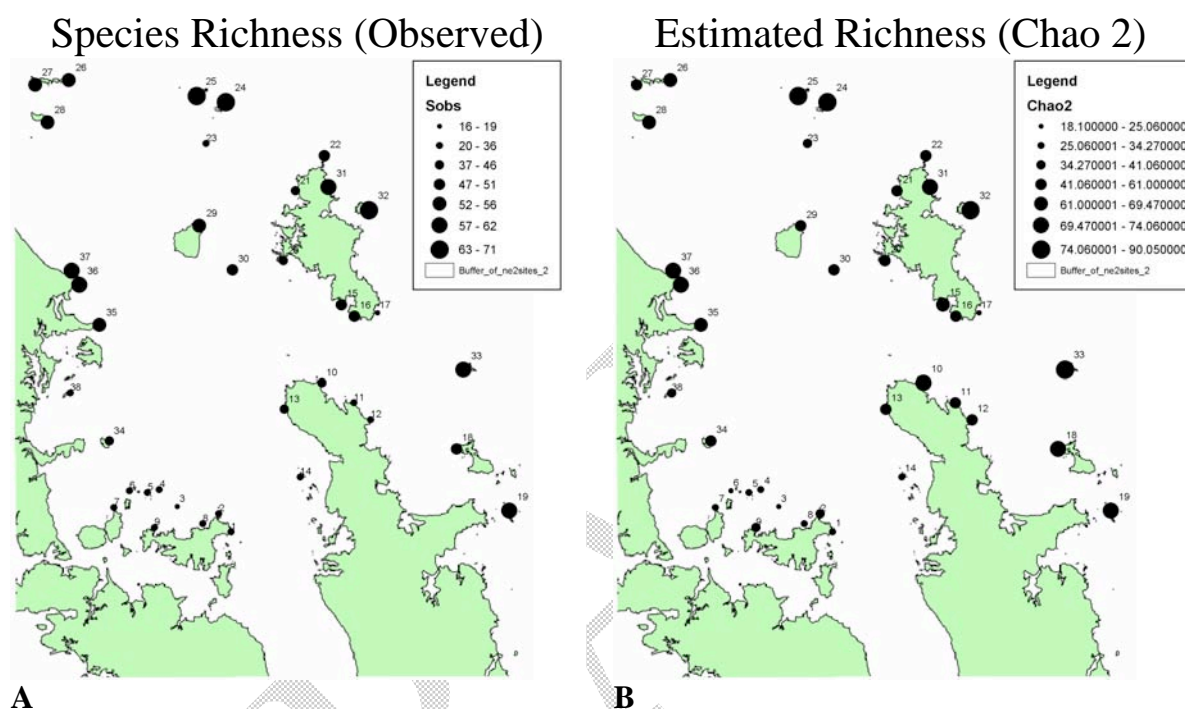


Figure 7. Spatial pattern of (A) species richness, the number of species observed at a site, and (B) estimated species richness per site, according to the Chao 2 index.

Distribution and Abundance of Cryptic Fishes. About 16 species of benthic fishes were recorded during the survey, with an average density of all species ranging from 3.10 to 0.13 fishes per 5 m² block. The highest density recorded at an individual site was 26.44/5 m² (*Fosterygion flavonigrum* at the Pinnacles 28). Some species showed clear trends in abundance from inner to outer Gulf (e.g. *Fosterygion flavonigrum*), while other species had a more varied pattern of abundance (e.g. *Ruanoho whero* and *Fosterygion malcolmi*). The spectacled triplefin, *Ruanoho whero*, had a highly variable pattern of abundance throughout the Gulf, showing peak abundance in the outer Gulf (e.g. sites 19 and 23) and in the inner and middle regions of the Gulf (e.g. sites 2, 36, and 38)(Figure 6A). The blue-eyed triplefin, *Notoclinops segmentatus*, showed a pattern with peak abundance in the middle regions of the Gulf (e.g. Little Barrier 29, the Watchman 36, Goat Island 37, and Moturoa Island 38), with