# An Interim Bioregionalisation for the continental slope and deeper waters of the South-East Marine Region of Australia.

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## Report to the National Oceans Office

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# 1 Introduction

## *1.1 Need*

Ecosystem-based management via regional marine planning is a central policy principle of *Australia's Oceans Policy*, and the National Oceans Office is charged with putting regional marine planning into effect. The Biological and Physical Assessment currently being carried out by the National Oceans Office is intended to contribute to the implementation of ecosystem-based management in the South-east Marine Region by developing a shared understanding of the ecosystem.

The assessment has two streams, ecosystem structure and ecosystem function. This project is part of the ecosystem structure stream, which is focussed on the spatial distribution of the physical and biological components of the Region. The focus of ecosystem function stream is the key processes that link the biological and physical components and how they drive the dynamics of the ecosystem.

*Ecosystem Structure - bioregionalisation*
Developing operational boundaries for regional marine planning based on ecosystem characteristics will be a significant step towards ecosystem-based management. To accomplish this in Australia's South-east Marine Region, the National Oceans Office is coordinating a bioregionalisation: a process of identifying spatial structures (bioregions) based on ecological attributes (e.g. geology, ocean currents, biota).

The South-east Marine Region consists of three Large Marine Domains (LMD) identified by Lyne et al. (1998), the South-eastern, South Tasman Rise, and Macquarie. While the LMD's provide a large-scale classification, based principally on oceanographic and geological features, the implementation of regional marine plans will require that the LMD's be divided at a finer spatial scale based on ecological characteristics (geological, chemical, physical, biological, etc). The aim is to produce an Interim Bioregionalisation that has a hierarchical structure that reflects ecosystem processes.

The Interim Bioregionalisation will be used to:

- Assist in designing a nested spatial framework for designing potential management options for the Region that reflect ecosystem characteristics.
- Select the appropriate spatial scale on which to analyse information from the assessments for the Region so that they relate logically to ecosystem characteristics.
- Provide an operational basis for setting management targets and assessing the state of the ecosystem as part of the performance assessment process for the SEMR.

It is possible to explore, measure and describe the marine environment in myriad ways and there is no single best or correct bioregionalisation. The best approach to identifying bioregions in any one instance depends on their intended use. For the South-east Regional Marine Plan (SEMR) the purpose of classifying bioregions is to support integrated, ecosystem-based marine planning and management. This purpose differs from that of previous bioregionalisations in Australia, including the Interim Biogeographic Regionalisation for Australia (IBRA; Thackway and Cresswell 1995), the Interim Marine and Coastal Regionalisation for Australia (IMCRA Technical Group 1998) and the Great Barrier Reef – Representative Areas Program (Day et al. 2000) which were designed primarily to support the conservation of biodiversity, especially the development of a representative system of protected areas. This project nevertheless builds upon the experience of IBRA, IMCRA, the GAB-RAP, the numerous regionalisation and habitat-mapping projects being undertaken by the Australian States, and overseas experience.

The developers of IMCRA built on the success of IBRA to create a series of marine bioregions. The final product was composed of three different bioregionalisations: a meso-scale plan and two provincial plans. The 60 meso-scale regions arose from a compilation effort similar to IBRA (Thackway and Cresswell 1995). State/Territory agencies contributed regionalisations which generally covered their jurisdictional waters (from the territorial baseline out to 3 nautical miles) although spatial coverage varied. These component projects varied widely in methodology.

Both provincial regionalisations cover the area from the territorial baseline to the edge of the continental shelf (defined as the 200 m isobath). One of these is based on demersal fish species composition and richness; the other is based on the same data for pelagic species (IMCRA Technical Group 1998). (*Demersal* organisms remain close to the seafloor; *benthic* organisms live on, or burrow within, the seafloor; *pelagic* organisms are those that live in the water column, sometimes far above the seafloor). The developers extended the pelagic regions to the edge of the EEZ on the basis of a physical oceanography regionalisation (seasonal regions for three depth layers calculated with multivariate cluster analysis) (CSIRO 1996). The demersal regions were extended offshore of the shelf-break using benthic habitat regions (based on topography, sediment type and water mass signature at the seabed). Both provincial products contain 'biotones', transition zones between 'core' regions characterised by relatively large changes in the observed ecological assemblages.

The work reported here is concerned only with the parts of the South-east Marine Region (SEMR) *beyond* the continental shelf (i.e., in depths greater than 200 m). Unlike shelf waters, biological data has never been used in regionalisation for these deeper waters. This report is also concerned mainly with the demersal environment.

The procedures used here assume a hierarchy of levels at which we can 'focus' on the structure of an ecosystem. Since this idea is central to this report, we explain it here in some detail.

## *1.2 A hierarchical view of marine ecosystems*

The natural world has to be viewed as a hierarchically structured system (Allen and Starr, 1982; O'Neill *et al.*, 1986). It is now widely recognised that the structure and function of (marine) ecosystems is a multi-scale process (e.g. Greene *et al.*, 1994, 1995, 1999; Holling, 1992; Langton *et al.*, 1995; Garcia-Charton and Perez-Ruzafa, 1999; Poiani *et al.*, 2000; Roff and Taylor, 2000) and that this has to be taken into account in management practice. The ecosystem-based approach to planning uses natural regions as planning units, but natural regions need to be identified on a range of hierarchically nested scales for different planning and management purposes. The property of *scale* that distinguishes different hierarchical levels in natural systems is a continuously-varying function (Allen and Starr, 1982) – thus, sharp, unequivocal boundaries are the exception rather than the rule. Nevertheless, in most systems there are real discontinuities that can be recognised, and these have allowed the development of a number of classification schemes for different purposes. Examples in habitat classification include Greene *et al.* (1994, 1995, 1999), and Davies and Moss (1999). These authors (e.g. Greene, pers. comm.) are not wedded to the fine details; what they stress is the importance of the hierarchical view, and the need for an agreed classification scheme as a working language for their particular purposes.

Within the complexity of the natural world, different hierarchies can be identified that allow different interpretations and uses, and there are fundamental conceptual differences, not merely small details, behind these various forms. In brief, the differences are about appropriate surrogates and indicators (for habitats, "biodiversity" and "ecosystem" structuring), and about providing the hierarchical context whenever one speaks of such things as habitats. We need to think of biodiversity as a hierarchy and not as a singular concept such as indicator species or "habitats". The classification scheme adopted in our case must be linked to management actions (what actions are appropriate at what level).

The levels in habitat classification schemes cannot usually be specified simply in terms of a spatial scale. This is because it is difficult to put even rough spatial scales on the units being mapped, unless they are first placed in the context of the level above. Thus, deep ocean biotopes are likely to have very different (greater) spatial scales than those in the coastal environment.

In this report we do not review the various habitat-classification schemes, but we outline the scheme adopted for this project. The scheme has been devised for the Northwest Shelf Joint Environmental Management Study (WA Department of Environmental Protection and CSIRO Marine Research), primarily by V. Lyne and P. Last (CMR), but is designed to be useful anywhere in Australian waters.

### 1.2.1 A scheme of habitat classification

The following hierarchical scheme to classify the structure of marine habitats is under development by CSIRO Marine Research (V. Lyne, P. Last and others) for the Northwest Shelf Joint Environmental Management Study. It takes account of other published schemes but is adapted for Australian needs. This is Version 1.2 (February 2001). Here it is applied to the South-east Region to illustrate the concept using existing information for part of the continental shelf.

**Level 1. Province**: Evolutionary biogeography is the key process at this Level as reflected by the presence of regions of endemism determined from the presence/absence and distributional range of informative species. These regions correspond to the biogeographic IMCRA Provincial units and comprise both pelagic and continental shelf demersal provinces along with the overlap regions or biotones between provinces. We restrict our attention here to the demersal provincial units only.

**Level 2a. Biome**: Here, the sea is divided into the neritic and oceanic zones with the boundary between the two at the continental shelf break (nominally defined by the 200m isobath). The neritic zone has four primary biomes: estuarine, coastal marine, demersal shelf and pelagic shelf. The oceanic zone consists of: three primary demersal biomes (continental slope, abyssal, and hadal), and five pelagic biomes (epi-, meso-, bathy-, abysso- and hadopelagic biomes).

**Level 2b**. **Sub-biome**: Mesoscale structuring or subdivisions within the Level 2a biomic units which may be operationally more useful units at this level. For example, on the SE shelf, Williams and Bax (2001) identified seven sub-biomic units from a multivariate analysis of informative fish species: northern and southern communities on the inner, outer and shelf-break. As another example, on the NW shelf, data on demersal fish and benthic invertebrates led to the recognition of inner-, mid- and outer-shelf sub-biomes. Generally sub-biomic units may be expected to contain distinct collections of biotas.

**Level 2c. Sub-biomic structure**: Further mesoscale substructure, again based on recognisably distinct composition of the biota, within level 2b. For example, along-shelf subdivision of the inner-, mid- and outer-shelf sub-biomes. (Note: The IMCRA-derived "mesoscale regions" contain a mixture of biomes (Level 2) and morphological units (Level 3).)

**Level 3. Biogeomorphological units**: Within each biome, there are major meso-scale biogeomorphological subdivisions that can be easily identified and which usually have distinct biotas. These biotas can be mapped within levels above to provide a generalised expression of a geographic area. On the continental shelf, typical units include (Shepard, 1959): glaciation structures, sand banks and depressions, deltaic bottoms, submarine plains and valleys, seamounts, bioherms ("hills that owe their growth to some type of calcareous organism" - Shepard, 1959), rocky banks and islands, coral atolls, and regions of strong current/bottom stress. In the coastal biome typical units include fringing reefs, beaches, tidal flats, mudflats, and shallow embayments. (Note use of plural forms (eg., beaches not beach) to denote a general category, not denying that there are various types within it). On the southeastern shelf these units include biotas associated with sediment plains, rocky banks, and valleys and cliffs at the shelf-break. Continental slope units include biotas associated with canyons and seamounts.

**Level 4. Primary Biotopes**: Within a geomorphological level, primary biotopes refer to soft, hard or mixed substrate-based units, together with their associated suites/collections of floral and faunal communities, modified by hydrological variables such as wave exposure, turbidity, tidal effects and current speed. Maps to this level can generally be obtained from some targeted acoustic discrimination work (hardness/softness and roughness, and bathymetry) and a desktop study – although without providing details of community structure and compositon or biodiversity. Delineation of features, with relief and approximate boundary positions may be possible.

**Level 5. Secondary Biotopes**: Substructural units of the primary biotopes distinguished by the generalised types of biological and physical substrate within the soft/hard/mixed types (e.g. igneous, calcareous, silts, sands, gravels, seagrasses, sponges). Biological and physical sampling provides ground-truthing for geological, biological and ecological understanding (community structure and composition or biodiversity) at this level.

**Level 6.  Biological Facies**: These are identifiable biological and physical units defined by a biological indicator, or suite of indicator species, that identify a biological assemblage used as surrogate for a biocoenosis or community. They include, for example, a particular species of seagrass, or group of corals, sponges, or other macro-fauna strongly adherent to the facies.  Down to this level, the hierarchy is pseudo-spatial and involves a mix of biogeophysical definitions that reflect the primary scale-dependent biogeophysical processes and associations needed by biodiversity managers.

**Level 7.  Micro Communities**: Within Facies there exist assemblages of species that depend on member species of the Facies (eg holdfast communities in *Macrocystis*). It is assumed that conservation of the Facies will generally ensure conservation of associated micro-communities.

This scheme is summarised in Table 1.

**Table 1 Hierarchical scheme for habitat mapping and classification**

| **Level** | **Names** | **Examples** |
|---|---|---|
| 1 | Province | Large-scale biogeographic units. For example, IMCRA Technical Group (1998) recognised three demersal provinces and two biotones on the continental shelf in the SEMR and one for Macquarie Island.. Provinces are typically of the order of ~1,000 km in extent. |
| 2 | 2a Biome | Continental shelf, slope, abyssal plain and offshore continental blocks (e.g. South Tasman Rise) are dictated by gross geomorphology. These are nested within provincial units and are typically several 100's of km or more in extent. |
| | 2b Sub-biomes | Shelf-break and upper slope; lower slope. These subdivisions are dictated by the distributions of animal communities, some of which have quite narrow depth ranges. |
| | 2c Mesoscale units | Along-slope subdivisions within, e.g., mid-slope unit, again typically dictated by faunal distributions. IMCRA identified 12 mesoscale units on the continental shelf in the SEMR, from 50 to 350 km in size. |
| 3 | Geomorphological units | Areas characterised by similar geomorphology. These may include (on the continental shelf) fields of sand-waves, rocky outcrops, incised valleys, flat muddy seabeds, etc., and (on the slope and at abyssal depths) submarine canyons, seamounts, oceanic ridges and troughs, etc. Such units may typically be about 100 km in extent. |
| 4 | Primary Biotopes | Low-profile reefs; soft-sediment areas between reefs. Such units may be 10s of km in extent. |
| 5 | Secondary Biotopes | Rock types (e.g. fossiliferous limestone; granite); sediment types (e.g. poorly sorted shelly sands) or biota (e.g. seagrasses) |
| 6 | Biological Facies | Biological indicator (e.g. a seagrass species ) |
| 7 | Microcommunities | Species that depend on facies (e.g. isopods on seagrass) |

Note in Table 1 that *size* is not a criterion for level in the hierarchy. Thus, some level 2b units may actually cover less area than some level 3 units. Nevertheless, size typically decreases from level 1 to level 7, and so in Table 1 we give some indicators of spatial extent.

Although the above hierarchical scheme has at least 7 levels, at this stage in the SE Bioregionalisation project we are reporting only on levels 1 – 3; that is, Provinces, Biomes, some subdivisions within biomes, and fairly large-scale geomorphological units.

### *1.3 The challenge*

Ideally, a bioregionalisation for Australian waters should be undertaken nationally, and should use data on the continental shelf, slope and beyond – so that the structure of each area is examined in the context of neighbouring areas. Further, we should collect the necessary data to fill major gaps. However, in reality it was necessary to tackle only the SEMR, to do it only with available data, to consider only the areas beyond the continental shelf (which had already been regionalised, albeit only in an interim way, by IMCRA), and to do the work in a very short time. Therefore this is an, **Interim** bioregionalisation and we also do not consider the pelagic regionalisations.

## 2 Projects contributing to the SEMR Bioregionalisation

The National Oceans Office commissioned a number of projects to deliver data for the bioregionalisation. Each of them delivered data to the analysis team (as well as to the NOO). Some other data sets were obtained directly by the analysis team from CMR or GA data archives. The projects are listed in Table 2 and briefly outlined below.

**Table 2: List of individual projects for the South-east Marine Region Bioregionalisation.**

| | Project | Project Team |
|---|---|---|
| 1 | Production of a consistent, high quality bathymetric data grid for the south-east marine region. | Australian Geological Survey Organisation (now Geoscience Australia) |
| 2 | Seabed characterisation of the south-east marine region (including geomorphology, acoustic facies and seabed sample data). | |
| 3 | Upgrade of computer sediment model (GEOMAT). | |
| 4 | Refine Broad Scale Bioregionalisation (Provinces and Biomes). | CSIRO Marine Research |
| 5 | Upgrade deepwater nutrient, water properties and ocean current models. | |
| 6 | Rapid assembly of ecological fish data (community composition and distribution) for the South-east region. | CSIRO Marine Research (in collaboration with Australian Museum, Victoria Museum and NSW Fisheries) |
| 7 | Rapid assembly of ecological invertebrate data (community composition and distribution) for the South-east region. | Museum Victoria (in partnership with Australia Museum and CSIRO Marine Research) |
| 8 | Bioregionalisation analysis for the South-east Marine Region: integration of geological, oceanographic and biological data as the basis for bioregionalisation (*This project*). | CSIRO Marine Research and Australian Geological Survey Organisation (now Geoscience Australia) |

### 2.1 Production of a consistent, high quality bathymetric data grid for the south-east marine region.

This project added approximately 400,000 new bathymetry data points to the Geoscience Australia (formerly AGSO) bathymetry database for the continental shelf area to supplement data already entered from shelf, slope and rise to develop a consistent, high quality bathymetric data grid in the south-east marine region. Analysis of this map provided estimates of slope, aspect and geomorphological units.

### 2.2 Seabed characterisation of the south-east marine region (including seabed sample data).

This project captured, analysed and interpreted existing seabed sediment data and other ship based acoustic survey results to provide maps of sediment distribution and seabed characterisation for the south-east marine region. The aim was to provide geological proxies for the occurrence of benthic habitats. Seabed sediment maps included carbonate content, mean grain size and sorting (standard deviation), percentage gravel, sand and mud content. The acoustic facies maps use the Damuth (1980) scheme and were based upon an assessment of available high frequency echograms (3.5 and 12 kHz) together with backscatter data collected by the various swath surveys. Geomorphological units were identified on the basis of bathymetry and a review of previous geological studies.

### 2.3 Upgrade of computer sediment model (GEOMAT).

Habitat types may be differentiated on the basis of the mobility of the substrate in response to oceanographic processes. The goal of GEOMAT is to predict the percentage of time that surficial sediments at shelf water depths (ie <200 m) are mobilised by surface swell waves and tidal currents on an annual basis. The aim is to provide geological proxies for the occurrence of benthic habitats.

### 2.4 Refine broad scale bioregionalisation (province and biomes).

This project was designed to confirm and/or amend the existing broad scale bioregionalisation (province and biomes) as a basis for the development of an interim bioregionalisation for the South-east Marine Region (allowing for additional refinement of provincial boundaries as necessary and development of biogeographical units if possible). It took into account existing data sets made available by Geoscience Australia, viz. Sedimentary basins, Tectonic elements, Crustal age, and Earthquake epicentres/magnitudes, as well as appropriate aspects of the data provided by the other projects listed here.

### 2.5 Upgrade deepwater nutrient, water properties and ocean current models.

This project provided consistent, high quality models for deepwater nutrients and water properties based on the methodologies developed by Ridgway et al. (2002), as well as ocean current fields based on hydrodynamic model outputs (Bruce et al. 2001) Apart from their use in the bioregionalisation, these products could serve as core data sets for physical and biological studies within the South-east Marine Region, and to assist in identifying areas requiring specific management actions. The project provided:

- A gridded dataset of seasonal nutrient distributions (nitrate, phosphate, silicate) covering the South-east Marine Region at a resolution of 0.125° in latitude and longitude, and at 56 depth levels down to 5500 m.
- A gridded dataset of seasonal temperature and salinity distributions covering the South-east Marine Region at a resolution of 0.125° in latitude and longitude, and at 56 depth levels down to 5500 m.
- A dataset of seasonal dissolved oxygen distributions covering the South-east Marine Region at a resolution of 0.125° in latitude and longitude, and at 56 depth levels down to 5500 m.
- Maps of nutrient, temperature, salinity, and oxygen distributions showing the South-east Marine Region at selected times and depths.
- A dataset of seasonal currents covering the South-east Marine Region at a resolution of 0.2°, and at 37 depth levels down to 1900 m. These fields were output from a circulation model of the region.
- Maps of current vectors showing the South-east Marine Region at selected times and depths.
- An animation of seasonal near surface currents and temperatures in the South-east Marine Region.

### *2.6 Rapid assembly of ecological fish data (community composition and distribution) for the South-east region.*

This project used information on the distributions of fish species, assembled from fisheries databases, fish collection databases, and published data to deliver:

- an assessment of provincial substructure (level 1) within the region,
- an assessment of biomic substructure (level 2) within the region,
- a matrix and classification of south-east regional fish species into their primary biomes, and
- a listing of metadata used to produce the regional maps.

### *2.7 Rapid assembly of ecological data on key invertebrate groups of the South-east Marine Region*

This project provided a database of collection data relating to key invertebrates from the South-east Marine Region shelf and slope. Echinoderms and decapods were considered key taxa in the marine invertebrate communities and reliable information could be rapidly assembled from existing data sets; pycnogonids (sea-spiders) were also included because their close association with hydroids and bryozoans meant that they would be indicators of a number of invertebrate community types and factors influencing community structure, and the pycnogonid data could be assembled in time to meet the project deadlines. Unidentified material from existing collections was identified and added to the data set.

### *2.8 Task for this Project*

This project, entitled "*Bioregionalisation analysis for the South-east Marine Region: integration of geological, oceanographic and biological data as the basis for bioregionalisation*", aimed:

- To analyse biological, geological and oceanographic data sets for the South-east Marine Region with the aim of developing an Interim Bioregionalisation appropriate for regional marine planning.
- To delineate bioregions of the outer shelf, slope and abyssal waters among and within each of the three Large Marine Domains of the South-east Marine Region, complementing where possible existing meso-scale IMCRA bioregions.
- To work in close consultation with the Bioregionalisation Working Group to refine the analytical approach, interpret the outputs and develop the Interim Bioregionalisation.

## 3 Methods

### *3.1 Workshops*

An initial meeting of all the successful tenders for Related Projects was held in early August to ensure that all parties shared a common understanding of what they needed to deliver and what would be done with their data. Issues of data attributes, data formats, timing of deliverables etc were clarified so that these urgent projects could proceed smoothly and successfully. Administrative and operational arrangements were also confirmed.

In early October, the Bioregionalisation Working Group met with the project teams to discuss progress in the delivery of their various data sets, and in particular, to discuss with the analysis team the approaches that would be taken to the analysis. Thus, the methodology below reflects discussion amongst the teams, and input from the Working Group, at that meeting.

### *3.2 Data available*

The data provided by the related projects (above) were delivered in stages (some by 30 September; the remainder by 1 November). Some preliminary interpretation, and discussion of analysis options began as soon as some of the data were in hand, but from early November the team had available to it the following data sets:

- A high-resolution (250 m grid spacing) bathymetric model of the two regions (SE Continental Margin and Macquarie Island).
- Maps of geomorphological units.
- GIS with coverages of the available seafloor sediment data (grain size, sorting, carbonate, mud, gravel and sand content).
- Interpreted acoustic faces derived from available echosounder and swath bathymetry backscatter data, including the previous published acoustic facies map of Whitmore and Belton (1997).
- GIS coverages of ocean crust age, tectonic elements and sedimentary basins.
- GEOMAT sediment modelling output, including three years of wave data presented as a series of maps showing the percentage of time that surficial sediments at shelf water depths (i.e. <200 m) are mobilised plus two weeks (one neap-spring cycle) of tidal current data analysed to estimate the percentage of time that surficial sediments at shelf water depths (i.e. <200 m) are mobilised. The ratio of wave and tide mobilisation will be derived to provide a spatial assessment of their relative importance.
- A preliminary refinement of the broad-scale bioregionalisation based on data already to hand during October.
- A gridded dataset of seasonal nutrient distributions (nitrate, phosphate, silicate) covering the South-east Marine Region at a resolution of 0.125° in latitude and longitude, and at 56 depth levels down to 5500 m (Dunn and Condie 2001).
- A gridded dataset of seasonal temperature and salinity distributions covering the South-east Marine Region at a resolution of 0.125° in latitude and longitude, and at 56 depth levels down to 5500 m (Dunn and Condie 2001).
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- Maps of nutrient, temperature, salinity, and oxygen distributions for the South-east Marine Region at selected times and depths (Dunn and Condie 2001).
- A dataset of seasonal currents covering the South-east Marine Region at a resolution of 0.2°, and at 37 depth levels down to 1900 m. These fields were output from a circulation model of the region (Dunn and Condie 2001).
- Maps of current vectors for the South-east Marine Region at selected times and depths (Dunn and Condie 2001).
- An assessment of provincial structure (level 1) within the region, based on the distributions of fish species, assembled from fisheries databases, fish collection databases, and published data (CSIRO et al. 2001).
- An assessment of sub-biomic structure (level 2b) within the region, based on fish distributions (CSIRO et al. 2001).
- A database of collection data relating to key invertebrates (echinoderms, decapods and pycnogonids) from the South-east Marine Region shelf and slope. The database gave positions and depths of collection for each specimen.

## 3.3 Analytical procedures

Our procedures were to use numerical analyses to identify patterns in the data, where the data were of sufficient quantity and quality, and otherwise to overlay the patterns produced by different data sets and to assess their agreement or disagreement. This qualitative consideration was done by a group of experts with experience of each aspect of the science underlying the patterns (geology, sedimentology, tectonic history, oceanographic patterns and processes, ecology and evolution of fishes and invertebrates).

Where open questions were identified that could not be dealt with in the limited time available, these were noted for later attention.

Because of the patchy distribution of the data, and the scales that they naturally represent, different data sets were emphasised at different levels of the hierarchy. Other data sets were then used to corroborate the patterns identified. Thus (for example), data on fish gave us the main pattern at level 1, but we then asked whether each of the other data sets is in accordance with the pattern identified in the fish data.

The roles of the data sets were:

## *Level 1 - Provinces*

Analysis of the distributions of fish species gave Level 1 provincial structures (provinces and provincial biotones) where these data were available (there are no fish data deeper than 2000 m). The report from the fish project (section 2.6 above) was important for discriminating Levels 1 and 2b. The fish database contained information on presence and abundance of each species in neighbouring regions, as well as their presence, abundance and depth-distribution within the SEMR, for fish occurring deeper than 150 m. An expert workshop chose fish species that were informative in suggesting biological patterns reflecting biogeographic and evolutionary history, for use at Level 1, and small-scale spatial patterns for use at Level 2. Distributions of fish species were recorded as 'strings' along the 500m depth contour. For the analyses, the string was partitioned into smaller segments of about one degree latitude length (about 120km) into which tabulations of species occurrences were maintained.. The similarity or difference between adjacent string segments was measured using the Jaccard statistic. This allowed us to identify locations of relatively rapid change in faunal composition moving along the depth contour. A similar approach was used to identify depth-patterns. A simultaneous analysis, along the string and by depth, was possible but would require better data coverage in order for the results not to be unduly biased by data density problems.

In deeper water, where there are no fish data, potential Level 1 patterns were inferred from geological structure (bathymetry, tectonic elements and fault-lines, plate age). These patterns from fish and geological structure were corroborated by comparison with the patterns seen in:

- seawater temperature,
- oxygen,
- nitrate and phosphate.
- invertebrates – these data are much more sparse than the fish data but were analysed using a similar Jaccard analysis.

It was not possible to do complex, multivariate statistical analyses or modelling, combining different datasets, due to the patchiness of much of the data. Further, any multivariate analysis with a number of datasets of quite disparate forms would be a large statistical task which could not be attempted in the time available. Some of it could be done later, but our judgement is that it would be unlikely to alter conclusions.

Refinement and more precise positioning of the Provincial boundaries was undertaken with reference to the Biome and Geomorphological Units. Thus the fish data indicated a core Province whose boundaries were located off the southwest and south-southeast continental margins of Tasmania, and these were extrapolated from the shelf break to the EEZ limits along the closest boundaries identified at Levels 2 and 3. This illustrates the point that data at lower levels are required to locate boundaries at higher levels in the hierarchy. The strength of the Province is uncertain at this stage as it cannot be placed in the context of other (slope) provinces which may exist elsewhere in the national EEZ. We suspect it is a relatively weak province as the fish analyses showed considerable overlap in the species mix across the whole of the south east domain.

## *Level 2 – Demersal Biomes, Sub-biomes and Mesoscale units*

**Level 2a** Identification of the shelf edge, base of the continental slope, abyssal plains and location of continental blocks was based on analysis of available bathymetric and geological data. The biological data could not contribute here, being truncated at the upper limit by the decision not to include the shelf, and being unavailable at depths greater than 2000 m. The shelf edge was taken as the 200 m depth countour, the generally accepted standard, while the base of the continental slope was identified as being the sharp change in depth gradient where the continental slope meets the abyssal plain.

**Level 2b** Structure at this level was identified from the fish data down to 2000m, with some indication of deeper structures from the invertebrate information.

Patterns identified from fish were again corroborated by examining the following datasets.

- slope analysis of the bathymetry and implications regarding local environments,
- time-averaged patterns in currents,
- temperature,
- oxygen,
- nitrate,
- phosphate and.
- invertebrates – the analyses were similar to those for fish, but the data are much more sparse. Multiple Jaccard analyses at various separation scales were averaged to achieve smoothing of the sparse dataset.

Continental blocks rifted from the mainland were identified by Geoscience Australia. These and other large-scale structural features were considered by the team to be Level 2 units (surrogate), in areas where we had no pattern identified from fish.

**Level 2c** From the available sparse biological data, it was considered impossible to resolve any level 2c boundaries for this study.

### *Level 3 – Geomorphological units*

Level 3 units are intended to be biogeomorphological (see above) but, given available information, structure at this level was identified by the interpretation of the detailed bathymetry data in terms of geomorphological units. The units identified were bounded by the shelf break and the base of slope, and the features were: smooth continental slope, submarine canyons, seamounts, continental crust blocks, volcanic cones, volcanic ridges, trenches, saddles, plateaux and abyssal plains (see Results for definitions).

Each of the geomorphic units was defined using Geoscience Australia's 250 m spatial resolution bathymetry model with reference to previous geological studies of Hill *et al*. (1995; 1997), Exon *et al*. (1997a,b), Massell *et al*. (1999) and Bernardel *et al*. (2000). The identification of individual submarine canyons was aided by using the results of a drainage analysis of the bathymetric model (including the 250m grid AUSLIG topographic map for Australia) carried out using ARCINFO.

Patterns identified from the geological structure were corroborated by examining the following data-sets:

- crustal age,
- seabed sediment type,
- sedimentary basins,
- acoustic facies,
- ocean current speed and direction (both mean and maximum).

In some cases, the geomorphic units were further subdivided on the basis of patterns suggested by these corroborative data sets, particularly the acoustic facies maps.

## 3.4 Numbering and naming of units

The Provincial units (these comprise true Provinces and Biotones but for convenience in numbering we refer to the units with a prefix P) and Geomorphological units were each assigned a preliminary number. The numbering was initially from west to east (i.e. P1 - Provincial unit 1 is the westernmost and P3 - Provincial unit 3 is the in the east). Some Level 3 numbers were later inserted out of sequence in cases where areas were later subdivided on the basis of secondary (corroborative) information.

The Level 2a Biomes are cited according to their common (publicly accepted) names. Hence we have 3 continental slopes (in P1, P2 and P3), the South Tasman Rise (in P2) the East Tasman Rise (in P3) and 3 abyssal plains (in P1, P2 and P3).

The Level 2b Sub-biomes have not been numbered separately because they occur as specific depth bands on the continental slope and rises. Level 2b Sub-biomes are cited, however, in the Level 3 descriptions as Sub-Biome A1 (320-550 m), A2 (850-1120 m), A3 (1600-2000 m) and B (2000 m to base of slope).

For the Macquarie Ridge, there was only one Province and there was only enough biological data to define one Level 2b sub-biome. Three Level 2a Biomes and 21 Level 3 Geomorphological Units were numbered sequentially generally from north to south.

# 4 Results

## *4.1 The analysis process and results*

The process of interpretation was iterative, as indicated above, so the 'results' became part of the 'methods'. Therefore, in this section we outline the iterative decision-making process and its outcomes.

### *Level 1 – Provinces and Biotones*

Analysis of the distributions of fish species gives Level 1 provincial units where these data are available (there are no fish data deeper than 2000 m). At Level 1, the Jaccard analysis of fish distributions led to the interpretation that there is one core Province in the SEMR (corresponding to the one we have called Province P2 here) and that the others to E and W of it are probably biotones, grading into provinces which we may expect eventually to be identified in the neighbouring regions. The analysis also confirmed that Macquarie should be considered a separate Province from the continental part of the SEMR.

In deeper water, where there are no fish data, Level 1 patterns have been inferred from geological structure (bathymetry, tectonic elements and fault-lines, plate age). These patterns from fish and geological structure were corroborated by comparison with the patterns seen in:

- seawater temperature,
- oxygen,
- nitrate and phosphate.
- invertebrates – these data are more limited than the fish data. By a similar Jaccard analysis, they showed faunal discontinuities not far from those of the fish off south-southeastern Tasmania and off western Bass Strait, but the level of confidence in these patterns was low, simply due to the sparse data.

The data on tectonic elements, fault-lines and plate age showed that the seafloors E and W of Tasmania differ structurally, in both orientation of spreading centres and plate age. The South Tasman Rise is a continental block, but both geologically (in the nature of the spreading at the margin) and biologically (fish) it is related to the south-western side of Tasmania, rather than to the eastern side.

We concluded that we have a core Province, based on fish and geomorphology (corroborated by other data) that comprises western Tasmania and the South Tasman Rise. To the E and W may be "overlap zones" if this were being viewed in a continental context but, in the present limited (SEMR) context, these are two other Level 1 units. Each Provincial unit extends offshore to the extended EEZ. The inshore limits were set at the 200 m contour (shelf break) so that they complementthe IMCRA Mesoscale Units.

In the definition of the western edge of Level 1 off western Bass Strait, we considered including (with the slope, and South Tasman Rise) a section of abyssal plain with continental block portions, but decided to confine the province to the edge of the slope break; thus that portion of abyssal plain with continental block fragments is assigned to the same area as the rest of the abyssal plain to the W, even though it is identified as a level 3 unit within that province.

It was not possible to do complex, multivariate statistical analyses or modelling, combining different datasets, due to the patchiness of much of the data. Further, any multivariate analysis with a number of datasets of quite disparate forms would be a large statistical task which could not be attempted in the time available. Some of it could be done later, and it would be possible to use Monte-Carlo-type tests to assess the significance of patterns identified, but our judgement is that it would be unlikely to alter conclusions.

In selecting the Level 1 Provincial boundaries, we referred to boundaries also identified at levels 2 and 3. Thus the fish data indicated Provincial boundaries located off the southwest and south-southeast continental margins of Tasmania, and these were extrapolated from the shelf break to the EEZ limits along the closest boundaries identified at levels 2 and 3. This illustrates the point that data at lower levels are required to locate boundaries at higher levels in the hierarchy.

## *Level 2 – Demersal Biomes, Sub-biomes and Mesoscale units*

**Level 2a**

Identification of the shelf edge, base of the continental slope, abyssal plains and location of continental blocks (South Tasman Rise and East Tasman Rise) was based on bathymetric and geological data. The biological data could not contribute here, being truncated at the upper limit by the decision not to include the shelf, and being unavailable at depths greater than 2000 m. The definitions used were:

- The shelf break was defined as the 200 m bathymetric contour.
- The continental slope is the zone of sloping sea floor extending from the shelf break and terminating at the continental rise where the gradient becomes less than 1:40 or where the slope is bounded by a deep-sea trench or a continental block. Around the Tasmanian margin, the continental slope begins at the 200 m bathymetric contour (i.e. shelf break).
- Abyssal plains are regions occupying the deepest portions of the ocean basins generally below 4000 m water depth and characterised by a low-gradient surface with a slope of <1:1000. These units extend out as far as the Exclusive Economic Zone (EEZ) in the SEMR.
- Continental Blocks are discrete pieces of locally subsided continental crust that are elevated above the surrounding sea floor. Around the Tasmanian Margin the continental blocks often occur as local highs in the underlying subsided continental crust which have been rotated on their side during separation of Australia and Antarctica, and include the South and East Tasman Rises.

**Level 2b**

Structure at this level was identified from the fish data, using the 'Jaccard' analysis reported by the fish project (above). This revealed some clear patterns, particularly a strong structuring by depth.

Patterns identified from fish were again corroborated by examining the following data-sets, particularly seeking any patterns that might contradict those seen in the primary dataset.

- slope analysis of the bathymetry and implications regarding local environments,
- time-averaged patterns in currents,
- temperature,
- oxygen,
- nitrate,
- phosphate and.
- invertebrates – the approach taken to analysis here was similar to that for fish, but the data are much more sparse. The invertebrate data, when analysed by multiple Jaccard analyses at various separation scales which were then averaged to achieve smoothing of the sparse dataset, appear to give a different depth-related structure from the fish. There is a depth relationship, but with transition points at different depths from those of the fish data. If this pattern is real, then it means that depth patterns are taxon-specific; it would mean that, although it is an overall property of the ecosystem that fauna changes with depth, it does so in such a way that there are no particular discontinuities common to all faunal groups. However, at present the invertebrate data are far less reliable than the fish data. We

have therefore chosen, for this *interim* bioregionalisation, to recognise the pattern in the fish data as indicating biomic structure on the slope. This may be revised following further collection of data on invertebrates.

Continental blocks rifted from the mainland were identified by Geoscience Australia. Some of these are small portions of continental rock rotated during the rifting process, some (like the South Tasman Rise) are enormous pieces of locally subsided continental crust. These and other large-scale structural features were considered by the team to be level 2 units (surrogate), in areas where we had no pattern identified from fish.

**Level 2c**
From the available biological data, it was considered impossible to resolve any level 2c boundaries for this study.

## *Level 3 – Geomorphological units*

Structure at this level was identified by the interpretation of the detailed bathymetry data in terms of geomorphological units. The units identified were bounded by the shelf break and the base of slope, and the features were smooth continental slope, submarine canyons, seamounts, continental crust blocks, volcanic cones, volcanic ridges, trenches, saddles, plateaux and abyssal plains. Three of these terms, Continental Slope, Abyssal Plains and Continental Blocks, are defined above for units comprising Level 2a; the remainder are::

Submarine Canyons **-** Deep, steep-sided valleys running wholly or partially across the continental slope, the bottoms of which grade continually downwards. Around the Tasmanian Margin, submarine canyons are typically excavated by gravity flows (e.g. turbidites) and are the major conduits for sediment transport downslope from the shelf to ocean basins. Canyon geomorphology was identified by a “catchment analysis” which involved analyses of the flow paths taken by particles moving downhill under the influence of gravity. Seamounts - Large, steep-sided, often irregularly-shaped elevations of the sea floor, rising up to 1000 m or more. In the SEMR, seamounts may be either discrete, arranged in a linear pattern or as random groups, and are associated with local upwelling of magma from the mantle during the opening of the south Tasman Sea. Isolated seamounts were easily identified from bathymetry.

Volcanic Cones - Steep-sided, conical volcanic vents or fissures in the crust. Identified from bathymetry as for seamounts but the cones are of smaller scale. Generally smaller than seamounts, volcanic cones on the Tasmanian Margin occur as parasitic cones on the flanks of seamounts or as fields containing many individual cones on the continental slope. On the south Tasmanian margin, many of the volcanic cones are the products of volcanism associated with the separation of Australia and Antarctica and the concomitant subsidence of the South Tasman Rise. The peaks in the Tasmanian Seamounts Marine Reserve are in fact volcanic cones of this sort.

Volcanic Ridges - Elongate, steeply-sided, linear-arcuate narrow elevations of the deep-sea floor, rising up to 1000 m or more. Occurring only in the Macquarie Ridge region of the SEMR, the volcanic ridges are comprised of oceanic crust and are associated with the Australia-Pacific plate boundary; the ridges being formed by the strike-slip movement of the two plates against one another and associated volcanism. Identified from elongation and gradients in the bathymetry contours.

Trenches - Long, narrow, relatively steep-sided depressions of the deep-sea floor, whose bottoms can exceed 6000 m water depth. Identified as for ridges. On the South Tasmanian Margin, a trench is part of the Tasman Fracture Zone and defines the boundary between oceanic and continental crust. In the Macquarie Ridge region of the SEMR, the trenches are part of an alternating oceanic trench/volcanic ridge complex formed by strike-slip movement of the Australia and Pacific plates.

Saddle - Broad, flat-topped ridges of the sea floor connecting two higher elevations located in water depths of 3,500 to 4,500 m. In the SEMR, saddles connect the South and East Tasman Rises to the base of the continental slope, and the Hjort Ridge to the Macquarie Ridge. Readily identified from bathymetric contours.

Plateau - Extensive, relatively flat region of the sea floor located at higher elevation. In the SEMR, plateaux occur on the western flank of the South Tasman Rise.

Geomorphological units, identified using the bathymetry model, were corroborated by examining the following data-sets:

- crustal age,
- seabed sediment type,
- sedimentary basins,
- acoustic facies,
- ocean current speed and direction (both mean and maximum).

In some cases, the geomorphic units were further subdivided on the basis of patterns suggested by these corroborative data sets, particularly the acoustic facies maps.

## 4.2 Maps of bioregionalisation

The definitive product from this project is a GIS containing the raw data and interpreted bioregionalisations at Levels 1, 2 and 3 for the SE regional marine plan. At the time of writing this report, we have produced maps for levels 1, 2 & 3 for both the SE continental margin and Macquarie Ridge (Figures 1-4).

## 4.3 Descriptions of units

The task of fully describing the units, and of making the descriptions electronically available, linked to the GIS and searchable, is a major one which has not been undertaken in the present project. In this section the units are verbally described.

**Level 1**

Demersal Provincial Unit P1 incorporates the continental slope and abyssal plain west of Tasmania and the South Tasman Rise (STR) (Figure 1). The Provincial boundaries are recognised, on the upper continental slope, by the distributions of fish species parallel to the coast; there is a discontinuity in these distributions broadly west of the NW tip of Tasmania and in the deeper water by the underlying geologic structure of oceanic crust and plate age. In fact, it is likely that, when examined in a whole-continental context, this area will be found to be an biotone between two well-defined faunal provinces – one being our Province P2 in the SEMR and the other lying further to the north and west. Invertebrate data broadly corroborate this picture but are sparse and therefore do not give a clear pattern. Beyond the upper slope, the lower slope and abyssal plain contain several small, rotated blocks of underlying continental crust protruding above the sea floor. These blocks are remnant continental crust that has locally subsided during and after the separation of Australia from Antarctica. The sea floor of the abyssal plains has broadly E-W trending features that have been inherited from the underlying structure of the oceanic plates.

Demersal Province P2 incorporates the southern continental slope of Tasmania and the large continental block of the South Tasman Rise (STR). Its boundaries on the slope are determined by discontinuities in the distributions of fish species parallel to the coast; these are broadly corroborated by discontinuities in the much more limited data available on invertebrate animals. Beyond the slope, the province has been defined to incorporate the continental block of the STR, and the abyssal plain further south. The western boundary is the escarpment of the Tasman Fracture Zone (TFZ), its eastern boundary the eastern edge of the STR. The STR is geologically and biologically (fish) related to the western Tasmanian Margin (i.e. P1). East of the STR, the boundary curves eastward because the abyssal seafloor to the south is structurally related to the spreading of Australia from Antarctica, rather than the earlier opening of the south Tasman Sea. Consequently, the provincial boundary has been placed at the boundary between these two structurally different regions.

Demersal Provincial Unit P3 incorporates the continental slope (including Bass Canyon), East Tasman Rise (ETR), and abyssal plain east of Tasmania. The boundary with Province P2 is recognised, on the upper slope, by the distributions of fish species parallel to the coast; there is a discontinuity in these distributions broadly south of Hobart. In fact, it is likely that, when examined in a whole-continental context, this area will be found to be a biotone between two well-defined faunal provinces – one being our Province P2 in the SEMR and the other lying further to the north. Invertebrate data broadly corroborate this picture but are sparse and therefore do not give a clear pattern. Beyond the slope, this province includes the submerged continental block of the ETR which locally subsided from Tasmania and the STR during the opening of the south Tasman sea approximately 80 million years ago. Beyond the continental slope, the sea floor of the abyssal plains has broadly N-S trending features that have been inherited from the underlying structure of the oceanic plates, and thus differs from associated regions in Provincial Units P1 and P2.

**Level 2a**

Level 2A (sub-biomes) distinguishes the shelf (which is not covered in this report), Continental Slope, Abyssal Plains and features such as locally submerged continental blocks (i.e. STR and ETR).
We have identified 11 biomes in the SEMR:

The East Tasman Rise (ETR), located approximately 100 km southeast of Tasmania, is a 50,000 $km^2$ roughly circular fragment of locally subsided continental crust. The ETR rises from water depths of >3300 m to almost 700 m at the summit of the younger volcanic cone of the Soela Seamount. The eastern flank of the ETR forms a steep (14°) 1400 m high scarp that gives way to a gently rising terrace which intersects the base of the steeply-sided Soela Seamount. The ETR also contains several smaller parasitic cones, both on the flanks of the seamount and along the terrace. The morphology of the western flank is similar to the eastern flank, starting out flat but then becoming more rugged. Analysis of planktonic foraminifers and calcareous nannofossils contained in seafloor dredges indicates that the formation of the ETR may have involved multiple phases of subaerial and submarine volcanism. Fish fauna on the ETR is more akin to that of eastern Tasmania but poorly sampled; there has been limited fishing on the shallowest (<1000 m) portion.

The South Tasman Rise (STR), is a 200,000 $km^2$ fragment of locally subsided continental crust that rises from water depths of >4000 m to an elevation of 800 m. The STR forms a NW-trending broad dome approximately 1000 km long and 500 km wide that is characterised by a rough, irregular surface surrounded by gentle slopes. North of the STR, in water depths of 4000-1800 m, steep (>20°) northwest-oriented scarps bound topographic highs of rotated continental basement rocks. Basins separating these highs have shallow floors (0-2°) which form numerous channels extending over tens of kilometres into the ocean basin. On the northwest flank of the STR, perched basins are floored by hardgrounds, possibly comprised of manganese nodules. The TFZ, on the western flank of the STR, is comprised of a series of high relief ridges and troughs, with escarpments up to 2-3 km high. Previous deep seismic and geologic studies (e.g. Exon et al. 1997a) have confirmed that the TFZ separates high-standing continental rocks of the STR from low-standing oceanic crust underlying the abyssal plain to the west. Ichthyologically, the STR has more in common with western Tasmania (hence its inclusion in Province 2) but because of its shallow depth it has species of fish otherwise found on the upper continental slope. Its invertebrate fauna are poorly known.

The P1 Continental Slope contains numerous submarine canyons that connect the continental shelf from water depths of 300 m to the top of the continental rise at water depths of ~3500 m. The submarine canyons are characterised by straight axes and v-shaped cross-sections with relief of between 25 m and 200 m. In the canyons, the gradient of the longitudinal profile decreases down slope, causing them to coalesce on the rise to form wide, shallow channels, particularly in the south. Large (up to 180 km long pieces of continental crust protrude from the sea floor on the lower slope (particularly near the boundary with Province 2). South of Cape Sorell, ~40% of the seafloor is exposed bedrock, which forms extensive WSW-trending canyons, escarpments and basement blocks with moderate to steep relief.

The P2 Continental Slope is characterised by rugged topography, with extensive rock exposure on the upper part of the slope, including jagged canyons (up to 250 m deep) and volcanic cones (up to 600 m high). Over the entire slope, small, localised areas containing ridges, pinnacles and valleys with relief of >100 m occur between extensive areas of moderately-graded, rough slopes and >70 volcanic cones. The seafloor on the lower continental slope contains numerous irregular, steep-sided ridges, separated by deep valleys. The axes of these ridges and valleys are aligned both parallel and sub-parallel to the TFZ, indicating that they probably were formed after folding of basement rocks, during strike-slip movement of the TFZ. Southwest of Tasmania, the continental slope is incised by an extensive network of linear to curvilinear submarine canyons that extend >60 km from the shelf edge to the base of the slope.

The P3 Continental Slope is a steep and rugged. The slope is incised with numerous submarine canyons that are up to 30 km long and >500 m deep and connect directly to the abyssal plain. The submarine canyons are more numerous in the north. East of Bass Strait, the continental slope also includes Bass Canyon, an ESE-trending funnel-shaped chasm 60 km long and 10-15 km wide at its mouth. The canyon has incised to a depth of >2 km and is bounded in the north and south by steep bedrock walls that attain 1000 m in height. The main canyon floor, located in water depths of >4000 m, is connected to the continental shelf by three large, deeply-incised tributary canyons and numerous smaller valleys. Erosion in the main canyon has exposed large vertical sections of the underlying continental crust.

The P1 Abyssal Plain is characterised by gently undulating relief associated with irregular and faulted underlying basement blocks imparting a broad E-W trending fabric on the sea floor. The P1 abyssal plain is characterised by the accumulation of fine pelagic ooze, implying very little subsequent reworking by currents. However, the fauna on the P1 abyssal plain is virtually unknown, and the area is relatively poorly sampled.

The P2 Abyssal Plain is characterised by gently undulating relief associated with irregular and faulted underlying basement blocks imparting a broad E-W trending fabric on the sea floor. The seafloor of the south Tasman margin is characterised by foraminiferal/nannofossil ooze and foraminiferal sand.

The P3 Abyssal Plain is characterised by gently undulating relief, with numerous seamounts, located in groups and as isolated elevations in the seafloor rising up to 1,000 m in height. In Bass Canyon, sediment transported down the canyon debouches at its mouth and spreads out onto the abyssal plain via a network of distributary channels.

The P4 Macquarie Ridge complex is characterised by and extensive kinked-linear to arcuate ridge complex extending more then 1500 km with a maximum relief of 1,500 m, but rises above sea level in places (e.g. Macquarie Island). The ridge complex defines the boundary between the Australia and Pacific plates, and is comprised of oceanic crust that has been thrust up as a result of the weakly oblique strike-slip movement along the plate boundary. The ridge is steeply-sided and has a uneven and heavily dissected surface.

The P4 Macquarie Trench complex is a long, narrow, relatively steep-sided arcuate depression of the deep-sea floor to the southwest of the Macquarie Ridge. The trench formed from the buckling of oceanic crust associated with the strike-slip movement of the plate boundary, and is a section of oceanic crust that has been buckled downwards due to compression of the Australian Plate adjacent to the plate bounary. The Macquarie Trench is characterised on its western margin by gently sloping sea floor of exposed underlying oceanic crust and patches of relatively thin pelagic sediment. The steeper sides of the trench are characterised by gravity flows which deposit fine pelagic sediment in the bottom of the trench in water depths exceeding >6,500 m.

The P4 Macquarie Abyssal Plain is a broad region of mostly gently undulating topography, that also contains several seamounts and numerous rotated and faulted crustal blocks up to 50 km in length. To the east of the Macquarie Ridge, the abyssal plain contains a SE-trending chain of large steeply-sided seamounts and numerous smaller volcanic cones. The seamounts and volcanic cones have formed from local upwelling of mantle magma during the opening of the south Tasman Sea. The flanks of the seamounts are characterised by small cones, representing subsidiary volcanic vents. Large areas of the abyssal plain are exposed oceanic crust or warped crustal blocks protruding above the sea floor which have been locally uplifted by compression adjacent to the plate boundary.

**Level 2b**
The sub-biome level, level 2b, is identified by faunal patterns within biomes. In the SEMR at present, the only data set containing sufficient information to do this with some confidence is that on the distributions of fishes. Analysis of data on depth-distributions of fish species shows that there are distinct faunal groups in depth-ranges of 320-550 m, 850-1120 m, and 1600-2000 m. Between these bands are zootones or (since we are using the distributions of species as a surrogate for ecological patterns and processes) ecotones. These depth-related sub-biomes have been identified within each Province and within the level 3 units (below) as sub-areas A1, A2, A3. We consider the sub-biomes as *nested within* provinces in the

hierarchical scheme.  Thus, the fauna in Sub-Biome 3 (depth-range 1600-2000 m) in Provincial Unit P3 off eastern Tasmania is expected to differ from the fauna in Sub-Biome 3 in Provincial Unit P1 off western Victoria.  For this reason, a different shade of yellow is used for Sub-Biome 3 in each of the three provinces in Figure 1.

**Level 3**

Level 3 (geomorphological) units identified for the Southeastern Continental Margin are shown in Table 3, and those for Macquarie in Table 4. In general, Level 3 units are considered to be nested within Level 1 and 2 units but in the case Level 2b units (Sub-biomes), a strict application of this nesting would have led to a proliferation of Level 3 units.  Instead, we treat the Level 3 units as being (where applicable) subdivided by the Level 2b Sub-biomes, which are depth-bands (see above), as follows: A1 (320-550 m), A2 (850-1120 m), A3 (1600-2000 m) and B (2000 m to base of slope).  For the Macquarie Province, no level 2 Biomes have been identified, due to insufficient biological data.  There, as for the SE continental margin, Level 3 units are based primarily on interpretation of geomorphology.  Data on ages of continental crust were examined to test for any variability in the seafloor and hence likely sediment drape. Fish data did not provide any breakdown of the region at this level.  Invertebrate data identified a very general north/south split, but were not sufficiently detailed to provide units at either levels 2 or 3.  Oceanographic data were not available in sufficient detail to refine the regionalisation for this region.

**Table 3. Level 3 (geomorphological) units identified for the Southeastern Continental Margin (EEZ waters adjacent to Tasmania, Victoria, part of South Australia and New South Wales). Where applicable, Level 3 units are subdivided by Level 2b units (Sub-biomes). These are shown in columns 4 and 5 or the table. The Level 2b Sub-biomes (see text) are depth-bands, as follows: A1, 320-550 m; A2, 850-1120 m; A3, 1600-2000 m; B, 2000 m to base of slope.**

| | Region | Feature | Sub-biomes | Bottom Currents ($cms^{-1}$ / Dir.) | Acoustic facies | Description |
|---|---|---|---|---|---|---|
| **Province 1** | | | | | | |
| | 1 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 20 / NW; Max.: 40 / NW-SE<br>Mean: 20 / SE; Max.: 40 / NW | No acoustic facies data available | Extensively incised with submarine canyons spaced 14 to 17 km apart. In Area A, maximum currents diverge at 137°E. |
| | 2 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 15 / NE; Max.: 35 / SE<br>Mean: 15 / NW; Max.: 40 / S-SE | No acoustic facies data available | No submarine canyons. |
| | 3 | Continental Rise | N/A | Mean: 15 / E; Max.: 20 / E | No acoustic facies data available | Several rotated continental blocks between 11-30 km diameter. |
| | 4 | Continental Slope | Area A: A1, A2, A3<br>Area B | Mean: 40 / S-SE; Max.: 50 / S-SE<br>Mean: 20 / E-SE; Max.: 25 / NE | Rough (Classes III) | Extensively incised with submarine canyons spaced every 15 km. In Area B, bottom currents are part of a clockwise gyre centered at 40.8°S and 141°E. |
| | 5 | Continental Rise | N/A | Mean: 5 / S; Max.: 15 E | No acoustic facies data available | Several rotated continental blocks between 7 to 28 km in diameter. |
| | 6 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 20 / S; Max.: 35 / S<br>Mean: 20 / S; Max.: 20 / S | Rough (Classes III) | Extensively incised with submarine canyons spaced 7 km apart. |
| | 11 | Abyssal Plain | N/A | Mean: 15 / Var.; Max.: 20 / Var. | Rough (Classes III) SE corner only. | Contains several continental blocks and 180 km long NW-trending ridge. Mean currents form an anti-clockwise gyre (flowing into Area 7B). Max. currents flow to the southwest (north of 43.6°) and northeast (associated with the clockwise gyre in area 7). |
| | 13 | Continental Rise/ Abyssal Plain | N/A | Mean: 15 / E-S; Max.: 25 / Var. | No acoustic facies data available | Mean currents modelled only for the northern part of this area (to latitude 45°S). Mean currents flow towards the east in the northernmost part of the area (north of 41°S) but towards the southwest in the area south of this latitude. Max. flows are complicated by an anticlockwise gyre centred at 39°S 138.6°E and other down-slope flows at 137.6°E and 141.8°E. |
| | 34 | Continental Slope | Area A: A1, A2, A3 | Mean: 25 / S; Max.: 45 / S | Smooth (Classes I & II) - A1, A2 and rough (Classes III) - A3 | Extensively incised with closely spaced submarine |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Area B: | Mean: 15 / S-N; Max.: 20 / Var. | Smooth (Classes I & II) | canyons, spaced 7 km apart. |
| **Province 2** | | | | | | |
| | 7 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 30 / S; Max.: 25 / SE<br>Mean: 20 / Var.; Max.: 20 / Var. | Rough (Classes III)<br>Smooth (Classes I & II) | Extensively incised with submarine canyons spaced 14 km apart. Contains several rotated continental blocks. In Area A, mean currents form complex clockwise and counterclockwise rotating gyres. |
| | 8 | Saddle | N/A | Mean: 20 / Var.; Max.: 20 / Var. | Smooth (Classes II) in west and equal Rough (III) and smooth (II) in east | Numerous protruding rotated continental blocks. Mean and Max. currents form a clockwise gyre located at 45°S 147°E. |
| | 9 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 20 / N; Max.: 25 / NW<br>Mean: 15 / N-NW; Max.: 20 / NW | Rough (Classes III)<br>Smooth (Classes I & II) | No submarine canyons. Contains several rotated continental blocks and a few seamounts. |
| | 10 | Continental Slope | Area A: A1, A2, A3<br>Area B | Mean: 20 / E; Max.: 20 / Var.<br>Mean: 25 / S; Max.: 35 / S | Rough (Classes III)<br>Rough (Classes III) | Abundant seamounts, submarine canyons and small rotated continental blocks. |
| | 12 | Ridge/Trench | N/A | Mean: 5 / N; Max.: 10 / S | Rough (Classes III) | Tasman Fracture Zone. Currents only associated with very north of area. |
| | 14 | Continental Block | Area A: A1, A2, A3<br>Area B: | No current data available | Equally smooth and rough with pronounced N-S aligned rough area through centre. | Region of South Tasman Rise with extensive plateau areas. East boundary shifted to include acoustic facies classes IA and IIID indicative of flat plateau areas. |
| | 15 | Continental Block | N/A | No current data available | Smooth (Classes II) - edges<br>Rough (Classes III) - centre | Region of South Tasman Rise containing prominent ridges and swales. |
| | 16 | Abyssal Plain | N/A | No current data available | No acoustic facies data available | Containing several small protruding continental blocks. |
| | 17 | Continental Block | Area A: A2, A3<br>Area B: | No current data available | Smooth (Classes I & II) - north only. | ~200,000 $km^2$ of locally subsided, broad low relief dome of the South Tasman Rise. |
| | 18 | Continental Block | Area A: A3<br>Area B: | No current data available | Smooth (Classes I & II) | Contains submarine canyons spaced 30 km apart. |
| | 19 | Abyssal Plain | N/A | No current data available | No acoustic facies data available | Contains some seamounts and numerous protruding continental blocks. |
| | 35 | Continental Block | Area A: A3<br>Area B: | Mean: <5 / Var.; Max. 10 / Var.<br>Mean: <5 / Var.; Max. 10 / Var. | Rough (Classes III)<br>Rough (Classes III) | Domed continental block of South Tasman Rise with extensive plateaus and ridges rising above 2000 m isobath. |
| | 36 | Continental Block | N/A | Mean: <1 / Var.; Max. 10 / Var. | Equally rough (Classes III) and smooth (Classes I & II) types | Domed continental block of South Tasman Rise with extensive plateaus and ridges below 2000 m isobath. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 38 | Continental Rise / Abyssal Plain | N/A | No current data available | Smooth (Classes II) | Acoustic facies data only available for 5% of the area. |
| | 39 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 15 / N; Max.: 20 / Var.<br>Mean: 15 / N; Max.: 15 / Var. | Smooth (Classes I)<br>Rough (Classes III) | Contains submarine canyons, spaced 14 km apart, and several small protruding continental blocks. Canyons are incised and steep-sided cliffs. Boundary between 26 and 27 adjusted to include Class IIIA so that 26 includes all of this class. |
| **Province 3** | | | | | | |
| | 20 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 25 / S; Max.: 45 / S<br>Mean: 25 / S: Max.: 35 / S | Rough (Classes III) and equal rough (III) and smooth (I & II) types | Contains numerous submarine canyons spaced 15 km apart, but locally abundant at 6 km apart. |
| | 21 | Saddle | N/A | Mean: 20 / N-NW; Max.: 20 N | Smooth (Classes I) - south only | Low-relief surface containing several protruding continental blocks. |
| | 22 | Continental Block | Area A: A2, A3<br>Area B: | Mean: 10 / N-NW; Max.: 15 / NW<br>No current data available | Smooth (Classes I & II)<br>No acoustic facies data available | East Tasman Rise, ~50,000 $km^2$ locally subsided block containing the Cascade Seamount (67 km in diameter). Max. currents part of a anticlockwise gyre located at 44.4°S, 148.2°E. |
| | 23 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 10 / N; Max.: 20 / S<br>Mean: 20 / S; Max.: 20 / N | Rough (Classes III) - south and smooth (Classes I & II) - north<br>Smooth (Classes I & II) | Few or absent submarine canyons. Includes broader “flattened” area of Darcey’s Patch. |
| | 24 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 5 / Var.; Max.: 15 / Var.<br>Mean: 20 / W-N; Max.: 20 / S | Equal rough (Classes III) and smooth (Classes I)<br>Rough (Classes III) | Contains numerous, deeply-incised submarine canyons, spaced 16 km apart. |
| | 25 | Canyon | Area A: A1, A2, A3<br>Area B: | Mean: 15 / Var.; Max.: 15 / Var.<br>Mean: 20 / E; Max.: 15 / E | Smooth (Classes I) for A1, A2 and rough (Classes III) for A3<br>Rough (Classes III) | Bass Canyon and associated continental slope |
| | 26 | Continental Slope | Area A: A1, A2, A3<br>Area B: | Mean: 15 / N; Max.: 15 / S<br>Mean: 15 / N; Max.: 20 / S | Rough (Classes III)<br>Rough (Classes III) | Extensive submarine canyons spaced 14 km apart and several continental blocks. Canyons have heavily-incised with steep cliffs. Boundary between 26 and 27 were adjusted to include acoustic facies classes IIIA so 26 includes all of this class. |
| | 27 | Continental Slope | Area A: A1, A2, A3<br>Area B: | No current data available<br>No current data available | Rough (Classes III)<br>No acoustic facies data available | Few submarine canyons. |
| | 28 | Abyssal Plain | N/A | Mean: 15 / Var. See description. | No acoustic facies data available | Currents modelled only far north as 37°S. Var currents except for a 70km wide eastward flowing jet that extends from the base of slope to ~151°E and has a mean of 20 cm/sec and a max. of 25 cm/sec., and a 70 km wide anticlockwise gyre up to 15 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | cm/sec (20 cm/sec max.) centered at 45°S 148.4°E. |
| | 29 | Abyssal Plain | N/A | Mean: <1 / Var. Max. <5 / Var. | No acoustic facies data available | Contains seamounts. |
| | 30 | Abyssal Plain | N/A | Mean: <1 / Var. Max. <5 / Var. | No acoustic facies data available | Contains seamounts. |
| | 31 | Abyssal Plain | N/A | Mean: <1 / Var. Max. <5 / Var. | No acoustic facies data available | Contains seamounts. |
| | 37 | Abyssal Plain | Area A: A3<br>Area B: | Mean: 5 / N; Max.: 10 / N<br>Mean: 5 / N; Max.: 10 / N | Equally rough (Classes III) and smooth types (Classes I & II)<br>No acoustic facies data available | Contains numerous seamounts and continental blocks. Bottom currents modelled only north of 46.8°S. |
| **Shelf** | | | | | | |
| | 32 | Continental Shelf | | | | Not described as it overlaps IMCRA zones. |
| | 33 | Continental Shelf | | | | Not described as it overlaps IMCRA zones |

**Table 4. Level 3 (geomorphological) units identified for the Macquarie Ridge. There is only one province in the Macquarie Large Marine Domain. No level 2 Biomes have been identified for this province, and Level 3 units are based primarily on interpretation of geomorphology (see text).**

| | Region | Feature | Sub-biomes | Bottom Currents ($cms^{-1}$ / Dir.) | Acoustic facies | Description |
|---|---|---|---|---|---|---|
| **Province 4** | | | | | | |
| | 1 | Oceanic Crust | N/A | No current data available | No acoustic facies data available | Low-relief undulating surface with E-W oriented ridges and swales. Small basin is present in the west. |
| | 2 | Volcanic Ridge | N/A | No current data available | No acoustic facies data available | Linear-arcuate narrow, steep sided ridge complex that locally rises above sea level (Macquarie Island). Top of ridge is deeper towards the south. |
| | 3 | Submarine Trench | N/A | No current data available | No acoustic facies data available | Broad (80 km). Contains some rotated and faulted oceanic crustal blocks up to 50 km in length. |
| | 4 | Abyssal Plain | N/A | No current data available | No acoustic facies data available | Contains several seamounts and numerous rotated and faulted oceanic crustal blocks. |
| | 5 | Abyssal Plain | N/A | No current data available | No acoustic facies data available | Undulating surface probably consisting of uplifted oceanic crustal blocks. |
| | 6 | Oceanic Crust | N/A | No current data available | No acoustic facies data available | Contains several seamounts. |
| | 7 | Abyssal Plain | N/A | No current data available | No acoustic facies data available | Contains an E-W trending chain of seamounts (<30 km diameter) and numerous smaller volcanic cones on their flanks. Largest seamount rises up to 390 m. |
| | 8 | Submarine Trench | N/A | No current data available | No acoustic facies data available | Broad (<80 km) but narrows considerably to the south. |
| | 9 | Basin | N/A | No current data available | No acoustic facies data available | NE trending basin (40 km long x 8 km wide), separates north and middle ridge systems. |
| | 10 | Abyssal Plain | N/A | No current data available | No acoustic facies data available | Undulating surface, possibly seamounts. Strong low-relief, E-W ridge and swale fabric. |
| | 11 | Seamount | N/A | No current data available | No acoustic facies data available | Single, steeply-sided (~23 km diameter). |

| | | | | | |
|---|---|---|---|---|---|
| 12 | Saddle | N/A | No current data available | No acoustic facies data available | Narrow (<2 km) elevated saddle. Separates middle and south ridge systems. |
| 13 | Volcanic Ridge | N/A | No current data available | No acoustic facies data available | Broad (<70 km) arcuate with peaks typically <3,000 m. Western flank characterised by W-SW corrugations. Several large volcanic cones occur on the eastern flank. |
| 14 | Submarine Trench | N/A | No current data available | No acoustic facies data available | Broad (<20 km) with steep-sided cliffs and undulating floor. Separates western ridges from main volcanic ridge. |
| 15 | Submarine Trench | N/A | No current data available | No acoustic facies data available | Broad (<50 km) steeply-sided to east where abuts Volcanic Ridge. U-shaped bottom profile in north and V-shaped in south. Trench bottom >6,000 m. |
| 16 | Submarine Trench | N/A | No current data available | No acoustic facies data available | Narrow (<6 km) arcuate, bounded by steep cliffs. Comprises an undulating floor at depths of >4500 m. |
| 17 | Oceanic Crust | N/A | No current data available | No acoustic facies data available | Undulating surface with some higher peaks. Probably formed by speading ridge to south. |
| 18 | Submarine Trench | N/A | No current data available | No acoustic facies data available | Narrow (~5 km) E-W trending, sinuous profile. |
| 19 | Volcanic Ridge | N/A | No current data available | No acoustic facies data available | Narrow (~5 km) N-NW trending ridge up to 1,000 m high. Forms southward extension of Macquarie Ridge. |
| 20 | Submarine Trench | N/A | No current data available | No acoustic facies data available | Narrow (5-10 km) with ridged floor. |
| 21 | Oceanic Crust | N/A | No current data available | No acoustic facies data available | Undulating surface with 40 km wide plateau on western flank. |

# 5 Discussion

## *An interim bioregionalisation*

Despite being based on the best available data, and having been discussed at a workshop on 30 November 2001, the demersal bioregionalisation presented here is an **interim** product, because of the limited nature of the data available to prepare it. Since our aim is an **ecosystem-based** classification, we would ideally like to have information with a reasonable data density on many ecosystem characteristics, so as adequately to describe the ecosystem and identify its hierarchical structure. A short list of possible characteristics follows, with comments on the data available at different depths beyond the continental shelf.

- Bathymetry – we have a digital bathymetry model but the data on which it is based is much better in some areas than others; these data cover the entire SE region and provide a comprehensive and essential data set. In the deep waters off the continental slope, swath bathymetric mapping tools provide the most accurate and highest quality data. However, such swath data have been collected over less than 30% of the SE region.
- Physical oceanography – we have detailed modeling, again based on better data in some regions than others but in general this is a strong data set, and is 4-dimensional (it deals with the water column as well as the seafloor, and has a seasonal pattern).
- Geology – much information is available concerning structure and gross geomorphology of the seafloor because of the inferences that can be made from patterns in bathymetry and geophysical data. These data sets cover the entire SE region and provide a regional view that is unavailable from other, less comprehensive data sets. Knowledge of the detail of the seafloor, however, depends on acoustic echos (available only for some areas and difficult to interpret, e.g. Kloser et al 2001) and direct sediment sampling. Sediment samples from deep water areas (i.e., beyond the continental shelf) are sparse and difficult to interpret in isolation. Information derived from the fossil assemblages preserved in the sediments may prove to be valuable indicators of habitats but were not considered in this study due to insufficient time and resources.
- Fauna – fish are taken deliberately or incidentally in fishing operations and this has given a reasonably good data set, but there is very little fishing below 1000 m and we have no samples below 2000 m. Most data on macroscopic invertebrates come from incidental catches in fish trawls (which are not designed to catch these animals) and very few from deliberate research sampling. Again, almost none is available for depths greater than 2000 m. Microscopic invertebrates (microfauna and meiofauna) and microorganisms have hardly been sampled at all in deep waters in the SEMR; their ecology and biogeography could be extremely interesting.

Statements of accuracy of the variables are given in the individual reports of the projects providing those data.

A further reason why the bioregionalisation is “interim” is that, at these large Province (Level 1) and Biome (Level 2) scales, it is inefficient to consider one region at a time, without placing it in the context of neighbouring regions. In particular we do not know the relative strength, in a National context, of the Province (P2) that we identified in the SEMR. Time constraints made it necessary to do this for the SEMR alone, but a clearer pattern will emerge from consideration of fish distributions, invertebrate distributions, oceanographic patterns, and geological structures around Australia as a single task. This is true at levels 1-2; at finer scales (levels 3-7 in Table 1) it is feasible to map geomorphological units and biotopes within smaller regions without immediately taking a national view. Nevertheless, such mapping should always be thought of as nested within the large-scale regions, provinces and biomes.

Similarly, it is not satisfactory to exclude the continental shelf from a bioregionalisation of this kind. The full effects that this decision had upon the final bioregionalisation are difficult to assess, but it seems likely that there was some impact. For the present exercise, it has been accepted that IMCRA 3.3 (IMCRA Technical Group 1998) is in place and (although entitled “Interim”) is not yet due to be reviewed. In fact, however, there are improved data on some variables (e.g., sediments) that were not available to the creators of IMCRA, and scientific tools, such as GEOMAT, provide a more realistic view of the dynamics (and habitats) of shelf environments. Further, the analysis of data sets (e.g. the fish distributions) should logically not be truncated at a boundary such as the 200 m bathymetric contour, just as they should not be truncated to the north or west by a Large Marine Domain boundary. The geological and biological data sets continue across, and may not conform with, an imposed arbitrary boundary (in this case the 200 m isobath). We have noted, for example, locations where the heads of submarine canyons (such as the Bass Canyon) intrude onto the shelf; locations where strong boundary currents influence both the outer shelf and upper slope; and species of fishes that occur on both the outer shelf and upper slope. Rather than imposing arbitrary boundaries, we prefer to let patterns in the data dictate whether or not there is a boundary at (for example) the 200 m contour, and whether the changes are sharp or gradual, etc.

### *Aspects of the system not considered*

Marine ecosystems, of course, are 4-dimensional; they have a 3-dimensional spatial structure, because much of the action occurs in the water column, not only on the seafloor, and the time dimension is crucial (seasonal variations, differences between years; ecosystems also respond over longer time scales – decades to millennia – to climatic events such as El Nino). So, ultimately we want the bioregionalisation to consider pelagic organisms as well as benthic ones, and their spatio-temporal variability. There is some information available on pelagic fishes, less on invertebrates, and huge gaps in our knowledge of their distributions and movements. Studies of the palaeoceanography and changes to planktonic communities of the SE region have been published but there was not time to analyse what data do exist and so, for the pelagic realm, we use the patterns seen in oceanographic data as a surrogate for likely ecosystem patterns.

Quaternary sea level changes affect all shelf areas but the affects on the slope and rise may be more subtle. For example, sediment shed from continents is more readily transported to the deep sea during glacial low stands of sea level. Although it might be argued that such long-term dynamics are of little interest to regional marine planning, they could have a substantial effect on the nature of sediments on the slope, and thus on the habitats which *are* the concern of the present study. There was not time to examine such effects.

### *Desirable additional analyses*

Even with the present data sets, it would have been desirable to conduct more thorough analyses. These would initially be exploratory, using different statistical methods to search for patterns in the data, and might not lead to any change in the conclusions, but would give greater confidence in those conclusions. For the technically inclined reader, such analyses might have included (but not be limited to) the following ideas discussed by the team but not used in the time available:

- Cluster analyses (of some suitable kind dependent on characteristics of the data) to examine the similarity between route bins without spatial constraint (cf. the present analysis of fish and invertebrate data which examined the similarity between neighbouring bins)
- Cluster analyses to examine the relationships between geomorphological units (once they had been identified purely on geomorphological grounds) with respect to the suite of other variables.
- A thorough examination of the statistical relationships between all GIS layers.

Such additional analyses would enable a quantitative approach and could lead to more robust relationships (eg. boundaries between units) to be established.

### *Assessment of accuracy and reliability of the Interim Bioregionalisation*

The accuracy of the bioregionalisation is limited by the quality of the data. The accuracy of individual data sets is discussed in the reports that accompany them. For example, the maximum resolution of the bathymetry is 250 m, so features smaller than this have not been resolved in our analysis. On this basis, it is evident that the Macquarie ridge region, which was lacking in biological data, is not well defined by our analysis (particularly at the Level 2, sub-biomes). Indeed, we were unable to subdivide any of the SE region to level 2c (mesoscale units) due to the lack of biological data.

The reliability of the bioregionalisation, on the other hand, is dependent upon the expertise and experience of the team. A key factor that affects the reliability is clearly the lack of time that the team had available to study the data and develop the bioregionalisation. Given further time and with more detailed analysis of the data, it is likely that a more refined bioregionalisation could be developed. However, given these constraints, it is our opinion that the bioregionalisation that we have produced is a reasonable representation of the available data.

## *Collection of additional data in the SEMR*

As noted above, data coverage in all of the GIS layers was less than 100%. For example, the key data set was the high-resolution bathymetry model upon which all other layers were draped, but even this did not have full coverage. Consequently a strategy to fill the gaps of the different data sets should be scoped to identify and prioritise those data that would make the greatest improvement to the interim bioregionalisation. One example will illustrate the possible effects of this:

The data on fish and invertebrates both give depth related patterns but perhaps not the same pattern – changes in faunal composition occur at different depths in the two data sets. (We say “perhaps” because the invertebrate data are sparse, from spatially widely-separated samples often taken incidentally in fishing gear; this means that we have little confidence in the reality or the locations of the faunal discontinuities which were tentatively identified). If the difference between the two faunal groups is real, this might imply that management *should* take account of a depth gradient but *not* of particular boundaries, except for particular purposes where the appropriate data would be used, e.g. the depth-distribution of some particular endangered species of animal, or of some particular commercially-exploited species. On the other hand if the two faunal groups truly have coincident discontinuities at particular depths, then that could have profound implications for management – management, for a range of purposes, might be “zoned” using those discontinuities. We do not believe that this issue can be resolved by further analysis of existing data. It requires better data on invertebrates.

## *Lessons for other Marine Regions and for a National Program*

*Australia’s Oceans Policy* proposes regional marine plans for each Marine Region in the Australian Marine Jurisdictional area. The SEMR is merely the first, and this project was asked to provide comments that may improve approaches to the other MRs. Further, the *Oceans Policy* calls for exploration of the AMJ, beyond the idea of regional marine planning *per se*. We have made some pertinent comments above, namely that

- At large scales (levels 1, 2 & perhaps 3) bioregionalisation should be done by examining national data sets together, not by truncating them at regional boundaries or at the shelf edge.
- More time is needed than was available for this project, to permit more thorough analysis of the available data.

Beyond those points, however, there are additional remarks to be made about the National situation:

- Despite our cautionary comments above, the data that were readily accessible for the SEMR were in fact superior to what is available for most other Australian MRs. There will be exceptions, of course; *particular* data sets will be strong in *particular portions* of some MRs. But much of the available information for other MRs does not exist in the kinds of electronic databases that were used to produce the present product in a short time. For example, the ichthyologists worked from electronic data bases for the SEMR. For other regions, it would be necessary for them to check many of the identifications by examining museum specimens, and then to have information entered into databases. (The invertebrate biologists had to do some of this, even for the SEMR). The message is obvious;

bioregionalisation for other MRs, even given existing holdings of samples, etc., will take more time than for the SEMR.

- For some variables, holdings – even of unprocessed specimens, or of data not yet entered into databases – will be inadequate. For these variables (and the fundamental underlay, bathymetry, is one of them) field work will be necessary. It is impossible to conduct high-density sampling over the whole AMJ or even over the whole of one MR, and so a careful discussion will be needed to prioritise this field work. This discussion must involve, on the one hand, the NOO and other agencies responsible for planning and management and, on the other hand, scientists who know the present status of Australia's data holdings and what would be involved in the necessary field work.

# 6 Conclusion

Despite the difficulties indicated above, we consider that the Interim Bioregionalisation presented here is a robust identification of patterns in ecosystem structure at a large scale (levels 1 – 3) as a working framework for ecosystem-based planning in the SEMR.

The use of this framework should facilitate improved understanding of the ecosystem structure and function. The concept of 'ecosystem' means more than a collection of physical and biological entities; it concerns *processes*. Thus, a bioregionalisation is not in itself a description of the ecosystem. Nevertheless, it gives a picture of the spatial distribution of the large-scale physical and biological components of the Region. Notwithstanding its 'interim' status, this bioregionalisation provides improved knowledge of boundaries that can be applied in regional marine planning to provide a significant step towards ecosystem-based management.

We anticipate that the Interim Bioregionalisation for the SEMR will be used to:

- Provide a nested spatial framework (SER, LMD, bioregions) for designing potential management options for the Region that reflect ecosystem characteristics.
- Select the appropriate spatial scale on which to analyse information from the assessments for the Region so that they relate logically to ecosystem characteristics.
- Provide an operational basis for monitoring the state of the ecosystem and for use as part of the performance assessment process for the SEMR.

# 7 References


Allen, T.F.H. and Starr, T.B. (1982) *Hierarchy. Perspectives for ecological complexity*. University of Chicago Press, Chicago and London.

Bernardel, G., Alcock, M., Petkovic, P., Thomas, S. and Levinson, M. 2000. *AUSTREA-2 cruise report: south-east of Tasmania and southern Macquarie Ridge*. AGSO Record 2000/46, Canberra

Bruce, B.D., Condie, S.A. & Sutton, C.A. (2001) Larval distribution of blue grenadier (*Macruronus novaezelandiae* Hector) in southeastern Australia: further evidence for a second spawning area. *Marine and Freshwater Research* 52, 603-610.

CSIRO (1996). *Interim Marine Bioregionalisation for Australia: Towards a National System of Marine Protected Areas.* CSIRO Division of Fisheries, CSIRO Division of Oceanography. Report to Department of the Environment, Sport and Territories. Ocean Rescue 2000 report series on a National Representative System of Marine Protected Areas. Canberra.

CSIRO Marine Research, Museum Victoria, Australian Museum and NSW Fisheries (2001) *Rapid assembly of ecological fish data (community composition and distribution) for the south-east marine region.* Report to the National Oceans Office. CSIRO Marine Research, Hobart.

Damuth, J. E. (1980). Use of high-frequency (3.5 - 12 kHz) echograms in the study of near bottom sedimentation processes in the deep sea. *Marine Geology*, 38, 51-75.

Day J., Fernandes L., Barnett B., Slegers S., Kerrigan B., Breen D., De'ath G., Lewis A., Innes J., Oliver J.. (2000). The Representative Areas Program-Protecting the Biodiversity of the Great Barrier Reef World Heritage Area. Pp 687 – 696 in *Proceedings of the 9th International Coral Reef Symposium*, Bali.

Davies, C.E. & D. Moss, 1999. *The EUNIS classification*. European Environment Agency. ITE project T0809219: 1-124.

Dunn, J.R. & Condie, S.A. (2001) *Nutrients, water properties and model ocean currents in the South-East Marine Region of Australia.* Report to the National Oceans Office. CSIRO Marine Research, Hobart. (in preparation).

Ridgway, K. R., Dunn, J.R. and Wilkin, J.L. (2002) Ocean interpolation by four-dimensional least squares - Application to the waters around Australia, *J. Atmos. Ocean. Tech., 19 (9), 1357-1375.*

Exon, N. F., Berry, R. F., Crawford, A. J., & Hill, P. J. (1997a). Geological evolution of the East Tasman Plateau, a continental fragment southeast of Tasmania. *Australian Journal of Earth Science*, 44, 597-608.

Exon, N. F., Moore, A. M. G., & Hill, P. J. (1997b). Geological framework of the South Tasman Rise, south of Tasmania, and its sedimentary basins. *Australian Journal of Earth Science*, 44, 561-577.

Garcia-Charton, J.A. and Perez-Ruzafa, A. (1999). Ecological heterogeneity and the evaluation of the effects of marine reserves. *Fisheries Research*, 42, 1-20.

Greene, HG, Yoklavich, MM, Barry, JP, Orange, DL, Sullivan, DE, Cailliet, GM (1994) Geology and related benthic habitats of Monterey canyon, central California. *EOS transactions of the American Geophysical Union Supplement* 75:3, p.203

Greene, H.G., Yoklavich, M.M., Sullivan, D., and Cailliet, G.M. (1995). A geophysical approach to classifying marine benthic habitats: Monterey Bay as a model. In 'Applications of Side-Scan Sonar and Laser-Line Systems in Fisheries Research'. pp. 15-30. (Alaska Department Fish and Game Special Publication No. 9, Juneau, Alaska.)

Greene, H.G., Yoklavich, M.M., Starr, R.M., O'Connell, V.E., Wakefield, W.W., Sullivan, D.E., McRea, J.E. Jr., and Cailliet, G.M. (1999). A classification scheme for deep seafloor habitats. *Oceanologica Acta* 22, 663-678.

Hill, P.J., Exon, N.F. and Royer, J.-Y. 1995. Swath-mapping the Australian continental margin: results from offshore Tasmania. *Exploration Geophysics*, 26, 403-411.

Hill, P.J., Meixner, A.J., Moore, A.M.G. and Exon, N.F. 1997. Structure and development of the west Tasmanian offshore sedimentary basins: results of recent marine and aeromagnetic surveys. *Australian Journal of Earth Sciences*, 44, 579-596.

Holling, C.S. (1992). Cross-scale morphology, geometry and dynamics of ecosystems. *Ecological Monographs* 62, 447-502.

IMCRA Technical Group (1998). *Interim Marine and Coastal Regionalisation for Australia: an ecosystem-based classification for marine and coastal environments*. Version 3.3. Environment Australia, Canberra.

Kloser, R.J., Bax, N.J., Ryan, T., Williams, A.and Barker, B.A. (2001) Remote sensing of seabed types in the Australian South East Fishery; development and application of normal incident acoustic techniques and associated 'ground truthing'. *Marine and Freshwater Research* 52, 475-489.

Langton, R.W., Auster, P.J. and Schneider, D.C. (1995). A spatial and temporal perspective on research and management of groundfish in the northwest Atlantic. *Reviews in Fisheries Science* 3, 201-229

Lyne, V., Last, P., Scott, R., Dunn, J., Peters, D. and Ward, T. (1998) *Large Marine Domains Of Australia's EEZ.* Report to Environment Australia. CSIRO Division of Marine Research, Hobart.

Massell, C., Coffin, M.F., Mann, P., Mosher, S., Frohlich, C., Duncan, C.S., Karner, G., Ramsay, D. and Lebrun, J.-F. 1999. Neotectonics of the Macquarie Ridge Complex, Australia Pacific plate boundary. *Journal of Geophysical Research*, 105, p.13,457-13,480.

O'Neill, R.V., DeAnglelis, D.L., Waide, J.B. and Allen, T.F.H. (1986) *A hierarchical concept of ecosystems*. Princeton University Press., Princeton, New Jersey

Poiani, K.A., Richter, B.D., Anderson, M.G., and Richter, H.E. (2000). Biodiversity conservation at multiple scales: functional sites, landscapes, and networks. *Bioscience* 50, 133-146.

Roff, J.C. and Taylor, M.E. (2000). National frameworks for marine conservation – a hierarchical geophysical approach. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10, 209-223.

Shepard, F.P. (1959) *The Earth Beneath the Sea*. Johns Hopkins Press. Baltimore. 275pp

Thackway, R. and I. Cresswell (1995). *An Interim Biogeographic Regionalisation for Australia: a framework for establishing the national system of reserves.* Version 4. Australian Nature Conservation Agency, Canberra.

Whitmore, G. P., & Belton, D. X. (1997). Sedimentology of the South Tasman Rise, south of Tasmania, from 'groundtruthed' acoustic facies mapping. *Australian Journal of Earth Science*, 44, 677-688.

Williams, A. and Bax, N. (2001). Delineating fish-habitat associations for spatially-based management: an example from the south-eastern Australian continental shelf. *Marine and Freshwater Research*. 52, 513-536

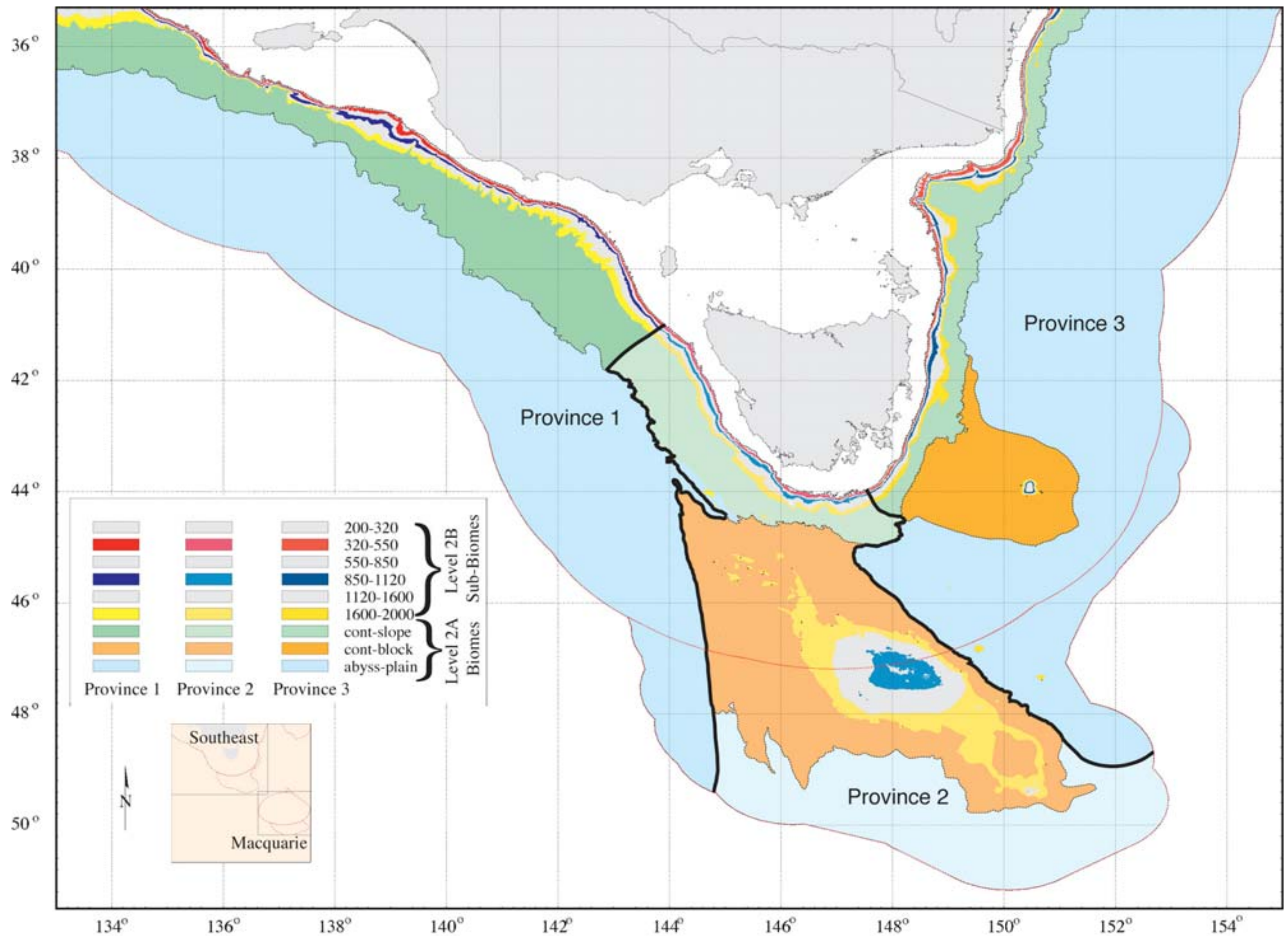


Figure 1. An interim demersal bioregionalisation for the continental slope and deeper waters of the South-east continental margin within the South-east Marine Region of Australia: Map showing units at Level 1 (Province), Level 2a (Biome) and Level 2b (Sub-biome). The region is divided into three Provincial units. Biomes include the Continental Slope, Continental Blocks and Abyssal Plains. Boundaries for Level 2b are based on the distribution of fish species with depth down to 2000 m. Below 2000 m, Level 2b depth boundaries are based on geomorphology. See text for full details and descriptions of the units.

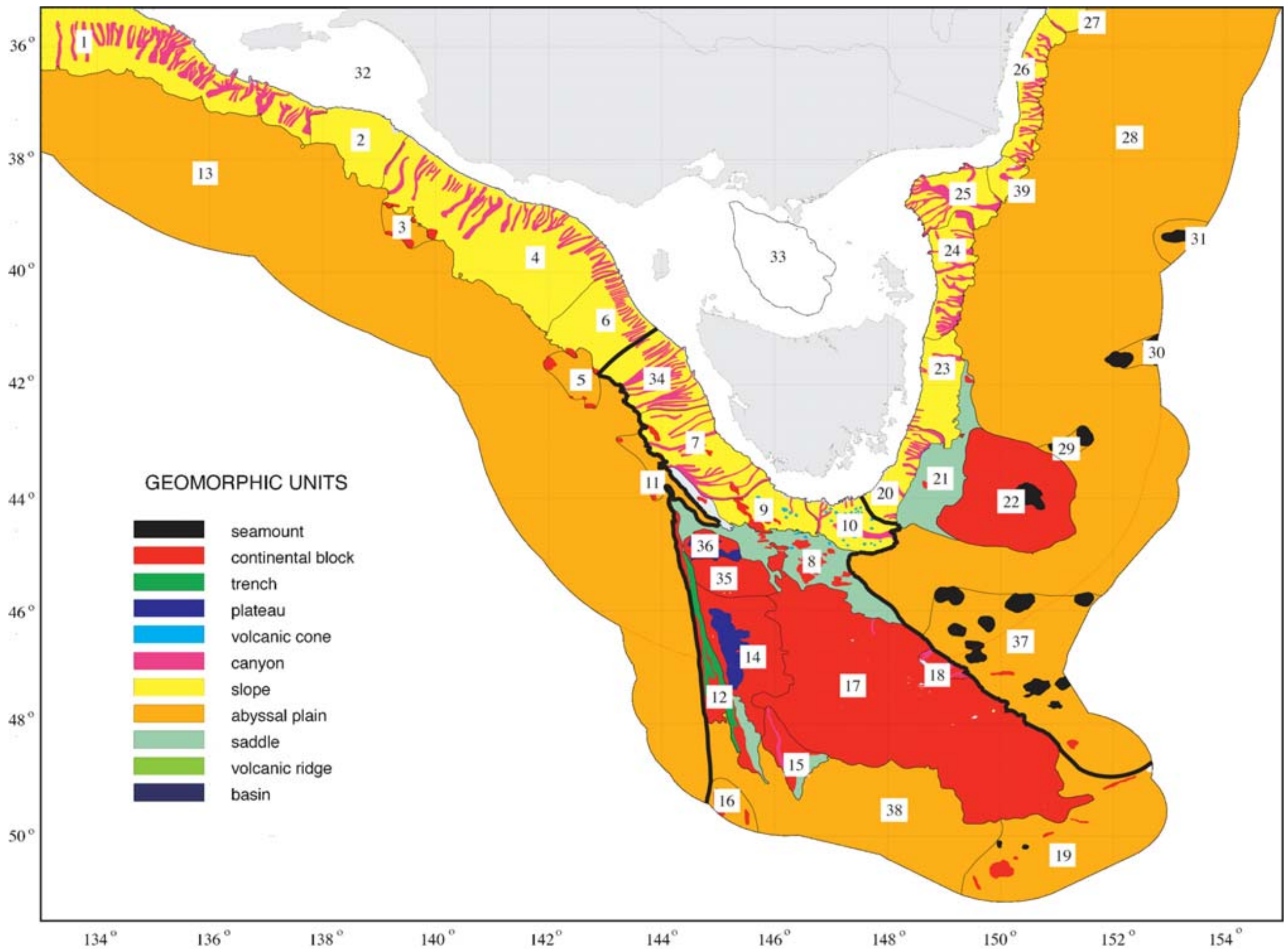


Figure 2. An interim demersal bioregionalisation for the continental slope and deeper waters of the South-east continental margin within the South-east Marine Region of Australia: Map showing Level 3 (Geomorphological) units. Geomorphological unit boundaries were determined from bathymetry and previous geological studies of the region. Note that shelf areas (units 32 and 33) are not included in the present bioregionalisation. See text for full details and descriptions of the units.

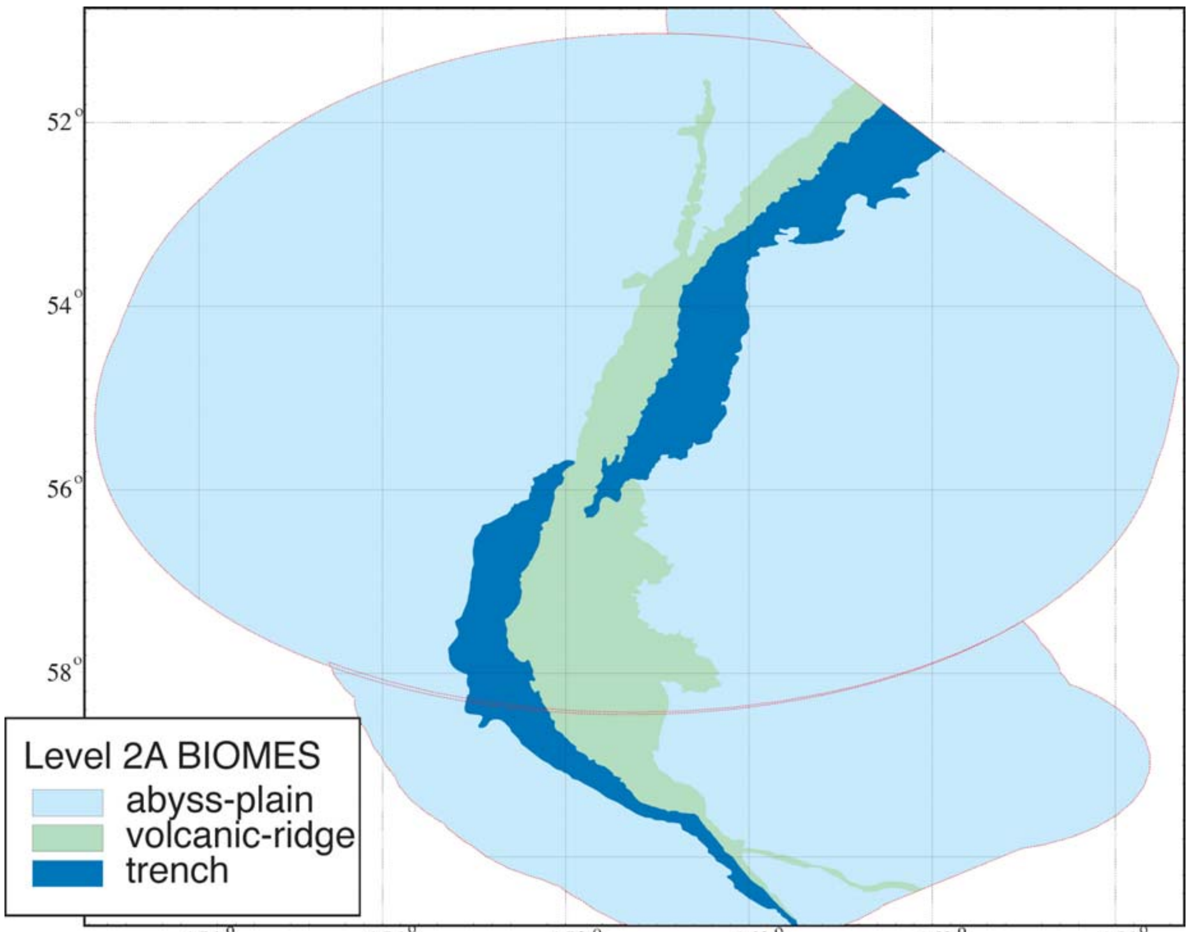


Figure 3. An interim demersal bioregionalisation for waters surrounding the Macquarie Ridge within the South-east Marine Region of Australia: Map showing Level 1 (Province) and level 2 (Biome) units. Macquarie Ridge comprises one Province and three Biomes; the biomes comprise a linear-arcuate volcanic ridge/trench complex of oceanic crust. See text for full details and descriptions of the units.

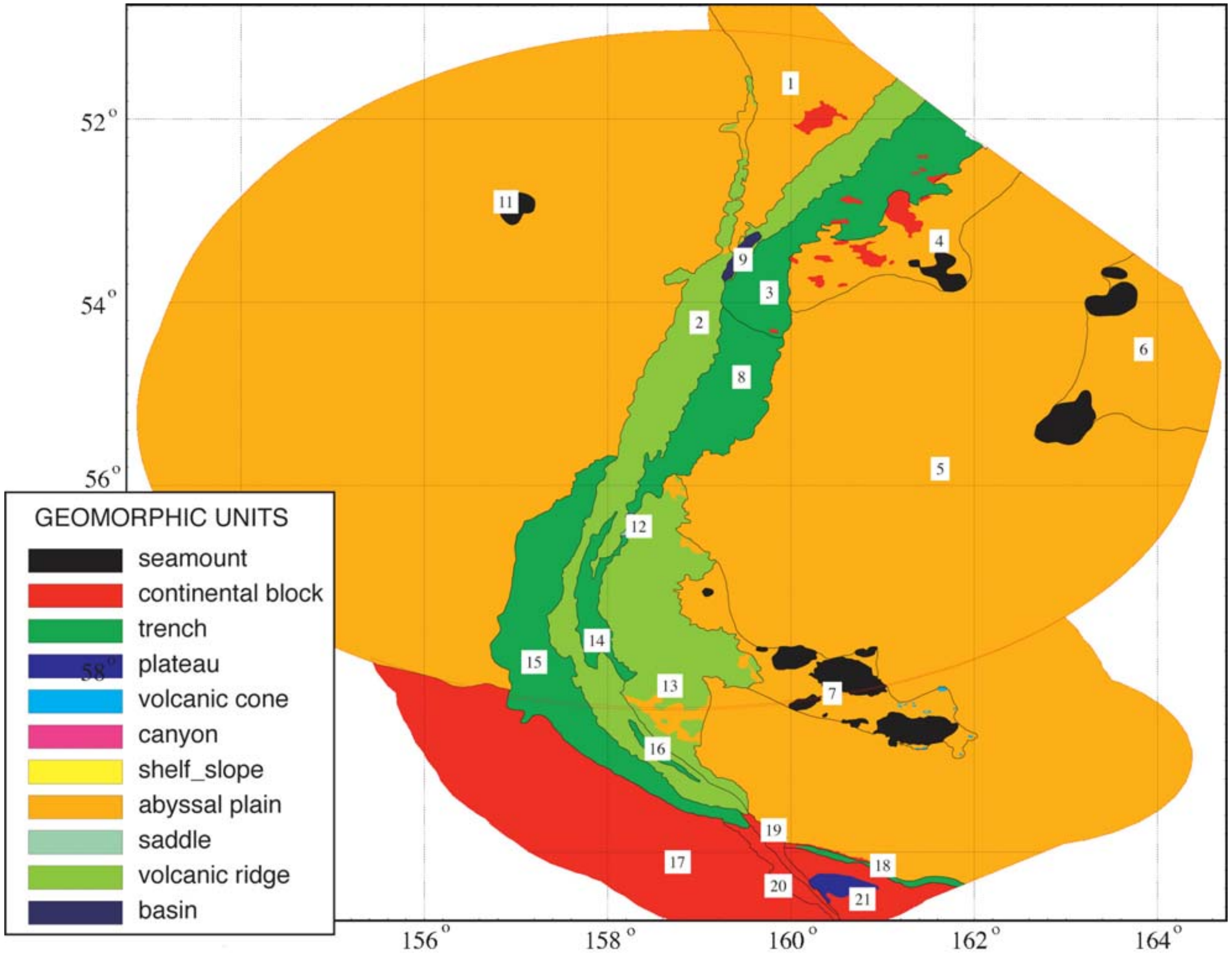


Figure 4. An interim demersal bioregionalisation for waters surrounding the Macquarie Ridge within the South-east Marine Region of Australia: Map showing Level 3 (Geomorphological) units. The Macquarie Ridge region is made up of oceanic crust and the gross geomorphology is produced by the oblique strike-slip movement of the boundary between the Australian and Pacific plates. See text for full details and descriptions of the units.