The New Zealand Marine Environment Classification

June 2005

Ministry for the
Environment
Manatū Mō Te Taiao

Marine Environment Classification

Ton Snelder
John Leathwick
Katie Dey
Mark Weatherhead
Graham Fenwick
Malcolm Francis
Richard Gorman
Janet Grieve
Mark Hadfield
Judi Hewitt
Terry Hume
Ken Richardson
Ashley Rowden
Michael Uddstrom
Michelle Wild
John Zeldis

Acknowledgements

The Ministry for the Environment recognise the work and commitment of the steering group who oversaw the development of this project. This group included:

Clinton Duffy (DoC)
Don Robertson (NIWA)
Dominic McCarthy (Auckland Regional Council)
Mathew Batholomew (MFish)
Jacqui Burgess (MFish)
Ben Sharp (MFish)
Bob Cooper (Tai Perspectives)
Brigit Stephenson (MfE)
Kirsty Johnston (MfE)
Eric Verstappen (Tasman District Council)
Stephanie Turner (Environment Waikato)
Malene Felsing (Environment Waikato)
Franz Smith
Kevin Stokes (Seafood Industry Council)
Nici Gibbs (Seafood Industry Council)
Philippe Lallemand (Seafood Industry Council)
Peter Hamill (Marlborough District Council)
Steve Wing (University of Otago).

Published in June 2005 by the
Ministry for the Environment
Manatū Mō Te Taiao
PO Box 10-362, Wellington, New Zealand

ISBN: 0-478-25908-5
ME number: 594

This document is available on the Ministry for the Environment's website:
www.mfe.govt.nz

Ministry for the Environment
Manatū Mō Te Taiao

Contents

List of Tables

List of Figures

Executive Summary

The Ministry for the Environment, the Ministry of Fisheries and the Department of Conservation commissioned the National Institute of Water and Atmospheric Research (NIWA) to develop environmental classifications covering both New Zealand's Exclusive Economic Zone and the Hauraki Gulf region collectively known as the Marine Environment Classification (MEC). The Ministry for the Environment was the lead agency responsible for coordinating the development of the classification. The purpose of these classifications is to provide spatial frameworks for structured and systematic management by subdividing the geographic domain into units having similar environmental and biological character.

Development of the Marine Environment Classification occurred in six specific phases over a four-year period from 2000 to 2004. The details of each of these phases have been fully documented in a number of reports that are listed in the references section of this report. The purpose of this report is to summarise those development phases in sufficient detail to provide future users of the Marine Environment Classification with a single source of documentation for it. The report overviews the development process, discusses the results of testing of the classification and describes the physical and biological characteristics of classes that are defined by the classifications.

The Marine Environment Classification has been defined using multivariate clustering of several spatially explicit data layers that describe the physical environment. This produces a classification that is hierarchal, enabling the user to delineate environmental variation at different levels of detail and a range of associated spatial scales. A physically based classification was chosen because data were available or could be modelled and because environmental pattern is a reasonable surrogate for biological pattern, particularly at larger spatial scales. Large biological datasets were used to tune the classification so that the physically based classes maximise discrimination of variation in biological composition at various levels of classification detail. The classification has not been optimised for a specific ecosystem component (e.g. fish communities or individual species) but has sought to provide a general classification that has relevance to a broad range of biological groups.

The Marine Environment Classification was developed at two levels of spatial resolution. First a broad scale classification was developed for the entire EEZ, covering the area below the mean high water line (but not including estuaries) from approximately 25 to 58 degrees South and 158 degrees East to 172 degrees West. This classification has a nominal spatial resolution of 1 km, allowing mapping at scales of 1:4,000,000 and above. While the classification can be mapped at finer scales, the 'grain' of the underlying data will become increasingly prominent as the scale is increased. A second classification was developed for the Hauraki Gulf region. This region encompasses waters below the mean high water line (but not including estuaries) and within a line drawn eastward from Bream Head (approximately 36 degrees South) to meet a line drawn from south to north and intersecting Cape Barrier on Great Barrier Island (approximately 176 degrees East). This classification has a nominal spatial resolution of 200 m (i.e. consistent with a maximum map scale of 1:250,000). The purpose of this regional classification was to assess the feasibility of producing higher resolution inshore classifications relevant to the more intensive management issues that frequently occur there.

Statistical tests determined that the Marine Environment Classification classes are biologically distinctive. Thus, the classifications provide managers with useful spatial frameworks for broad scale environmental and conservation management. However the full utility, and indeed limitations of the classifications will only become clear as the classifications are applied to management issues.

At the conclusion of this four-year development project the steering group was satisfied that the Marine Environment Classification provides a useful broad-scale classification of biotic and physical patterns in New Zealand's marine environments and supported its use as a spatial framework for analysis and management of marine conservation and resource management issues. It is important to recognise that a spatial framework is a tool to organise data, analyses and ideas and is only a component of the information that would be employed in any analysis. The steering group considered that the development of the Marine Environment Classification should now move into a phase where it is tested by application to management issues.

1 Introduction

Conservation and environmental management agencies in New Zealand, along with similar agencies in other countries, are increasingly adopting an ecosystem-based approach to marine management. Effective implementation of such an approach requires a range of tools, including classifications that identify geographic areas having similar ecosystem character (e.g. Bailey 1985; Longhurst 1998). These provide spatial frameworks for structured and systematic management (Margules and Pressey 2000) by subdividing the geographic domain into units having similar biological and/or environmental character (Bailey 1995; McMahon et al. 2001; Omernik 1995).

Spatial frameworks are mapped ecological classifications that have the same purpose as any other classification, i.e. "to obtain classes such that any member of a class can be treated as if it possessed certain properties" (Jones 1970). Subdivision of the geographic domain into labelled units that share similar ecological characteristics establishes a common language for description that can then be used as an inventory for storage and retrieval of information. Stakeholders in the development of the classification of New Zealand's marine environments specifically intended that it would provide a tool for analysis and management of conservation and resource management issues. As such, the Marine Environment Classification would be utilised in a variety of applications including:

- mapping management units that are relatively homogenous with respect to certain ecosystem properties rather than administrative boundaries
- transferring knowledge of processes and values to other areas on the basis of similarity
- defining management units that will be subject to similar objectives, policies and methods
- predicting the potential impacts of events and resource uses based on ecosystem susceptibility (e.g. the effects of marine invaders on certain habitat types and species)
- identifying priorities for protection (e.g. which parts of the environment should be included in marine protected areas)
- identifying areas within which certain activities should be closely managed or avoided (e.g. in what kinds of areas should trawling be prohibited)
- structuring monitoring programmes to ensure representativeness of all environment types, and providing a context for reporting state of the environment information
- identifying priorities for further research (e.g. to identify or confirm the whereabouts of certain habitat types about which baseline information is required).

New Zealand's conservation and environmental agencies commissioned the development of environmental classifications covering both New Zealand's Exclusive Economic Zone, and the Hauraki Gulf region, collectively known as the Marine Environment Classification. The Ministry for the Environment (MfE) was the lead agency responsible for coordinating the development of the classification. Development of the Marine Environment Classification occurred in six specific development phases over a four year period from 2000 to 2004. The details of each of these development phases have been fully documented in a number of reports that are listed in the references section of this report. The purpose of this report is to summarise those development phases in sufficient detail to provide future users of the Marine Environment Classification with a single information source. This report overviews the development process, discusses the results of testing the classification and describes the physical and biological characteristics of classes that are defined by the classifications.

2 Spatial Frameworks

Developing a spatial framework involves the systematic identification and labelling of distinctive spatial units and the mapping of their geographic distributions. There is no perfect method for developing spatial frameworks. Different spatial frameworks possess different properties and the application of the framework defines which of these properties are important. Thus, it is important to understand the way in which a spatial framework has been developed.

Spatial frameworks can be broadly subdivided into those based on classification and those based on regionalisation. For classifications, the systemic guiding principles establish a strict procedure for measuring difference and similarity between spatial units and for defining class structure. Classifications can be distinguished by the characteristics (or variables) that are used to determine difference and similarity between spatial units and the procedure that is used to develop a structure of classes. Classifications may be defined using biological or environmental characteristics of the spatial units being classified. Importantly, in classification the geographic location of spatial units is not generally taken into account by the definition procedure. Classes are generally defined by grouping spatial units that are similar with respect to their biological or environmental attributes. The proximity of spatial units is therefore measured in a multi-dimensional space (*sensu* Austin and Smith 1989) where each dimension is represented by one of the biological or environmental characteristics. Because the classes are defined independently of geographic location, the spatial framework generally shows a mosaic of patches of similar biological or environmental characteristics that recur across the classified area.

Regionalisation differs from classification in that the geographic location, as well as similarity in environmental and/or biotic character, is used to define a structure of distinctive spatial units. Regionalisation and classification have much in common. However, regions are generally singular geographic units that cover a contiguous area. The definition procedure for regionalisations is carried out in geographic space (*sensu* Austin and Smith 1989) by experts who use maps of biotic and/or environmental attributes. Subjective judgement is used to delineate regions within which there is a certain degree of homogeneity with respect to the defining attributes (deBlij 1978; Wicken 1986). In the past, regionalisation has been a common approach to developing spatial frameworks (e.g. Knox 1995). However, classifications that are defined using quantitative analyses are becoming increasingly feasible with the continued growth in computing power, and the wider availability of spatially explicit descriptions of both the environment and biota. For reasons that are discussed later, quantitative classifications have a variety of advantages over regionalisations and, in New Zealand at least, this is becoming the more common method for defining spatial frameworks.

3 Approach to New Zealand Marine Environment Classification

3.1 Development process

The development of the Marine Environment Classification began in 1999 with a series of consultative workshops that established the need for a spatial framework of New Zealand's marine environments. A steering group was assembled by MfE to oversee the development of the Marine Environment Classification. The purpose of the steering group was to ensure that the classification would provide a suitable management tool. The steering group membership was made up of people from the Department of Conservation, SeaFIC, NIWA, regional councils and MFish. Specifically the steering group was required to:

1. discuss and define the needs of users and the scope of the Marine Environment Classification and decide on the approach for its development
2. agree on the processes and techniques for the development of the classification system
3. review the outputs at various stages of development of the classification and where necessary choose from among options for subsequent development stages.

A second group of experts was involved in the detailed design and technical development of the classification system. The experts contributed to each of the following development phases:

1. choice of approach to design and development of the marine classification system and spatial resolution (mapping scale)
2. candidate environmental variable selection
3. development of environmental variables
4. validation of environmental variables
5. classification definition and tuning
6. testing.

The purpose of the development phases are outlined in general terms below.

3.2 Development phases

3.2.1 Choice of approach and spatial resolution

Various approaches to developing the classification were considered. One of the most desirable attributes of a spatial framework is the ability to resolve differing characteristics at a range of levels of detail and spatial scales. Regionalisation was rejected as an appropriate methodology at the outset because of its very limited ability to meet this requirement. Instead we concluded that an automated numerical classification of individual cells in a grid that are described by multiple variables was the most easily defended approach. Numerical methods are ideally suited to the production of classifications that are hierarchical. Hierarchic classifications can seamlessly expand and contract their resolution of character and are, therefore, suitable for use across a range of spatial scales. In addition, classes are defined in this approach solely on the basis of their environmental or biological similarity (i.e. independent of their geographic location). The geographic independence of such methods allows them to more accurately describe the inherent geographic configuration of variation in ecological character. Finally, the explicit measurement of similarity between geographic units that are produced by numerical methods has benefits for specific applications of the spatial framework, particularly in conservation applications that are considering trade-offs between locations (e.g. Belbin 1993, Leathwick et al.. 2003b).

The approach taken is similar to that used for the Land Environments of New Zealand (LENZ) framework (Leathwick et al. a and b). The multivariate approach of LENZ and Marine Environment Classification is, however, different to another spatial framework that has been developed for New Zealand – the River Environment Classification (REC) (Snelder and Biggs 2002). The REC is a ‘controlling factor’ approach. In this approach rules are used to sequentially subdivide the environmental domain according to differences in a set of environmental factors. The rules are based on a hierarchical model which proposes that variation in a single factor (e.g. climate, topography, geology) is the cause of ecological pattern at a series of spatial scales. While the controlling factor approach is appealing, we considered that its application to marine ecosystems was problematic because a robust hierarchy of factors is not easily defined and may be spatially unstable.

The next consideration was whether environmental or biological attributes should be used to define the classification. Biological data is limited for New Zealand’s marine area. Indeed, a primary reason for developing a spatial framework is to make inferences about biological distributions for locations for which minimal or no biotic data are available. By contrast, a range of data describing the physical environment was either already available or could be modelled reasonably robustly for the entire Exclusive Economic Zone (EEZ). For this reason, plus the need to consider environmental and biological factors in the integrated management of marine resources, an environmental classification (i.e. based on attributes of the physical environment) was chosen.

In this context, the key assumption of an environmental classification is that the pattern of the physical environment can be used as a surrogate for biological pattern. This assumption is most plausible at extensive spatial scales where the broad distributions of many individual species and communities are determined largely by physiological limitations imposed by the environment. At more local scales there is an increasing likelihood that biological interactions (e.g. predation) and processes (e.g. disturbance, recruitment) influence the pattern.

The Marine Environment Classification was developed at two levels of spatial resolution. First, a broad scale classification was developed of the entire EEZ, covering the area from approximately 25 to 58 degrees South and 158 degrees East to 172 degrees West. The environmental data layers used to define this classification have a nominal spatial resolution of 1 km. Approximately 8.4 million cells are contained within the 1 km grid environmental variable layers describing the EEZ. This resolution enables aesthetically acceptable mapping at scales of 1:4,000,000 and above. While the classification can be mapped at finer scales, the grain of the underlying data will become increasingly prominent as the scale is increased.

Second, a finer scale classification was developed for the Hauraki Gulf region. The purpose of this regional classification was to assess the feasibility of producing higher resolution inshore classifications relevant to the more intensive management issues that frequently occur there. The region is defined by a line drawn eastward from Bream Head (approximately 36 degrees South) to meet a line drawn from south to north and intersecting Cape Barrier on Great Barrier Island (approximately 176 degrees East). This was based on environmental layers with a nominal spatial resolution of 200 m (i.e. consistent with a maximum map scale of 1:250,000).

Approximately 220,000 cells are contained within the 200 m grid of environmental variable layers describing the Hauraki Gulf.

3.2.2 Selection of candidate environmental variables

The selection of candidate environmental variables was based on an initial design (see Snelder et al. 2001). The design process used published descriptions of relationships between environmental and biological patterns at extensive spatial scales (i.e. greater than 200 metres for the regional classification and greater than 1 km for the EEZ classification). In conceptual terms, our overall objective was to identify a set of environmental variables that could be used to define classes that maximize the discrimination of variation in the total biological composition, a task that was complicated by the highly diverse range of organisms that occur in marine environments. As a consequence of this diversity, the selection of variables required the careful balancing of generality (i.e. relevance to a broad range of biological groups) and specificity (i.e. relevance to perhaps a narrow set of organisms). Our overall emphasis tended towards the first of these (i.e. we aimed to produce a single classification that would be reasonably relevant to a broad range of ecological components). We anticipated that a general classification might provide discrimination of variation in chlorophyll biomass at the surface, pelagic and demersal fishes and benthic communities.

In practical terms, candidate environmental variables also had to be able to be derived as systematic coverages or layers. By 'systematic' we mean objectively defined data that show the spatial variation in the variable across the area to be classified at a consistent level of resolution.

3.2.3 Validation

The aim of the validation work was to confirm that the candidate environmental variables were useful as predictors of biological characteristics and to determine which had the strongest statistical relationships with biological pattern. There was an expectation that this would reduce the initial set of candidate environmental variables to a core set for which quantifiable statistical relationships with biological patterns could be demonstrated. The available biological data was researched (Fenwick 2001) and datasets were assembled and/or groomed for both the EEZ (Image et al. 2003) and the Hauraki Gulf (Fenwick and Flanagan 2002) classifications.

3.2.4 Definition of the classifications

The classifications of the EEZ and Hauraki Gulf were defined using a numerical classification based on clustering. In clustering, classes are defined by iteratively joining individual cells, and then groups of cells (i.e. clusters), based on their similarity according to the combination of environmental variables that are chosen to define the classification (Zonneveld 1994). Each step in the clustering process is shown graphically by a tree structure, or dendrogram, which shows the order in which clusters are joined. The number of classes depends on the 'cut level' in the dendrogram. The classes are then mapped using a Geographic Information System (GIS) to show the mosaic of patches. Patches show the geographic location of cells belonging to the classes. In general, the size of the patches is large at high levels of the classification (i.e. a small number of classes) and patches are smaller at lower levels. The user is able to map the classification at any level so that the number of classes defines a spatial resolution that is suitable for the particular application.

3.2.5 Testing

The aims of the testing process were twofold. First, the strength of the classification is dependent on its ability to define classes that are biologically distinctive (i.e. classes should be different from one another in terms of fish assemblages and chlorophyll concentration, for example). In a strong classification, locations belonging to a class should show a high level of similarity to other locations within the class, relative to their similarity to locations in other classes. Thus, the testing aimed to determine whether there are statistically significant differences between classes and to quantify the overall strength of the classification using biological samples. It was expected that the strength of the classification would vary with the level of the classification hierarchy and between different sets of biological data. Therefore, the testing also aimed to establish the levels at which biological distinctiveness was maximised. As a secondary output of the testing process, we aimed to describe the biological characteristics of the classes.

4 Data

4.1 Environmental variables

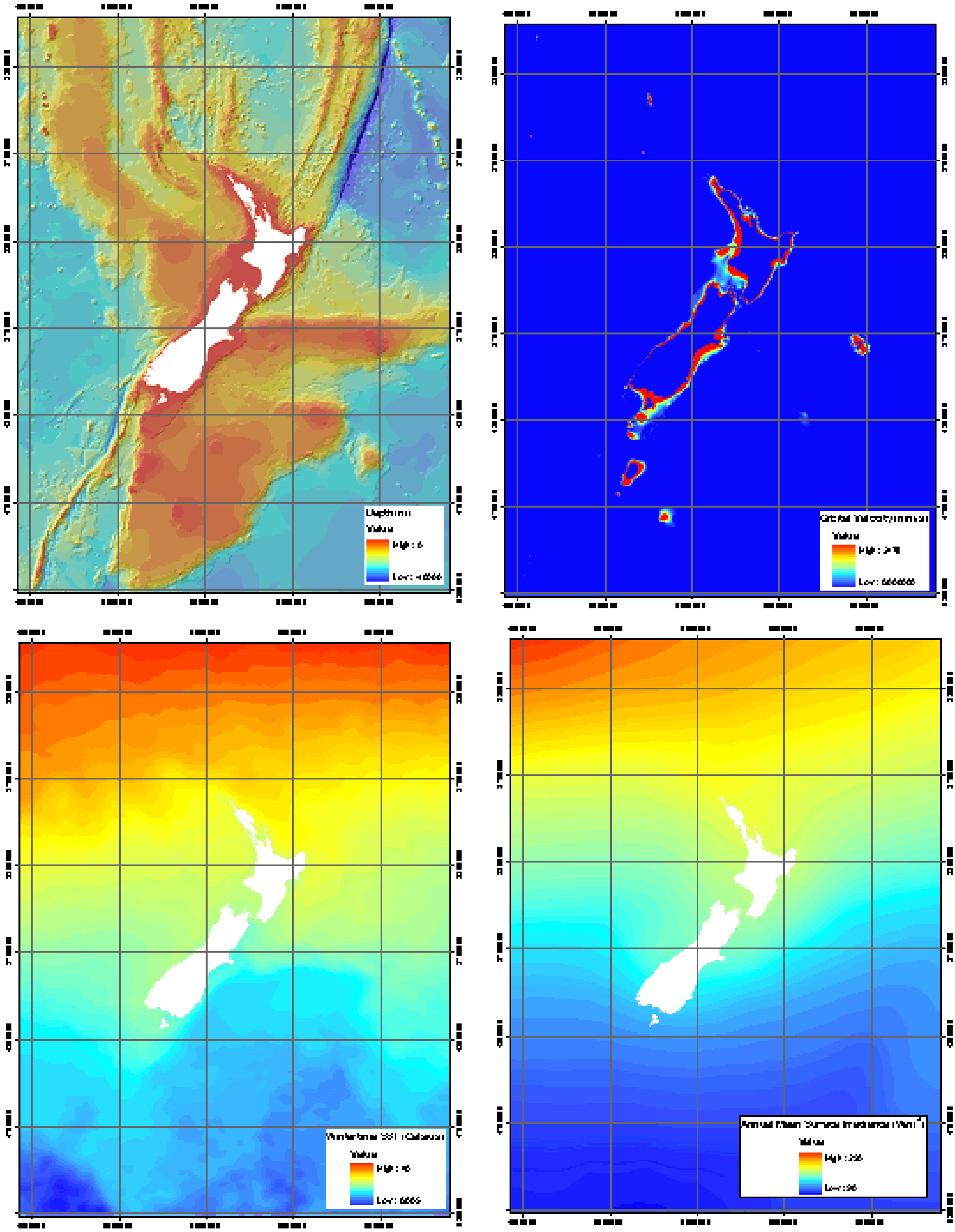
4.1.1 EEZ

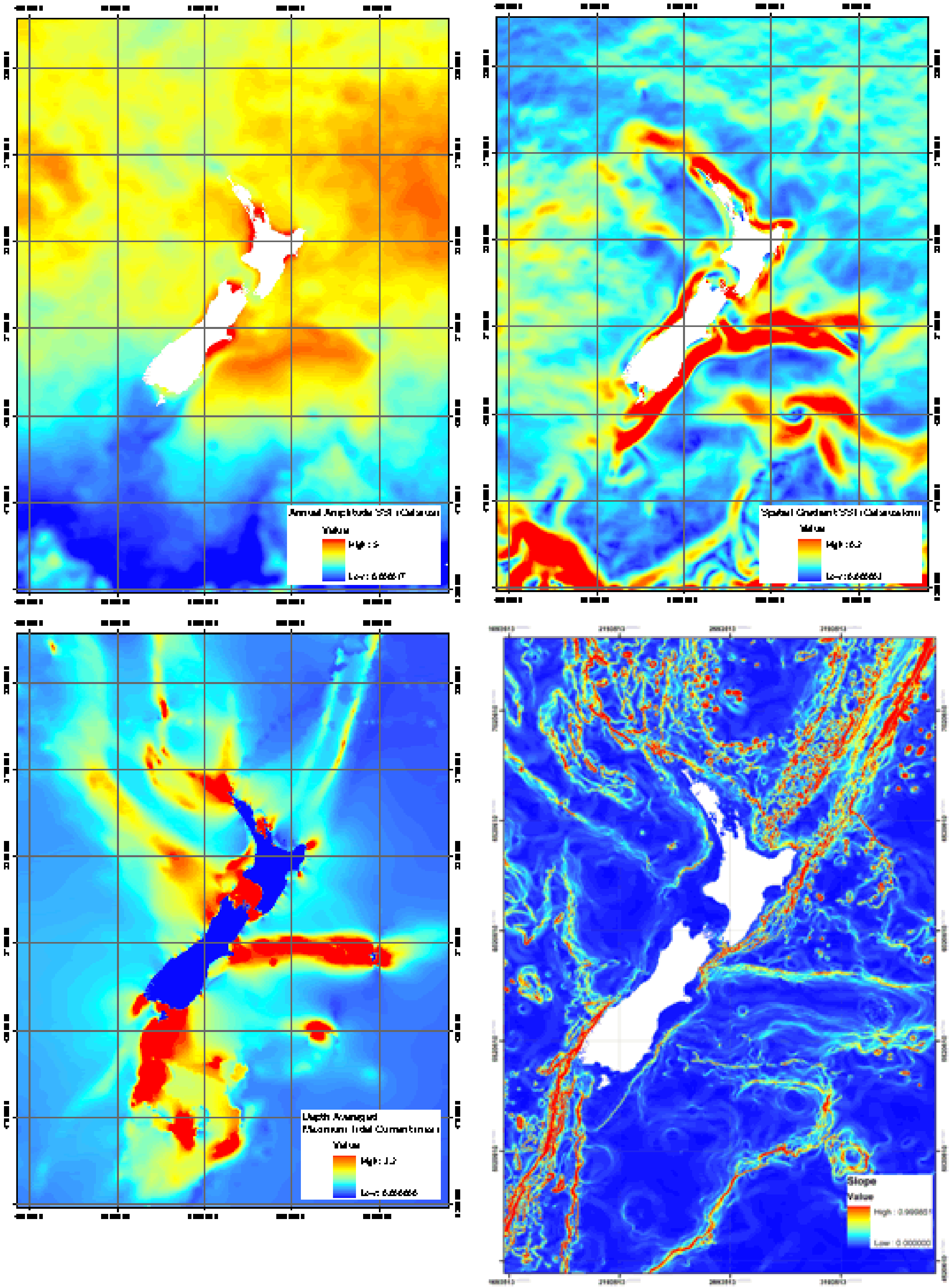
Table 1 lists the candidate environmental variables for the EEZ classification. Maps of some of these variables are shown in Figure 1. The rationale for these candidate variables was fully discussed in the draft design report (Snelder et al. 2001) and the development of each variable is more fully discussed in Hadfield et al. (2002). Many of these variables are temporally variable (e.g. solar radiation, orbital velocity). Therefore, the variables represent the long-term average value and have been designed to discriminate differences in mean characteristics between locations (not between times). The following section provides a brief discussion of the relevance of these variables and the development of spatial coverages describing them. Figure 1 maps the eight variables that were eventually chosen to define the EEZ classification (see Hadfield et al. 2002 for maps of all candidate variables).

Table 1: Candidate environmental variables derived for the EEZ classification

Environmental variable	Abbreviation	Description	Units
Depth	Depth	Bathymetry grid (1 km resolution)	m
Annual mean solar radiation	Rad_mean	Mean extra atmospheric solar radiation modified by mean annual cloud cover	Wm^{-2}
Winter solar radiation	Rad_wint	Extra atmospheric solar radiation in June, modified by mean annual cloud cover	Wm^{-2}
Wintertime sea surface temperature	SSTwint	Mean of daily data from early September when SST is typically lowest	^{o}C
Annual amplitude of sea surface temperature	SSTanamp	Smoothed annual amplitude of SST	^{o}C
Spatial gradient annual mean sea surface temperature	SSTgrad	Smoothed magnitude of the spatial gradient of annual mean SST	$^{o}C\ km^{-1}$
Summertime sea surface temperature anomaly	SSTanom	Spatial anomalies with scales between 20 and 450 km in late February when SST is typically highest	^{o}C
Mean orbital velocity	Orb_v_mean	Orbital velocity at the bed for the mean significant wave height calculated from a 20-year wave hindcast	m/s
Extreme orbital velocity	Orb_v_95	Orbital velocity at the bed for the 95th percentile significant wave height calculated from a 20-year wave hindcast	m/s
Tidal current	Tidal	Depth averaged maximum tidal current	m/s
Sediment type (categorical variable)	Sed	Sediment type as a categorical variable	na
Seabed rate of change of slope (profile)	Bed_prof	The rate of change of slope for each cell	$0.01m^{-1}$
Seabed curvature	Bed_curv	Curvature of the surface surrounding each grid cell	$0.01m^{-1}$
Seabed planform curvature	Bed_plan	Curvature of the surface perpendicular to the slope direction	$0.01m^{-1}$
Freshwater fraction	FW	Proportion of fresh water based on river inputs	proportion

Figure 1: **Maps of the environmental variables derived for the EEZ classification (Depth, Mean orbital velocity, Wintertime SST, Annual mean solar radiation, Annual Amplitude SST, Spatial gradient SST, Tidal currents, Slope)**




Slope
Value

Depth was chosen because it is correlated with many physical drivers of biological distributions. Light, temperature, pressure and salinity all vary with depth, although mostly in a non-linear fashion. Depth also mediates the supply of organic matter from the surface to the seabed. Depth was estimated for each cell in the 1 km classification grid from a NIWA bathymetric layer interpolated from a large quantity of depth data of variable quality and resolution.

Annual mean surface solar radiation is an important factor controlling rates of primary production. The pattern of solar radiation variation over the EEZ is essentially one of latitudinal variation, which is modified by cloud cover. The clear-sky solar irradiance was calculated from the instantaneous solar elevation using the method of Davies et al. (1975), with allowances for atmospheric water vapour and dust appropriate for clean oceanic air at 40°S (water vapour content = 1.6 cm, dust transmission coefficient = 0.95). Daily mean solar irradiance was then calculated by numerical integration of clear-sky solar irradiance for noon-time solar elevation calculated for the mid-date of each month, combined with monthly-mean cloud cover data from the International Satellite Cloud Climatology Project D2 dataset of global cloud parameters monthly means from July 1983 through December 1995 (Rossow and Schiffer 1999).

Winter surface solar radiation was derived in order to discriminate between locations that have similar mean annual solar radiation, yet have differences in maximum summer or minimum winter solar radiation and, therefore, have different productivity. Winter surface solar radiation was calculated as for annual mean surface solar radiation for the shortest day of the year (day 172, late June) and combined with cloud cover data for June.

Sea surface temperature (SST) was expressed by four variables formulated to capture specific oceanographic processes, both physical and chemical, that affect biological pattern (Snelder et al. 2001). The variable layers based on SST are all calculated from a SST climatology dataset derived from the NIWA SST archive. The procedures for collecting satellite radiometer data, detecting cloud and retrieving SST are described by Uddstrom and Oien (1999). The climatology was prepared by compositing data for each of the 96 months in the years 1993 to 2000 on a grid with approximately 9 km resolution. The climatologies were later interpolated onto the 1 km^2 classification grid. This interpolation was considered reasonable because of the relatively smooth and slowly changing character of most of the SST variables. **Wintertime SST** was chosen as a proxy for water mass, which is related to differences in both temperature and chemical characteristics of the water including nutrient availability. Wintertime SST was evaluated by spatial smoothing of temperature at the time of typically lowest SST (day 250, early September). The **annual amplitude of SST** was chosen to reflect differences in stratification and wind mixing that together produce a mixed layer across the classified area. Annual amplitude of SST was evaluated from the annual harmonic which is spatially smoothed. The **spatial gradient of annual mean SST** is used to recognise fronts in oceanic water masses that are expected to correlate with variation in primary productivity. Spatial gradient of annual mean SST was produced by smoothing annual mean SST then evaluating the magnitude of the spatial gradient (in °C km^{-1}) for each grid cell by centred differencing. The s**ummertime SST anomaly** is expected to define anomalies in temperature that are due to hydrodynamic forcing, such as upwelling and vigorous mixing due to eddies. Areas with high summer SST anomaly are expected to correlate with high primary productivity. Summer SST anomaly was derived from SST measured in late February data (day 50), the time of year when SST is typically highest by band-pass filtering at scales between 20 and 450 km.

Mean orbital velocity and **Extreme orbital velocity** describe the variation in velocity at the sea bed that is induced by swell waves. This velocity plays an important role in structuring benthic communities by inducing bed stress and re-suspension of bed material. Both average and extreme (represented here by the 95th percentile) orbital velocities were considered to be potentially important. The mean orbital velocity represents the variation in mean wave energy whereas extreme orbital velocity discriminates locations on the basis of rare high magnitude wave events. The EEZ scale orbital velocity variables were based on a wave climatology derived from a 20-year hindcast (1979–1998) of swell wave conditions in the New Zealand region (Gorman and Laing 2000). The wave climatology was used to interpolate the mean and 95th percentile values of significant wave height and mean values of wave peak period onto the 1 km bathymetry grid. The wave height, period and depth were used to estimate mean and 95th percentile bed orbital velocities. Bed orbital velocities were assumed to be zero where depth was greater that 200 m. No accounting was made for refraction or sheltering by land inside the 50 m isobath, resulting in some unreasonably high values in sheltered coastal environments.

Tidal current can be important in structuring benthic communities and also affects mixing properties of the water column. Variation in tidal currents was described using the modelled maximum depth-averaged tidal currents (m s^{-1}). The tidal current layer was derived using the model described by Walters et al. (2001).

Seabed relief was developed into four layers from analysis of the 1 km bathymetry grid. These were (1) **curvature**, (2) **profile**, (3) **plan**, and (4) **slope.** Each of these variables was computed for each grid cell by analysis of the surrounding cells in the bathymetry grid (Hadfield et al. 2002).

Sediment type is a factor that determines the composition of benthic communities. Variation in sediment types was derived from the New Zealand Region Sediments chart (scale of 1:6,000,000) (Mitchell et al. 1989). The chart was digitised and converted to a grid showing 23 categories based on the dominant and subdominant sediment type. These sediment types were also converted to effective particle size and averaged and ranked to give the continuous variable rank sediment size, a variable suitable for correlation analyses. Although this variable showed some relationships with biological datasets (see Image et al. 2003), it was eventually discarded because of difficulties with including this categorical variable in the classification procedure (see section 7.1.1).

Freshwater input was recognized as an important variable, particularly in coastal waters (Snelder et al. 2001). Although a freshwater fraction layer for the EEZ would probably best be developed from remotely sensed data, such a product was not available and a placeholder for the freshwater fraction variable was used instead. This was based on a simple GIS-based routine that modelled the mixing and dispersal of freshwater inputs from rivers into the coastal environment (Hadfield et al. 2002). Although this variable showed some relationships with biological datasets (see Image et al. 2003), it was eventually discarded because of concerns about its accuracy.

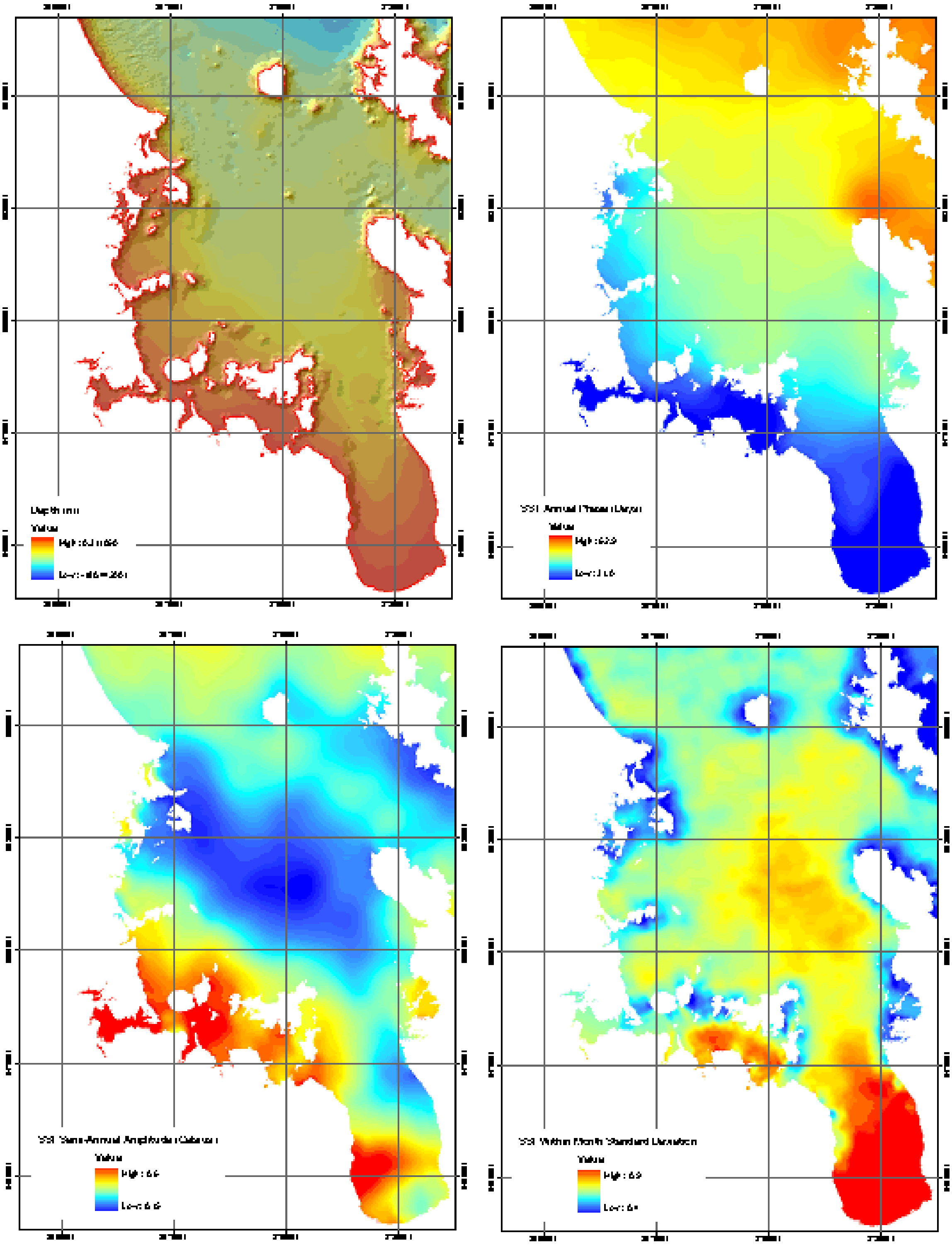
4.1.2 Regional scale – Hauraki

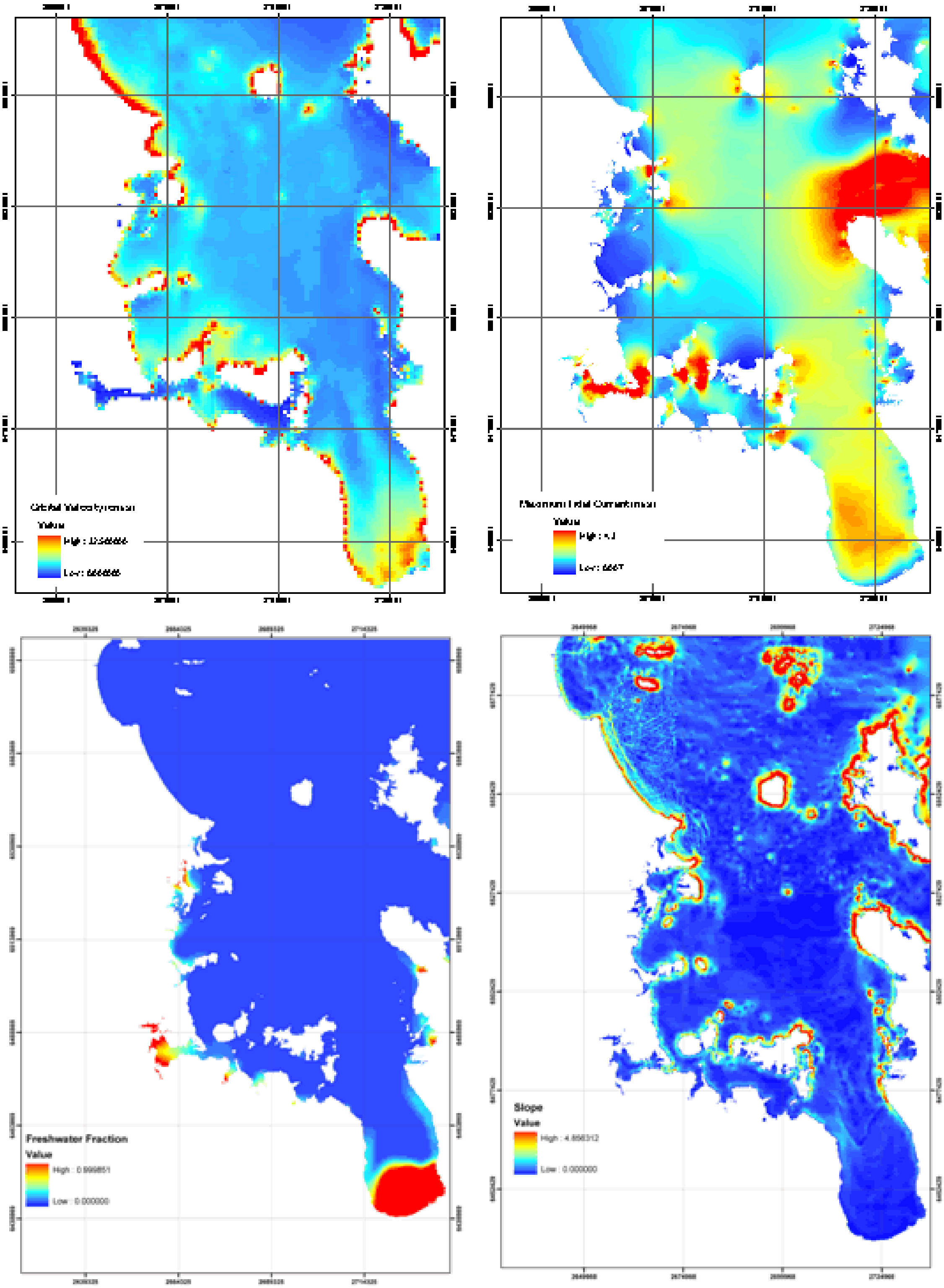
Table 2 lists the candidate environmental variables for the Hauraki Gulf classification. Maps of the eight variables eventually chosen to define the Hauraki Gulf classification are shown in Figure 2. The rationale for the selection of these candidate variables is fully discussed in the draft design report (Snelder et al. 2001) and the development of each variable is more fully discussed in Hadfield et al. (2002).

Table 2: Candidate environmental variables derived for the Hauraki Gulf classification

Physical variable	Abbreviation	Description	Units
SST annual amplitude	SST_ann_ampl	SST annual amplitude	^{o}C
SST annual phase	SST_ann_phase	SST annual phase	Days
SST mean	SST_mean	Mean SST	^{o}C
SST semi-annual amplitude	SST_sann_ampl	SST semi-annual amplitude	^{o}C
SST within-month standard deviation	SST_mth_std	SST within-month standard deviation	^{o}C
Mean freshwater fraction	Fresh_fract	Mean freshwater fraction	na
Depth	Depth	Depth	M
Seabed relief curvature	Hau_curv	Curvature of the surface surrounding each grid cell	$0.01m^{-1}$
Seabed relief-profile	Hau_prof	The rate of change of slope for each cell	$0.01m^{-1}$
Seabed relief-planiform	Hau_plan	Curvature of the surface perpendicular to the slope direction	$0.01m^{-1}$
Seabed slope	Slope	Slope based on adjacent cells in depth grid	$0.01m^{-1}$
Mean peak bed orbital velocity	Orb_vel_mean	Orbital velocity at the bed for the mean significant wave height calculated from a 20-year wave hindcast	dm/s
95th percentile peak bed orbital velocity	Orb_vel_95	Orbital velocity at the bed for the 95th percentile significant wave height calculated from a 20-year wave hindcast	Cm/s
Depth averaged maximum tidal current	Tidcurmax1	Depth averaged maximum tidal current	m/s

Figure 2: Maps of the environmental variables derived for the Hauraki Gulf classification (Depth, SST annual phase, SST semi-annual amplitude, SST monthly standard deviation, Mean orbital velocity, Tidal currents, Freshwater fraction, Slope)




Freshwater Fraction
Value
Slope
Value

In general, similar variables were developed for the Hauraki Gulf and EEZ classifications. However, there were some differences in choice of variables due to differences in scale. For example, solar radiation was not included as a candidate variable because at the scale of the Hauraki Gulf, solar radiation is effectively spatially invariant. The SST statistics were also different to those used for the EEZ classification. In addition, the need for increased spatial resolution for the Hauraki Gulf layers, compared to the EEZ, meant that higher resolution data and more detailed modelling was used to generate the Hauraki Gulf variables. The following section provides a brief discussion of the relevance and development of spatial coverages describing these variables.

Depth for each cell in the 200 m classification grid was interpolated from a large quantity of depth data of variable quality and resolution. Five SST variables were formulated to capture specific oceanographic processes (Snelder et al. 2001). The variables that were based on SST were calculated from the same NIWA SST Archive as the EEZ classification variables but the grid spacing for the composited monthly data was reduced to 2 km. The data were later interpolated onto the 200 m classification grid. **SST mean** was used to capture the contrast between cool inner-gulf water and warmer East Auckland current water offshore. **SST annual amplitude** is related to the depth of the mixed layer, large amplitudes corresponding to deeper mixed layers. Annual amplitude decreases inshore because the mixed layer depth is limited by the depth of the water. **SST annual phase** is also related to mixed layer depth. Deeper mixed layers take longer to warm and cool seasonally so the phase of the annual cycle lags. It was considered that this variable may also have some direct effect on biota, in that, where the annual phase lag is large, the time of maximum irradiance may not coincide with the time of maximum temperature. **SST semi-annual amplitude** was chosen because the semi-annual harmonic causes the seasonal cycle to be distorted. The physical processes controlling this quantity are not well understood. One process that should be significant offshore is the seasonal variation in the mixed layer depth, which tends to allow the sharp SST maximum in summer but a broad SST minimum in winter. The **SST within-month standard deviation** was used as a measure of variability in SST. This quantity was expected to be large where strong eddy activity occurs in regions of strong spatial gradients. It may also be large in regions of large, variable freshwater influence.

For the Hauraki Gulf classification an existing hydrodynamic model was used to estimate **freshwater fraction** and **tidal current** across the Hauraki Gulf. Tidal currents and freshwater dispersion in the Hauraki Gulf were simulated using the three-dimensional model MIKE 3, with one (depth-averaged) layer and a 750 × 750 m cell size. Tides were forced at the open boundaries using the M_2 tidal component (i.e. no spring-neap variation). The model output the resulting depth-averaged maximum tidal current at each node in the model grid. The estimated mean freshwater inflows for the significant river systems draining into the Gulf were added to the model and it was run for a two-month period to allow the freshwater to disperse and modelled values to stabilise. The equilibrium freshwater fraction at each node in the grid was used to represent the mean freshwater fraction. The values at each model node were interpolated onto the 200 m grid.

Mean orbital velocity and **extreme orbital velocity** were derived from a simulation of the Hauraki Gulf using the SWAN shallow-water wave model (Booij et al. 1999; Ris et al. 1999). The model was driven using a boundary swell derived from NIWA's 20-year hindcast of wave conditions in the New Zealand region, and associated ECMWF (European Centre for Medium-Range Weather Forecasts) winds. The spatial grid had a 750-metre resolution covering the Hauraki Gulf.

The Hauraki Gulf **sediment** layer was derived by digitising the Hauraki Coastal Sediment Series chart (scale 1:200,0000) (DSIR 1992). The dominant and subdominant sediment codes from the chart were used to categorise each grid cell. These sediment types were also converted to an ordinal variable representing effective particle size, which was suitable for correlation analyses. Although sediment showed some relationships with biological datasets (see Hewitt and Snelder 2003), it was eventually discarded because of difficulties with including categorical variables in the classification procedure (see section 8.1.1).

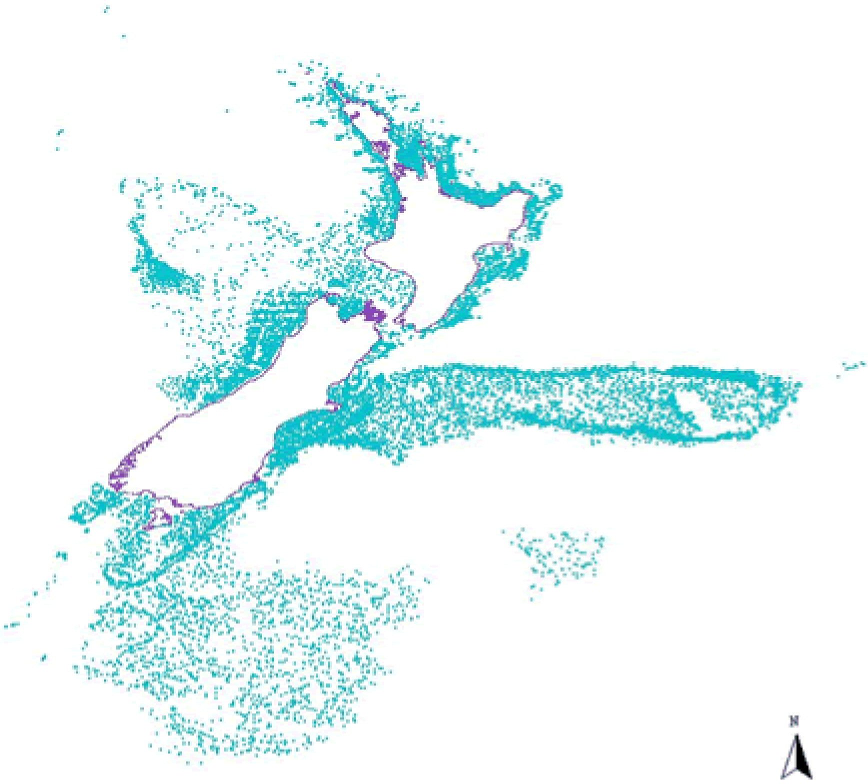
Four layers representing seabed relief were developed from analysis of the 200-metre bathymetry grid. These were (1) **curvature**, (2) **profile**, (3) **plan** and (4) **slope**. Each of these variables was computed for each grid cell by analysing the surrounding cells in the bathymetry grid (Hadfield et al. 2002).

4.2 Biological data

4.2.1 EEZ biological data sets

Biological data used in the EEZ validation were drawn from four sources as follows. Research trawlers have collected a large dataset describing the distributions of mainly demersal fish species since 1961 (Figure 3). This data, herein after called the ‘fish dataset’ is fully described by Francis et al. (2002) who used it to describe demersal fish assemblages in New Zealand waters. The dataset contained 19,232 stations and 123 species after removal of stations that fell outside the scope of the environmental variable grids and rare species that did not occur in more than 1% of the trawls. Because sampling efficiency varies due to differences in nets (types and sizes), and vessels (towing power) this dataset was amenable to presence/absence analysis only.

Figure 3: Ministry of Fisheries research demersal fish trawl survey stations within the New Zealand Exclusive Economic Zone

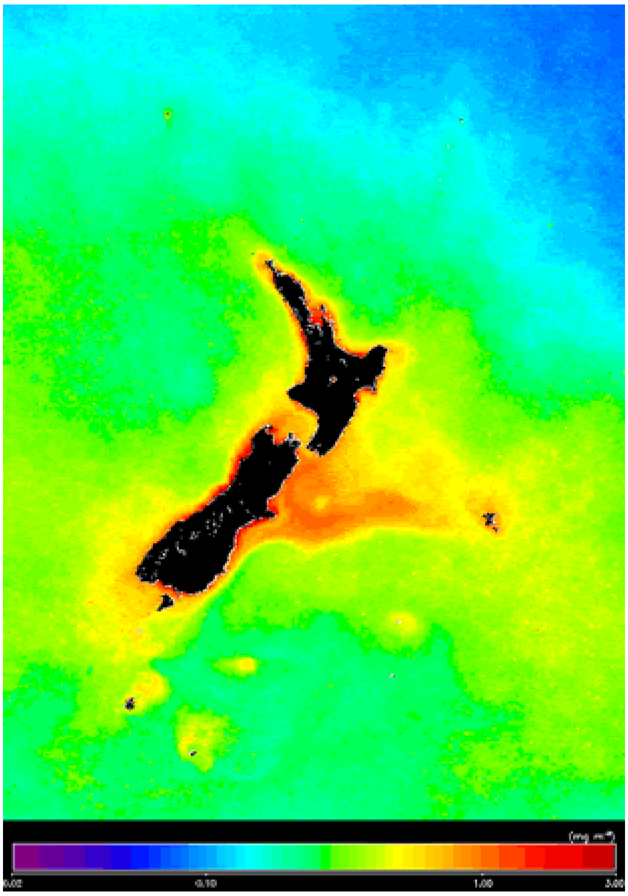


Benthic species data (presence/absence) were available from three continental shelf surveys, jointly called hereafter the 'shelf dataset'. In order to reduce any likely error associated with species level identifications, data were analysed at the taxonomic level of family. Analysis of data at the family level can be sufficient to identify natural spatial pattern in marine macrofauna assemblages (see Olsgard and Somerfield 2000). This dataset comprised 274 stations and 145 species.

Additional benthic data were obtained from NIWA's AllSeaBio database. Limitations with this data (see Image et al. 2003) restricted its use to species belonging mainly to the echinoderm orders Asteroidea and Ophiuroidea. These two orders were selected for their commonality and broad geographic/depth distribution. In addition, their taxonomic identification within the database was reliable due to recent attention (McKnight 2000; Clark and McKnight 2000; Clark and McKnight 2001).

Ocean colour data derived from Sea-viewing Wide-Field-of-view Sensor (SeaWiFS) was used to estimate the mean chlorophyll concentration. Light data from the ocean surface in six visible wavebands collected between September 1997 and July 2001 were composited at a variety of spatial and temporal scales, partly to help overcome problems with cloud cover. This product was used in an empirical algorithm to retrieve the concentration of chlorophyll-*a* at a spatial resolution of about 9 km (Figure 4). The coverage of estimated long term mean chlorophyll was randomly subsampled at approximately 9600 points and this 'chlorophyll dataset' was used for the validation, testing and tuning analyses. Because chlorophyll estimates in coastal waters are unreliable due to suspended solids in the water column, we only used data from water that was deeper than 30m.

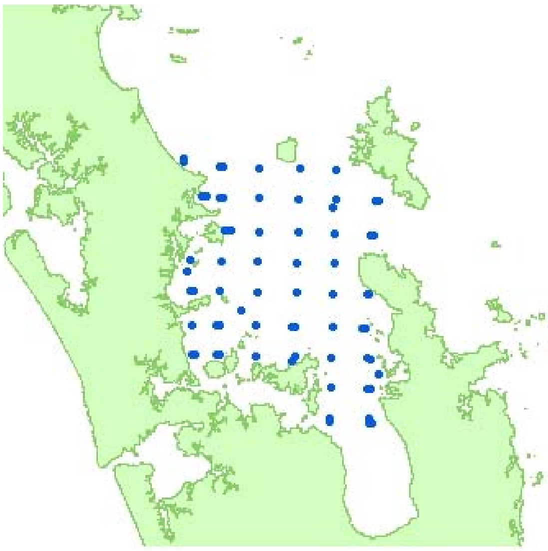
Figure 4: Mean annual sea surface chlorophyll concentrations within the New Zealand Exclusive Economic Zone derived from remotely-sensed (satellite) ocean colour data collected between September 1997 and July 2001



4.2.2 Hauraki biological data

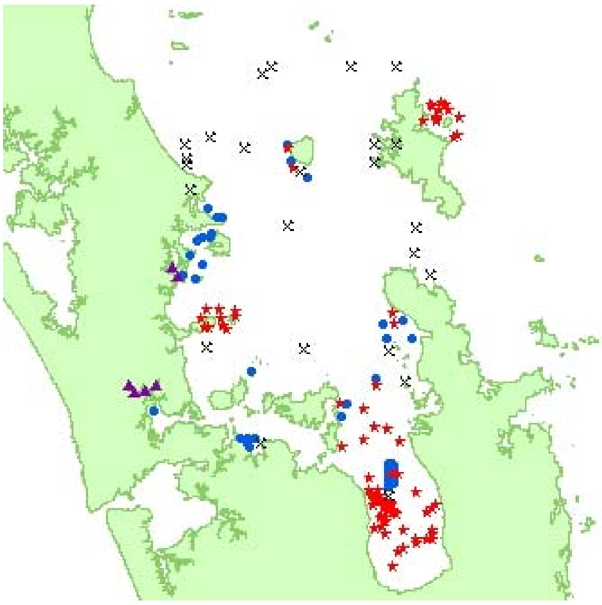
Biological data used in the Hauraki Gulf validation are fully described by Fenwick and Flanagan (2002) and were drawn from four sources as follows. A large plankton dataset, hereafter called the pelagic dataset, was amenable to analysis of abundance/concentration. The pelagic dataset included chlorophyll concentration and abundance data for five types of large zooplankton (brachyuran and decapod shrimp larvae, *Sagitta* sp., medusae and enteropneust), a number of types of microzooplankton, and fish larvae and eggs. This data were collected from 54 stations (see Figure 5) at approximately 10 and 30 m depths from the months of November, December and January in 1985–87; September, October, December, January and February in 1996–98; and throughout 1999–2001. The validation analysis was restricted to the chlorophyll, large zooplankton and microzooplankton components of this dataset and for specific sampling occasions. In the subsequent tuning phase of the work, all biological components were amalgamated in a single community analysis and all sampling occasions were combined into a single average abundance/concentration for each station.

Figure 5: Location of stations for the Hauraki plankton dataset



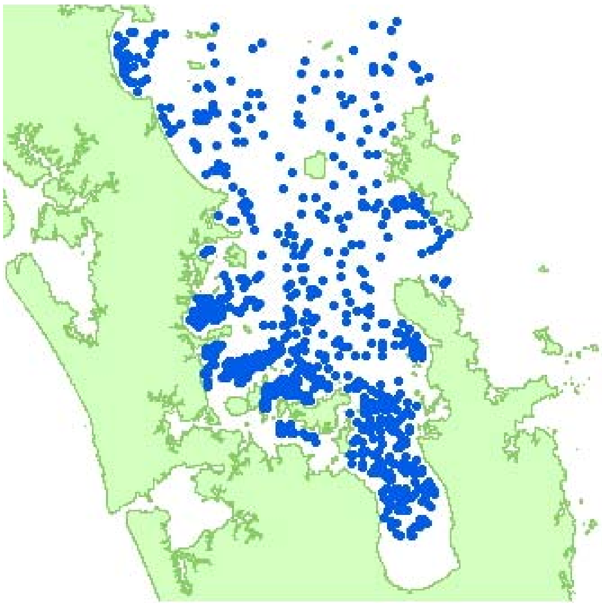
Benthic datasets from within the Gulf, including the Allseabio database and data collected by other investigations comprising epifauna and infauna data were collated and combined (see Fenwick and Flanagan 2002). Infaunal data that was sampled by coring, hereafter called the core dataset, were available for 216 stations. All but 39 of the core dataset stations were in the Firth of Thames; there were none in the middle deep areas or in the vicinity of Great Barrier Island. Infaunal data from grab sampling were available for 121 stations, hereafter called the grab dataset. All but 31 stations from the grab dataset were in the Firth of Thames; there were none in the middle deep areas or in any harbours or estuaries (see Figure 6). Not all of these sites were in the area covered by the environmental variables layers. In addition, a stratified (by location) random selection of the Firth of Thames samples was used to prevent the data from this area biasing the analyses.

Figure 6: Locations of benthic macrofauna sites. Blue circles are core sites, red stars are grab sites, black crosses are sites from the Allseabio dataset and purple triangles are sites that could not be used because they fell outside the data grid.



Demersal fish data, hereafter called the fish dataset, were as used in Kendrick and Francis (2002), except for 107 points outside the Hauraki grid and 86 points for which no environmental data were available (see Figure 7). These data were collected between 1982 and 1997 in spring and autumn using the same net type and ship (Kaharoa).

Figure 7: Locations of fish data stations in the Hauraki Gulf



4.2.3 Limitations of biological datasets

Before any analyses were performed, we examined the environmental distribution of the sampling stations for the biological datasets relative to the total environmental variation described by the EEZ and Hauraki Gulf environmental variable layers. The representation of the environmental space by biological data was summarized in a frequency plot for each environmental variable that is overlaid with the corresponding frequency of biological sites. Examples of these plots are shown in Figures 8 and 9. The graphs show that large parts of the range of many of the environmental variables are not sampled by the biological datasets. This restricted our ability to validate the environmental variables and to test the effect of classification decisions such as transforming and/or weighting variables. In addition, these data were also used to test the classification. The lack of data over much of the environmental domain limited our ability to fully test the classification and to describe the biological characteristics of many environmental classes.

Figure 8: **Representation of the environmental 'space' for the EEZ by the fish dataset. Each plot shows the frequency distribution for each environmental variable (solid blue), which is overlaid by the corresponding frequency of fish stations (green line).**

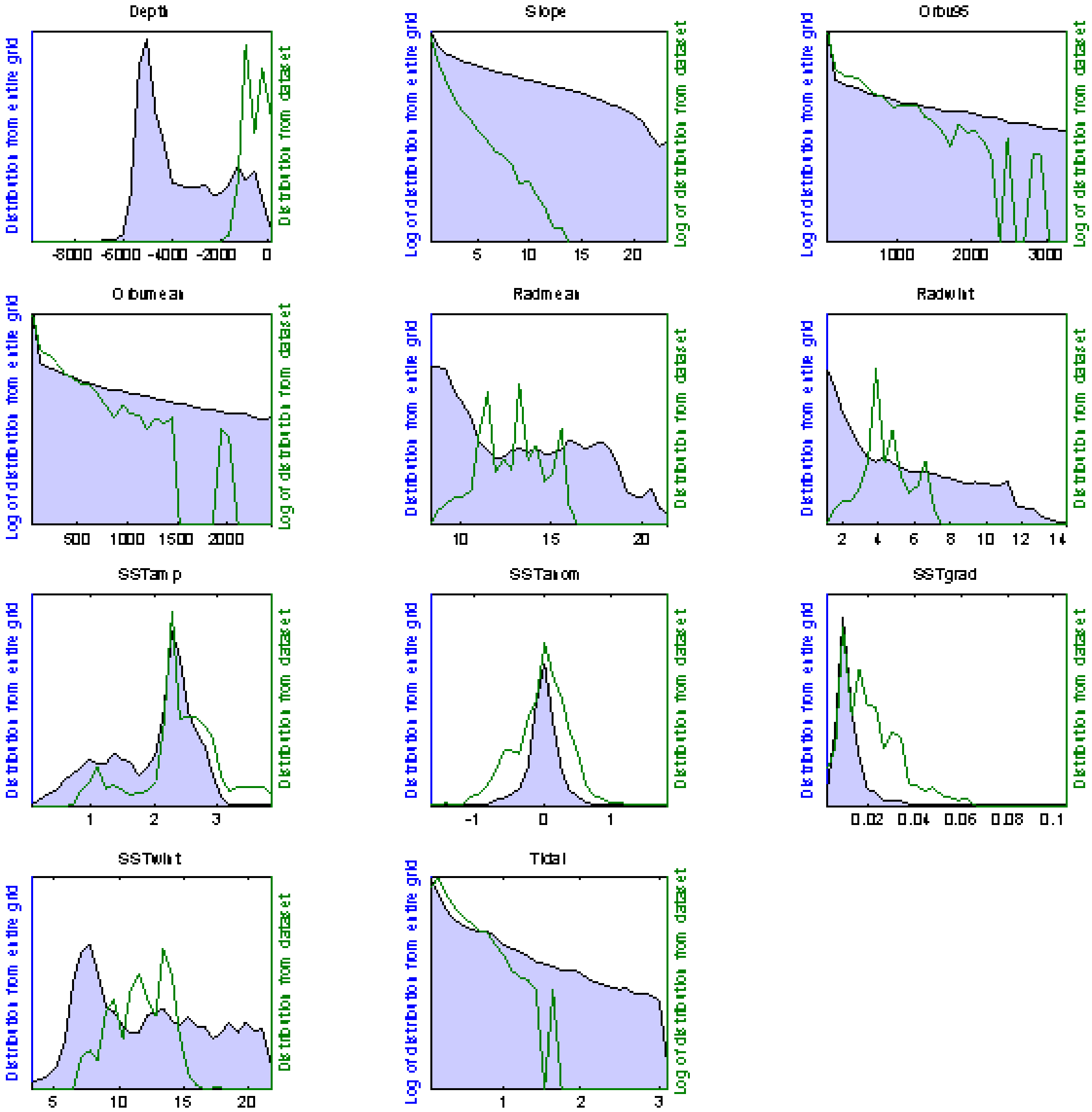
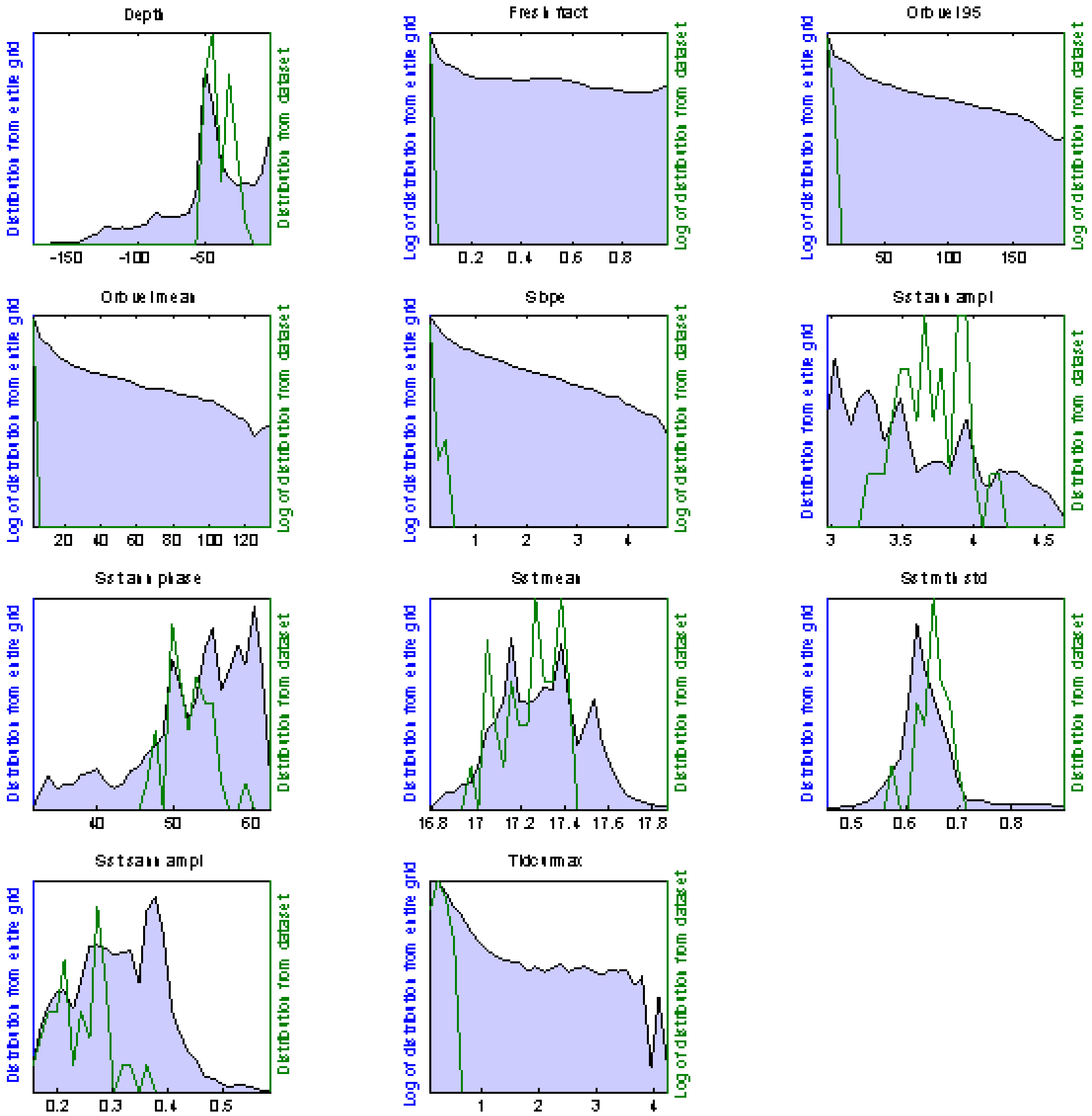


Figure 9: **Representation of the environmental 'space' for the Hauraki Gulf by fish dataset. Each plot shows the frequency distribution for each environmental variable (solid blue), which is overlaid by the corresponding frequency of biological stations (green line).**



5 Analytical Methods

5.1 Validation

The validation phase of this project sought to provide a robust basis for the selection of a final set of environmental variables with which to define the classifications. In particular, we aimed to explore correlations between the candidate environmental variables and both species and communities using a variety of biological datasets and a mixture of analytical techniques. The latter included clustering combined with analysis of variance (ANOVA), Generalised Additive Models (GAM), classification and regression trees (CART), canonical correspondence analysis (CCA), and analysis of correlation of biological and environmental spaces (BVSTEP). It was considered that general agreement among multiple statistical methods would provide confidence in the final choice of environmental variables.

5.1.1 EEZ analysis

Table 3 summarises the statistical methods used for each of the EEZ biological datasets. The methods are discussed briefly below. A complete description of the validation analyses is contained in Image et al. (2003).

Classification of community data, followed by use of ANOVA to test the magnitude of environmental differences between groups, was used with both the fish and benthic datasets. In the classification phase, sampling stations were grouped on the basis of biological similarity measured using the Bray-Curtis distance measure (Digby and Kempton 1987). When used with presence/absence data this compares numbers of species in common between sites, with distances ranging from 1 (no taxa in common between sites) to 0 (all species in common). Cluster analyses were performed on the resulting biological distance matrices using hierarchical agglomerative, group-average linkage (Clarke and Warwick 2001). Membership of sample stations in fish and invertebrate community groups was defined by pruning the cluster dendrogram at a level of similarity that produced 10 and 20 groups. Analysis of variance (ANOVA) was then used to assess the magnitude of environmental differences between the biological groups. Although the use of biological groups as treatments might be considered unconventional, the ANOVA F-ratios provide an indication of which environmental variables co-varied most strongly with variation in biological composition. Because we were not interested in the actual statistical significance of the calculated F-ratios, any violation of the normality assumptions of ANOVA were considered to be unimportant.

Table 3: Summary of the statistical methods used for each data type

Dataset	Classification and ANOVA	GAM	CART	CCA	BVSTEP
Chlorophyll *a*		Yes	Yes		Yes
Fish species			Yes		
Fish community	Yes		Yes	Yes	Yes
Benthic species			Yes		
Benthic community	Yes		Yes	Yes	Yes

The relationships between the environmental variables and the concentration of chlorophyll, and the probability of occurrence of 12 fish and 10 benthic species, were analysed using generalised additive models. In this approach the abundance or probability of occurrence was modelled as a function of smoothed responses to a set of environmental variables. Both the marginal contribution of each variable and the order in which it was fitted gave an indication of its importance, while the overall abilities of the environmental factors to predict the biological responses were assessed using cross-validation procedures (Image et al. 2003).

A regression tree analysis was used to examine correlations between the environmental variables and chlorophyll concentration, and classification trees were used to relate environment to the presence/absence of both fish and benthic species. Classification trees were used to assess the environmental relationships of the fish and invertebrate community groups defined by the numerical classifications described above.

Canonical correspondence analysis (CCA) as described by Francis et al. (2002) was used to explore relationships between environment and the composition of both fish and benthic communities. Because CCA is sensitive to the presence of rare species (Ter Braak and Smilauer 1998), only species occurring in 1% or more of the stations were included in these analyses.

The multivariate routine BVSTEP (Clarke & Warwick 2001) was used to compare dissimilarity matrices generated for combinations of environmental variables with the matrix generated for taxa data (using Bray-Curtis dissimilarities). Spearman's correlation coefficient (rho) quantified the correlation between biological and environmental space and enabled comparisons to be made between alternative definitions of environmental space (i.e. defined using different combinations of environmental variables). Forward stepwise selection was used and new variables were added into the model only if they increased the correlation coefficient by > 0.001.

5.1.2 Hauraki analysis methods

Techniques similar to those used for the EEZ were used to model individual species, namely multiple regression based on generalised linear models (GLM), logistic regression (based on presence/absence data) and general additive models (GAM) (Table 4). Two multivariate procedures were used to identify environmental variables that most affected community composition (CCA and BVSTEP). Forwards selection was used for both procedures and new variables were only added into the model if they increased the correlation coefficients by ≥ 0.05.

Table 4: Analysis types carried out on the different Hauraki Gulf biological datasets

Data type	GLM	Logistic regression	GAM	CCA	BVSTEP
Chlorophyll	Yes		Yes		
Large zooplankton	Yes		Yes		
Microzooplankton	Yes		Yes		
Fish		Yes	Yes	Yes	Yes
Benthic macrofauna	Yes	Yes	Yes	Yes	Yes

5.2 Classification procedure

The values of each of the chosen environmental variables for each grid cell were used as input for a two-stage multivariate classification process. In the first stage we used ALOC (Belbin 1995), a non-hierarchical clustering strategy designed for use with very large datasets, to amalgamate grid cells into up to 300 clusters (i.e. each cluster is a class). The Gower metric (Sneath and Sokal 1973) was used as the measure of environmental distance. The Gower metric is defined as:

$$D = \sum_{i=1}^{n} \left| \frac{x_{ij} - x_{ik}}{range(x_i)} \right|$$

where D is the environmental distance between points j and k, which are described by a set of variables x_i, $i = 1, 2, \ldots$ n. Therefore, x_{ij} is the value of variable x_i at site j. This distance measure incorporates implicit range standardisation of each variable. Therefore, all variables have equal weight and contributed equally to the definition of environmental distance. In the second stage, relationships between the 300 clusters were defined using their average environmental conditions as input to a sequential agglomerative clustering technique, again using the Gower metric. The classification results comprised a table of group membership of all grid cells from the 2 to 30 class level of the classification hierarchy. In order to map the final classification at any hierarchical level this table was imported into a desktop geographic information system and linked to the classification grid.

5.3 Classification definition

5.3.1 Complicating factors

During the development of the Marine Environment Classification, the steering group agreed that the aim of the classification was to divide environmental space into units that maximise discrimination of variation in biological composition. The classification's discrimination of biotic composition is influenced by:

(1) including variables that have functional linkages with, or at least are correlated with, variation in biological composition

(2) transformation of variables to increase their correspondence with biological composition

(3) increasing the weighting of variables where there is clear evidence of their dominant role in driving, or correlation with, variation in biological composition.

While the validation analyses described above were informative for choosing a set of environmental variables for use in the classification phase, the results were relatively uninformative regarding how best to combine these variables to define classification units. We therefore sought a more objective means of tuning the classification that would guide our selection of environmental variables so as to maximise the ability of the resulting classification to discriminate variation in biological composition. Three issues needed to be carefully considered and addressed in deciding how to best define such a classification.

First, in deciding which variables should be included in the classification, we were aware that the relative importance of some environmental variables was dependent at least in part upon the geographic scale and/or location at which this was assessed. In large measure, this reflects the markedly different geographic scales over which different environmental factors vary. For example, some environmental variables show relatively continuous variation throughout the EEZ (e.g. depth, annual mean solar radiation and wintertime sea surface temperature), while others remain relatively invariant over large areas but show pronounced changes in particular locations (e.g. orbital velocity, SST gradient and slope). As a consequence, any techniques used for deciding either which variables to include in the classification, or what weightings and/or transformations should be applied to them, had to be performed at more than one spatial scale. In practical terms, our aim was to produce a classification that gave good discrimination at higher classification levels of global variation (i.e. at the scale of the whole area being classified) in broadly varying factors such as depth and mean annual solar radiation, while also separating at more detailed classification levels variation in factors such as tidal current and orbital velocity that are important at more local scales in particular locations.

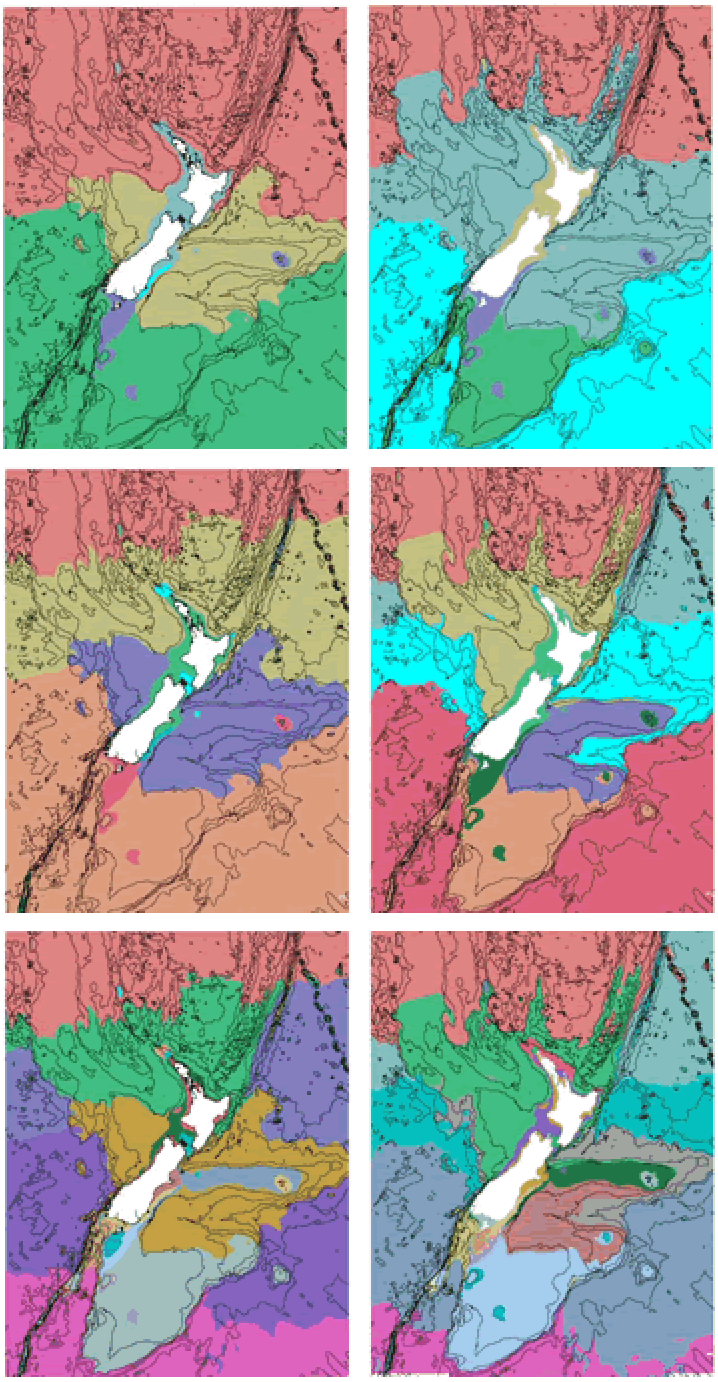
Second, while the classification procedure treats equally any given interval of change in a variable regardless of its value, rates of biological turnover (i.e. change in biological composition) do not necessarily remain constant along environmental gradients. For example, the classification treats changes in depth in steps of say 10 m independently of the depth at which they occur, so that 10–20 ≡ 110–120 ≡ 5010–5020. By contrast, examination of fish trawl data suggests that turnover in fish community composition with increasing depth is relatively rapid in shallow waters but becomes progressively more muted in deeper water. This observation suggests that the discriminatory power of a classification could be increased by use of transformations of input variables that make the relationship between a variable and biological turnover more linear. Another useful feature of transformations is their ability to mute the influence of extreme values of variables that are highly skewed. For example, the distributions of the tidal current and orbital velocity variables were highly skewed with a small part of the environmental domain comprising extremely high values of these variables relative to the mean. If left untransformed, the extreme values in the distributional tails of these variables can unduly influence the classification while variation at lower levels is largely ignored.

Third, unless explicitly altered, the multivariate classification procedure that we used places equal weight on all environmental variables. Although intuitively this suggests that all variables make an equal contribution, in practice the contribution made by variables at different classification levels will largely reflect their spatial variability. Thus, variables that change in a continuous fashion over the whole domain (e.g. for the EEZ wintertime SST and mean annual solar radiation, for the Hauraki Gulf, SST phase and SST annual amplitude) will tend to dominate the definition of classes at higher levels (i.e. a small number of classes) of the classification. By contrast, more spatially patchy variables (e.g. tidal current, mean orbital velocity in both classifications) will tend to determine class boundaries at lower levels of the classification (i.e. a large number of classes).

One way to improve the ability of an environmental classification to discriminate variation in biological composition is to alter the default contributions of different variables to more closely match their varying degree of influence on biological patterns. For example, most of the validation analyses indicated that depth has a stronger correlation with biological variation than other variables. This suggests that a judicious increase in the weighting given to depth has the potential to increase the correspondence between classification classes and biological patterns. The subsequent increase in the influence of the weighted variable on class definition can be clearly seen in Figure 10, where an increase in the weighting given to depth is reflected in the class boundaries showing a higher correspondence with variation in bathymetry. However, as weighting increases the contribution of the weighted variable at all levels of the classification hierarchy, care has to be taken to insure that the weighted variable does not overly dominate the classification outcome at the expense of other variables. This, in particular, may result in more locally important variables making insufficient contribution at finer levels of classification detail.

The problem of how best to weight the variables used in a classification is also inextricably linked to the problems caused by their inter-correlation. When two variables are correlated, the component that is common to both is effectively given a double weighting while the unique component of each variable may make only a small contribution relative to the common component. One possible solution to this problem is to use the Mahalanobis distance measure (Mahalanobis 1936) rather than the Gower metric (Gower 1971) because this distance measure automatically corrects for inter-variable correlations and calculates site to site distances based on the uncorrelated components. However, use of the Mahalanobis measure also requires the normalisation of variables, a procedure that we were reluctant to implement given the advantages of transformation as a tool to maximise the matching of environment to biological turnover as discussed above.

Figure 10: Comparison of two pilot EEZ classifications at the 6 (top), 10 (centre) and 25 (bottom) class levels. Both classifications are defined using the same eight variables but with different weightings of depth. The classifications on the left have a double weighting of depth and the classifications on the right have a triple weighting of depth. The 1000-metre depth contours are shown as black lines. Environmental classes are discriminated by colour.



5.3.2 Method used for tuning the classifications

Given that our overall objective was to define an environmental classification that maximises discrimination of variation in biological character (see above), we used Mantel tests (Mantel 1967) to refine the final mix of variables used for the classification. These allowed us to objectively explore the effects of including or excluding, and transforming and/or weighting the different candidate variables on the subsequent measurement of environmental differences between different sets of sample sites (= environmental distances). Matrices containing environmental distances created using particular combinations of variables were compared with equivalent matrices describing biological distance for the same test sites, and the degree of correlation (*r*) between these two measures of 'distance' was calculated. Using this process, we sought to find a combination of variables, weightings, and transformations that would maximise the correlation between measures of environmental and biological distances between different sets of sample sites.

Test sites for this process were selected from the same biological datasets as the earlier validation analyses. Measures of biological distance for the community datasets were defined using the Bray-Curtis distance measure. Because of the length of the biological gradients described by these datasets, a large proportion of sites had no species in common resulting in many of the individual dissimilarities having the maximum possible value for this measure, i.e. a value of one. An estimate of the true biological distances for these pairs of sites was recalculated using a flexible shortest path adjustment method (De'ath 1999). This involved recalculating any dissimilarities above a nominated limit (e.g. 0.9) using sites with lower dissimilarities as stepping stones and allowing dissimilarities greater than one to be estimated. Because the chlorophyll concentration data was univariate, the Euclidean distance measure was used.

In order to better understand the relative importance of spatial scale and different geographic contexts we carried out Mantel tests at two scales of analysis. Tests were performed for sites distributed across the entire EEZ and for geographic sub-samples of the biological datasets that were constrained to a smaller spatial scale defined by a tile covering approximately one sixteenth of the spatial extent of each biological dataset. The fish trawl dataset was the only one large enough to allow a multi-scale analysis for the Hauraki Gulf and when these analyses were performed, no significant differences in correlation were found; therefore these results are not shown here. For the EEZ data, the results of the spatial sub-samples were averaged to provide an overall result, while variability among subsamples indicated the degree to which the definition of environmental space was dependent on the geographic context.

In order to determine the level of statistical confidence for differences between definitions of environmental space, the datasets were randomly subsampled and the analyses replicated. For each subset, we computed Mantel *r* for two competing definitions of environmental space. We subtracted the two Mantel *r* values for each subset to obtain the values delta-*r*. We then tested the distribution of the delta-*r* values to determine if there was a significant difference between the competing definitions. For the fish trawl and chlorophyll datasets we took 100 random subsets of 300 sites each without replacement at both the full EEZ and the sub EEZ scale. We used paired *t*-tests to assess whether any departure of mean delta-*r* values from a value of zero were significant. For the shelf dataset the number of sites was too small (274 sites) to subsample without replacement. We therefore took 100 random subsets of the 274 sites with replacement (both within each subset and between subsets). After applying the Mantel test to the distance matrices formed using each of these samples, we ranked the 100 delta-*r* values and took the fifth and 95th values as an estimate of the 5% and 95% confidence bounds. We interpreted the mean delta-*r* value as significant if the 5% confidence bound did not encompass zero (a one-tailed test). Only the significant delta-*r* values are shown in the graphs in this report. Where a delta-*r* value was not statistically different from zero it has not been shown.

As discussed above, large parts of the range of many of the environmental variables were not sampled by the biological datasets. This restricted our ability to test the effect of classification decisions such as transforming and/or weighting variables. The tuning analyses therefore provided an indication of whether the classification's strength would be improved or weakened by different definitions of environmental space. However, the lack of biological representation meant that Mantel test alone could not be used to define the environmental space so that inspection of the mapped classification and expert judgements were also used to finalise the classification.

5.4 Statistical testing of classifications

The overall objectives of the testing component of the Marine Environment Classification project were to:

1. assess the strength of environmental classifications for the Hauraki Gulf and the New Zealand region (i.e. their ability to discriminate variation in biological composition)
2. typify the biological character for classes at one level from environment-based classifications for the Hauraki Gulf and the New Zealand region.

Information about biological distributions was derived from point-based surveys of species presence or abundance, with surveys generally focussed on particular functional groups (i.e. fish, benthic invertebrates, chlorophyll *a*). While in the previous phase these data were used to fine-tune the selection of environmental variables and their weighting and transformation, here we used the same data to assess the ability of the resulting environment-based classifications to summarise variation in ecosystem character.

ANOSIM (Clarke and Warwick 2001) was used to test the strength of the EEZ and Hauraki Gulf classifications (i.e. to assess the ability of these environment-based classifications to summarise variation in biological composition). The *r*-values calculated by ANOSIM indicated the average difference between ranked biological distances calculated for sites located in the same environmental classes, versus ranked distances calculated for sites in contrasting environmental classes. Values of *r*, therefore, indicated the degree to which points within the same environmental classes have closer biological similarity to each other than average levels of similarity occurring across the wider dataset. These analyses can be used to calculate either the global (i.e. overall) average difference in compositional distances taken across all classes or to make comparisons for sites occurring in particular pairs of classes. A brief graphical description of the ANOSIM test is provided in Appendix 4.

This ANOSIM analysis was complicated by the continuous nature of the environmental classifications, i.e. they are able to viewed at any level of detail from 1 to around 300 classes. The large number of sample points for some of the EEZ biological data sets also complicated the analyses so that subsets of biological sample points had to be randomly selected to prevent excessive memory demands for the analysis. However, despite this apparent plethora of biological data for some environmental classes, both the ANOSIM analyses and the subsequent description of the biological character for other classes were hampered by the very uneven sampling of classes by most of the biological sample sets, i.e. with the exception of the remotely sensed and hence spatially extensive chlorophyll data, a large proportion of classification classes at any particular classification level had either few biological sample points or lacked them altogether, particularly in the Hauraki Gulf.

As a consequence, we commenced our analysis by assessing the number of classes with adequate biological data (five or more sites) at each level of classification for both the EEZ and Hauraki Gulf and the significance of differences in biological composition between these classes. Results from these analyses were then used to identify one level of detail (20 classes) for both the EEZ and Hauraki classifications at which the significance of biological differences for all possible pair-wise combinations of classes was assessed. The average species composition of environmental classes at this level of classification detail was also summarised using MATLAB with frequencies of occurrence calculated for each fish species or invertebrate family. While chlorophyll data were available for 15 out of 20 classes in the EEZ classification, the number of classes at a 20-class level of classification for which adequate data were available from the biological data sets varied between three and eleven.

6 Results of Validation

6.1 EEZ classification variables

An issue that arose during the validation was the high degree of correlation between some pairs of variables. This made it difficult to determine whether the correlated variables were being used interchangeably or whether both variables were useful despite their high correlation (i.e. the uncorrelated component of the variables contained additional information). To help resolve this issue, we calculated combination variables and used these in place of one of the correlated variables particularly in the generalised additive model analyses. The combination variable *(x')* expressed the deviation of a variable *(x)* from its expected value, expressed in standard deviations *(s)*, given the value of the second variable (y):

$$x' = \left(\frac{x - \bar{x}}{s._x}\right) - \left(\frac{y - \bar{y}}{s._y}\right)$$

The following combination terms were created:

- Deviations in winter surface solar radiation with respect to mean annual solar radiation. This replaced winter solar radiation.
- Deviations in wintertime SST with respect to winter solar radiation replaced wintertime SST.
- Deviations in extreme orbital velocity with respect to mean orbital velocity replaced extreme orbital velocity.

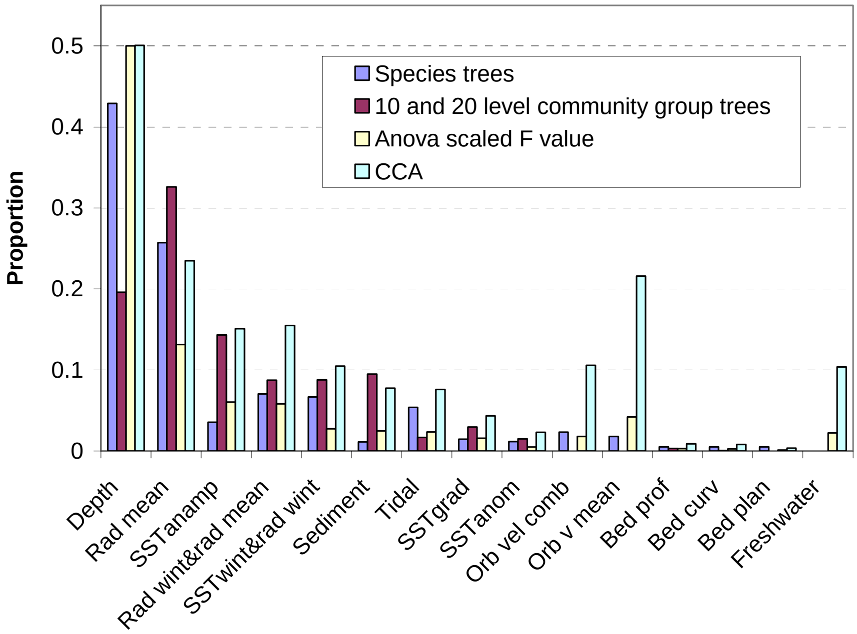
Results of the validation analyses are summarised in Table 5, Figures 11 and 12. Results for the GAM and CART models show the variables ranked by the order that they were fitted (GAMs) or by overall marginal contribution of each environmental variable to the final model (CART). Results for the ANOVA and CCA analyses show the relative explanatory power of each of the variables individually.

Table 5: Comparison of the order of importance in chlorophyll models

GAMs rank order	Trees rank order
SST winter	Rad_mean
Rad_mean&Rad_wint	Rad_mean&Rad_wint
Depth	Depth
SST gradient	SSTwint&Rad wint
SST annual amplitude	Sediment
Rad_mean	SSTanamp
Tidal	Tidal
Rad_wint	Freshwater
Orb_v_mean	Orb vel comb
Sediment	Orb_v_mean
Freshwater	SSTgrad
Orb_v_95	SSTanom
SSTanom	

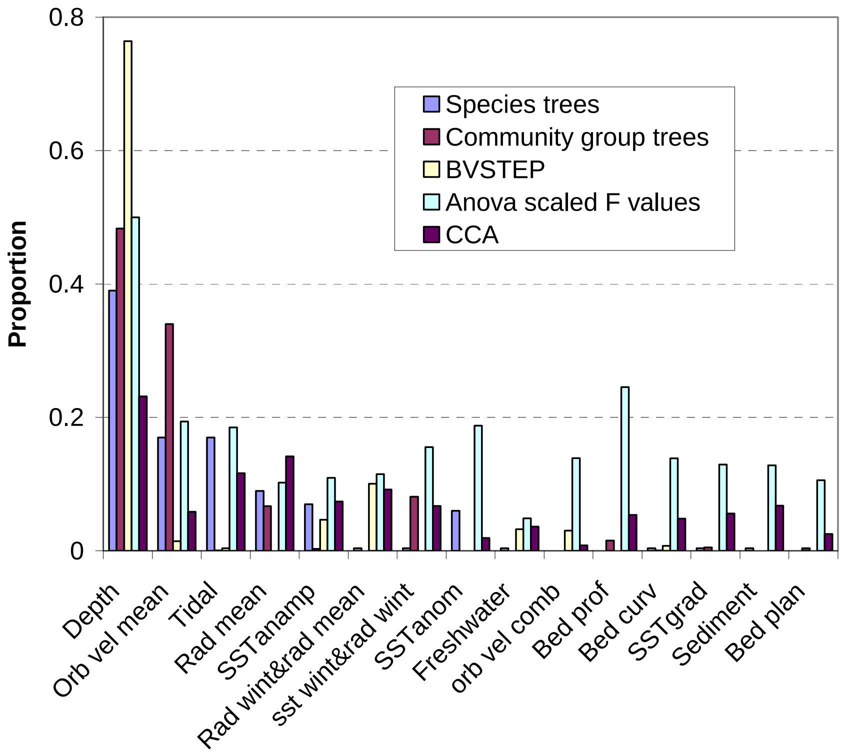
Note: GAMs used only one combination term (Rad_mean&rad_wint). Variables shaded blue made a contribution of less than 1% to the model (for tree models) and variables shaded red were not selected.

Figure 11: Comparison of results from all analyses on the fish dataset



Note: The ANOVA F values have been scaled so that the highest value is 0.5 so they could be graphed at the same scale as the other values. The variables are ordered by the average of their marginal contribution to results that were based on the tree analyses.

Figure 12: Comparison of results for all analyses on the shelf dataset



Note: The ANOVA F values have been averaged over the three datasets then scaled to maximum 0.5 so they could be plotted on the same scale as the other data. The variables are ordered by the average of their marginal contribution to results that were based on the tree and BVSTEP analyses.

Depth was indicated a very important variable by almost all analyses and with all datasets. **Annual mean surface solar radiation** was important to the chlorophyll and fish datasets and was of some importance to some benthic models. **Annual amplitude of SST** was important to the fish models, and made some contribution to the chlorophyll and shelf models. The **combination of mean annual solar radiation and winter solar radiation** was important to the chlorophyll and fish models and had a medium contribution to the shelf models. The **combination of wintertime SST and winter solar radiation** was important to the chlorophyll and fish models and of medium importance in the benthic models. **Tidal current** had a small contribution to the chlorophyll, fish and shelf models and was correlated (CCA and ANOVA) with the ophiuroidea and asteroidea community datasets. **Spatial gradient annual mean SST** was not important to chlorophyll, was of medium importance to the fish models, and made only a small contribution to the shelf and *echinocardium* models. **Mean orbital velocity** was not important for predicting chlorophyll, but was correlated with fish communities (CCA) and asteroidean communities (ANOVA), and made a significant contribution to models of the shelf data. **Summertime SST anomaly** was not important in the chlorophyll analyses, but made a small contribution to some individual fish and shelf species models. **Sediment type** had a medium contribution to the chlorophyll and fish models and a small contribution to the shelf models. The **combination of mean and extreme orbital velocity** made a small contribution to the chlorophyll models but showed little relationship with any other dataset. The seabed shape variables **(profile, curvature, plan)** made small contributions to the tree models of fish species, fish groups, and both the community and species analyses (ANOVA, CCA) for the ophiuroidea, asteroidea and benthic shelf datasets. **Freshwater fraction** had only a weak correlation with the benthic shelf survey dataset. Based on the results of the validation analyses, Weatherhead and Snelder (2003) ranked the 15 candidate environmental variables based on their average contribution across all analyses and biological datasets. The relative contribution of the environmental variables had the following order:

1. Depth
2. Mean annual solar radiation
3. Annual amplitude of SST
4. Combination of mean annual solar radiation and winter surface solar radiation
5. Combination of wintertime SST and winter solar radiation
6. Tidal currents
7. Spatial gradient annual mean SST
8. Mean orbital velocity
9. Summertime SST anomaly
10. Sediment type
11. Combination of mean and extreme orbital velocity
12. Seabed rate of change of slope (profile)
13. Seabed curvature
14. Seabed planform curvature
15. Freshwater fraction.

6.2 Hauraki classification

Ranking of the variables was used to summarise the results of the validation study performed for the Hauraki Gulf (Hewitt & Snelder 2003). The relative importance of each variable was ranked (on scale of 0 to 1) over each analysis and then averaged for the plankton, benthos and fish datasets (see Table 6). An overall ranking was made by summing across each biological dataset (see Table 6). The most apparent conclusion was that the variables selected differed between the datasets. Unsurprisingly, variables representing water column processes and sea-surface temperature are better correlates for the plankton; whereas sea-bed variables such as topography, sediment rank/type, bed velocities and currents were better correlates with the benthos. Fish represented a middle point between these two.

Table 6: Summary of the relative importance of variables derived from models of the plankton, benthos and fish, in decreasing order from the most to the least important

Plankton	Benthos	Fish	Overall	Weights
Sst_ann_phase	Temperature at depth	Sediment rank	Depth	0.126
Sst_sann_ampl	Sediment rank	Depth	Sediment rank	0.100
Depth	Sst_ann_ampl	Sst_ann_ampl	Sst_ann_phase	0.092
Orb_vel_mean	Depth	Tidcurmax1	Sst_mth_std	0.082
Sst_mth_std	Sst_mth_std	Sst_mth_std	Sst_ann_ampl	0.080
Sst_mean change	Orb_vel_95	Sst_ann_phase	Tidcurmax1	0.075
Orb_vel_95	Tidcurmax1	Hau_curv	Orb_vel_mean	0.061
Tidcurmax1	Sst_ann_phase	Orb_vel_mean	Sst_sann_ampl	0.060
Sst_ann_ampl	Sediment type	Sst_sann_ampl	Orb_vel_95	0.049
	Sst_sann_ampl	Orb_vel_95	Hau_curv	0.026
	Hau_plan	Current change	Sediment type	0.011
	Hau_prof	Hau_plan	Hau_plan	0.007
	Orb_vel_mean	Sst_mean	Hau_prof	0.006
	Hau_curv		Fresh_fract	0.004
	Sst_mean change		Sst_mean	0.001
	Fresh_fract			

Note: Variables shaded blue have a weight of <5%, variables shaded red have a weight of ≤1%. Weights for the overall relative importance of variables is also given.

7 EEZ Classification

7.1 Classification definition decisions

7.1.1 Pilot classifications

The ranking of the candidate environmental variables derived from the validation analyses was used to subjectively select a reduced set of variables for subsequent development of pilot classifications (Snelder et al. 2004). In order to define pilot classifications, we eliminated variables with low rankings because of their relatively poor ability to discriminate biological patterns. This included two variables for which we had major concerns regarding their reliability: sediment type and freshwater fraction. The three bed-shape variables were also eliminated. However, we added slope, reflecting our subjective judgement as to its likely importance in differentiating variation in at least some marine communities. These subjective decisions were tested by the classification tuning process that is described below.

Weatherhead and Snelder (2003) showed that there were particular problems with the inclusion of sediment type in the prototype classification. The sediment data layer is based on the 1:6,000,000 scale regional sediment chart which is low resolution relative to the other variable layers and based on a categorical subdivision. Although we experimented with different methods of including this variable in the classification, we found that the classification was always dominated by sediment patterns when it was included (Weatherhead and Snelder 2003). This dominance was out of proportion to sediment's actual value as a predictor as shown by the validation analyses. We concluded that the resolution of the existing sediment data layer is too low and that, until there is a better source of data, sediment should be excluded from the classification.

Various pilot classifications of the EEZ were developed based on the following variables: depth, wintertime SST and mean annual solar radiation, slope, mean orbital velocity, annual amplitude of SST, spatial gradient annual mean SST, and tidal current (Snelder et al. 2004). In addition, Snelder et al. (2004) suggested transformations and weighting of some variables in the definition of the pilot classifications based on subjective decisions that were guided by inspection of the mapped classifications.

7.1.2 Tuning the classification

Leathwick et al. (2004) used Mantel tests to test the decisions included in the pilot classifications and made some small changes to tune the classification in accordance with the criteria set out for defining the classification. Leathwick et al. (2004) found that transformations of some variables and weighting of depth improved the classification's correlation with the available biological data. The Mantel tests also justified the inclusion of slope as a measure of bed shape over the three bed variables that were included in the validation analyses. In addition, Mantel tests indicated that some small gains in correlation could be achieved by adding some of the variables that had been omitted from the pilot classification for some biological datasets but not others. However, the overall benefit (i.e. averaged across all datasets) of adding any of the omitted variables at either scale of analysis was negligible and the tests provided little evidence that the classification of the EEZ would be improved by adding further variables.

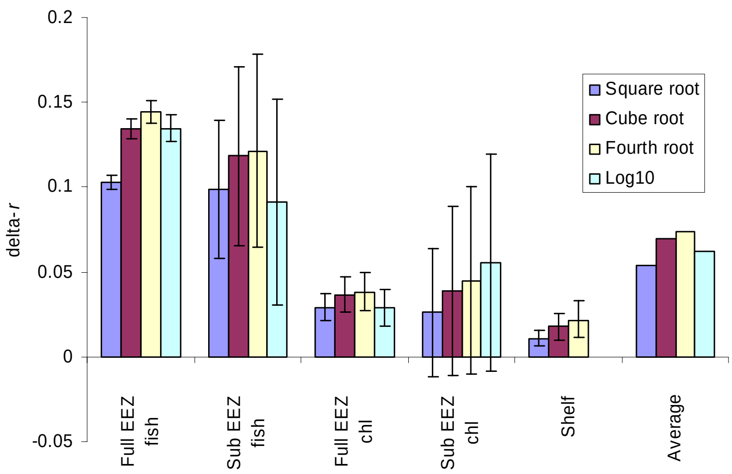
The final decisions for the appropriate transformation and weighting of variables were guided by the results of the Mantel tests (see Table 7). However, because there was a lack of biological data in many parts of the environmental domain, the test information was supplemented with inspection of trial classifications in order to make final decisions (Leathwick et al. 2004).

Table 7: The variables, transformations and weightings used to define the EEZ classification

Variable	Transformation	Weighting
Depth	Square root	2 times
Wintertime SST		
Mean annual solar radiation		
Annual amplitude of SST		
Spatial gradient annual mean SST		
Mean orbital velocity	Log10	
Tidal current	Cube root	
Slope	Square	

The most important set of decisions made by the tuning analysis were those concerning Depth. Mantel tests examined the change in correlation (delta-r) for transformations and weighting of Depth based on the eight-variable (pilot classification). The results of Mantel tests (Figure 13) showed improvements (i.e. positive delta-r) with various transformations of depth. When the results are averaged over all datasets, a fourth root transformation maximised the correlation. However, this relatively severe compression of depth was not eventually used and a more muted square root transformation was chosen. This decision was based primarily on inspection of mapped trial classifications that indicated that strong compression of depth resulted in the classification having little discrimination of environmental variability over a large part of the domain where depth were greater than 1000 m (Leathwick et al. 2004). We considered that this subjective decision was justifiable given the relative absence of fish data for depths greater than 1500 m, particularly given that this accounted for well over half of the spatial domain.

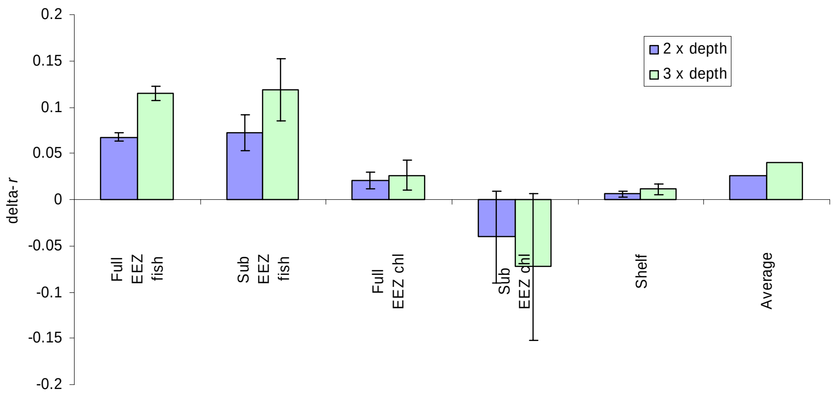
Figure 13: Mantel test results showing the change in correlation (delta-*r*) for various transformations of depth for the three biological data sets and at two scales (for the fish and chlorophyll data)



Note: For the first four datasets, whiskers show the standard deviation of delta-*r* values for the geographic sub samples. For the shelf data, whiskers show the 5% and 95% confidence bounds. Note that variability is higher for the sub-EEZ scale results indicating that there are large geographical differences in the effect of the transformations.

Mantel tests also provided some confidence for weighting depth. However, the tests showed that correlations reduced with increasing weighting of depth for the chlorophyll dataset at the sub-EEZ scale (Figure 14). This result indicated that the depth weighting detrimentally mutes the other variables that are important correlates with chlorophyll at the sub-EEZ scale. It was therefore decided that compromise position would be to apply a double weighting of depth. This acknowledges the consistent importance of depth at the whole EEZ and sub-EEZ scales, but seeks to minimize the muting of the spatially patchy variables that are important at scales smaller than the EEZ. The final decisions for definition of the EEZ classification are shown in Table 7.

Figure 14: Mantel test results showing the effect of weighting depth on the three biological data sets and at two scales (for the fish and chlorophyll datasets)



Note: Tests were performed for three biological data sets and at two spatial scales (for the fish and chlorophyll data). For the first four datasets, whiskers show the standard deviation of delta-*r* values for the geographic sub samples. For the shelf data, whiskers show the 5% and 95% confidence bounds.

7.2 Classification

Figure 15 shows the EEZ classification at four different hierarchical levels and illustrates the subdivision of environmental variation at successive (hierarchical) levels of classification detail. Each class is labelled by a number, which has no specific meaning but is associated with the order in which groups of cells are agglomerated by the clustering procedure. Table 8 shows the average value of each of the variables used to define the EEZ classification at the 20-class level. Inspection of this table indicates that classes are distinctive from one another with respect to at least one variable. Table 8 also shows the how the classification has differentiated environmental variation at the 2, 4, 9 and 20-class levels. The division at the two-class level occurs between classes 273 and 12 (bold line on Table 8). This level subdivides the relatively coastal environments from the deeper oceanic environments (see Figure 15). Within the oceanic environments, further divisions occur at the four-class level that are associated with differences in the mean annual solar radiation and SST winter (thin solid line on Table 8). These subdivisions approximately define the subtropical shelf and sub-tropical front, and the sub-Antarctic waters.

The nine-class level further subdivides the subtropical waters into deep and abyssal, the shelf and sub-tropical front waters into the deep sub-tropical front, and central continental shelf and southern continental shelf (dotted lines on Table 8). The nine-class level also subdivides the coastal environment into three class that are associated with differences in the mean annual solar radiation and SST winter, northern, central and southern continental shelf (dotted lines on Table 8).

Figure 15: The EEZ classification at the 2, 4, 9, and 15-class levels

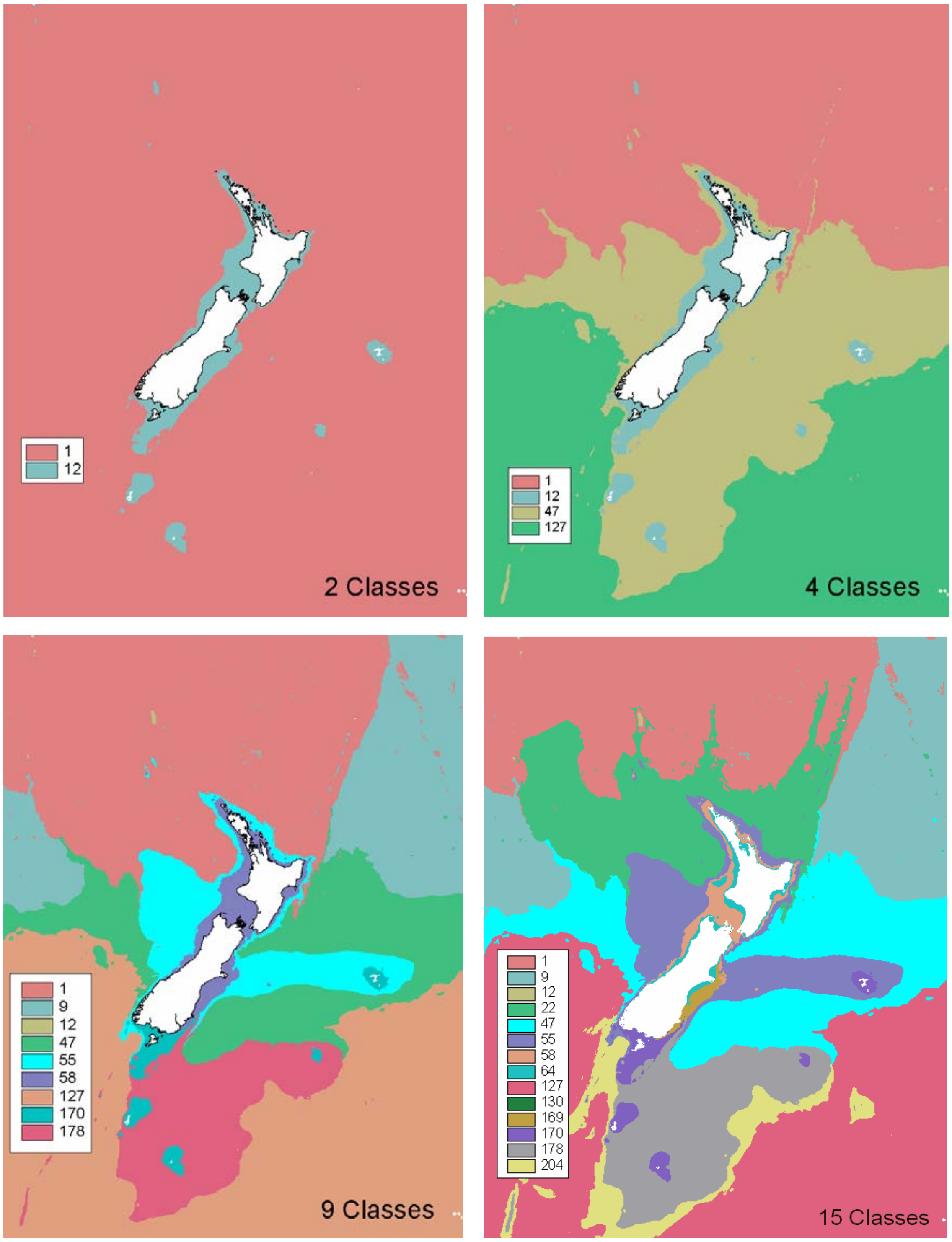


Table 8: Average values for each of the eight defining environmental variables in each class of the 20-class level of the EEZ classification

Class	Area (km^2)	Depth	Slope	Orbital velocity	Radiation mean	SST amplitude	SST gradient	SST winter	Tidal current	2-class level	4-class level	9-class level
1	88,503	-3001	1.4	0	17.5	2.3	0.01	19.5	0.06	Oceanic	Subtropical	Deep
22	53,368	-1879	1.5	0	15.4	2.4	0.01	16.3	0.11			
9	64,306	-5345	1.4	0	14.8	2.6	0.01	16.1	0.03			Abyssal
47	60,053	-2998	1.0	0	12.1	2.4	0.01	11.6	0.07		Shelf and subtropical front	Central
55	2,213	-334	1.6	0	15.5	2.4	0.02	15.1	0.20			
63	26,626	-754	0.9	0	12.8	2.4	0.02	12.1	0.18			
178	39,360	-750	0.4	0	9.5	1.3	0.01	7.6	0.15			Southern
127	60,884	-4830	0.5	0	10.7	1.7	0.01	10.0	0.05		Sub-Antarctic	
204	18,277	-2044	3.0	0	9.2	0.9	0.01	8.0	0.08			
273	805	-2550	9.1	0	8.4	1.4	0.03	4.4	0.05			
219	93,982	-4779	0.6	0	8.9	1.0	0.01	6.7	0.04			
12	149	-94	0.9	113	17.8	2.3	0.01	19.3	0.30	Coastal		Northern
58	394	-117	0.7	57	14.7	2.2	0.03	13.0	1.09			Central
60	4,084	-112	0.3	21	14.4	2.5	0.02	13.2	0.26			
64	2,689	-38	0.3	272	14.2	2.9	0.02	12.6	0.19			
124	68	-8	0.4	836	13.4	2.3	0.02	12.7	0.00			
130	14	-10	0.4	353	14.1	2.4	0.09	11.9	0.21			
169	932	-66	0.2	113	12.4	2.7	0.04	9.9	0.21			
190	339	-321	1.9	3	12.3	2.3	0.06	9.4	0.10			
170	5,208	-129	0.3	99	10.2	1.3	0.02	9.3	0.55			Southern

Note: See Figure 16 for location of the classes. The divisions within the table show how environmental variation has been differentiated at the 2, 4 and 9-class levels. The total area of each class at the 20-class level is shown in the second column and can be summed to derive the area in classes at the 2, 4 and 9-classes levels.

The 20-class level (Figure 16) further defines variation in the shallow coastal environments. The following environments are discriminated; class 58 – high tidal current, class 60 – middle mid depths, class 64 – middle shallows, class 124 – high wave energy coastlines, class 130 – Marlborough Sounds, class 169 – Southland current, class 190 – Southland front.

The relationships between classes are described in greater detail by the dendrogram on Appendix 1, Figure A1.1. The dendrogram shows how the classes are progressively amalgamated to form a single large group. Note that the class numbers are assigned during the clustering procedure and are derived from the order in which amalgamation of the groups occur.

Although the classification is generally used at a set number of classes (e.g. 9-classes), the numerical procedure treats variation in a continuous manner. The proximity of any two classes or even grid cells (i.e. locations) can, therefore, be described as an environmental distance. To illustrate this we generated an alternative continuously varying colour scheme to reflect environmental distances. Details of this approach are set out in Snelder et al. (2004) and briefly described below.

A principle components analysis (PCA) of the environmental variables was performed on the mean values of each environmental variable (the cluster centroids) for each of the 290 classes generated by non-hierarchical classification. Each class was assigned varying levels of red, green or blue colour based on the value of the first three principle components of the PCA analysis. Hence each classification group is assigned a colour based on its position in a three dimensional configuration so that the closer the proximity of two groups the more similar their colours will appear. The colour assigned to each PCA axis was chosen to make intuitive sense. Thus, for the EEZ classification, blue was assigned to the first PCA axis that was correlated with the variables depth, tidal current and mean orbital velocity. Thus the bluer areas are deeper, with higher slopes, and lower tidal current and mean orbital velocity. Red was assigned to the second PCA axis, which was correlated with SST winter and annual mean surface solar radiation. Thus the redder areas have higher values of these two variables. Green was assigned to the third PCA axis which was most correlated with slope and SST gradient. Thus the greener areas are associated with the higher slopes and areas of high SST gradient. Figure 17 shows the resulting map.

Figure 16: The EEZ classification at the 20-class level

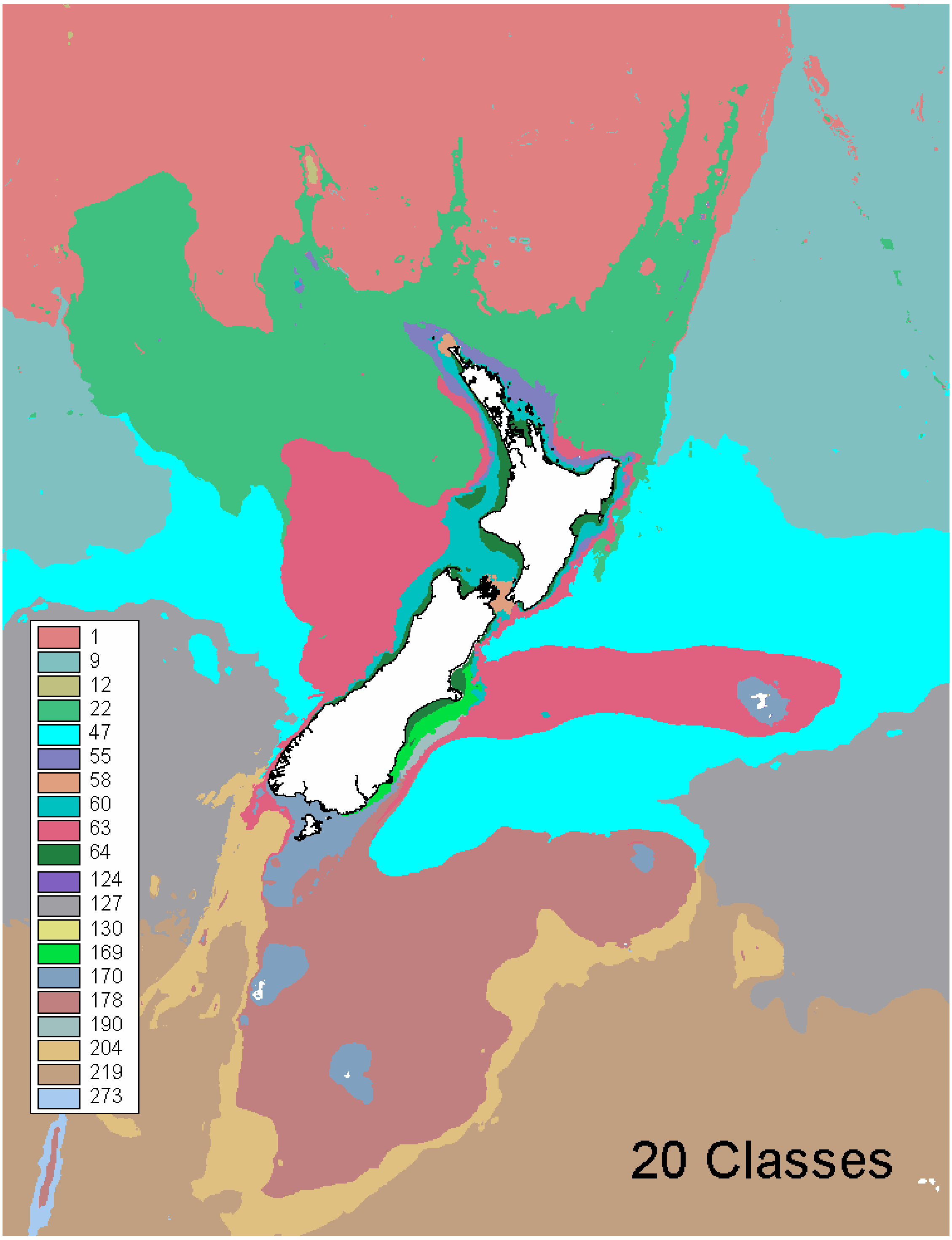
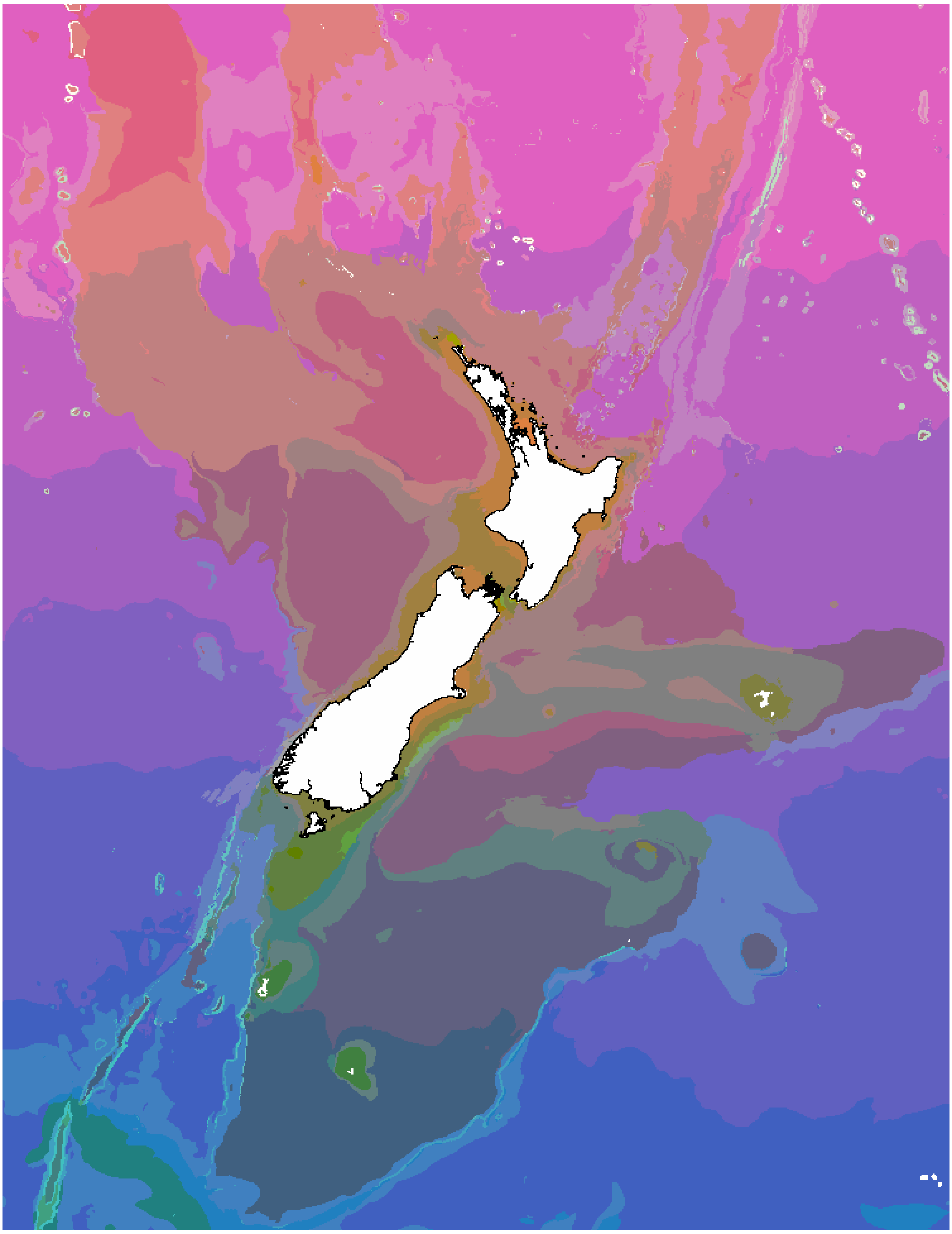


Figure 17: Classification of the EEZ using the continuous colour scheme based on the principal components of the eight variables used to define the classification



Note: Bluer areas are deeper with lower tidal current and mean orbital velocity. Redder areas have higher values of SST winter and annual mean surface solar radiation. Greener areas are associated with the higher slopes and areas of high SST gradient.

Each cell has been coloured according to the mix of blue, red and green associated with the location of its cluster centroid on the first, second and third axes of the PCA. The map shows sharp colour boundaries where environmental characteristics have abrupt changes and shows the continuous nature of variation in environment across the spatial domain.

7.3 Classification strength of the EEZ classification

A full description of the biological testing of the EEZ classification is contained within Leathwick et al. (2004). Because large parts of the environmental domain were not represented by the biological datasets not all the classes that are defined at any given level of the classification could be tested. ANOSIM analyses were performed on classes at each level of the classification provided classes had at least five biological samples. Thus, with the fish dataset 14 classes could be tested at the 20-class level and 20 classes could be tested at the 50-class level. A much larger proportion of the environmental classes had adequate samples when using the chlorophyll *a* dataset, i.e. 16 groups had adequate biological data at the 20-class level and around 23 at a 50-class classification level. For the 274 benthic invertebrate sites represented in the shelf dataset, 9 and 16 sites had sufficient biological data for testing at the 20- and 50-class levels respectively.

ANOSIM *r*-values generally increased for all datasets as the classification detail was increased, indicating that lower levels of classification defined more biologically distinctive environments. However, for the fish and chlorophyll *a* datasets the increase in classification strength was minimal from about 20-classes on because the number of testable classes begun to plateau.

ANOSIM *r*-values for the fish dataset were significant at $p < 0.01$ for all levels of the classification up to 50 classes. This indicates that classes that are distinctive with respect to their fish assemblages are defined at all the tested levels of the classification. Indeed, the individual pair-wise comparisons of fish communities at the 20-class level indicated that all but 73 of the 78 potential contrasts are significantly different in their biological composition ($p < 0.01$). For the chlorophyll dataset ANOSIM *r*-values increase steadily from the five-class level and stabilised at about the 45-class level. All *r*-values were significant at $p < 0.01$. Examination of the 105 possible pair-wise comparisons for the 15 classes with available chlorophyll data (at the 20-class level of the classification) indicated that all but 13 are significant at $p < 0.05$.

For shelf dataset (274 benthic invertebrate sites) 9 and 16 sites had sufficient biological data for ANOSIM tests at the 20- and 50-class levels respectively. ANOSIM *r*-values were low at low classification levels, but increased rapidly up to a 20-class level, and more slowly thereafter. The *r*-values for classification levels with less than 15 classes were not statistically significant, i.e. at the 15-class level of classification no significant differences in benthic invertebrate composition were apparent. Although the overall ANOSIM *r*-value was significant at the 20-class level, a lower classification strength than for the other biological groups was also evident. Examination of the 36 possible pair-wise comparisons for the nine classes with available chlorophyll data (at the 20-class level of the classification) indicated that 16 of the possible comparisons were non-significant at a 5% level. Thus, it can be concluded that the strength of the classification, at any given level, is relatively lower for invertebrates than for fish and chlorophyll.

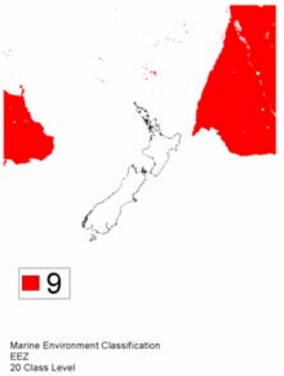
7.4 Biological characteristics of the EEZ classes

The biological character of classes defined by the 20-class level and for which data was available is shown for chlorophyll concentration (Appendix 2, Figure A2.1), fish assemblages (Appendix 2, Table A2.2), and benthic invertebrates (Appendix 2, Table A2.3). Description of the biological character of the environmental classes was hampered by the limited range of sampling of some geographic locations and/or environmental combinations and could therefore only be produced for some classes. Information about average chlorophyll concentrations was available for 16 classes and fish assemblage data was available for 14 classes, but information about invertebrates was only available for nine classes. In the following descriptions classes are ordered according to the dendrogram (Appendix 1, Figure A1.1) rather than in strict numerical order, so that closely related classes are grouped together in proximity to each other.

7.4.1 Oceanic subtropical environments

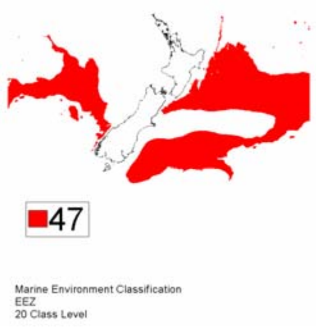
Class 1 – is extensive in the far north, occurring in deep (mean = 3001 m) subtropical waters with high solar radiation and warm winter sea surface temperatures. Average chlorophyll *a* concentrations are very low, but there are insufficient trawl or benthic invertebrate records to provide descriptions of these components.

Class 22 – is extensive in moderately deep waters (mean = 1879 m) over a latitudinal range from about 33–38°S. It is typified by cooler winter SST than the previous class. Chlorophyll *a* reaches only low average concentrations. Characteristic fish species (i.e. occurring at 50% or more of 20 sites) include orange roughy, Baxter's lantern dogfish, Johnson's cod, and hoki.

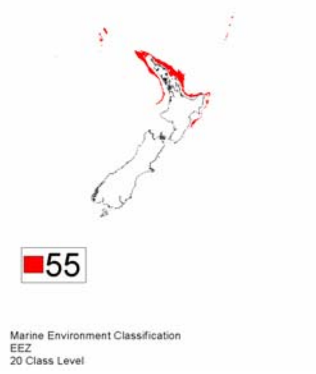


Class 9 – occurs in offshore waters of considerable depth (mean = 5345 m) both in the northeast and northwest of the study area. Average chlorophyll *a* concentrations are very low, but no benthic invertebrate or trawl samples have been collected in waters of these depths.

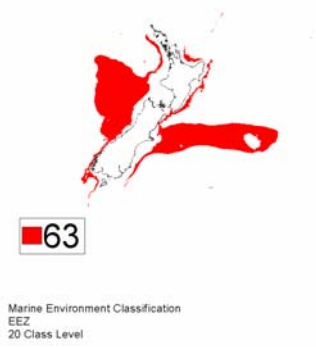
7.4.2 Oceanic, shelf and subtropical front environments



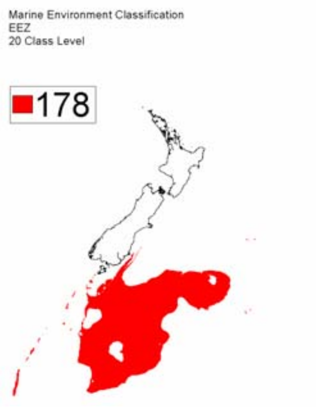
Class 47 – occurs extensively in deep waters (mean = 2998 m) over a latitudinal range from around 37–47°S. Average chlorophyll *a* concentrations are moderately low. Characteristic fish species (24 sites) include smooth oreo, Baxter's lantern dogfish, the rattail *Macrourus carinatus*, Johnson's cod and orange roughy.



Class 55 – is of restricted extent occurring at moderately shallow depths (mean = 224 m) around northern New Zealand and has high annual solar radiation and moderately high wintertime SST. Average chlorophyll *a* concentrations are moderate. Characteristic fish species (26 sites) include sea perch, red gurnard, snapper and ling, while arrow squid are also caught frequently in trawls. The most commonly represented benthic invertebrate families (i.e. occurring at 50% or more of 27 sites) are Dentallidae, Nuculanidae, Pectinidae, Carditidae, Laganidae and Cardiidae.



Class 63 – is extensive on the continental shelf including much of the Challenger Plateau and the Chatham Rise. Waters are of moderate depth (mean = 754 m) and have moderate annual radiation and wintertime SST. Average chlorophyll *a* concentrations are also moderate. Characteristic fish species (29 sites) include orange roughy, Johnson's cod, Baxter's lantern dogfish, hoki, smooth oreo and javelin fish. The most commonly represented benthic invertebrate families (14 sites) are Carditidae, Pectinidae, Dentaliidae, Veneridae, Cardiidae, Serpulidae and Limidae.

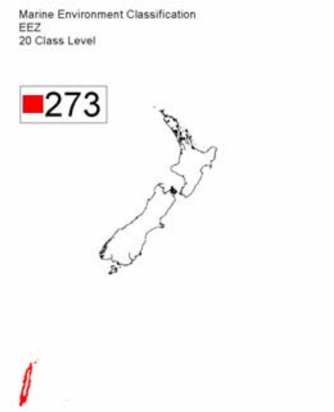


Class 178 – is extensive to the south of New Zealand occurring in moderately deep water (mean = 750) as far south as latitude 55°S. It experiences low annual solar radiation and cool wintertime SST. Chlorophyll *a* reaches only low to moderate average concentrations. Characteristic fish species (26 sites) include ling, javelin fish, hoki and pale ghost shark. The most commonly represented benthic invertebrate families (eight sites) are Terebratellidae, Serpulidae, Pectinidae, Temnopleuridae, Veneridae, Carditidae, Glycymerididae, Spatangidae and Limidae.

7.4.3 Oceanic sub-Antarctic environments

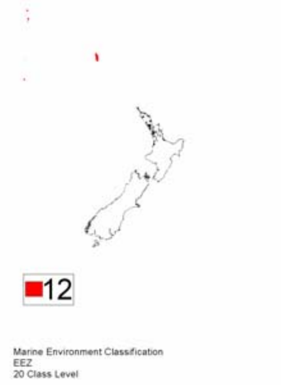
Class 127 – is the most extensive class, occurring in deep waters of the southwest Pacific and Tasman basins (mean = 4799 m) from about latitude 42°S south. Both annual solar radiation and wintertime SST are low, and there is minimal seasonal variation in SST. Chlorophyll *a* reaches only moderate concentrations.

Class 204 – occurs in moderately deep waters (mean = 2044 m) on the continental slope south of about latitude 46°S. Conditions are otherwise similar to that in the previous class (Class 127), and chlorophyll *a* reaches only low average concentrations. Some of the most commonly occurring fish species are orange roughy, smooth oreo, Baxter's lantern dogfish, the rattail *Macrourus carinatus*, hoki, Johnson's cod and javelin fish.



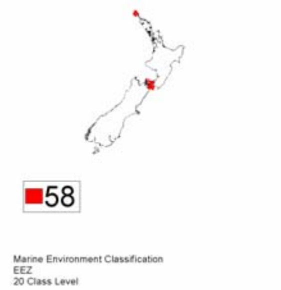
Class 273 – occurs in the far south of the study area encompassing deep water sites (mean = 2550 m) along the MacQuarie Ridge where the ocean floor slopes very steeply. Mean annual solar radiation and wintertime SST have the lowest values of any class and chlorophyll *a* reaches only low average concentrations.

7.4.4 Northern coastal environments

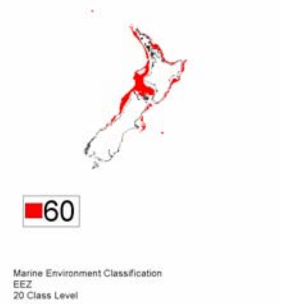


Class 12 – occupies a small area of shallow waters (mean depth = 94 m) on the shelf that surrounds Norfolk Island. It experiences high mean annual solar radiation, warm wintertime SST and moderately high orbital velocities.

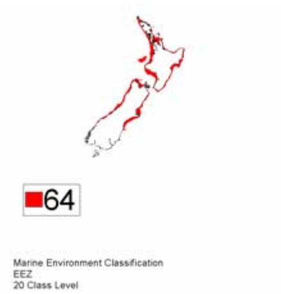
7.4.5 Central coastal environments



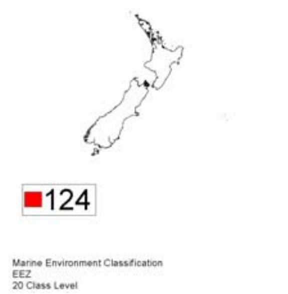
Class 58 – is of relatively restricted extent occurring in moderately shallow waters (mean = 117 m) around the northern tip of the North Island and in Cook Strait. Strong tidal currents are the dominant feature of this class. Some of the most commonly occurring fish species are red gurnard, snapper, leather jacket, spiny dogfish, barracouta, hoki and eagle ray, while arrow squid are also frequently caught in trawls. The most commonly represented benthic invertebrate families are Veneridae, Carditidae and Pectinidae.



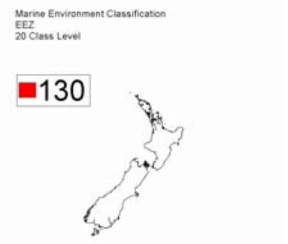
Class 60 – is much more extensive than the previous class, occupying moderately shallow waters (mean = 112 m) on the continental shelf from the Three Kings Islands south to about Banks Peninsula. It experiences moderate annual solar radiation and wintertime SST and has moderately high average chlorophyll *a* concentrations. Some of the most commonly occurring fish species are barracouta, red gurnard, john dory, spiny dogfish, snapper and sea perch, while arrow squid are also frequently caught in trawls. The most commonly represented benthic invertebrate families are Dentaliidae, Cardiidae, Carditidae, Nuculanidae, Amphiuridae, Pectinidae and Veneridae.



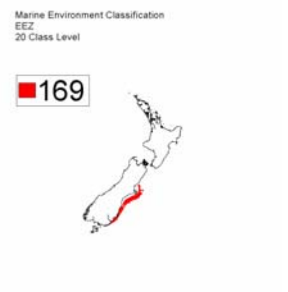
Class 64 –occupies a similar geographic range to the previous class but occurs in shallower waters (mean = 38 m). Seabed slopes are low but orbital velocities are moderately high and the annual amplitude of SST is high. Chlorophyll *a* reaches its highest average concentrations in this class. Some of the most commonly occurring fish species are red gurnard, snapper, john dory, trevally, leather jacket, barracouta and spiny dogfish. Arrow squid are also frequently caught in trawls. The most commonly represented benthic invertebrate families are Veneridae, Mactridae and Tellinidae.



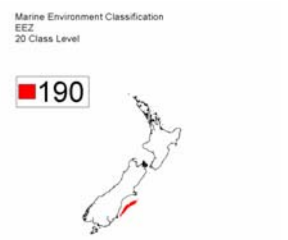
Class 124 – although of limited extent, occurs around the entire New Zealand coastline occupying shallow waters (mean = 8 m) with very high orbital velocities. Some of the most commonly occurring fish species are leather jacket, snapper, red gurnard, eagle ray, trevally and john dory. The most commonly represented benthic invertebrate families are Veneridae, Mactridae, Carditidae and Terebratellidae.



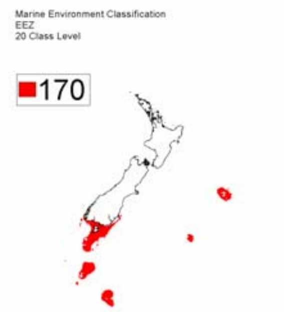
Class 130 – occurs only in the Marlborough Sounds, occupying sites with a distinctive set of environmental conditions typified by very shallow water (mean = 10 m), minimal slope, moderate orbital velocities and tidal currents, and high gradients of SST.



Class 169 – is moderately extensive east of the South Island, occupying shallow waters (mean = 66 m) with low to moderate orbital velocities, moderately low annual solar radiation and wintertime SST, and moderate tidal currents. It supports high average concentrations of chlorophyll *a*. Some of the most commonly occurring fish species are barracouta, spiny dogfish, hapuku, red gurnard, ling and sea perch, while arrow squid are also taken frequently in trawls. The most commonly represented benthic invertebrate families are Veneridae, Terebratellidae, Mactridae, Pectinidae, Cardiidae, Amphiuridae, Nuculidae, Balanidae and Carditidae.



Class 190 – is of limited extent, occurring in waters of moderate depth (mean = 321 m) along the Southland Coast. It experiences moderately low mean radiation and wintertime SST, and high gradients of SST. It supports high average concentrations of chlorophyll *a*. Some of the most commonly occurring fish species are spiny dogfish, barracouta, ling, hapuku, hoki and sea perch. Arrow squid are also frequently taken in trawls.



Class 170 – is extensive in moderately shallow waters (mean = 129 m) on the continental shelf surrounding the Chatham Islands, and from Foveaux Strait south, including around the Bounty Islands, Auckland Islands and Campbell Island. Annual solar radiation and wintertime SST are both moderately low, as is the annual amplitude of SST. Tidal currents are moderate and average concentrations of chlorophyll *a* reach moderate levels. Some of the most commonly occurring fish species are barracouta, spiny dogfish, hapuku and ling, while arrow squid are taken with very high frequency in trawls. The most commonly represented benthic invertebrate families are Terebratellidae, Serpulidae, Veneridae, Pectinidae, Temnopleuridae, Carditidae Cardiidae, Glycymerididae, Spatangidae and Limidae.

8 Hauraki Gulf

8.1 Classification definition decisions

8.1.1 Pilot classifications

The ranking developed by the validation analyses was used to subjectively select a reduced set of variables for subsequent development of pilot classifications (Snelder et al. 2004). In order to simplify the classification, variables ranked lower than 9 in Table 6, except freshwater fraction, were excluded because they made only very small contributions to the statistical models. Although freshwater fraction was also ranked very low by the validation analysis, it was considered that it is likely to be important and the reasons for its low ranking in the validation analysis may have been associated with a lack of data representing areas with high values of freshwater fraction. We have a high level of confidence in the method used to derive the freshwater fraction and, therefore, considered that it should be included in the classification. Thus, the following variables were excluded: seabed rate of change of slope (profile), seabed curvature, seabed planform curvature, mean annual SST.

One of each pair of highly correlated ($r > 0.95$) variables was removed for the same reasons as outlined for the EEZ variables. Thus, SST annual amplitude was excluded because it was highly correlated with SST annual phase ($r = 0.97$) and because SST annual phase was the higher ranking of the two in the validation analysis. In addition, extreme orbital velocity was removed because it was highly correlated with mean orbital velocity ($r = 0.96$) and was ranked lower in the validation analysis. In addition, for the same reasons as outlined for the EEZ scale classification, we concluded that the existing sediment data layer is too coarse and that, until there is a better source of data, sediment should be excluded from the classification.

Various pilot classifications of the Hauraki Gulf were developed based on the following eight variable: depth, slope, tidal current, freshwater fraction, mean orbital velocity, SST annual phase, SST monthly standard deviation and SST semi-annual amplitude (Snelder et al. 2004). In addition, Snelder et al. (2004) suggested transformations and weighting of some variables in the definition of the pilot classifications based on subjective decisions that were guided by inspection of the mapped classification.

8.1.2 Tuning

Leathwick et al. (2004) used similar analyses, based on Mantel tests, to those used to tune the EEZ classification to help tune the definition of the Hauraki classification. The analyses performed by Leathwick et al. (2004) indicated that transformation and weighting could do little to improve correlation of environmental and biological space for most datasets. A log transformation of depth, which makes intuitive sense, improved correlation for two datasets (fish and pelagic) but decreased correlation for the core (benthic) dataset. A subjective decision was, therefore, made not to transform depth. However, it was decided that tidal current and mean orbital velocity should be transformed. This decision was supported mainly by inspection of the pilot classifications (Snelder et al. 2004) which indicated that some compression of tidal current and mean orbital velocity improved the definition of environments. The final decisions for definition of the Hauraki classification are shown in Table 9.

Table 9: The variables and transformations used to define the Hauraki classification

Variable	Transformation
Depth	
Freshwater fraction	
SST annual phase	
SST monthly standard deviation	
SST semi-annual amplitude	
Mean orbital velocity	Log10
Tidal current	Cube root
Slope	

8.2 Classification

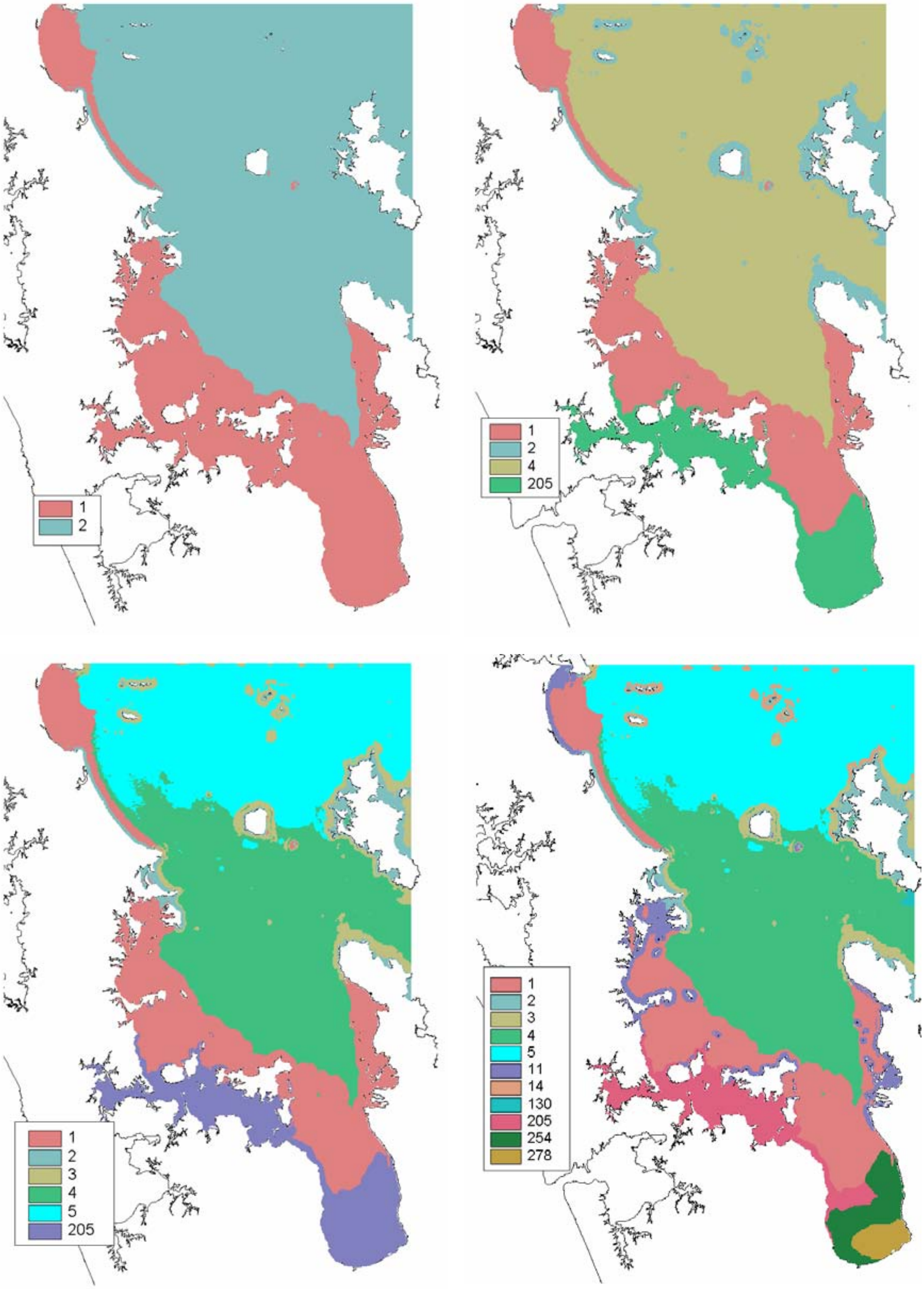
Table 10 shows the within-class average value of each of the variables used to define the Hauraki Gulf classification. Each class is labelled by a number which has no specific meaning but is associated with the order in which groups of cells are agglomerated by the clustering procedure. Inspection of this table indicates that classes are distinctive from one another with respect to at least one variable. Table 10 also shows how the classification has differentiated environmental variation at the 2, 4, 6 and 9-class levels. The division at the two-class level (bold line on Table 10) predominantly subdivides the inner gulf from the mid to outer gulf (see Figure 18). Within the inner and mid to outer gulf environments further divisions occur at the four and six-class levels (thin solid and dashed lines on Table 10). These subdivisions are predominantly associated with differences in depth and separate the coastal and deeper environments (see Figure 18).

Table 10: Average value of each of the eight defining environmental variables in each class of the 20-class level of the Hauraki Gulf classification

20 class	Area (km²)	Depth	Slope	Tidal current	Freshwater	Orbital velocity	SST phase	SST std dev	SST amp	2 class	4 class	6 classes	11 class
1	998.3	21	0.25	0.15	0.01	4.0	48.9	0.63	0.34	Inner	Deep		
150	6.6	3	0.28	0.15	0.03	0.8	44.2	0.56	0.30				
196	371.6	24	0.14	0.31	0.01	2.2	43.0	0.70	0.28				
11	148.1	5	0.38	0.08	0.03	19.8	48.9	0.60	0.36				
104	185.2	8	0.66	0.19	0.02	12.4	47.4	0.59	0.26				
205	431.7	6	0.23	0.27	0.01	8.4	39.6	0.67	0.43		Shallow		South-east Bays
211	92.4	2	0.15	0.33	0.09	12.5	36.2	0.65	0.51				Northern Bays
254	249.9	5	0.07	0.31	0.13	9.5	35.5	0.81	0.39				Firth
278	104.8	2	0.04	0.30	0.65	10.4	33.2	0.86	0.33				Firth Estuary
2	146.1	5	0.71	0.18	0.01	37.0	55.2	0.55	0.26	Mid to outer	Coastal	Shallow	
53	63.9	14	0.95	0.09	0.01	15.9	58.2	0.52	0.30				
22	21.6	10	1.90	0.21	0.01	39.4	60.1	0.57	0.35				
3	182.0	40	0.95	0.28	0.01	2.2	58.1	0.57	0.29			Deep	Steep mid
28	92.6	21	1.56	0.29	0.01	6.7	55.1	0.57	0.23				
14	107.9	52	2.24	0.16	0.01	2.8	60.5	0.59	0.37				Steep outer
130	2.8	25	2.11	1.80	0.01	18.5	57.4	0.57	0.19				Large tidal currents
136	7.9	52	0.16	2.69	0.01	0.6	57.1	0.60	0.20				
4	2886.6	45	0.12	0.27	0.01	0.7	52.9	0.65	0.23		Ocean	Shallow	
5	1563.6	65	0.26	0.15	0.01	0.3	58.0	0.61	0.34			Deep	
6	1121.2	112	0.27	0.10	0.01	0.0	60.5	0.62	0.40				

Note: See Figure 15 for location of the classes. The divisions within the table show how environmental variation has been differentiated at the 2, 4, 6 and 11-class levels.

Figure 18: Classification of the Hauraki Gulf mapped at the 2, 4, 6 and 11-class levels



The nine-class level differentiates the coastal areas of the inner gulf into those areas with high freshwater fraction (Firth of Thames) and similarly shallow areas with lower freshwater influence (South-Eastern Bays). The nine-class level also further subdivides the deeper coastal environments of the mid and outer gulf. Environments with high tidal currents and steep (probably rocky) seabed are differentiated (see Figure 18).

Figure 19 shows the Hauraki Gulf classification at the 20-class level. Figure 20 shows the classification using the continuously varying colour scheme that reflects environmental distances between the maximum number of classes defined by the classification (i.e. 280 classes).

The relationships between classes are described in greater detail by the dendrogram shown in Appendix 1, Figure A1.2. The dendrogram shows how the classes are progressively amalgamated to form a single large group. Note that the class numbers are assigned during the clustering procedure and are derived from the order in which amalgamation of the groups occur.

8.3 Classification strength of the Hauraki Gulf classification

A full description of the biological testing of the Hauraki Gulf classification is contained within Leathwick et al. (2004). Because large parts of the environmental domain were not represented by the biological datasets, not all the classes that are defined at any given level of the Hauraki Gulf classification could be tested. ANOSIM analyses were performed on classes at each level of the classification provided classes had at least four biological samples. The testing was limited because of uneven distribution of biological sample points across the classes. Thus for the fish dataset only seven classes could be tested at the 20-class level and only 11 groups at a 50-class level of classification. A new invertebrate dataset comprising 50 sample sites was used to test the classification. Three classes from this dataset could be tested at the 20-class level and seven classes had adequate biological data at a 50-class level. An ANOSIM analysis was attempted using a pelagic dataset containing 34 sample points. However, even when the minimum number of sites per class was reduced to three, only two classes had sufficient biological samples at a 20-class level of classification and biological differences between these two environments were non-significant.

Results of the ANOSIM analysis of classification strength for the fish dataset showed the *r*-values initially rose sharply with progression from a two-class to a five-class level of the classification, but beyond this remained relatively invariant with increasing numbers of classes. At the 20-class level, all individual pair-wise comparisons between classes were significantly different ($p < 0.01$) in their biological composition, indicating that all classes that were distinctive with respect to their fish assemblage.

Figure 19: Hauraki Gulf classification at the 20-class level

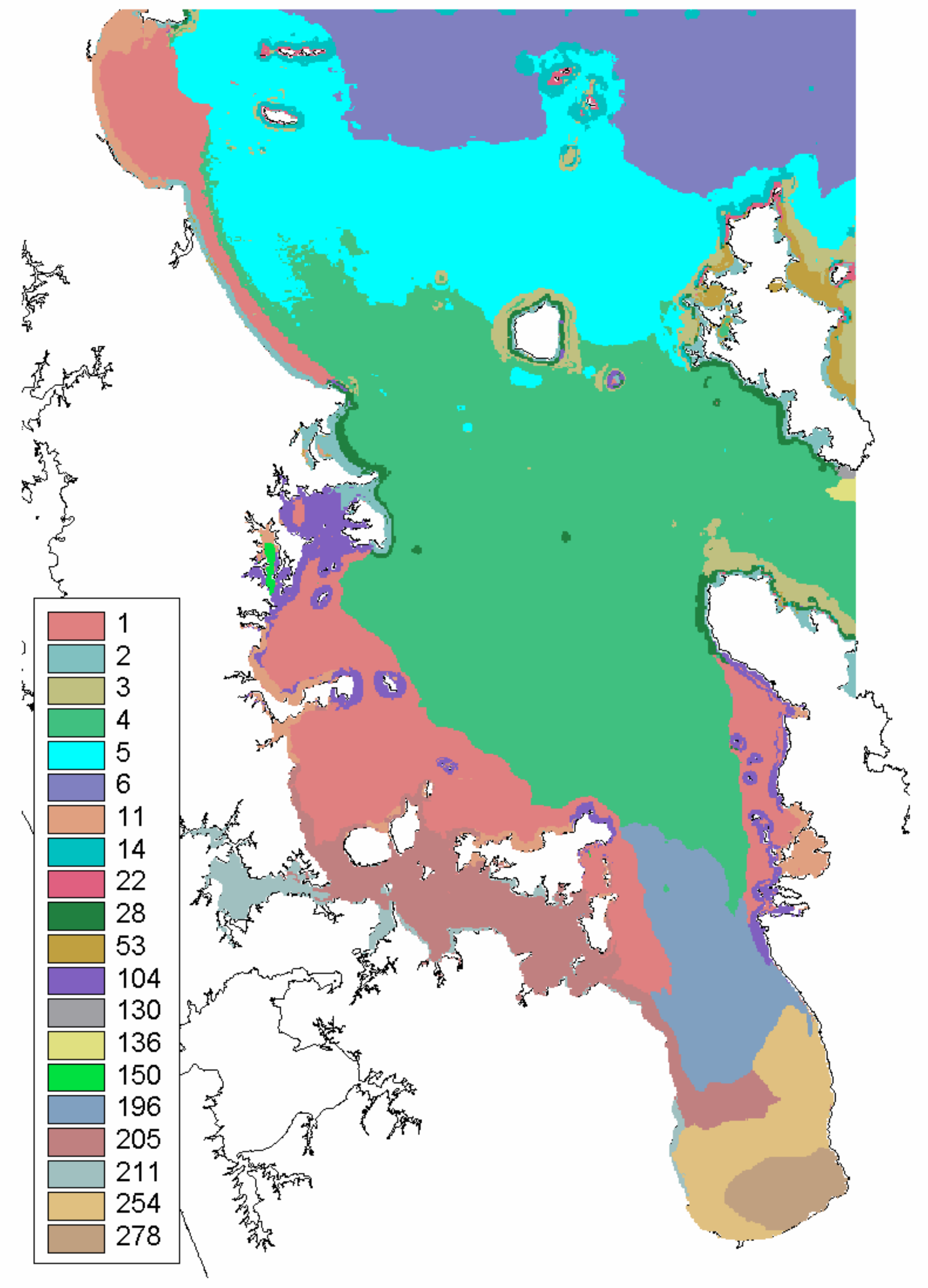
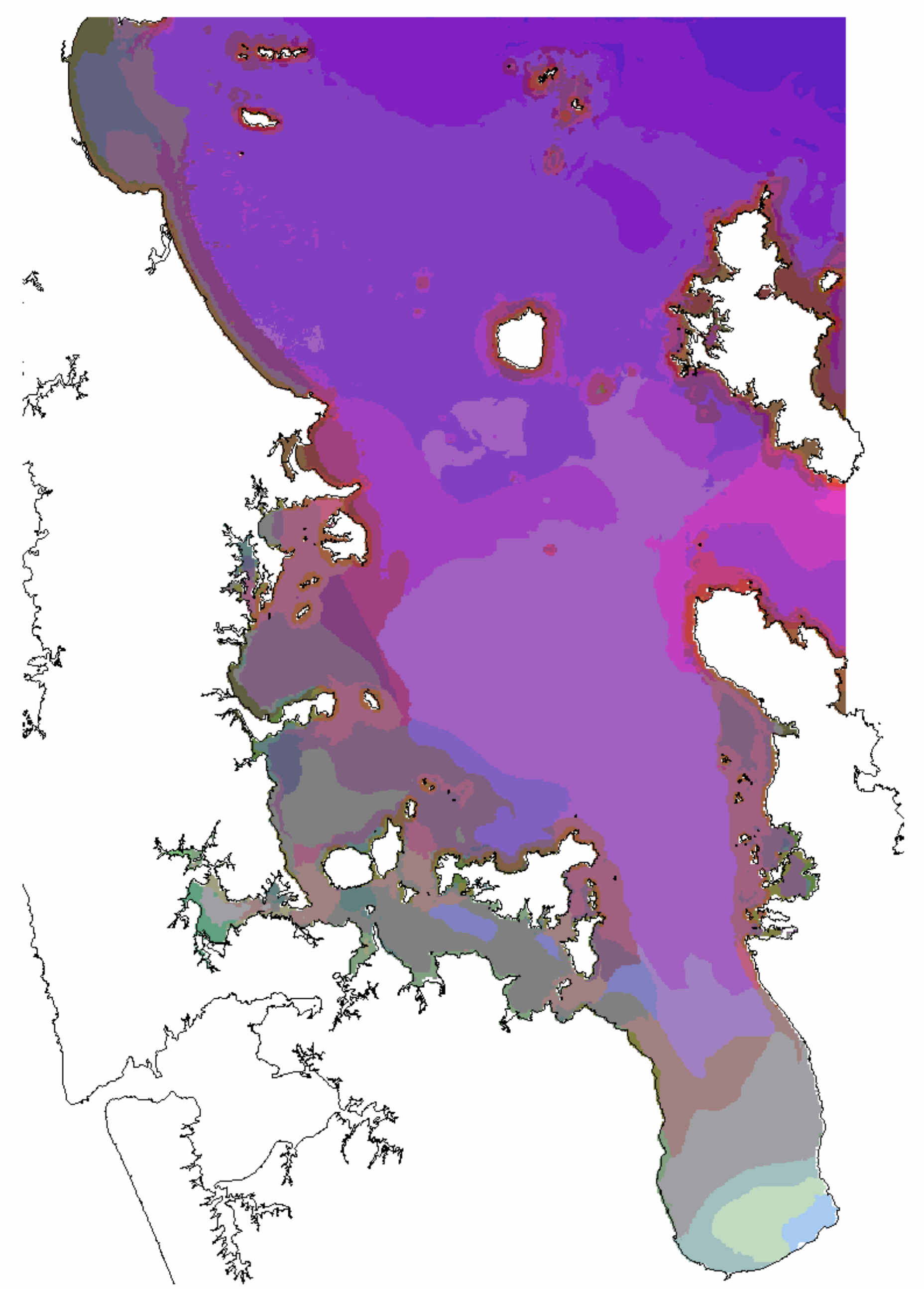


Figure 20: Classification of the Hauraki Gulf using the continuous colour scheme based on the principal components of the eight variables used to define the classification



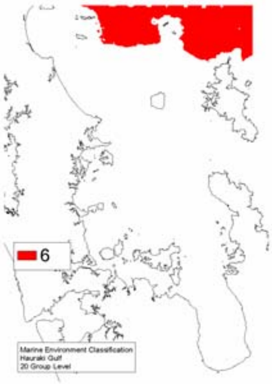
Note: Bluer areas are deeper, with lower mean orbital velocity. Redder areas have higher values of tidal current. Greener areas are associated with higher freshwater fraction and lower SST phase.

Results from the ANOSIM analysis of the invertebrate dataset indicate a steady increase in *r*-values for successive levels of the classification. This indicates that the strength of the classification for invertebrates increases at lower levels. However, examination of biological similarities between the three classes with adequate data at the 20-class level indicated that the groups are not biologically distinguishable from each other (i.e. $p > 0.1$).

8.4 Biological characteristics of Hauraki Gulf classes

Descriptions of the biological character could only be produced for those classes with adequate biological samples. Information about fish assemblages at the 20-class level was available for seven environments while information about invertebrates was only available for three environments. In the following descriptions, classes are ordered according to the dendrogram (Appendix 1, Figure A1.2) rather than in strict numerical order so that closely related classes are more likely to be located in proximity to each other. Tables showing the frequency of occurrence of various fish and benthic invertebrates species are appended (Appendix 3, Figure A3.1 and Appendix 3, Figure A3.2).

8.4.1 Deeper water classes of the middle to outer gulf



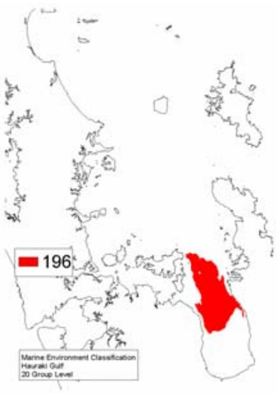
Class 6 – has the highest average depths (mean = 112 m) and occurs mostly north of Great Barrier Island. Commonly occurring species caught in trawls (occurrence > 50%) include snapper, red gurnard, john dory, scaly gurnard, leather jacket and arrow squid.

Class 5 – occurs in moderately deep water (mean = 65 m) from Great Barrier Island west to Bream Head. Fish species occurring commonly in this class are snapper, red gurnard, john dory and leather jacket – scaly gurnard are less common than in the previous class while skates are more common.

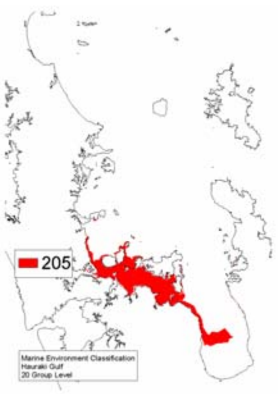
Class 4 – is the most extensive class at this classification level, occurring in water of moderate depth (mean = 45 m) south from about Little Barrier Island to occupy much of the Colville Channel and the mid gulf south to about Waiheke Island. Snapper, red gurnard and john dory are the most commonly occurring species, with moderate occurrences of leatherjacket, arrow squid and sand flounder. Brittle stars are by far the most commonly occurring species recorded from the invertebrate dataset (six sites).

8.4.2 Shallower water classes of the inner gulf

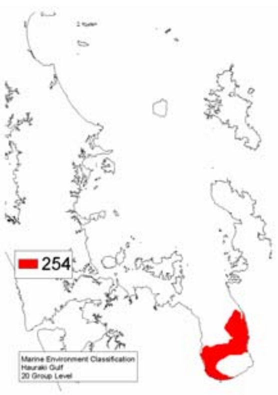
Class 1 – occurs in inshore waters of intermediate depth (mean = 21 m) from about Bream Bay south to Ponui Island, much of it lying to the north of Waiheke and Rangitoto Islands. Snapper, red gurnard and john dory are the most commonly caught fish species with sand flounder occurring in approximately half of the trawls. Brittle stars are the most commonly occurring species recorded from the invertebrate dataset (26 sites).



Class 196 – occurs at the northern end of the Firth of Thames, occupying sites of similar depth (mean = 24 m) to the previous class, but with higher tidal currents. Characteristic fish species include snapper, red gurnard, john dory and sand flounder, with moderately frequent catches of yellow-belly flounder, spotted stargazer, rig and barracouta.



Class 205 – occurs mostly in protected, shallow waters (mean = 6 m) between the mainland North Island and Rangitoto and Waiheke Islands. Snapper are the most frequently caught species in trawls, followed by john dory, spotty, trevally and kahawai. The most commonly occurring benthic invertebrates are Helice crassa, Lumbrinerid spp., Siglanoidea and brittle stars (16 sites).



Class 254 – occurs in the southern half of the Firth of Thames where average water depths are shallow (mean = 5 m) but tidal currents are moderately strong. Snapper are again the most common species caught in trawls along with red gurnard, rig, rays, sand and yellow-bellied flounder, kahawai and yellow-eyed mullet.

9 Closing Comments

The Marine Environment Classification project aimed to produce classifications of New Zealand's marine environment for resource and conservation management. The statistical process that was used to define the Marine Environment Classification has ensured that the classifications have defined distinctive environmental classes. The classification is hierarchical, enabling the user to delineate environmental variation at different levels of detail and a range of associated spatial scales. Statistical tests determined that the Marine Environment Classification classes are biologically distinctive. The classification provides managers with defensible definitions of environmental and biological pattern. This should provide a useful spatial framework for broad scale environmental and conservation management. The full utility of the classifications will only become clear as the classifications are applied to management issues.

While challenges were encountered all the way through the classification's development, good progress has been made with the analytical assessment of how best to combine, transform and weight candidate classification variables. Fundamental to this was the effort put into clarifying the overall conceptual framework within which we were operating, i.e. one driven by the objective of optimising the measurement of environmental differences in a way that maximises discrimination of biological differences – our choice of Mantel tests to tune variable selection, transformation and weighting stemmed directly from this conceptual starting point. Subsequent use of this test enabled us to substantially increase the correlations between our measures of environmental and biological distance. For example, at the full EEZ scale, environmental distances based on our tuned set of variables had substantially higher correlation with biological distances for the fish (+55%) and chlorophyll a (+50%) datasets than with the initial set of predictors. Smaller gains were made with the benthic dataset and with the geographic subsamples.

There are two points that should be borne in mind when applying the Marine Environment Classification. First, decisions were based on averaging results of tests performed on various biological datasets and based on whole assemblage measures of similarity. Thus, the classification has not been optimised for a specific ecosystem component (e.g. fish communities or individual species) and has sought to provide a general classification that has relevance to a broad range of biological groups. Second, the Marine Environment Classification is based on a particular approach to measuring environmental similarity and method for deriving a structure of classes. Other approaches exist and may have benefits.

The testing and biological characterisation phase (which tested how biologically distinctive the environmentally defined Marine Environment Classification classes were) was also limited by data availability. Testing, and in particular biological characterisation, of the Marine Environment Classification defined classes should be seen as an ongoing process that will continue to occur during the application of the Marine Environment Classification to management issues.

In future, the classification may be improved with new data. In particular, the EEZ classification may benefit from the addition of a freshwater fraction layer. In future, freshwater inputs around the New Zealand coastal region may be able to be described using products derived from remote sensing of ocean colour. Another obvious variable that was omitted from both the Hauraki and EEZ classification is seabed sediment. A point that needs consideration is whether sediment at the same resolution as the other variables (assuming this was available) is necessary. Patterns in seabed sediment may be correlated with bathymetry (depth, shape), tidal currents and swell as well as sources of sediment. It is possible that the Marine Environment

Classification classes, particularly at high levels of the classification, already capture broad scale variation in sediment.

One key limitation of both the EEZ and Hauraki Gulf classifications is their discrimination of environmental character in coastal areas. Neither classification includes seabed sediment or substrate (e.g. rocky reefs) as defining variables. Substrates vary at small spatial scales in the coastal area and are a specific cause of habitat heterogeneity. This means that some classes, in particular those that are shallow and coastal, may encompass significantly greater environmental and biological heterogeneity than other classes. Another limitation in coastal areas is the representation of estuaries by the classifications. We do not consider that the classification represents estuaries, even though these features are included in the classification grid. An estuary classification is currently under development (see Hume et al. 2003). This classification system defines estuaries around the New Zealand coastline and could be used to 'mask' the estuarine grid cells out of the Marine Environment Classifications.

At the conclusion of the Marine Environment Classification development project, the steering group was satisfied that the classification provides a useful broad-scale classification of biotic and physical patterns in New Zealand's marine environment. The steering group has supported the Marine Environment Classification as a spatial framework for analysis and management of marine conservation and resource management issues.

10 Acknowledgements

Development of the New Zealand Marine Environment Classification has been funded by the Ministry for the Environment (MfE), the Ministry of Fisheries and Department of Conservation (DoC). Development of the Marine Environment Classification began in 2000 and its evolution represents the collective involvement and support of many people. We are grateful for the financial support of these organizations and the stewardship of Megan Linwood of MfE during the course of the entire project.

We acknowledge the guidance of the steering group including: Clinton Duffy (DoC), Don Robertson (NIWA), Dominic McCarthy (Auckland Regional Council), Mathew Batholomew (MFish), Jacqui Burgess (MFish), Ben Sharp (MFish), Bob Cooper (Tai Perspectives), Brigit Stephenson (MfE), Kirsty Johnston (MfE), Eric Verstappen (Tasman District Council), Stephanie Turner (Environment Waikato), Malene Felsing (Environment Waikato), Franz Smith, Kevin Stokes (Seafood Industry Council), Nici Gibbs (Seafood Industry Council), Philippe Lallemand (Seafood Industry Council), Peter Hamill (Marlborough District Council) and Steve Wing (University of Otago).

The development of the Marine Environment Classification was only possible due to the collective knowledge and expertise of a wide range our colleagues at NIWA. We thank the following people for the contribution of their time, knowledge, data, models, analytical skills and enthusiasm: Ashley Rowden, Basil Stanton, Denis Gordon, Derek Goring, Geoff Read, Graham Fenwick, Graham Inglis, Helen Hurren, Janet Grieve, John Zeldis, Judi Hewitt, Ken Richardson, Keri Niven, Kevin McKay, Lionel Carter, Malcolm Francis, Mark Hadfield, Marty Flanagan, Matt Pinkerton, Michael Uddstrom, Spanners Watson, Prabu Chandramohan, Richard Garlick, Richard Gorman, Rob Bell, Scott Stephens, Simon Thrush, Terry Hume and Ude Shankar.

11 References

Austin MP, Smith TM. 1989. A new model for the continuum concept. *Vegetation* 83: 35–47.

Bailey RG. 1995. Ecosystem Geography. Springer-Verlag, New York, NY. 204 p.

Belbin L. 1993. Environmental representativeness: regional partitioning and reserve selection. *Biological Conservation* 66: 223–30.

Belbin L. 1995. PATN analysis package. Division of Sustainable Ecosystems, CSIRO, Canberra. 237 p.

Booij N, Ris RC, Holthuijsen LH. 1999. A third-generation wave model for coastal regions 1. Model description and validation. *Journal of Geophysical Research* 104(C4): 7649–66.

Clark HES, McKnight DG. 2000. The marine fauna of new Zealand: Echinodermata: Asteroidea (Sea-stars): Order Paxillosida, Order Notomyotida. *NIWA Biodiversity Memoir* 116.

Clark HES, McKnight DG. 2001. The marine fauna of New Zealand: Echinodermata: Asteroidea (Sea-stars): Order Valvatida. *NIWA Biodiversity Memoir* 117.

Clarke KR, Warwick RM. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 2. PRIMEr-E, Plymouth, UK. 172 p.

Davies JA, Schertzer W, et al.. 1975. Estimating global solar radiation. *Boundary–Layer Meteorology* 9(1): 33–52.

De'ath G. 1999. Extended dissimilarity: a method of robust estimation of ecological distances from high beta diversity data. *Plant Ecology* 144: 191–9.

deBlij HJ. 1978. Geography: Regions and concepts. John Wiley and Sons, Inc., New York NY.

Digby PGN, Kempton RA. 1987. Multivariate Analysis of Ecological Communities. Chapman and Hall, London.

DSIR. 1992. Coastal Chart Series; Sediments 1:200,000 Scale. New Zealand Oceanographic Institute. Department of Scientific and Industrial Research. Marine and Freshwater.

Francis MP, Hurst RJ, McArdle BH, Bagley NW, Anderson OF. 2002. New Zealand demersal fish assemblages. *Environmental Biology of Fishes* 65(2): 215–34.

Gorman RM, Laing AK. 2000. A long-term wave hindcast for the New Zealand coast. Sixth International Workshop on Wave Hindcasting and Forecasting, Monterey, California.

Hume TM, Snelder T, Weatherhead M, Liefting R. 2003. Estuary environment classification for resource management. Presented at the New Zealand Marine Sciences Society Conference 2002, Nelson, New Zealand.

Jones KS. 1970. Some thoughts on classification for retrieval. *Journal of Documentation* 26: 89–101.

Kendrick TH, Francis MP. 2002. Fish assemblages in the Hauraki Gulf, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 36: 699–717.

Knox GA. 1995. The marine benthic ecology and biogeography. In Kushel G (ed), Biogeography and Ecology in New Zealand, pp 353–403.

Leathwick JR, Overton JM, McLeod M. 2003. An environmental domain analysis of New Zealand, and its application to biodiversity conservation. *Conservation Biology* 17(6): 1612–23.

Leathwick JR, Overton JM, McLeod M. 2003a. An environmental domain analysis of New Zealand, and its application to biodiversity conservation. *Conservation Biology* 17(6): 1612–23.

Leathwick JR, Wilson G, Rutledge D, Wardle P, Morgan F, Johnston K, McLeod M, Kirkpatrick R. 2003b. Land Environments of New Zealand. Bateman, Auckland., New Zealand. 183 p.

Longhurst A. 1998. Ecological Geography of the Sea. Academic Publishers, London. 391 p.

Mahalanobis PC. 1936. Proceedings of the National Institute of Science of India 2, 49.

Mantel N. 1967. The detection of disease clustering and a generalized regression approach. *Cancer Research* 27: 209–20.

Margules CR, Pressey RL. 2000. Systematic conservation planning. *Nature* 405: 243–53.

McKnight DG. 2000. The marine fauna of New Zealand: Basket-stars and Snake-stars (Echinoderrmata: Ophiuroidea: Euryalinida). *NIWA Biodiversity Memoir* 115.

McMahon G, Gregonis SM, Waltman SW, Omernik JM, Thorson TD, Freeouf JA, Rorick AH, E, KJ. 2001. Developing a spatial framework of common ecological regions for the conterminous United States. *Environmental Management* 28: 293–316.

Mitchell JS, Carter L, McDougal JC. 1989. New Zealand Region Sediment 1:6,000.000. New Zealand Oceanographic Institute. Miscellaneous Series No. 67.

Olsgard F, Somerfield PJ. 2000. Surrogates in marine benthic investigations – which taxonomic unit to target? *Journal of Aquatic Ecosystem Stress and Recovery* 7: 25–42.

Omernik JM. 1995. Ecoregions: a spatial framework for environmental management. In Davis WS, Simon TP (eds), Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making, pp. 49–62. Lewis Publishers, Boca Raton, Florida.

Ris RC, Holthuijsen LH, et al.. 1999. A third–generation wave model for coastal regions 2. Verification. *Journal of Geophysical Research* 104(C4): 7667–81.

Rossow WB, Schiffer RA. 1999. Advances in understanding clouds from ISCCP. *Bulletin of the American Meteorological Society* 80(11): 2261–88.

Sneath PHA, Sokal RR. 1973. Numerical Taxonomy: The Principles and Practice of Numerical Classification. WH Freeman and Company, San Francisco.

Snelder TH, Biggs BJF. 2002. Multi-scale river environment classification for water resources management. *Journal of the American Water Resources Association* 38(5): 1225–40.

Snelder, T, Hill, G. (2004). Preliminary Evaluation of Hauraki Gulf Marine Environment Classification for Management Applications. NIWA Client Report chc2004-74. 33p

ter Braak CJF, Smilauer P. 1998. CANOCO release 4 reference manual and user’s guide to Canoco for Windows-Software for canonical community ordination. Microcomputer Power, Ithaca.

Uddstrom MJ, Oien NA. 1999: On the use of high resolution satellite data to describe the spatial and temporal variability of sea surface temperatures in the New Zealand Region. *Journal of Geophysical Research (Oceans)* 104: C9, 20729–51.

Walters RA, Goring DG, Bell RG. 2001. Ocean tides around New Zealand. *New Zealand Journal of Marine and Freshwater Research* 35: 567–79.

Wicken E. 1986. Terrestrial ecozones of Canada. Ecological Land Classification Series No. 19 Environment Canada, Ottawa, Ontario.

Zonneveld IS. 1994. Basic principles of classification. In Klijn F (ed) Ecosystem classification for environmental management, pp. 23-47. Kluwer Academic Publishers, Dordrecht, Netherlands.

Complete list of technical reports produced during the development of the MARINE ENVIRONMENT CLASSIFICATION

Fenwick G. 2001. Identification of regions and data for testing a marine environment classification system. *NIWA Report CHC01/62*. 26 p.

Fenwick G, Flanagan M. 2002. The New Zealand Marine Environment Classification: biological data for development of the Hauraki region classification (revised). *NIWA Report CHC2002-002*. 15 p.

Hadfield M, Uddstrom, M. Goring D, Gorman R, Wild M, Stephens S, Shankar U, Niven K, Snelder T. 2002. Physical Variables for the New Zealand Marine Environment Classification System: Development and Description of Data Layers. *NIWA Report CHC2002-043*. 59 p.

Hewitt J, Snelder T. 2003. Validation of environmental variables used for New Zealand Marine Environment Classification (Regional Scale – Hauraki Gulf). *NIWA Report HAM2003-020.* 38 p.

Image K, Richardson K, Rowden A, Francis M, Snelder T. 2003. Validation of environmental variables used for New Zealand Marine Environment Classification (EEZ scale). *NIWA Report CHC2003-029*. 46 p.

Snelder T. 2000. Towards a marine classification system for New Zealand. MFE01502. *NIWA Report HC00/89*. 20 p.

Snelder T, Grieve JM, Hume T, Zeldis J. 2001. Draft design for a classification system for New Zealand's marine environment. *NIWA Report CHC01/41*. 69 p.

Leathwick J, Image K, Snelder T, Weatherhead M, Wild M. 2004. Definition and testing of Marine Environment classifications of New Zealand's Exclusive Economic Zone and the Hauraki Gulf. *NIWA Report CHC2004*. 70 p.

Weatherhead M, Snelder T. 2003. Prototype Marine Environment Classification for New Zealand's Exclusive Economic Zone. *NIWA Report CHC2003-075*. 20 p.

Wild M, Weatherhead M, Snelder T. 2003. Prototype regional-scale marine environment classification for the Hauraki Gulf and its application to assessment of representativeness of various marine protected areas. *NIWA Report CHC2003-067.* 33 p.

Snelder T, Leathwick J, Biggs BJF, Weatherhead M. 2000. Ecosystem classification: A discussion of various approaches and their application to environmental management. *NIWA Report CHC00/92*. 37 p.

Snelder T, Leathwick J, Weatherhead M, Wild M. 2004. Pilot Marine Environment Classification of New Zealand's Exclusive Economic Zone and the Hauraki Gulf. *NIWA Report CHC2004-003*. 56 p.

Appendix 1: Dendrograms

Figure A1.1: Dendrogram of the EEZ classification showing how the classes are progressively amalgamated from 2 to 20 classes

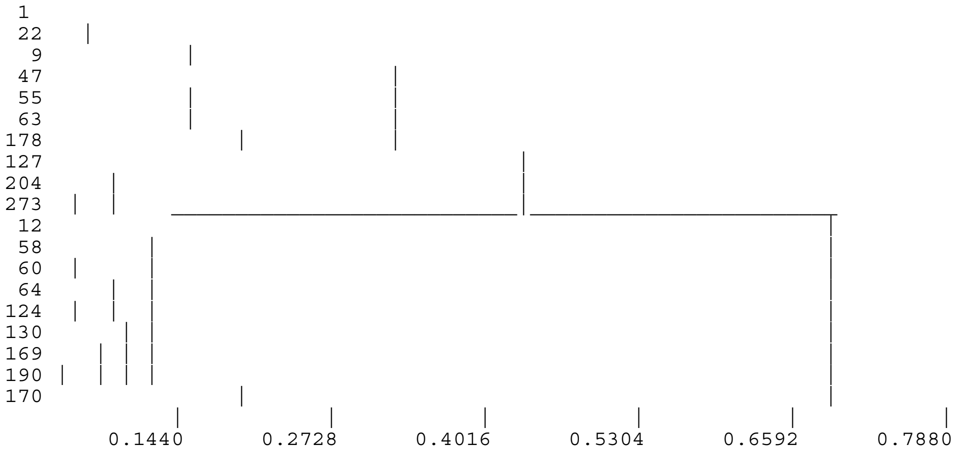
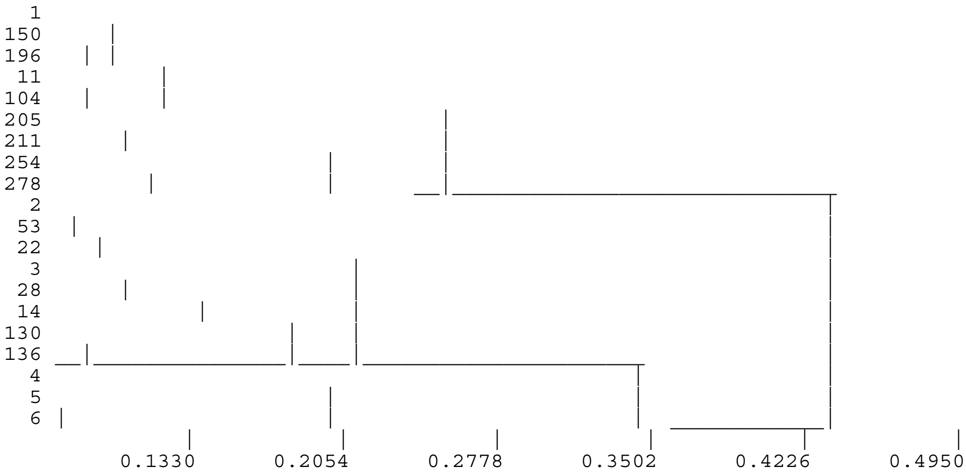
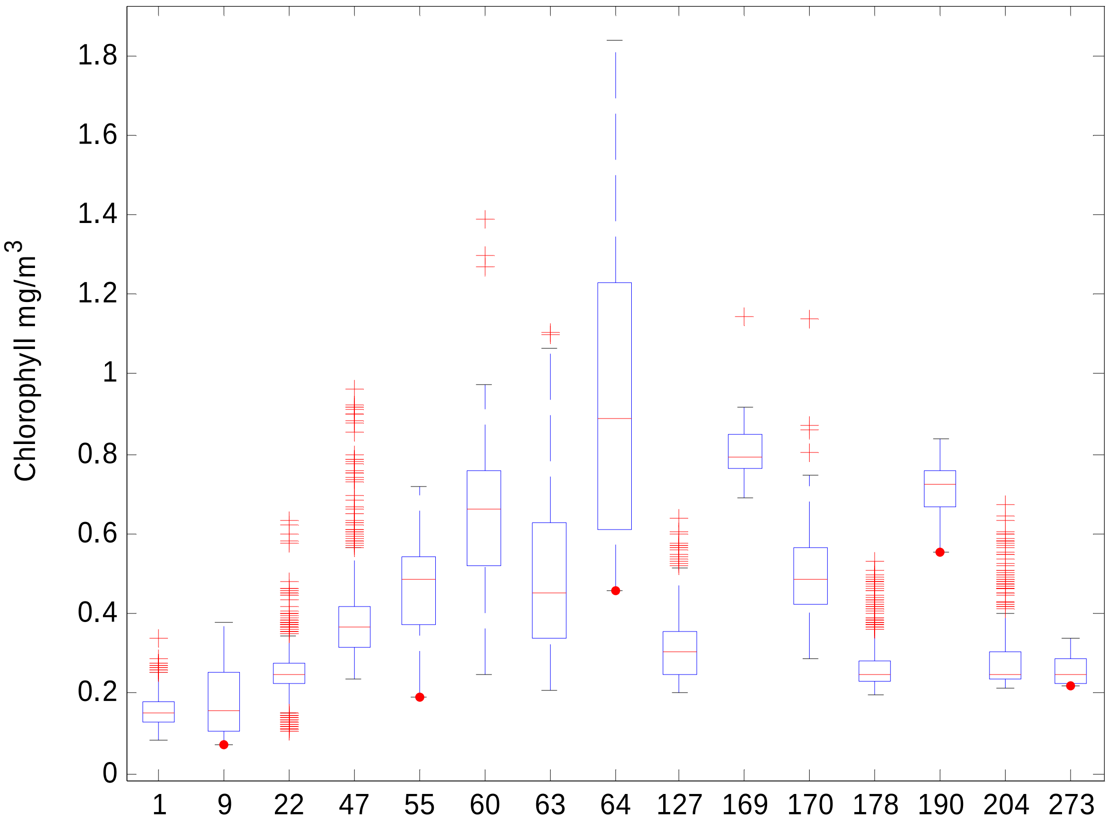


Figure A1.2: Dendrogram of the Hauraki Gulf classification showing how the classes are progressively amalgamated from 2 to 20 classes



Appendix 2: Biological Characteristics of EEZ Classes (20-class level)

Figure A2.1: Chlorophyll concentration in EEZ classes at the 20-class level



Note: The horizontal red line in each bar shows the median concentration by class. The box is defined by the 25th and 75th percentile, the whiskers define the 5th and 95th percentile and outliers are shown as red crosses.

Table A2.2: Characteristic fish species by classes at the 20-class level of the EEZ classification based on proportion of occurrences

Fish species	MARINE ENVIRONMENT CLASSIFICATION class												
	22	47	55	58	60	63	64	124	169	170	178	190	204
Spiny dogfish	0.00	0.00	0.02	0.19	0.52	0.13	0.26	0.00	0.92	0.83	0.31	0.86	0.00
Arrow squid	0.01	0.01	0.54	0.36	0.72	0.20	0.27	0.28	0.80	0.92	0.33	0.82	0.05
Red gurnard	0.00	0.00	0.46	0.55	0.60	0.00	0.82	0.64	0.44	0.30	0.00	0.03	0.00
Orange roughy	0.88	0.45	0.02	0.05	0.00	0.63	0.00	0.00	0.00	0.00	0.03	0.04	0.90
Leatherjacket	0.00	0.00	0.11	0.50	0.28	0.00	0.26	0.72	0.06	0.02	0.00	0.00	0.00
Barracouta	0.00	0.00	0.26	0.24	0.70	0.07	0.38	0.08	0.94	0.82	0.06	0.73	0.00
Snapper	0.00	0.00	0.51	0.48	0.44	0.00	0.73	0.88	0.00	0.00	0.00	0.00	0.00
Baxter's lantern dogfish	0.48	0.86	0.01	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.23	0.06	0.75
Hoki	0.27	0.18	0.19	0.31	0.17	0.62	0.07	0.00	0.07	0.05	0.85	0.33	0.60
Eagle ray	0.00	0.00	0.01	0.31	0.08	0.00	0.26	0.72	0.00	0.00	0.00	0.00	0.00
Javelin fish	0.12	0.04	0.19	0.12	0.01	0.44	0.00	0.00	0.00	0.02	0.82	0.17	0.61
Smooth oreo	0.15	0.88	0.00	0.02	0.00	0.43	0.00	0.00	0.00	0.00	0.04	0.05	0.72
Hapuku	0.00	0.00	0.03	0.14	0.14	0.04	0.04	0.00	0.53	0.77	0.05	0.35	0.00
Ling	0.05	0.01	0.27	0.17	0.19	0.27	0.07	0.00	0.51	0.51	0.87	0.66	0.11
Macrourus carinatus	0.08	0.81	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.13	0.04	0.45
Pale ghost shark	0.24	0.11	0.03	0.10	0.00	0.42	0.00	0.00	0.01	0.01	0.74	0.14	0.13
John dory	0.00	0.00	0.44	0.29	0.53	0.00	0.59	0.72	0.01	0.01	0.00	0.00	0.00
Johnson's cod	0.69	0.75	0.01	0.10	0.00	0.50	0.00	0.00	0.00	0.00	0.02	0.02	0.46
Sea perch	0.06	0.00	0.62	0.07	0.31	0.28	0.04	0.00	0.54	0.23	0.06	0.48	0.02
Trevally	0.00	0.00	0.12	0.19	0.16	0.00	0.38	0.56	0.00	0.00	0.00	0.00	0.00

Note: The cells show the average frequency of occurrence of each species based on a random sample of sites (number of site shown) located within the class.

Table A2.3: Characteristic invertebrates by classes at the 20 group level of the EEZ classification based on proportion of occurrences

Invertebrates	MARINE ENVIRONMENT CLASSIFICATION class								
	55	58	60	63	64	124	169	170	178
Terebratellidae	0.26	0.50	0.26	0.36	0.18	0.57	0.70	0.73	1.00
Serpulidae	0.11	0.19	0.10	0.50	0.06	0.14	0.40	0.67	1.00
Veneridae	0.44	0.81	0.43	0.57	0.68	0.86	0.90	0.79	0.88
Mactridae	0.22	0.25	0.36	0.07	0.55	0.86	0.70	0.24	0.00
Dentaliidae	0.81	0.31	0.71	0.57	0.28	0.29	0.40	0.18	0.00
Carditidae	0.59	0.56	0.51	0.71	0.29	0.71	0.60	0.67	0.75
Pectinidae	0.63	0.56	0.43	0.64	0.28	0.43	0.70	0.42	0.88
Laganidae	0.59	0.00	0.18	0.07	0.05	0.14	0.00	0.12	0.00
Nuculanidae	0.67	0.38	0.46	0.21	0.16	0.00	0.50	0.00	0.00
Cardiidae	0.59	0.50	0.57	0.57	0.28	0.43	0.70	0.39	0.50
Temnopleuridae	0.07	0.25	0.08	0.07	0.01	0.00	0.30	0.18	0.88
Amphiuridae	0.22	0.50	0.44	0.21	0.33	0.29	0.70	0.03	0.25
Nuculidae	0.26	0.38	0.40	0.21	0.39	0.29	0.70	0.03	0.00
Cidaridae	0.52	0.00	0.11	0.29	0.01	0.00	0.10	0.18	0.13
Balanidae	0.15	0.19	0.13	0.21	0.10	0.29	0.70	0.09	0.25
Tellinidae	0.19	0.50	0.29	0.29	0.41	0.00	0.40	0.00	0.00
Glycymerididae	0.26	0.25	0.15	0.07	0.15	0.43	0.20	0.55	0.75
Limidae	0.07	0.31	0.15	0.43	0.05	0.29	0.50	0.52	0.63
Psammobiidae	0.04	0.19	0.04	0.00	0.28	0.43	0.10	0.15	0.00
Spatangidae	0.11	0.13	0.11	0.21	0.04	0.00	0.00	0.12	0.75

Note: The cells show the average frequency of occurrence of each species based on a random sample of sites (number of site shown) located within the class.

Appendix 3: Biological Characteristics of Hauraki Gulf Classes (20-class level)

Table A3.1: Characteristic fish species by classes at the 20 class level of the Hauraki Gulf classification based on proportion of occurrences

Fish species	MARINE ENVIRONMENT CLASSIFICATION class						
	1	4	5	6	196	205	254
Snapper	1.00	1.00	0.95	0.94	0.98	0.97	1.00
Red gurnard	0.73	0.89	0.97	0.78	0.82	0.36	0.72
John dory	0.86	0.89	0.92	0.78	0.91	0.67	0.44
Scaly gurnard	0.00	0.09	0.52	0.78	0.01	0.00	0.00
Leatherjacket	0.20	0.41	0.92	0.39	0.04	0.00	0.00
Arrow squid	0.09	0.41	0.67	0.67	0.02	0.03	0.00
Spotty	0.24	0.19	0.02	0.00	0.13	0.58	0.39
Rig	0.18	0.27	0.06	0.06	0.46	0.42	0.67
Rays	0.16	0.06	0.11	0.11	0.27	0.36	0.67
Sand flounder	0.52	0.43	0.06	0.00	0.67	0.36	0.50
Trevally	0.30	0.07	0.05	0.00	0.08	0.55	0.22
Kahawai	0.16	0.03	0.00	0.00	0.28	0.55	0.61
Yellow-belly flounder	0.13	0.05	0.00	0.00	0.57	0.18	0.44
Yellow-eyed mullet	0.07	0.01	0.00	0.00	0.18	0.24	0.56
Eagle ray	0.30	0.20	0.13	0.00	0.18	0.39	0.44
Spotted stargazer	0.30	0.30	0.19	0.00	0.49	0.09	0.00
Broad squid	0.28	0.28	0.16	0.06	0.05	0.36	0.11
Witch	0.01	0.04	0.31	0.33	0.04	0.03	0.00
Barracouta	0.13	0.25	0.27	0.17	0.37	0.21	0.11
Skates	0.02	0.16	0.45	0.28	0.00	0.00	0.00

Note: The cells show the average frequency of occurrence of each species based on a random sample of sites (number of site shown) located within the class.

Table A3.2: Characteristic benthic invertebrates assemblage by classes at the 20-class level of the Hauraki Gulf classification based on proportion of occurrences

Invertebrates	MARINE ENVIRONMENT CLASSIFICATION class		
	1	4	205
Siglanoidea	0.1	0.1	0.1
Brittlestar	0.4	0.5	0.1
Aglophomus macrovra	0	0	0
Paleomon sp.	0	0	0
Crab sp. 3	0	0	0
Macroclymenella stewartensis	0	0.1	0
Onuphis aucklandensis	0	0	0
Nucula hartvigiana	0	0	0
Lumbrineridae	0	0	0.1
Glyceridae	0	0	0
Torridoharpinia hurleyi	0	0	0
Helice crassa	0	0	0.2
Echinocardium	0.1	0	0
Ampheritidae	0	0	0
Cumacean	0	0	0
Aquilasio aucklandia	0	0.1	0
Theora lubrica	0.1	0	0.1
Dosina sp.	0	0	0
Pectinaria australis	0	0	0
Zenatia acinaces	0	0	0

Note: The cells show the average frequency of occurrence of each species based on a random sample of sites (number of site shown) located within the class.

Appendix 4: Graphical Description of Mantels Test and ANOSIM

Mantel tests and ANOSIM work in similar ways but test slightly different things and provide slightly different output. This figure describes graphically how they work. Imagine five sites where biological data have been collected. The axes in biological space (on the left) represent the abundance of different species. This example uses only three species so that our space is three-dimensional and can be drawn. We have generally been working with a large number of species and therefore multi-dimensional space, however, the principles are exactly the same. Each point is plotted in a biological space using the abundance of each species as the coordinates. From this plot, we can measure the distance between each pair of points. These distances are recorded in a matrix called the biological (pair-wise) distance matrix.

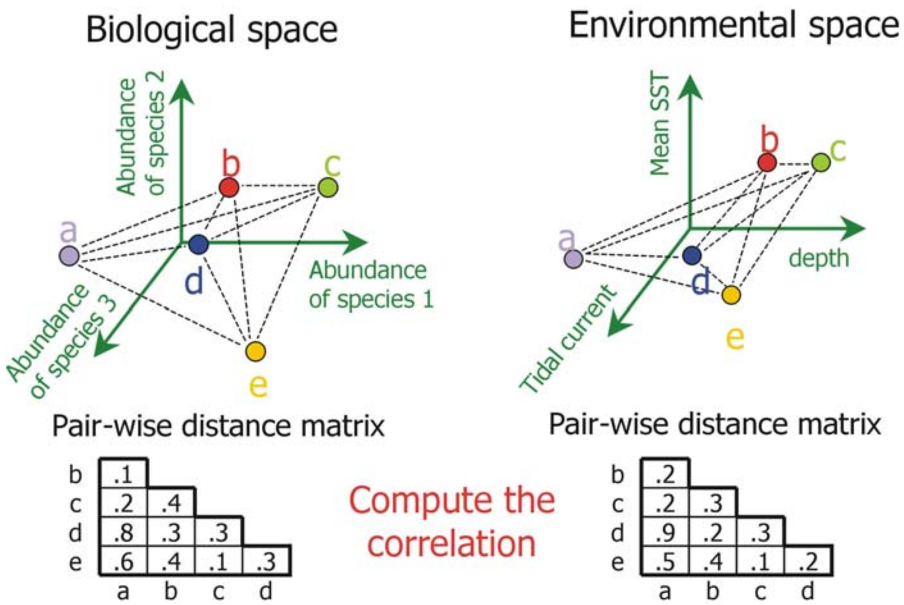
The same process is carried out with the environmental data, in an environmental space. Here the axes represent different environmental variables, e.g. depth, mean SST, tidal current. The environmental space can be changed by adding, weighting and transforming variables. Each axis represents a variable so if we can add or remove a variable we add or remove an axis, if we transform a variable we change the scaling along that axis, and if we want to weight a variable, we duplicate its axis. Once the variables, transformations and weighting have been decided, we plot the points in environmental space using the values of the environmental variables as coordinates and record the results in a matrix called the environmental (pair-wise) distance matrix. This environmental distance matrix can then be compared with the biological distance matrix.

In a **Mantels test** (Appendix 4, Figure A 4.1) the correlation between the two matrices gives an objective measure of the match between biological and environmental space. The correlation between the two matrices is a measure of how well the combination of our environmental variables represents the biological pattern. Different environmental spaces (defined by adding, weighting and transforming variables) can be tested to examine how correlation can be increased.

An **ANOSIM** tests how well an imposed grouping of the sites explains variation in actual biological data and is used to test the strength of the environmentally based classification. An ANOSIM works in the biological space with two values:

- the average distances between sites **within** each imposed class and
- the average distances **between** classes

Figure A4.1: Graphical representation of Mantel test



These distances are illustrated graphically in (Appendix 4, Figure A4.2) below. The statistic that ANOSIM reports is the between class distance minus the within class distance. This value is high (i.e. the classification is strong) when the within-class distances are small (i.e. the sites are biologically similar) and the between-class distances are large.

Figure A4.2: Graphical representation of ANOSIM test